Unit - II

Electro-dynamics

Formula

1. $I = \frac{Q}{t} \Rightarrow 1\,Amp = \frac{1\,Coulomb}{1\,sec}$

2. Ohm's law is $V = RI$

where R = Resistance of the conductor through which a current of I ampere is flowing

V = Potential difference between the two ends of the conductor

3. Resistances when connected in series the equivalent resistance is given by

$$R_s = R_1 + R_2 + R_3 + \text{-------}$$

4. Resistances when connected in parallel the equivalent resistance (R_p) is given by

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \text{-----}$$

5. Relation between e.m.f ($\mathcal{E}$) and p.d (V) is

$$\mathcal{E} = V + I.r$$

where r = Internal resistance of

a battery or cell

$\mathcal{E}$ = e.m.f

V = P.D across the external resistance.

= RI

(6) Resistance is related to length of the conductor (l) and area of cross section (A) by the formula

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

ρ = Specific resistance. which is a constant characteristic of the material of the conductor and temperature.

651 → 4, 10, 14, 23

— o —

<u>Problems</u> <u>629</u> → Try → 10, 14, 15, 17, 19, 21, 23, 24, 25

7.96 A 8 Ω 2.86 Ω 6.7 × 10

1. Calculate the number of electrons passing through a lamp in a day to which a current of 1.6 Amp is passing. (Ans → 8.64×10^{23})

2. 3 resistances 1 Ω, 12 Ω, 3 Ω are connected ~~for that~~ to form a triangle ABC. Find the equivalent resistance between A and B, B and C and C and A

(Ans :- $\frac{5}{6}, \frac{4}{3}, \frac{3}{2}$)

3. A battery is connected to a rheostat gives some current. When a lamp of resistance 150 Ω is inserted in series, the current is reduce to $\frac{1}{3}$ of the former value. What is the resistance of the rheostat

(Ans:- 75 Ω)

4. A uniform wire 2 meter long having resistance of 11 Ω is connected in series with a battery having a terminal voltage 6 volts, and a rheostat that has a resistance of 1 ohm. What is the reading of a volt meter i.e placed across 60 cm of the wire.

(Ans:- 1.65 V)

5. A wire of resistance 40 Ω is melted and another wire of radius half of the radius of the previous wire is ~~repaired~~ prepared out of it. Find the new resistance.

(Ans:- 640 Ω)

6. 1 kg of Cu is drawn in to a wire
(a) 1 mm in diameter
(b) 3 mm in diameter.
Compare their resistances at the same temperature
(Ans: 81 : 1)

7. Two Cu wires whose lengths are in the ratio 1 : 2 are of the same resistance. Compare the diameter of the wires (Ans: $1 : \sqrt{2}$)

8. Two coils when connected in series have an equivalent resistance of $18\,\Omega$ and when connected in parallel the equivalent resistance becomes $4\,\Omega$. Find the resistances (Ans: $6\,\Omega$, $12\,\Omega$)

9. Three resistances of which 2 are equal, when joined in series have an equivalent resistance of $250\,\Omega$. When they are joined in $\parallel$, the equivalent resistance becomes $25\,\Omega$. Find the resistances. (Ans: 100, 100, 50 Ω) or (62.5, 62.5, 125 Ω)

10. The terminal voltage of a battery is 9V when supplying a current of 4 Amp and 8.5 volt when supplying 6 Amp, find the internal resistance and e.m.f of the battery

(Ans: 0.25 Ω, 10V)

Answers

10. Relation between e.m.f and P.V

$$E_1 = V_1 + I_1 r$$

Terminal voltage of battery is $= 9V$, current supplied $= 4$ Amp

$$\Rightarrow E = 9 + 4r \quad \text{——(i)}$$

Terminal voltage connected to battery $= 8.5$ V, current supplied $= 6$ Amp

$$E = 8.5 + 6r \quad \text{——(ii)}$$

Subtracting eqn (ii) from eqn (i)

$$0 = .5 - 2r$$

$$\Rightarrow 2r = .5$$

$$\Rightarrow r = .25\ \Omega$$

$\therefore$ Internal resistance $= .25\ \Omega$

Putting this value in eqn (1)

$$E = 9 + 4.(\cdot 25)$$

$$\Rightarrow E = 9+1$$
$$= 10 \text{ volt}$$

9. Let the three resistance be R, R, R_1

When connected in ~~xxx~~ ~~xx~~ series

$$R_s = R+R+R_1 = 2R+R_1$$

$$\Rightarrow 250 = 2R+R_1 \quad \text{------- (i)}$$

$$\Rightarrow R_1 = 250-2R$$

When they are connected in ||

$$\frac{1}{R_P} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R_1}$$

$$\Rightarrow \frac{1}{25} = \frac{R_1+R_1+R}{RR_1}$$

$$\Rightarrow 25RR_1 = 2R_1+R$$

$$\Rightarrow 25R(250-2R) = 2(250-2R)+R$$

$$\Rightarrow 6250R - 50R^2 = 500-4R+R$$

$\Rightarrow \cancel{50R^2 - 6250R - 4R + 4R + 1500 = 0}$

$\Rightarrow \cancel{50R^2 - 6253R + 500 = 0}$

$\Rightarrow RR_1 = 250R_1 + 125R$

$\Rightarrow R(250-2R) = 50(250-2R) + 125R$

$\Rightarrow 250R - 2R^2 = 12500 - 100R + 125R$

$\Rightarrow 2R^2 - 75R - 250R + 12500 = 0$

$\Rightarrow 2R^2 - 325R + 12500 = 0$

$$\Rightarrow R = \frac{325 \pm \sqrt{(325)^2 - 4\cdot(2)\cdot(12500)}}{2\cdot 2}$$

$$= \frac{325 \pm \sqrt{105625 - 100000}}{4}$$

$$= \frac{325 \pm \sqrt{5625}}{4}$$

$$= \frac{325 \pm 75}{4}$$

$$= \frac{325+75}{4} \text{ or } \frac{325-75}{4}$$

$$= \frac{400}{4} \text{ or } \frac{250}{4}$$

$= 100\ \Omega$ or $62.5\ \Omega$

when $R = 100\ \Omega$

$R_1 = 250 - 2\cdot(100) = 50\ \Omega$

$\therefore$ Three resistance are (200, 100, 50 Ω)

Or $R = 62.5$

$R_1 = 250 - 2 \cdot (62.5)$

$= 250 - 125$

$= 125\ \Omega$

$\therefore$ Three resistances are (62.5, 62.5, 125 Ω)

8. When resistance coils are connected in series $R_s = 18\ \Omega$

$\Rightarrow R_1 + R_2 = 18\ \Omega$

$\Rightarrow R_1 = 18 - R_2$

When connected in ||

$\frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_p} = \frac{1}{4\ \Omega}$

$\Rightarrow \frac{R_1 + R_2}{R_1 R_2} = \frac{1}{4}$

$\Rightarrow \frac{R_1 R_2}{R_1 + R_2} = 4$

$\Rightarrow \frac{(18 - R_2) R_2}{(18 - R_2) + R_2} = 4$

$\Rightarrow 18R_2 - R_2^2 = 72$

$\Rightarrow R_2^2 - 18R_2 + 72 = 0$

$$\Rightarrow R_2 = \frac{18 \pm \sqrt{324 - 4\cdot(1)\cdot(72)}}{2\cdot(1)}$$

$$= \frac{18 \pm \sqrt{324 - 288}}{2}$$

$$= \frac{18 \pm \sqrt{36}}{2}$$

$$= \frac{18 \pm 6}{2}$$

$$\therefore R_2 = \frac{24}{2} \text{ or } \frac{12}{2}$$

$$= 12 \text{ or } 6$$

or $R_2 = 12\Omega$, $R_1 = 18 - 12 = 6\,\Omega$

or $R_2 = 6\Omega$, $R_1 = 18 - 6 = 12\,\Omega$.

$\therefore$ R_1 and R_2 are 12 and 6

or 6 and $12\,\Omega$

7. $\frac{l_1}{l_2} = \frac{1}{2}$

They have same resistance $R = R$.

$$R = \rho \frac{l_1}{A_1}$$

$$R = \rho \frac{l_2}{A_2}$$

Diving $\Rightarrow 1 = \frac{l_1}{A_1} \times \frac{A_2}{l_2} = \frac{l_1}{l_2} \times \frac{A_1}{A_2} = \frac{1}{2} \times \frac{A_2}{A_1}$

$\Rightarrow A_2 = 2A_1$

$\Rightarrow \cancel{\pi} r_2^2 = 2\cdot(\cancel{\pi} r_1^2)$

$\Rightarrow \dfrac{r_2^2}{r_1^2} = 2$

$\Rightarrow \dfrac{r_1^2}{r_2^2} = \dfrac{1}{2}$

$\Rightarrow \dfrac{r_1}{r_2} = \dfrac{1}{\sqrt{2}}$

$\Rightarrow \dfrac{\frac{d_1}{\cancel{2}}}{\frac{d_2}{\cancel{2}}} = \dfrac{1}{\sqrt{2}}$

$\Rightarrow d_1 : d_2 = 1 : \sqrt{2}$ (Ans)

6. We know that

$R_1 = \rho \dfrac{l_1}{A_1}$

$R_2 = \rho \dfrac{l_2}{A_2}$

$\Rightarrow \dfrac{R_1}{R_2} = \dfrac{l_1}{A_1} \times \dfrac{A_2}{l_2} = \dfrac{l_1}{l_2} \times \dfrac{\cancel{\pi}\frac{d_1^2}{\cancel{4}}}{\cancel{\pi}\frac{d_2^2}{\cancel{4}}}$

$= \dfrac{l_1}{l_2} \times \dfrac{d_1^2}{d_2^2} = \dfrac{l_1}{l_2} \times \dfrac{1}{9}$

$\Rightarrow \dfrac{R_1}{R_2} = \dfrac{l_1}{9 l_2}$

But Volume are same

$$\pi r_1^2 l_1 = \pi r_2^2 l_2$$

$$\Rightarrow \frac{l_1}{l_2} = \frac{r_2^2}{r_1^2} = \frac{d_2^2}{d_1^2} = \frac{9}{1}$$

$$\Rightarrow \frac{l_1}{l_2} = 9$$

$$\therefore \frac{R_1}{R_2} = \frac{l_1}{9 l_2} = \frac{1}{9} \times 9 = \frac{81}{1}$$

$\therefore$ Resistances are in the ratio $81:1$

5. A wire has resistance $R_1 = 40\Omega$.

It is melted to Another wire has resistance R_2.

But 2nd wire radius $= \frac{1}{2}$ 1st wire radius

$$\Rightarrow r_2 = \frac{1}{2} r_1$$

$$\Rightarrow d_2 = \frac{d_1}{2}$$

But $R_1 = \rho \frac{L}{A} = \frac{\rho L}{\frac{\pi d_1^2}{4}} = \frac{\rho L 4}{\pi d_1^2}$

$R_2 = \rho \frac{L}{A} = \frac{\rho L}{\frac{\pi d_2^2}{4}} = \frac{\rho L 4}{\pi d_2^2}$

$$\frac{R_1}{R_2} = \frac{\cancel{\rho} \cancel{L} \cancel{4}}{\cancel{\pi} d_1^2} \times \frac{\cancel{\pi} d_2^2}{\cancel{\rho} \cancel{L} \cancel{4}} = \frac{\left(\frac{d_1}{2}\right)^2}{d_1^2} = \frac{d_1^2}{4} \times \frac{1}{d_1^2} = \frac{1}{4}$$

$$\frac{R_1}{R_2} = \frac{1}{16}$$

$$\Rightarrow \frac{40}{R_2} = \frac{1}{16}$$

$$\Rightarrow R_2 = 640\ \Omega$$

40 / 640 (1
40
240

5.

$$R_1 = \frac{\rho L_1}{A_1}, \quad R_2 = \frac{\rho L_2}{A_2}$$

$$\Rightarrow \frac{R_1}{R_2} = \frac{\cancel{\rho} L_1}{A_1} \times \frac{A_2}{\cancel{\rho} L_2} = \frac{L_1}{L_2} \cdot \frac{\cancel{\pi}\left(\frac{d_2}{2}\right)^2}{\cancel{\pi}\left(\frac{d_1}{2}\right)^2}$$

$$= \frac{L_1}{L_2} \times \frac{d_2^2}{d_1^2} = \frac{L_1}{L_2} \times \frac{\left(\frac{d_1}{2}\right)^2}{d_1^2}$$

$$= \frac{L_1}{L_2} \times \frac{\cancel{d_1^2}}{4} \times \frac{1}{\cancel{d_1^2}}$$

$$\Rightarrow \frac{40}{R_2} = \frac{L_1}{4L_2} \qquad \text{--- (1)}$$

But Volume is Constant

$$\cancel{\pi} r_1^2 l_1 = \cancel{\pi} r_2^2 l_2$$

$$\Rightarrow \frac{r_1^2}{r_2^2} = \frac{l_2}{l_1}$$

$$\Rightarrow \frac{d_1^2}{d_2^2} = \frac{l_2}{l_1}$$

$$\Rightarrow \frac{d_1^2}{\left(\frac{d_1}{2}\right)^2} = \frac{l_2}{l_1}$$

$$\Rightarrow \frac{\cancel{d_1^2} \times 4}{\cancel{d_1^2}} = \frac{l_2}{l_1}$$

$\Rightarrow \cancel{\frac{l_1}{l_2} = 4:1}$ $\Rightarrow 4l_1 = l_2$

$\Rightarrow \frac{l_1}{l_2} = \frac{1}{4}$

$\therefore$ From eqn (i) $\frac{40}{R_2} = \frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$

$\Rightarrow R_2 = 640\ \Omega$.

(Ans)

Q:

(3) ~~A battery is connected to a rheostat.~~

~~Lamp has resistance $150\ \Omega$.~~

~~We know that $V = IR$~~

~~$\Rightarrow V_0 = I_1 R_1$~~

~~In second case $V_2 = I_2 R_2$~~

~~$\Rightarrow V_0 = \frac{I_1}{3} 150$~~

~~Dividing $1 = \frac{\cancel{I_1} R_1 \times 3}{\cancel{I_1} \times 150}$~~

3.

A battery connected to a rheostat.

there $V = IR$ —— (1)

When it is connected 150 Ω, then I becomes $\frac{I}{3}$

$\therefore \quad V = \frac{I}{3}(R+150)$

Dividing

$$1 = \frac{\cancel{I}R \times 3}{\cancel{I}(R+150)}$$

$\Rightarrow R+150 = 3R$

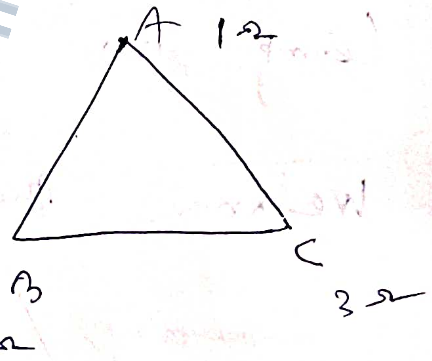
$\Rightarrow 2R = 150$

$\Rightarrow R = 75\ \Omega$

2.

Equivalent resistance

A cross AB



In this case A and B are connected in series and C is ||

$\therefore$ The equivalent resistance $= 1+2 = 3\ \Omega$

C has resistance $= 3\ \Omega$

$$\frac{1}{R_P} = \frac{1}{3} + \frac{1}{3}$$

$$\Rightarrow \frac{1}{R_P} = \frac{2}{3}$$

$$\Rightarrow R_P = \frac{3}{2}\ \Omega$$

$\therefore$ Across AB resistance $\frac{3}{2}\ \Omega$

When A, C are connected in series then resistance $= (1+3)\ \Omega = 4\ \Omega$.

B has resistance $= 2\ \Omega$

They are connected in parallel connection

$$\frac{1}{R_P} = \frac{1}{4} + \frac{1}{2} = \frac{1+2}{4} = \frac{3}{4}$$

$$\Rightarrow R_P = \frac{4}{3}$$

$\therefore$ A and C has resistance $\frac{4}{3}\ \Omega$.

B and C are connected in series

$$R_S = 2+3 = 5\ \Omega.$$

But A ~~ch~~ has resistance $1\ \Omega$.

R_S and A are connected in parall.

$$\therefore \frac{1}{R_P} = \frac{1}{5} + \frac{1}{1} = \frac{1+5}{5} = \frac{6}{5}$$

$$\therefore R_P = \frac{5}{6}\ \Omega$$

$\therefore$ Across B and C resistance $\frac{5}{6}\ \Omega$.

1.

$$I = 1.6 \text{ Amp.}$$

$t =$ Time $= 24$ hour $= (24 \times 3600)$ sec.

$$Q = It = 1.6 \times 24 \times 3600$$

$$= 138240 \text{ Coulomb}$$

each electron has charge $= 1.6 \times 10^{-19}$

on 1.6×10^{-19} C the electron remain $= 1$

1 C " " $= \dfrac{1}{1.6 \times 10^{-19}}$ ele

138240 C " "

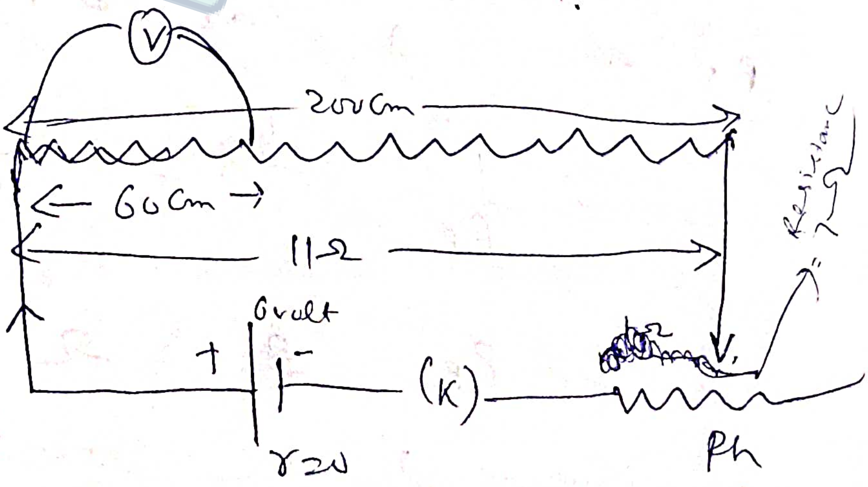
$$= \frac{138240}{1.6 \times 10^{-19}}$$

$$= 86400 \times 10^{19}$$

$$= 8.64 \times 10^{23} \text{ ~~Coulomb~~}$$

$\therefore$ Number of electrons 8.6×10^{23} electrons

4.



The resistors of resistances $11\,\Omega$ and $1\,\Omega$ are connected in series.

$\therefore R_s = 11 + 1 = 12\,\Omega$

When connected in battery.

$V = IR$

$\Rightarrow 6\,\text{volt} = I \cdot 12\,\Omega$

$\Rightarrow I = \frac{1}{2}\,\text{Amp.}$

In 2 cm, resistance $= 11\,\Omega$

1 " " $= \frac{11}{20}\,\Omega$

6 cm " $= \frac{11}{\cancel{20}_{10}} \times \cancel{6}^{3}$

$= \frac{33}{10}\,\Omega.$

$R = \frac{33}{10}\,\Omega$

$I = \frac{1}{2}\,\text{Amp.}$

$V = IR = \frac{1}{\cancel{2}} \times \frac{\cancel{33}^{16.5}}{10} = 1.65\,\text{Volt}$

Ans

$\frac{1}{2} \times 11 = V$ $\quad 5.5$

$I = \frac{V}{R} = \frac{5.5}{\frac{1}{2}}$

$= \frac{105}{220}$

10.

We know that

$$V = IR$$

A dry cell has emf 1.55 V.

and current passes through it

22 Amp.

Internal resistance $R = \frac{V}{I} = \frac{1.55}{22} = .0704$ Ohm

14.

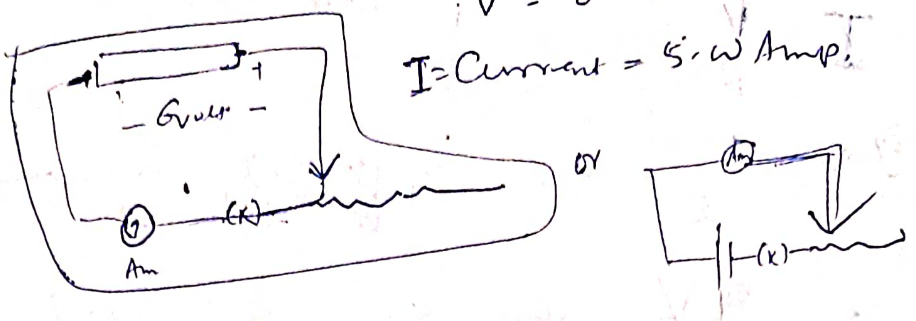
$$Q = It$$

$$\Rightarrow 600\,C = I \times (120\,s)$$

$$\Rightarrow I = \frac{600}{120} = 5\text{ Amp}$$

15. $V = 6.00\,V$

I = Current = 5.00 Amp.



$$r = \frac{V}{I} = \frac{6}{5} = 1.2\,\Omega$$

17. In a rheostat $I = .45\,A$

Potential between the terminals = 60 V.

$$r = \frac{V}{I} = \frac{60}{.45} = \frac{6000}{45}$$

$$= 133.33\,\Omega$$

19. wire has resistance $r = 1.75\,\Omega/ft$

i.e. for length 1 ft ; resistance = $1.75\,\Omega$

Toaster has $V = 115\,V$

$I = 8.25$

$$r = \frac{V}{I} = \frac{115}{8.25} = 13.93\,\Omega$$

for resistance $1.75\,\Omega$, wire needed = 1 ft

" $1\,\Omega$ " " $= \frac{1}{1.75}$ ft

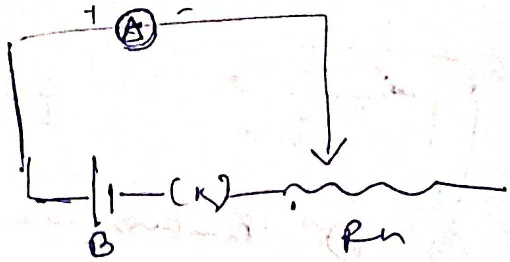
" $13.93\,\Omega$ " $= \frac{1}{1.75} \times 13.93 = 7.96$ ft

21. Ammeter reads $5A = I$

Rh has resistance R

According question

$I = \frac{V}{R} \Rightarrow 5 = \frac{V}{R}$ — (i)



$I = \frac{V}{(R+2)} \Rightarrow 4 = \frac{V}{R+2}$ — (ii)

~~$\Rightarrow V/R = 5$, $V/R + 2V = 4$ $\Rightarrow V/R = 4 - 2V$ Equating $5 = 4 - 2V$ $\Rightarrow 2V =$~~

$\therefore V = 5R$ — (iii)

$V = 4R + 8$

$\Rightarrow 5R = 4R + 8$

$\Rightarrow R = 8\ \Omega$

$V = 5 \cdot R = 5 \cdot 8 = 40$ Volt

$\therefore$ resistance of $R_h = 8\ \Omega$

23.

Fan motor is operated at $I = 3.50$ Amp

$V = 115\ V$

$R = \frac{V}{I} = \frac{115}{3.50} = 32.8\ \Omega$

When it is connected in ~~series~~ Crustine City,

$V = 125\ V$,

Rated Current $= 3.5\ A$,

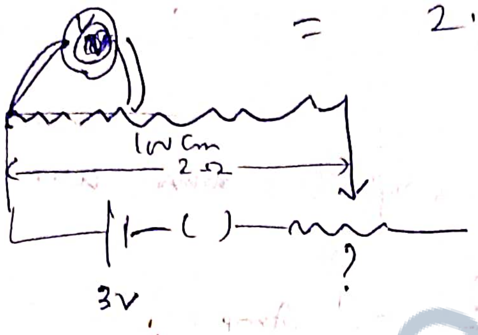
$R = \frac{V}{I} = \frac{125}{3.5} = 35.71\ \Omega$

Extra a resistor will be connected

of resistance = $35.71\Omega - 32.85\Omega$

$= 2.86\ \Omega$

21.



For the length 1mm voltage = 1mV

" " " 1000 mm " = 1000mV

= 1 Volt

(I) Current $= \dfrac{V}{R+r} = \dfrac{1}{2\Omega + r}$ (where r is resistance of Rheostat)

$\Rightarrow I = \dfrac{1}{2+r}$ Amp.

If passes through battery 3V.

R or Rh $= \dfrac{V}{I} = \dfrac{3}{\frac{1}{2}} = 6\ \Omega$

Current in the wire $I = \dfrac{V}{R} = \dfrac{1\text{ volt}}{2\Omega} = \dfrac{1}{2}$ Amp.

Total potential difference $= 3V + 1V = 4$ volt.

Total resistance $= R + r$

$= 2\Omega + r$

$V = IR$

$\Rightarrow 4 = \left(\frac{1}{2} + \frac{V}{r}\right)\cdot(2+r)$

$\Rightarrow 4 = \left(\frac{1}{2} + \frac{3}{r}\right)(2+r)$

$= \left(\frac{r+6}{2r}\right)(2+r)$

$\Rightarrow 8r = 2r + r^2 + 12 + 6r$

$I = \dfrac{V}{R+r}$

$\Rightarrow \dfrac{1}{2} + \dfrac{V_{battery}}{R+r} = \dfrac{V}{R+r} = \dfrac{4}{2+r}$

$\Rightarrow \dfrac{1}{2} + \dfrac{3}{2+r} = \dfrac{4}{2+r}$

$\Rightarrow \frac{1}{2} = \frac{1}{2+r}$

$\Rightarrow 2+r = 2$

Current through the ~~wire~~ wire

$I = \frac{V}{R} = \frac{1}{2} = \frac{1}{2}$ Amp.

~~Also~~ i.e Current passing through battery $= \frac{1}{2}$ Amp.

battery has $V = 3V$.

$I = \frac{1}{2}$ volt

$R = \frac{V}{I} = \frac{3V}{\frac{1}{2}V} = 6$ volt

This $R =$ Resistance of Rh + resistance of wire

$\Rightarrow 6 = r + 2\Omega$

$\Rightarrow r = ~~4\Omega~~ \; 4\Omega$

$\therefore$ resistance of Rh $= 4\Omega$

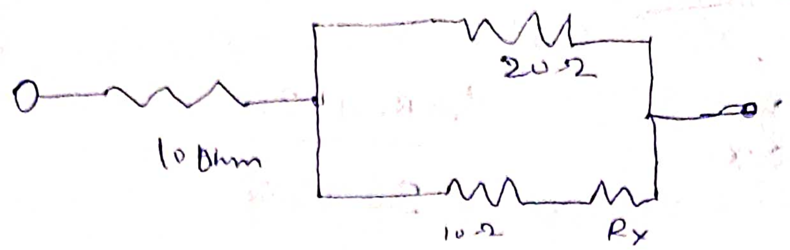
25. $Q = IT$

$\Rightarrow \cancel{1.6 \times 10^{-19} e}$ $Q = 1.25 \times (24 \times 3600)$

$= 108 \times 10^3 = 10.8 \times 10^4$

Number of electron $= \frac{10.8 \times 10^4}{1.6 \times 10^{-19}} = 6.75 \times 10^{23}$ electrons

4.



When 20Ω, 10Ω and Rx are connected in ~~series~~ parallel

$$\frac{1}{R_P} = \frac{1}{20} + \frac{1}{10} + \frac{1}{R_x}$$

$$\frac{1}{R_P} = \frac{R_x + 2R_x + 20}{20 R_x}$$

$$\Rightarrow R_P = \frac{3R_x + 20}{20R_x} = \frac{20R_x}{3R_x+20}$$

But R_P and 10 ohm are connected series

Then $R_s = \left(\frac{20R_x}{20 + 3R_x} + 10 \right)$

$\therefore$ Net resistance $= \left(\frac{20R_x + 200 + 30R_x}{20 + 3R_x} \right)$

But According to question

$$R_x = \frac{203 R_x + 20}{20 R_x}$$

$$\Rightarrow 20R_x^2 - 203R_x - 20 = 0$$

$$\Rightarrow R_x = \frac{203 \pm \sqrt{(203)^2 - 4.(20)(-20)}}{2 \cdot (20)}$$

~~= 203 ±~~

$$R_x = \frac{50R_x + 200}{20 + 3R_x}$$

$$\Rightarrow 20R_x + 3R_x^2 = 50R_x + 200$$

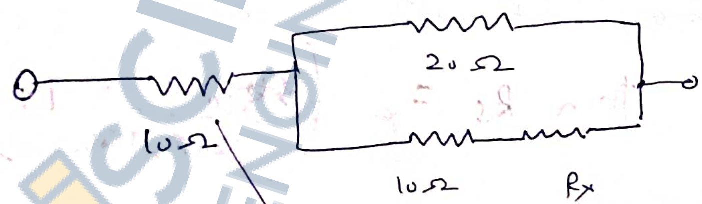
$$\Rightarrow 3R_x^2 - 30R_x - 200 = 0$$

$$\Rightarrow R_x = \frac{30 \pm \sqrt{900 - 4\cdot(3)(-200)}}{2\cdot(3)}$$

$$= \frac{30 \pm \sqrt{900 + 2400}}{6}$$

$$= 30 \pm \sqrt{3300}$$

Again



When 20, 10, R_x are connected in parallel.

$$\frac{1}{R_p} = \frac{1}{20} + \frac{1}{10} + \frac{1}{R_x} = \frac{R_x + 2R_x + 20}{20R_x} = \frac{3R_x + 20}{20R_x}$$

$$\Rightarrow R_p = \frac{20R_x}{20 + 3R_x}$$

Then R_p and 10Ω are connected in series.

∴ Net resistance $= 10 + \dfrac{20R_x}{20+3R_x}$

$$= \frac{200 + 30R_x + 20R_x}{20+3R_x}$$

$$= \frac{200 + 50R_x}{20+3R_x}$$

According to question

$$R_x = \frac{200+50R_x}{20+3R_x}$$

$$\Rightarrow 20R_x + 3R_x^2 = 200 + 50R_x$$

$$\Rightarrow 3R_x^2 - 30R_x - 200 = 0$$

$$\Rightarrow R_x = \frac{30 \pm \sqrt{900 - 4(3)(-200)}}{6}$$

$$= \frac{30 \pm \sqrt{900+2400}}{6}$$

$$= \frac{30 \pm \sqrt{3300}}{6}$$

∴

R_x = Net resis

$$R_x = 10\,\Omega + R_P = 10\,\Omega + \frac{20(10+R_x)}{30+R_x}$$

$$\cancel{= 10\,\Omega + \left(\frac{1}{20} + \frac{1}{10+R_x}\right)}$$

But $\dfrac{1}{R_P} = \dfrac{1}{20} + \dfrac{1}{10+R_x}$

$$= \frac{10+R_x+20}{20(10+R_x)} = \frac{30+R_x}{20(10+R_x)}$$

Solve it

$$\Rightarrow R_P = \frac{20(10+R_x)}{30+R_x}$$

$R_x = 22.36$

10.12.23

10. Two lamps ~~with Conjun~~

have potential difference $= (50+50)V$
$= 100V$.

They are connected in series in 120 Volt

Potential difference remain = 20 volt

Current = 2 Amp.

resistance of Rh will be $= \frac{V}{I} = \frac{20}{2} = 10\,\Omega$

14. $\frac{1}{R_P} = \frac{1}{20} + \frac{1}{30} + \frac{1}{40}$

$\Rightarrow \frac{1}{R_P} = \frac{6+4+3}{120} = \frac{13}{120}$

$\Rightarrow R_P = \frac{120}{13} = 9.23\,\Omega$

23. $5\,\Omega$ and $7\,\Omega$ are connect in ||.

$\frac{1}{R_P} = \frac{1}{5} + \frac{1}{7} = \frac{7+5}{35} = \frac{12}{35}$

$\Rightarrow R_{P_1} = \frac{35}{12}$

$4\,\Omega$ and $3\,\Omega$ are connected in parallel.

$$R_{P_2} = \frac{4 \times 3}{4+3} = \frac{12}{7}$$

Then R_{P_1} and R_{P_2} are connected in series.

$\therefore R_S =$ ~~Resistance~~ Total resistance

$$= \frac{12}{7} + \frac{35}{12}$$

$$= \frac{144 + 245}{12 \times 7}$$

$$\therefore R_S = \frac{389}{84}\,\Omega$$

$$= 4.63\,\Omega$$

Electrodynamics

It is a branch of physics that deals with change in motion.

When charges flow through a conductor, electric current is produced.

Rate of flow of charge is called current.

$$\therefore \quad I = \frac{Q}{t}$$

In S.I system, Q is in coulomb, t in sec and I is in ampere.

$$\therefore \quad 1 \text{ ampere} = \frac{1 \text{ coulomb}}{1 \text{ sec}}.$$

Defn of Ampere

When 1 coulomb of charge is made to flow through a conductor in 1 sec, a current of 1 ampere is developed in it.

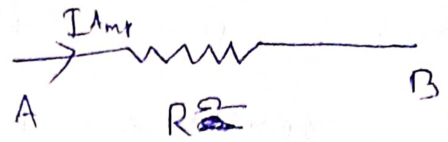
Ohm's law ÷

Statement:

Temp remaining constant, the potential difference between the two ends of a conductor is directly proportional to the current flowing through it.

If the two ends points of the Conductor be denoted by A and B, then

$$(V_A - V_B) \propto I$$



or $V_A - V_B = RI$

where R is a constant called Resistance which depends on temperature and nature of the material.

If we will write $V_A - V_B = V$, then Ohm's law will be given by

$$V = RI.$$

In practical system of units, V is expressed in volts, R in ohms and I in ampere.

Defn of volt

It is that amount of potential difference developed between the two ends of a conductor of resistance 1 ohm through which a current of 1 amp is flowing.

Defn of ohm

It is that amount of resistance of a conductor through which the flow of a current of 1 amp can develop a potential difference of 1 volt between the two ends.

Defn of amp

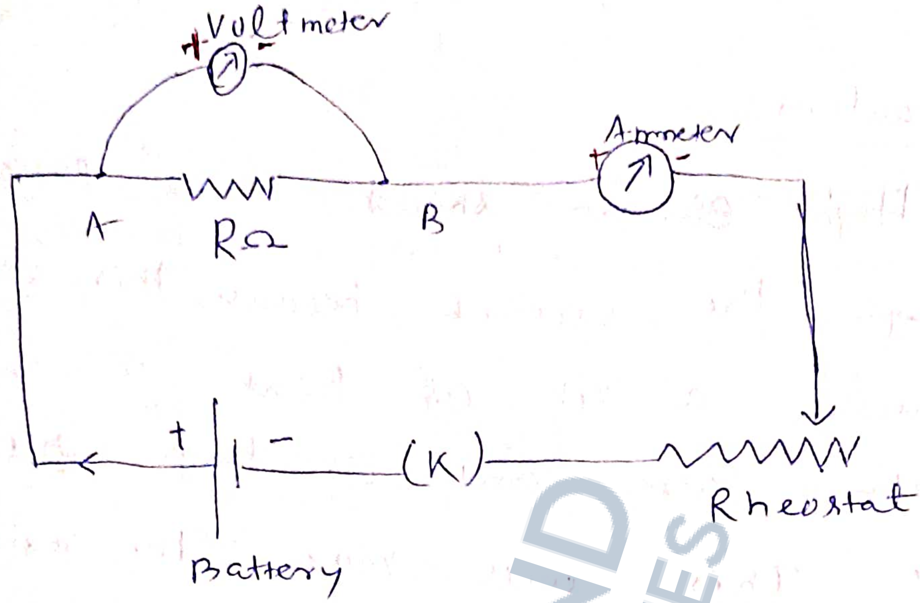
It is that amount of current which when flows through a conductor of resistance 1 ohm can develop a potential difference of 1 ~~ov~~ volt between its two ends.

Experimental verification of ohm's law in the laboratory

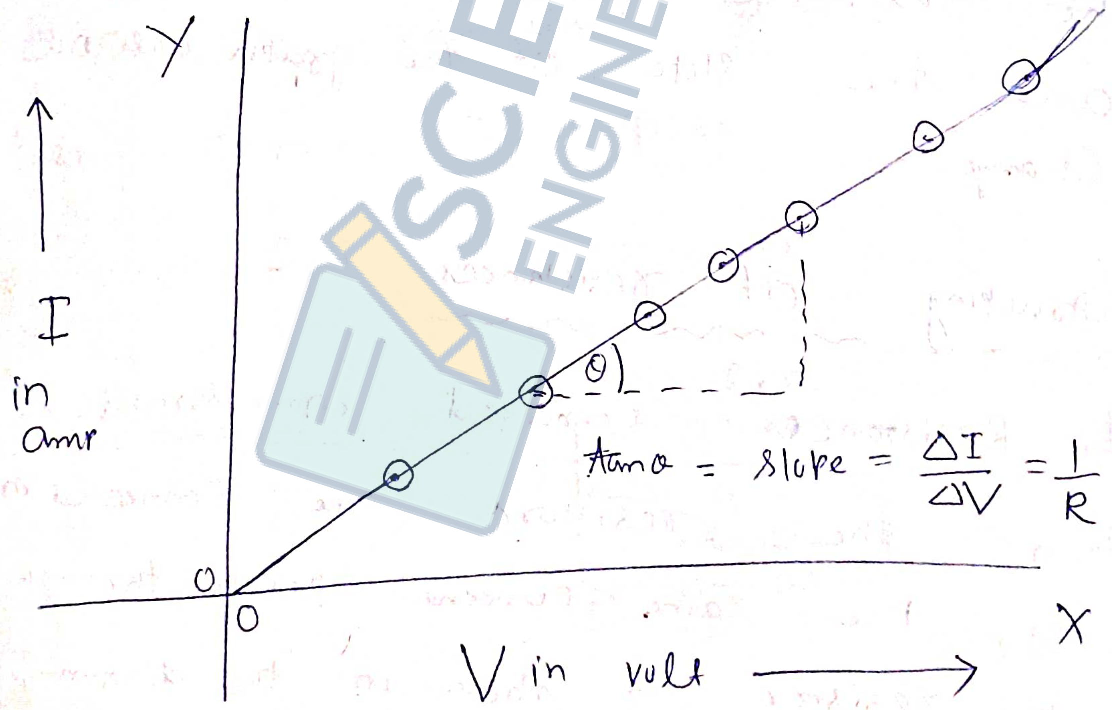
A closed series circuit is prepared with a D.C battery, a key (to start or stop current), a rheostat (by which resistance of the circuit can be changed), a resistance wire AB of fixed resistance R ohm, an ammeter (by which current can be measured).

A voltmeter is connected in parallel to the resistance wire AB as shown in the circuit diagram. By this instrument the potential difference between the two ends of the conductor can found out.

By changing the resistance of the rhestat, different currents are produced in the circuit which are



directly measured by the ammeter. Each time, the potential difference between A and B are also measured by the Voltmeter.



$\tan\theta = \text{slope} = \frac{\Delta I}{\Delta V} = \frac{1}{R}$

A graph can be plotted between P.d and current which comes out to be a straight line passing through the origin.

This verifies Ohm's law. Because $V \propto I$.

Precautions

1. High current should not be passed through the circuit because this will produce a lot off heat in the resistance wire and its temp will rise. This will make the resistance to increase, then we will not get a straight line graph.

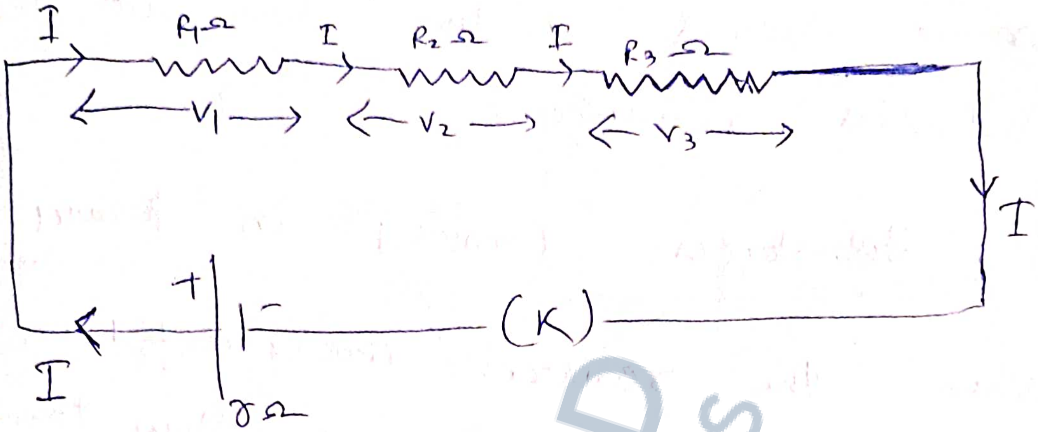
2. In between two observations, the key should be taken out so that the resistance wire will be cooled and the slope of the graph will not change.

Grouping of resistances

1. Resistances connected in series:

When the resistors are connected in series, the same current passes through each resistor as shown in the diagram. Therefore the p.d across each resistor will be different. Applying Ohm's law to each conductor, we have

$$V_1 = R_1 I \quad , \quad V_2 = R_2 I \quad , \quad V_3 = R_3 I \qquad \text{——— (1)}$$



V = Terminal p.d

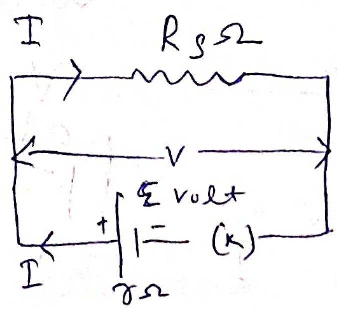
If the p.d across the three resistors be 'V' volt, then

$$V = V_1 + V_2 + V_3 \qquad \text{——— (2)}$$

If the equivalant resistance be R_s, then Ohm's law gives.

$$R_s I = V \qquad \text{——— (3)}$$

Equivalant circuit



Using eqn (1) in eqn (3), we get

$$R_s I = R_1 I + R_2 I + R_3 I$$

$$\Rightarrow R_s = R_1 + R_2 + R_3$$

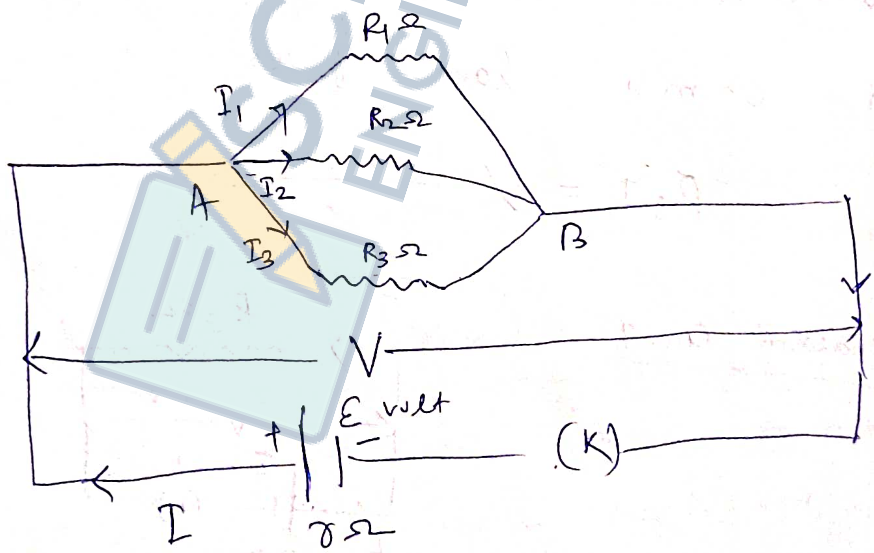
Thus the equivaland resistance when the resistors are connected in series is equal to the sum of the individual resistances.

2. Resistances Connected in parallel

When the resistors are connected in parallel, differrent currents flow through different resistor.

Applying Ohm's law to each resistors, we get

$$V = I_1 R_1 , \quad V = I_2 R_2 , \quad V = I_3 R_3 \quad \text{--- (1)}$$

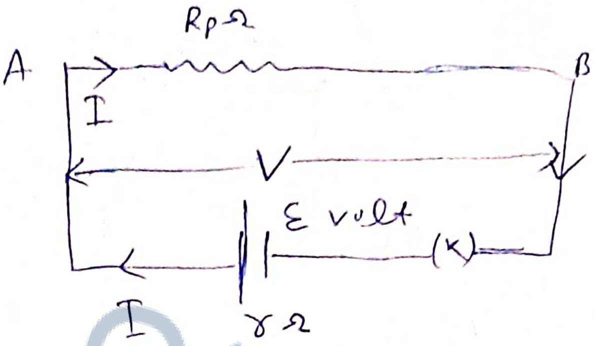


$$\therefore I_1 = \frac{V}{R_1} , \quad I_2 = \frac{V}{R_2} , \quad I_3 = \frac{V}{R_3} \quad \text{--- (2)}$$

But $I = I_1 + I_2 + I_3$ ——— (3)

If the equivalent resistance be R_P, then Ohm's law gives

$$IR_P = V$$



Equivalent circuit

$$\Rightarrow I = \frac{V}{R_P} \quad \text{——} \quad (4)$$

Using eqn (2) and (4) in eqn (3), we get

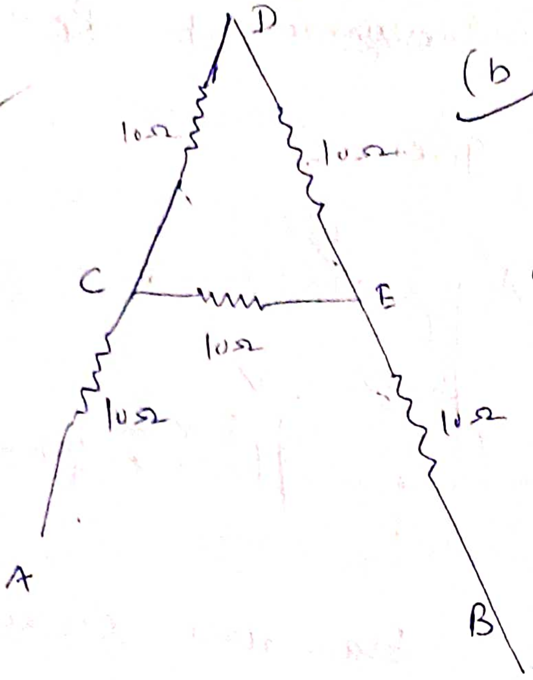
$$\frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\Rightarrow \boxed{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

∴ Thus the reciprocal of the equivalent resistance when the resistors are connected in parallel is equal to the sum of the reciprocals of the individual resistances.

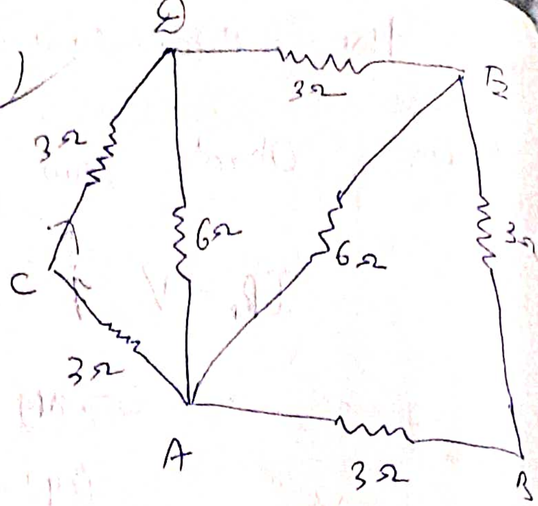
Problem: Find the equivalent resistances between A and B

(a)



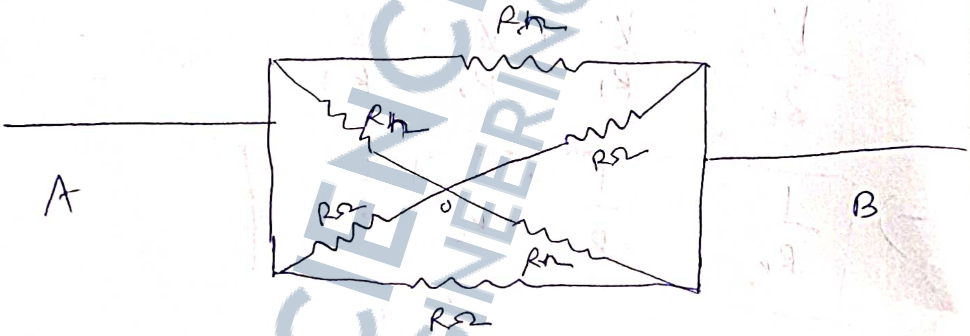
Ans: $\frac{80}{3}\,\Omega$

(b)

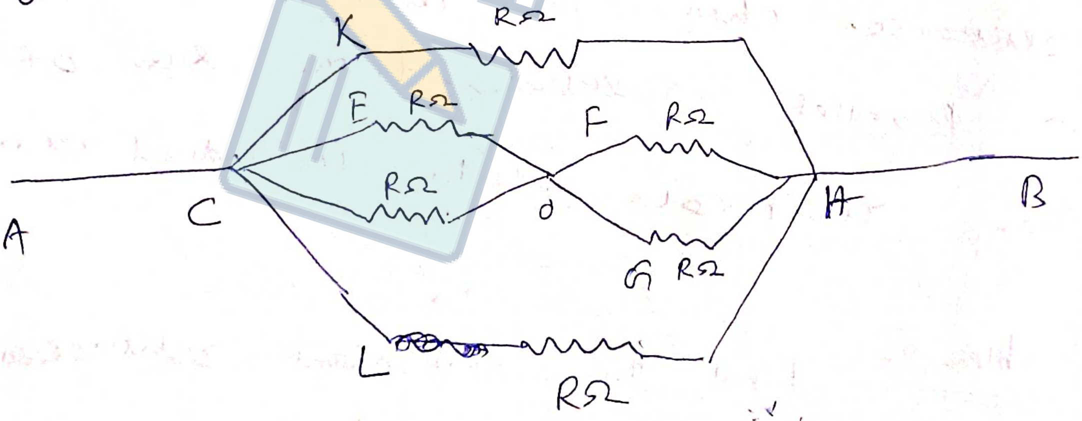


Ans: $2\,\Omega$

(d)

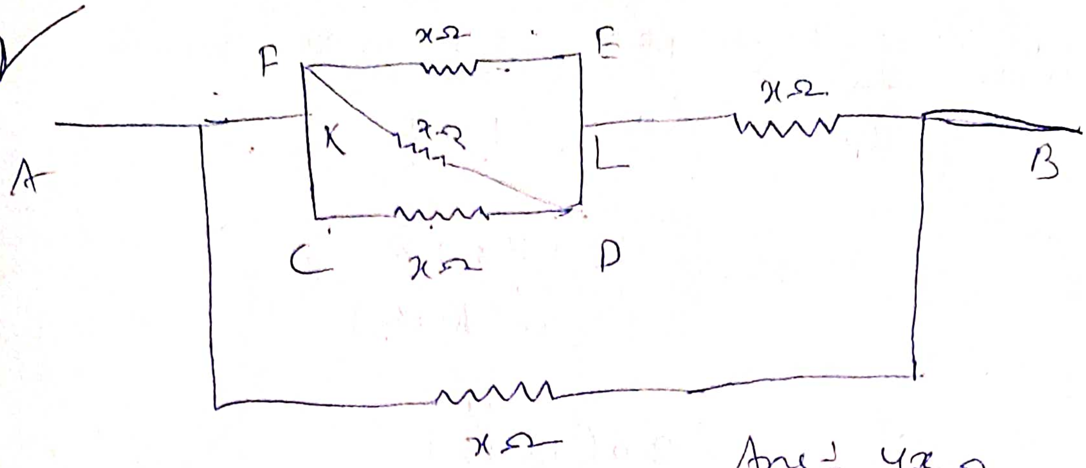


or



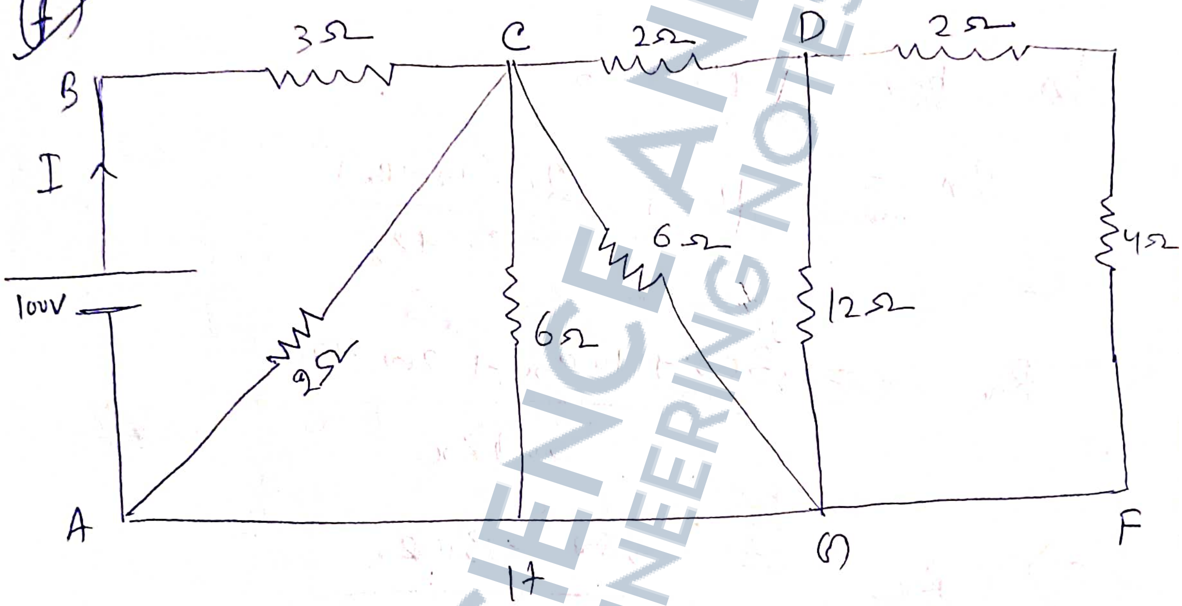
Ans: $\frac{R}{3}$

(e)



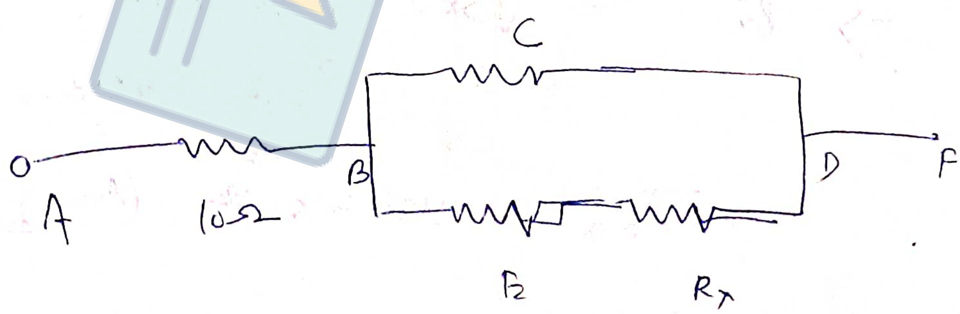
$$Ans = \frac{4x}{7}\ \Omega$$

(f)



$I = ?$ Ans = 25 Amp

4.



Given $R_{AF} = R_x$

Now $R_{AF} = R_{AB} + R_{BD} + R_{DF}$

$= 10 + R_P + 0$

Now $\frac{1}{R_p} = \frac{1}{20} + \frac{1}{10+R_x}$

$$= \frac{10+R_x+20}{20(10+R_x)}$$

$$\Rightarrow R_p = \frac{20(10+R_x)}{30+R_x}$$

As per question

$$R_x = 10 + \frac{20(10+R_x)}{30+R_x}$$

$$R_x = \frac{300+10R_x+200+20R_x}{30+R_x}$$

$$\Rightarrow R_x = \frac{500+30R_x}{30+R_x}$$

$$\Rightarrow \cancel{30R_x} + R_x^2 = 500 + \cancel{30R_x}$$

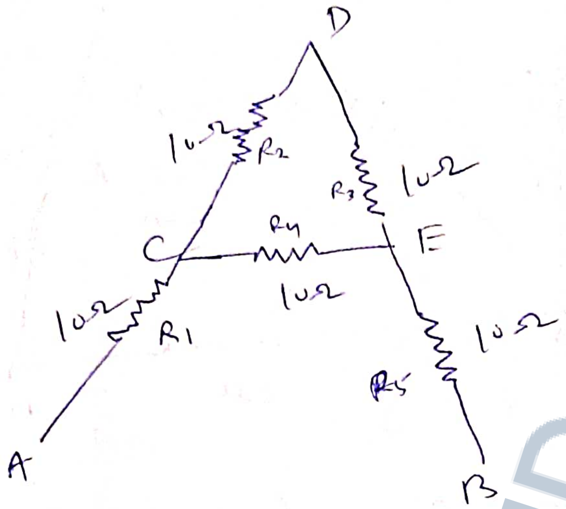
$$\Rightarrow R_x^{\cancel{2}} = \sqrt{500} = \sqrt{5} \times 10$$

$$= 2.236 \times 10$$

$$\therefore R_x = 22.36\,\Omega \quad (\text{Ans})$$

Answer to the Problems

1.



R_2 and R_3 are connected in series

Then the equivalent resistance

$$R_{S_1} = 10\Omega + 10\Omega = 20\Omega.$$

R_{S_1} and R_4 are connect in parallel.

$$\frac{1}{R_{P_1}} = \frac{1}{10} + \frac{1}{20} = \frac{2+1}{20} = \frac{3}{20}$$

$$\Rightarrow R_{P_1} = \frac{20}{3}\,\Omega$$

Also R_1 and R_{P_1} and R_5 are connected in series.

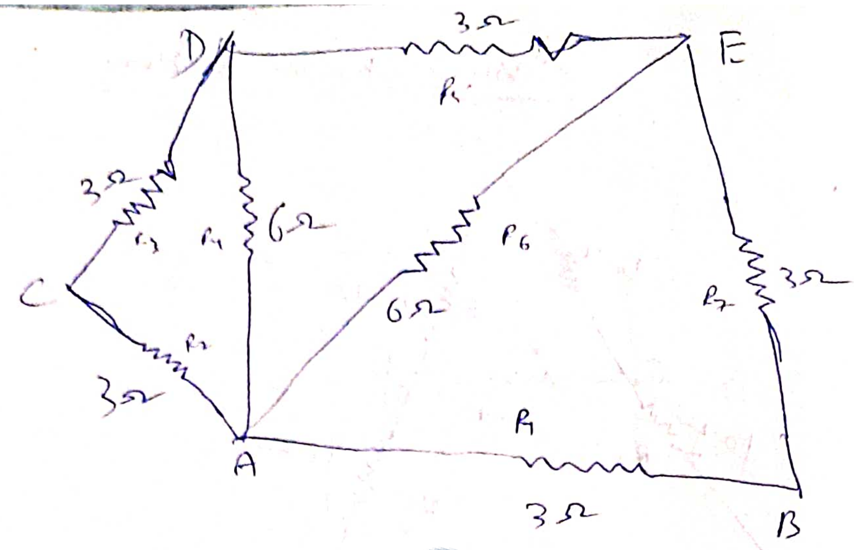
Then equivalent resistance

$$R_{S_2} = 10 + \frac{20}{3} + 10$$

$$= \frac{30+20+30}{3} = \frac{80}{3}\,\Omega$$

$\therefore$ Equivalent resistance between A and B $\frac{80}{3}\,\Omega$

(b)



R_2 and R_3 are connected in series.

Equivalant resistance $R_{s_1} = 6\,\Omega$

R_4 is connected in parallel then

Equivalant resistance

$$\frac{1}{R_{P_1}} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3}$$

$\Rightarrow R_{P_1} = 3$

R_{P_1} and R_5 are connected in series

$R_{S_2} = 3 + 3 = 6\,\Omega$

R_{S_2} and R_6 are connected in ~~series~~ parallel

$$\frac{1}{R_{P_2}} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3}$$

$\Rightarrow R_{P_2} = 3$

R_{P_2} and R_7 are Connected in series

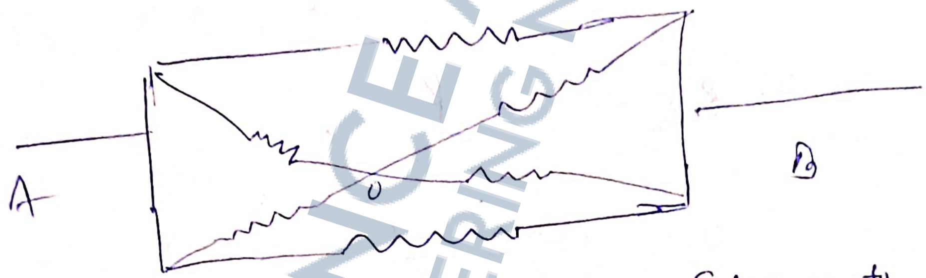
$\therefore R_{S_3} = 3+3 = 6\Omega$.

R_{S_3} and R_1 are Connected in Parallel

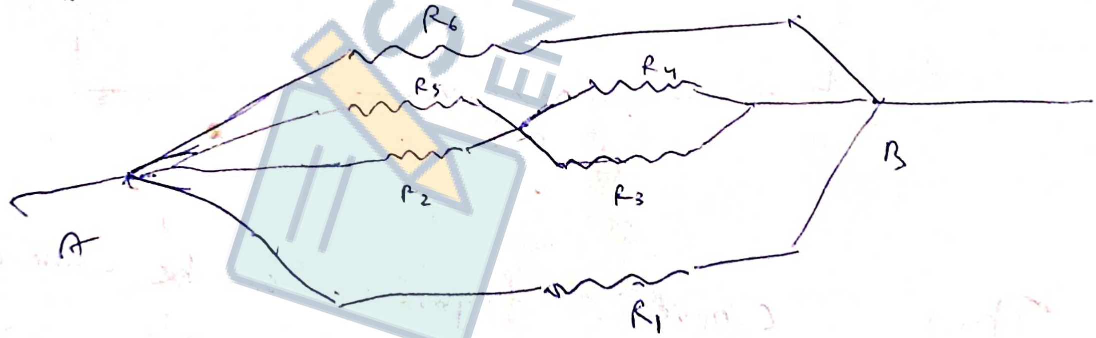
$$\therefore \frac{1}{R_{P_3}} = \frac{1}{6}+\frac{1}{3} = \frac{1+2}{6} = \frac{3}{6} = \frac{1}{2}$$

$\therefore R_{P_3} = 2\Omega$ (Ans)

(d)



This above figure can be change to bellow.



But $R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R$

R_2 and R_5 are Connected in parallel $\therefore R_{P_1} = \frac{R_2 R_5}{R_2+R_5} = \frac{R \cdot R}{2R} = \frac{R}{2}$.

R_4 and R_3 are Connected in Parallel

$\therefore$ Equivalent resistance $= \frac{R}{2}$

But $\frac{R}{2}$ and $\frac{R}{2}$ are in series.

$\therefore$ Net resistance $R_{S_1} = \frac{R}{2} + \frac{R}{2} = R$.

But R_1, R_{S_1} and R_6 are are in parallel

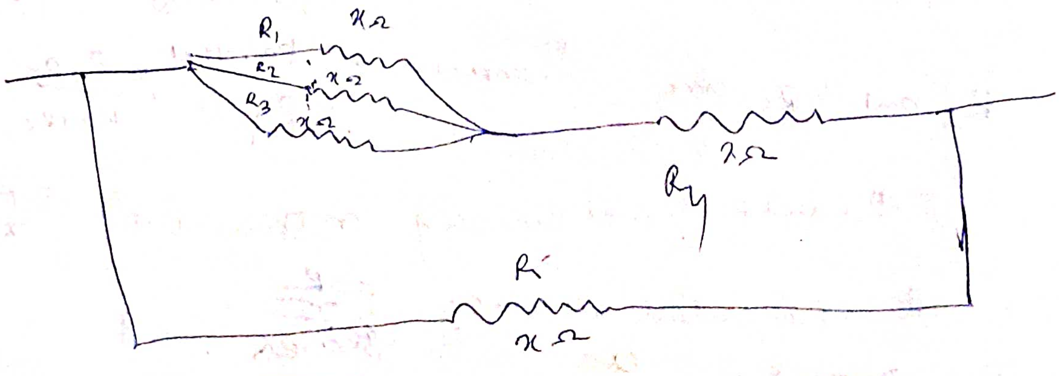
$$\therefore \frac{1}{R_{P_2}} = \frac{1}{R_1} + \frac{1}{R_{S_1}} + \frac{1}{R_6}$$

$$= \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$

$$\Rightarrow R_{P_2} = \frac{R}{3}$$

(e)

This above figure can be written as



From the figure R_1, ~~and~~ R_2 and R_3 are connected in series.

The equivalant resistance R_{P_1}

$$\therefore \frac{1}{R_{P_1}} = \frac{1}{x} + \frac{1}{x} + \frac{1}{x} = \frac{3}{x}$$

$$\Rightarrow R_{P_1} = \frac{x}{3}\ \Omega$$

then R_{P_1} and R_4 are ~~are~~ connected in series.

$$\therefore R_{C_1} = \frac{x}{3} + x = \frac{x + 3x}{3} = \frac{4x}{3}.$$

Then RS_1 is ~~para~~ connected in parallel with R_5

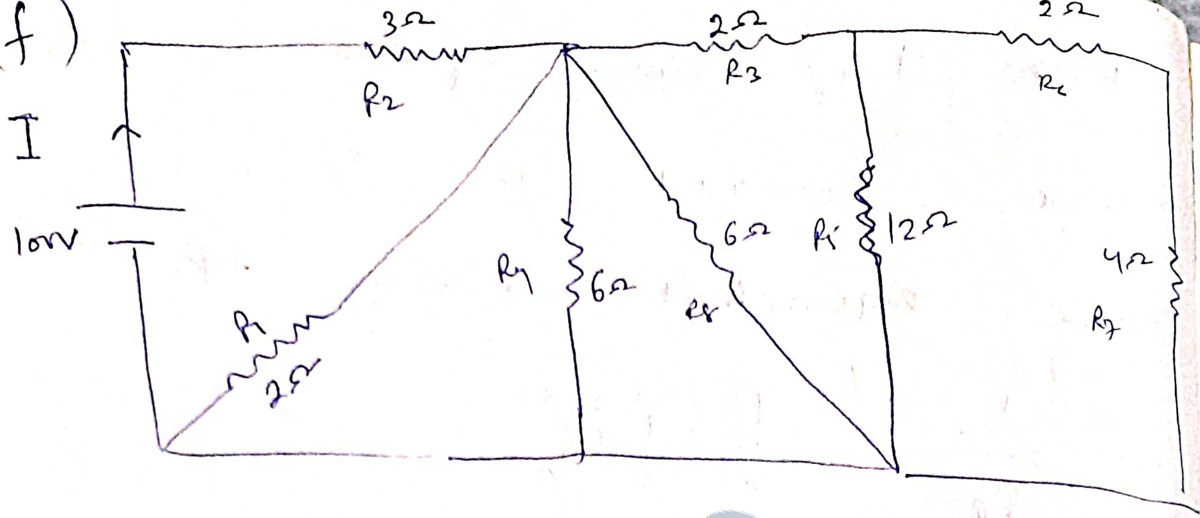
$$\therefore \frac{1}{R_{P_2}} = \frac{1}{x} + \frac{3}{4x}$$

$$\Rightarrow \frac{1}{R_{P_2}} = \frac{4+3}{4x} = \frac{7}{4x}\ \Omega$$

$$\Rightarrow R_{P_2} = \frac{4x}{7}\ \Omega$$

$\therefore$ Equivalant resistance between A and B is $\frac{4x}{7}\ \Omega$

(f)



R_6 and R_7 are connected in series.

$$R_{S_1} = 2+4 = 6\Omega$$

R_{S_1} and R_5 are connected in parallel

$$\frac{1}{R_{P_1}} = \frac{1}{6} + \frac{1}{12} = \frac{2+1}{12} = \frac{3}{12}\Omega$$

$$\Rightarrow R_{P_1} = \frac{12}{3} = 4\Omega$$

R_{P_1} and R_3 are connected in series

$$R_{S_2} = 4\Omega + 2\Omega = 6\Omega.$$

R_{S_2} and R_8 are connected in parallel

$$\frac{1}{R_{P_2}} = \frac{1}{6} + \frac{1}{6} = \frac{2}{6} = \frac{1}{3}$$

$$\Rightarrow R_{P_2} = 3\Omega$$

~~R_{P_2} and R_4 are connected in series.~~

$$\cancel{R_{S_3} = 6+3 = 9\Omega}$$

R_{P_2} and R_4 are connected in parallel.

$$\therefore \frac{1}{R_{P_3}} = \frac{1}{3} + \frac{1}{6} = \frac{2+1}{6} = \frac{3}{6} = \frac{1}{2}$$

$$\Rightarrow R_{P_3} = 2\,\Omega$$

R_{P_3} and R_1 are connected in parallel.

$$\therefore \frac{1}{R_{P_4}} = \frac{1}{2} + \frac{1}{2} = 1$$

$$\Rightarrow R_{P_4} = 1\,\Omega.$$

R_{P_4} and R_2 are connected in series.

$$\therefore R_{S_3} = 1\,\Omega + 3\,\Omega = 4\,\Omega.$$

$\therefore$ Net resistance $R = 4\,\Omega$.

Voltage = 100 V.

$$I = \frac{V}{R} = \frac{100\,V}{4\,\Omega} = 25 \text{ Amp.}$$

Variation of resistance with temperature

When a temperature of a wire is increased the atoms or molecules start to vibrate more and more. As a result the free electrons will experience greater number of collisions. and the resistance increases. The formula connecting the resistance at a higher temperature with a resistance at 0° is given by

$$\boxed{R_\theta = R_0(1+\alpha\theta)}$$

where, α is a constant for a particular material is called temperature Co-efficient of resistance.

R_0 = Resistance at 0° C

R_θ = Resistance at θ° C

$$\alpha = \frac{R_\theta - R_0}{R_0 \cdot \theta} = \frac{\frac{\Delta R}{R_0}}{\Delta\theta}$$

Because $\Delta\theta = \theta - 0$

= Rise of temp.

Thus, temp Co-efficient of resistance can be defined as the ratio of change in resistance to the original resistance at 0° C per degree rise of temp.

Unit of α

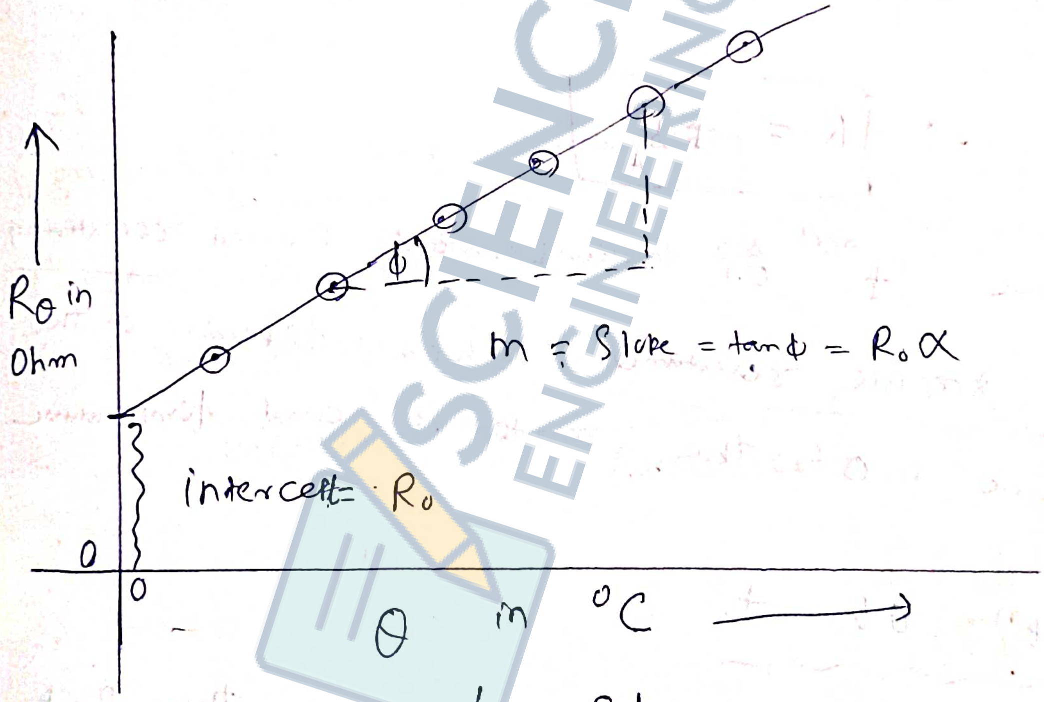
$/^{\circ}C = {}^{\circ}C^{-1}$ or F^{-1} ✓

If a graph be plotted with θ along X-axis and R_θ along Y-axis, it comes out to be a straight line having

Intercept $= R_0$ and slope $= R_0\alpha$.

([illegible])

$$R_\theta = R_0 + R_0\alpha\theta$$
$$y = c + mx$$



$$\alpha = \frac{\text{Slope}}{\text{intercept}}$$

Resistivity or specific resistance

Experimentally it is found that resistance of a conductor vary directly as the length of it when area of cross-section is kept constant.

$\therefore$ $R \propto l$, when A is kept constant.

Resistance of conductor is found to be inversely proportional to the area of cross section when length of conductor is kept constant.

$$\therefore \quad R \propto \frac{1}{A}, \text{ when } l \text{ is kept constant.}$$

Combining these two variations, we have

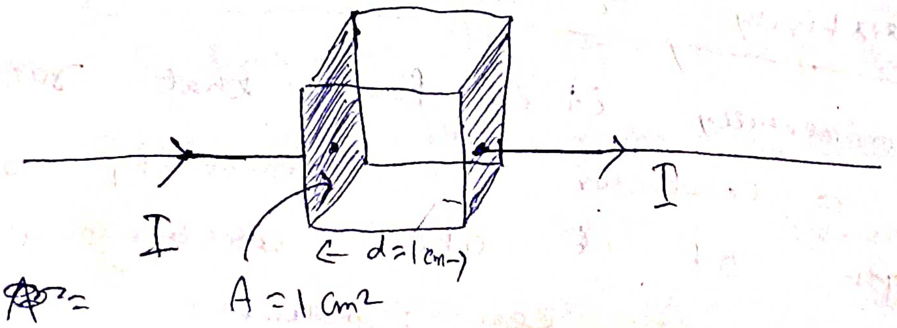
$$R \propto \frac{l}{A}, \text{ when both } l \text{ and } A \text{ vary.}$$

$$\therefore \quad \boxed{R = \rho \frac{l}{A}}$$

where ρ is a constant called <u>resistivity</u> or <u>specific resistance</u> which depends on the nature of the material and temperature.

Defn of ρ

If $l = 1$ cm, $A = 1\ cm^2$ then $R = \rho$



Thus, specific resistance or resistivity of a material can be defined as numerically equal to the resistance between the opposite faces of a unit cube made out of the material.

Unit of ρ

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

1. C.G.S unit $= \frac{\text{Ohm}.\text{Cm}^2}{\text{Cm}} = \text{ohm-Cm}$

2. M.K.S unit $= \frac{\text{Ohm}.\text{m}^2}{\text{m}} = \text{Ohm.metre}$

Conductivity and Conductance

Conductance is defined as the reciprocal of resistance.

i.e. Conductance $= \frac{1}{\text{Resistance}} = \frac{1}{\text{Ohm}} = (\text{Ohm})^{-1}$

or mho

$(\mho)$

Conductivity is defined as reciprocal of resistivity.

$$\text{Conductivity } (\sigma) = \frac{1}{\text{Resistivity } (\rho)}$$

(1) C.G.S unit of $\sigma = \frac{1}{\text{Ohm.cm}} = \frac{1}{\text{Ohm}} \cdot \frac{1}{\text{Cm}}$

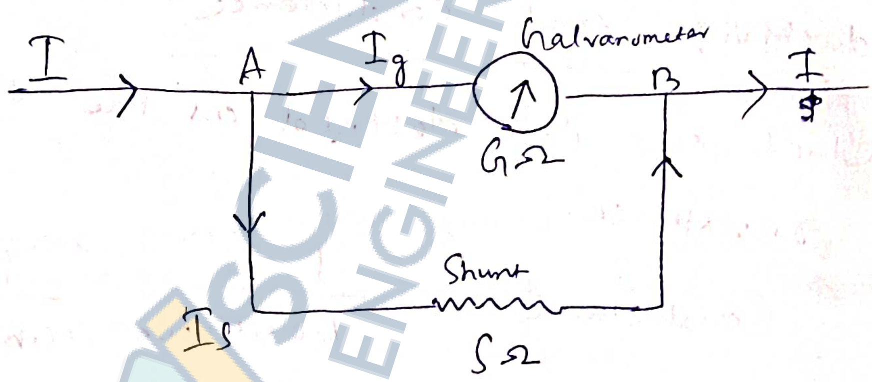
$= \text{mho} \cdot \text{cm}^{-1}$

② M.K.S unit of σ)

$$= \frac{1}{\text{Ohm. metre}} = \frac{1}{\text{Ohm}} \cdot \frac{1}{\text{metre}} = \text{mho} \cdot m^{-1}$$

* Shunt

It is a ~~low~~ low resistance connected in parallel to costly electrical instrument like galvanometres to save them from the damage caused by the passage of high current. (How) In this regard shunt acts like a bypass road of a city.



To express the galvanometre current (I_g) and the shunt current I_s in terms of the main current I, we see that

$$V_A - V_B = I_g \cdot G = I_s \cdot S$$

or $$\frac{I_s}{I_g} = \frac{G}{S}$$

~~Applying~~ Adding 1 to both the sides, we have

$$\frac{I_s}{I_g} + 1 = \frac{G}{S} + 1$$

$$\Rightarrow \cancel{\frac{I_s + I_G}{I_G}}$$

$$\Rightarrow \frac{I_s + I_g}{I_g} = \frac{G+S}{S}$$

$$\text{or} \quad \frac{I}{I_g} = \frac{G+S}{S}$$

$$\text{or} \quad \frac{I_g}{I} = \frac{S}{G+S}$$

$$\therefore I_g = I\left(\frac{S}{G+S}\right)$$

(My hints: S is ~~an~~ very very small, $\frac{S}{G+S}$ very small i.e fraction so $I_G < I$)

$$\therefore I_s = \frac{I_g \cdot G}{S} = \frac{\left(\frac{S}{G+S}\right) \times I \times G}{S}$$

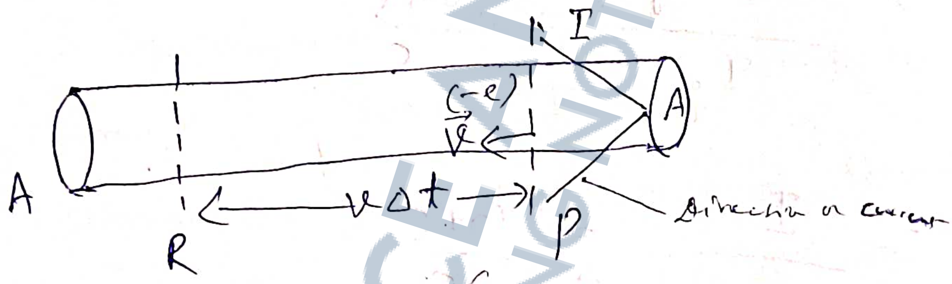
$$= \frac{\cancel{S} \times G \times I}{\cancel{S}(G+S)}$$

$$= \left(\frac{G}{G+S}\right) I$$

(S is very small, G+S is $\simeq$ G, $\frac{G}{G+S} \simeq 1$, $I_s \simeq I$. So most of the current passes through shunt. So the instrument is saved)

To prove that $I = nAve$

Let there be a conductor of area of cross section A in which a current of I ampere is flowing. Lets try to calculate the number of electrons crossing a particular reference mark P



In a time Δt, all the electrons crossing the reference line P will be within the line R. The volume of the cylinder between P and R is

$= A v \Delta t$

If n be the number of free electrons per unit volume, then total number of electrons present within this cylinder equal to $nAv\Delta t$. Magnitude of the charge contained by each electron equal to e.

$\therefore$ Total Charge present in the cylinder

$= n.A v \Delta t . e$

$= \Delta Q$ (say)

= Charge that has crossed the reference line at p during Δt sec.

$$\therefore I = \frac{\Delta Q}{\Delta t} = \frac{n A v \Delta t . e}{\Delta t} = n A v e \text{ (Proved)}$$

where n = number of electrons per unit volume.
A = Area of cross section of conductor
v = velocity of electron, e = Charge of electron.

Origin of resistance

It has been calculated that number of electrons present per meter^3 of a good conductor is 10^{28}. This is a large number. In the absence of an external electric field, these electrons move at random and the vector sum of the velocities becomes zero.

$$\vec{v}_{Avg} = \frac{\vec{u}_1 + \vec{u}_2 + \cdots \cdots + \vec{u}_N}{N}$$

$= 0$

If t_1 be the time taken by the first electron to collide with another electron, due to the application of an external electric field intensity, then the velocity at the time of collision is given by $\vec{V_1} = \vec{u_1} + \vec{a}t_1$

where $\vec{a}$ = accⁿ of the electron.

$$= \frac{\text{Force}}{\text{Mass}} = \frac{q.\vec{E}}{m} = \frac{-e\vec{E}}{m}$$

where $\vec{E}$ = Net external field intensity ~~along in the~~ acting on the first electron.

Similarly, the second electron will have a velocity $\vec{V_2}$, given by

$$\vec{V_2} = \vec{u_2} + \vec{a}t_2$$

and for the last electron

$$\vec{V_N} = \vec{u_n} + \vec{a}t_n$$

Average velocity of all these electrons colliding with other electrons is given by

$$\vec{V}_{avg} = \frac{\vec{V_1} + \vec{V_2} + \vec{V_3} + \cdots + \vec{V_N}}{N}$$

$$\vec{V}_{avg} = \frac{(\vec{u_1} + \vec{a}t_1) + (\vec{u_2} + \vec{a}t_2) + \cdots + (\vec{U_N} + \vec{a}t_N)}{N}$$

$$= \frac{(\vec{u_1} + \vec{U_2} + \cdots + \vec{U_n})}{N} + \frac{\vec{a}(t_1 + t_2 + \cdots + t_n)}{N}$$

$$= 0 + \vec{a}\tau$$

where τ is called Relaxation time which is defined as the average time taken by the electrons to collide with another electron.

The average speed of an electron inside the conductor is due to many collisions this average velocity of electron is called drift velocity given by the expression.

$$\vec{V_d} = \vec{a} \cdot \tau = \left(\frac{-e \cdot \vec{E}}{m}\right) \cdot \tau$$

We know that current is relate to the drift velocity by the formula

$$I = n \cdot A \cdot V_d \cdot e$$

$$= n \cdot A \cdot \left(\frac{-e \cdot \vec{E}}{m}\right) \cdot \tau \cdot e$$

$$\text{or } \frac{V}{R} = n \cdot A \left(\frac{-e \cdot \vec{E}}{m}\right) \cdot \tau \cdot e$$

or $\frac{V}{R} = -nA \cdot \left(-e \cdot \frac{\Delta V}{\Delta x}\right) \tau \cdot \frac{e}{m}$

$\Rightarrow \frac{V}{R} = nAe \frac{V}{l} \cdot \frac{\tau \cdot e}{m}$

Because

V = P.d across the Conductor of length l

$= \Delta V$

$\Rightarrow \frac{1}{R} = \frac{n \cdot A\, e^2 \cdot \tau}{ml}$ = Conductance —(1)

$R = \frac{ml}{n \cdot A \cdot e^2 \tau}$ = Resistance —(2)

But resistivity (ρ) is related to the resistance by the formula

$R = \rho \cdot \frac{l}{A}$ ———(3)

Comparing the eqns ② and ③ we get

$\rho = \frac{m}{ne^2\tau}$ —④

= Resistivity

Conductivity $= \sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$ —⑤

When the temp of conductor is increased the electrons will acquire thermal energy [($\frac{1}{2}KT$) per degree of freedom] and they will collide more often

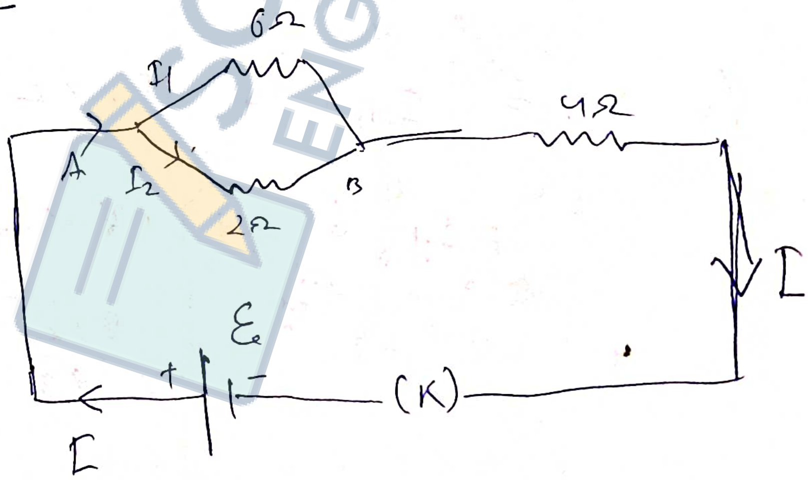
hence τ will be decrease from the expression (ii) and (iv) we see that resistance and resistivity will increase

on the other hand from the expression (5) and (i) we see that conductivity and conductance decreases..

— o —

Page → 654

3v.



$r = 0.5\Omega$

6 Ω resistance and 2 Ω resistance are connected in parallel

$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{2} = \frac{2+6}{12} = \frac{8}{12}$$

$\Rightarrow R_p = \frac{12}{8} = \frac{6}{4} = \frac{3}{2}$

R_p and $4\,\Omega$ are connected in series,

$R_{S_1} = R_p + 4\Omega = \frac{3}{2} + 4 = \frac{3+8}{2} = \frac{11}{2}$

Total resistance $= R_{S_1} + 8$

$= \frac{11}{2} + 0.5$

$= \frac{11+1}{2} = \frac{12}{2}$

$= 6\,\Omega$

Current $= \frac{e.m.f}{\text{total resistance}} =$

$V_A - V_B = I_1 6 = I_2 \times 2$

$= I_1\, 6 = .8 \times 2$

$\Rightarrow I_1 = \frac{.8 \times \cancel{2}}{\cancel{6}\,3}$

Total current $= I_1 + I_2$

$= \frac{.8}{3} + .8$

$= \frac{.8 + 2.4}{3} = \frac{3.2}{3}$

$$\cancel{E = \frac{I}{R+r} = \frac{\frac{3.2}{3}}{6}}$$

$$= \quad \text{Current} = \frac{\text{e.m.f}}{\text{Total resistance}}$$

Take ~~,20~~ 22 $\Rightarrow$ emf = Current $\times$ Total resistance

$$= \frac{3.2}{3} \times 6\,\Omega$$

$$= 6.4 \text{ volt}$$

$\boxed{20, 22}$

20.

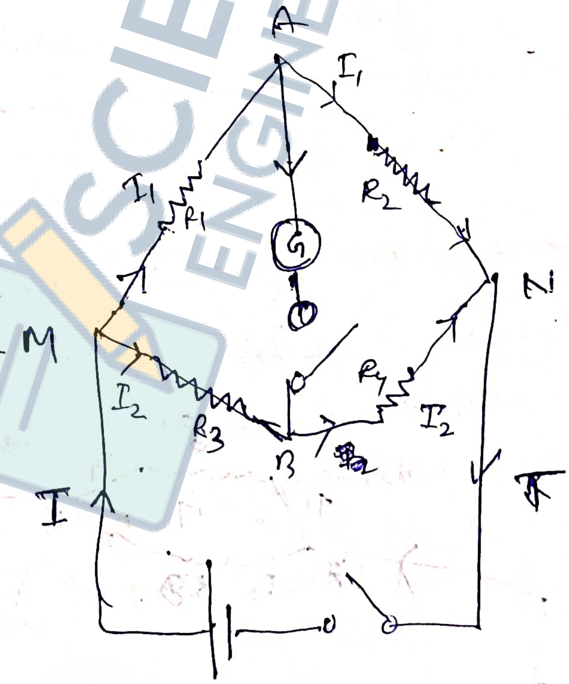
Given that

$R_1 = 12\,\Omega$, $R_2 = 15\,\Omega$

$R_3 = 60\,\Omega$, $R_4 = 75\,\Omega$

$R_n = 125\,\Omega$

$V = 2.48\,V$



The bridge is said to be balanced, when A and B are at same potential.

i.e $V_{MA} = V_{MB}$

$$\Rightarrow R_1 I_1 = I_2 R_3$$

$$\Rightarrow 12 \cdot I_1 = I_2 \cdot 60\,\Omega$$

Similarly $V_{AH} = V_{ABH}$

$$R_2 I_1 = R_4 \cdot I_2$$

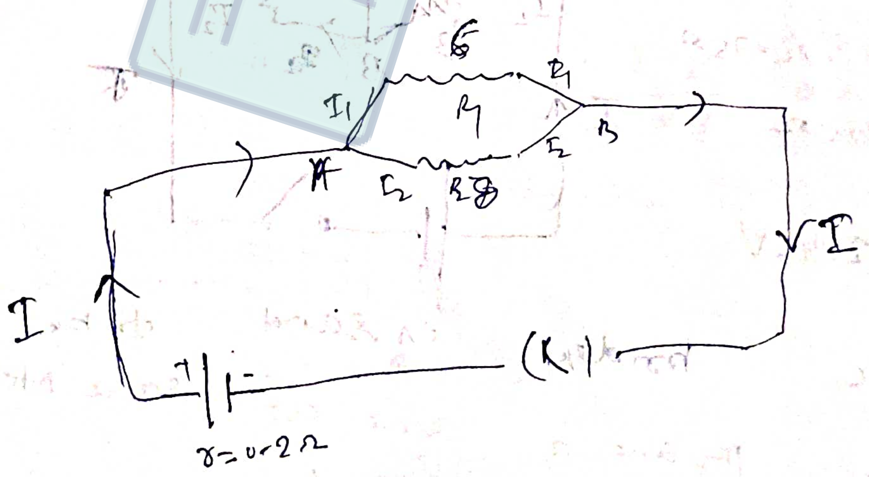
$$\Rightarrow 15\, I_1 = 75 \cdot I_2$$

But Galvanometer has $R = 125\,\Omega$.

Also

Chemical effect of electric current

2Q-..



R_1 and R_2 are connected in series

$$R_{P_1} = \frac{R_1 R_2}{R_1+R_2} = \frac{6\times 8}{6+8} = \frac{48}{14}\frac{24}{7} = \frac{24}{7}\Omega$$

R_{P_1} and r are connected in series.

$$(R+r) = R_{S_1} = \frac{24}{7} + \frac{2}{10} = \frac{240+14}{70} = \frac{254}{70}$$

$$V_A - V_B = I_1 6 = I_2 8$$

$$\Rightarrow I_1 \times 6 = 0.2\times 8$$

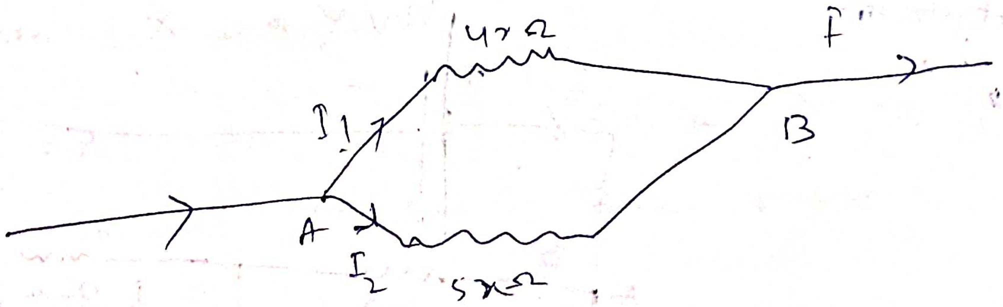
$$\Rightarrow I_1 = \frac{2}{10}\times 8\times \frac{1}{6} = \frac{8}{30}$$

$$\mathcal{E} = I(R+r) = (I_1+I_2)(R+r) \cancel{= \frac{8}{30}\times\frac{254}{70}} =$$

$$= \left(\frac{8}{30}+\frac{2}{10}\right)\times\frac{254}{70} = \frac{8+6}{30}\times\frac{254}{70} = \frac{14}{30}\times\frac{254}{70} = 1.69 \text{ Volt}$$

1. Problems

1. A Conductors carrying a current divides into two branches whose resistances are in the ratio 4 : 5. Compare the amounts of heat generated in the the branches (Ans: 5 : 4)



$V_A - V_B = I_1 \, 4x = I_2 \, 5x$

$\Rightarrow \frac{I_1}{I_2} = \frac{5}{4}$

$$\frac{H_1}{H_2} = \frac{\frac{I_1^2 R_1 \cancel{t}}{\cancel{J}}}{\frac{I_2^2 R_2 \cancel{t}}{\cancel{J}}} = \left(\frac{I_1}{I_2}\right)^2 \times \left(\frac{\rho_1 4x}{\rho_2 5x}\right)$$

$$= \frac{25}{16} \times \frac{4}{5}$$

$$= 5 : 4$$

(2) The resistance of a copper wire $\frac{1}{12}$ inch in diameter is $8\Omega/\text{mile}$

What will be the resistance of the copper wire $\frac{1}{20}$ inch in diameter and a mile long. (Ans: 22.22Ω)

$R_1 = \rho \cdot \frac{L_1}{\frac{\pi d_1^2}{4}}$

(3) Find voltmeter reading in the following circuit. (Ans : 3V)

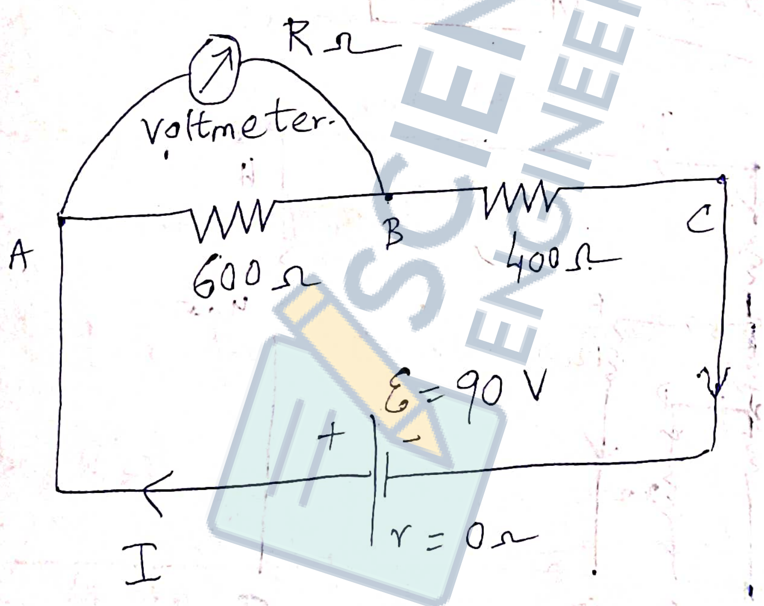
$V_A - V_B = 100 \times I_1 = 200 \times I_2 = I \cdot R_P$

4. A $600\,\Omega$ resistor and $400\,\Omega$ resistor are connected in series across a $90\,V$ line. A voltmeter across the $600\,\Omega$ resistor reads 45 Volt.

(a) Find the voltmeter resistance.

(b) Find the reading of the same voltmeter if connected across the $400\,\Omega$ resistor.

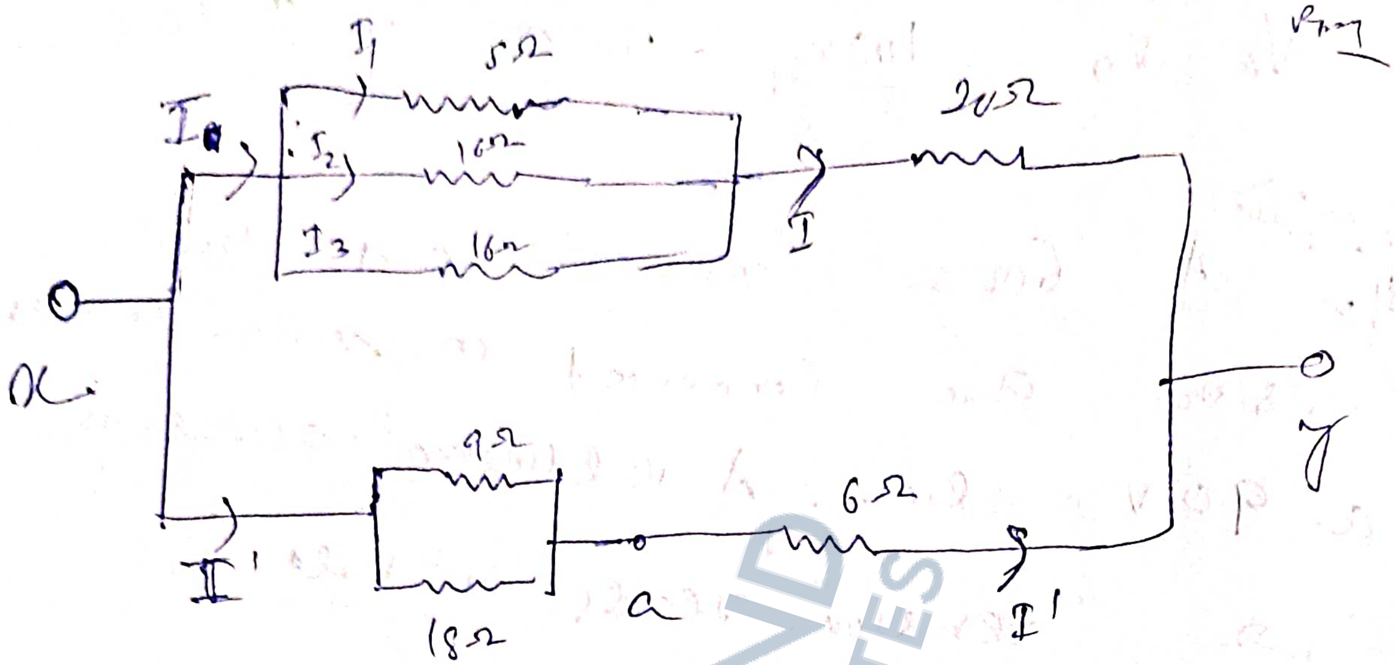
(Ans: $1200\,\Omega$, 30 volt)



5. (a) Calculate the equivalent resistance between X and Y.

(b) Find the P.D between X and a if current in the $8\,\Omega$ resistor is 0.5 Amp

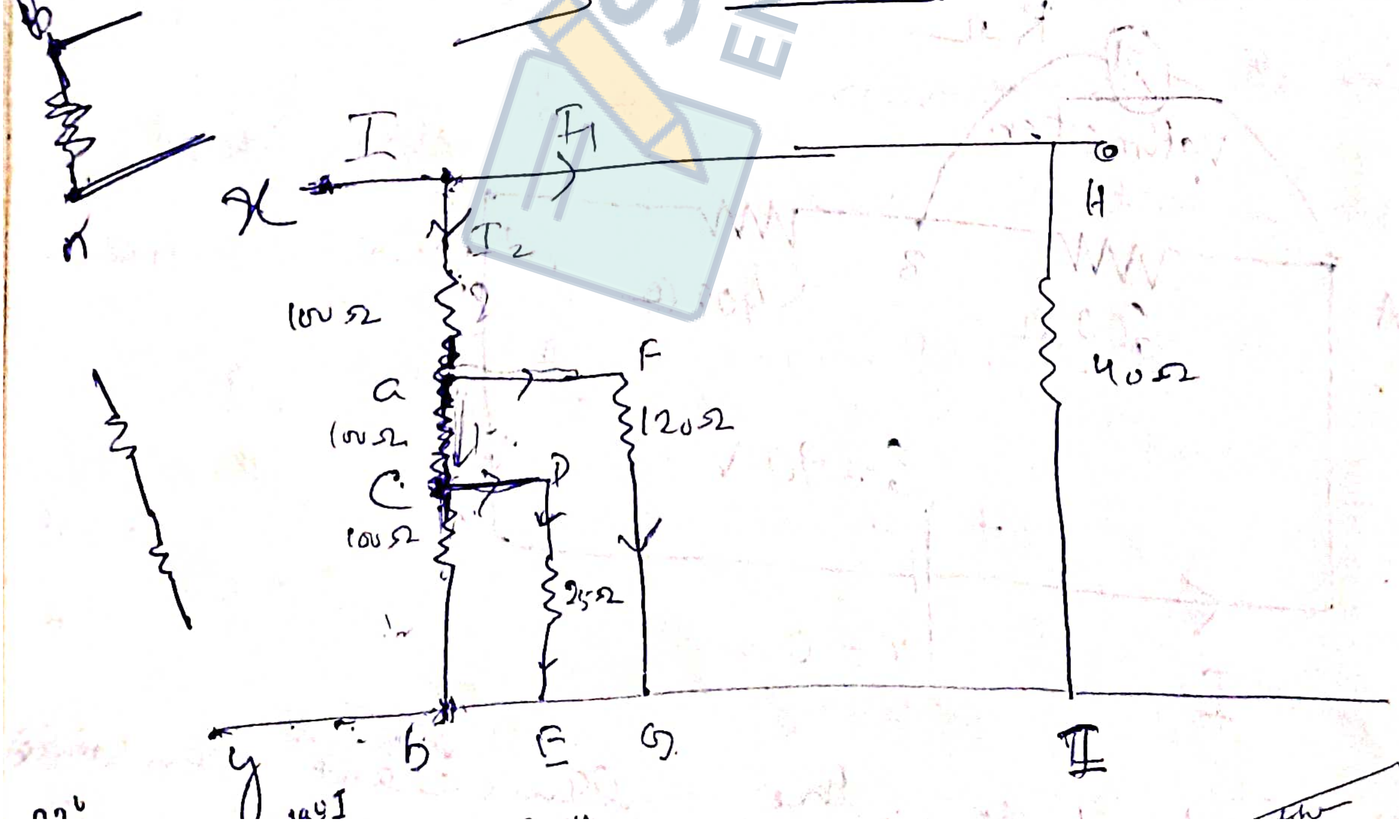
Ans: $8\,\Omega$, $12\,V$



6. What is the equivalent resistance between x and y

(b) If P.D between x and y is 320 Volt, Then find P.D between b and c

Ans: 32Ω, $\boxed{20\text{ volt}}$



17. Due to symmetry we can think that the current I entering at A will divide into 3 equal parts i.e $\frac{I}{3}$ along AB, AD, AE. Each such current will again divide into two equal parts i.e along BC and BF it is $\frac{I}{6}$, along DC and DH it is $\frac{I}{6}$, along EF and EH it is $\frac{I}{6}$.

Now the currents $\frac{I}{6}$ along BC and DC combine to become $\frac{I}{3}$ along CG. Similarly there are currents $\frac{I}{3}$ along FG and ~~HG~~ HG.

Let the equivalent resistance between A and G be $R'\Omega$

$\therefore V_A - V_G = R'I$ ——— (i)

But

$V_A - V_G = (V_A - V_B) + (V_B - V_C) + (V_C - V_G)$

$= \frac{RI}{3} + \frac{RI}{6} + \frac{RI}{3}$

$= \frac{5RI}{6}$ ——— (ii)

Comparing (i) and (ii)

$$\cancel{R' I' = \frac{5IR}{6}}$$

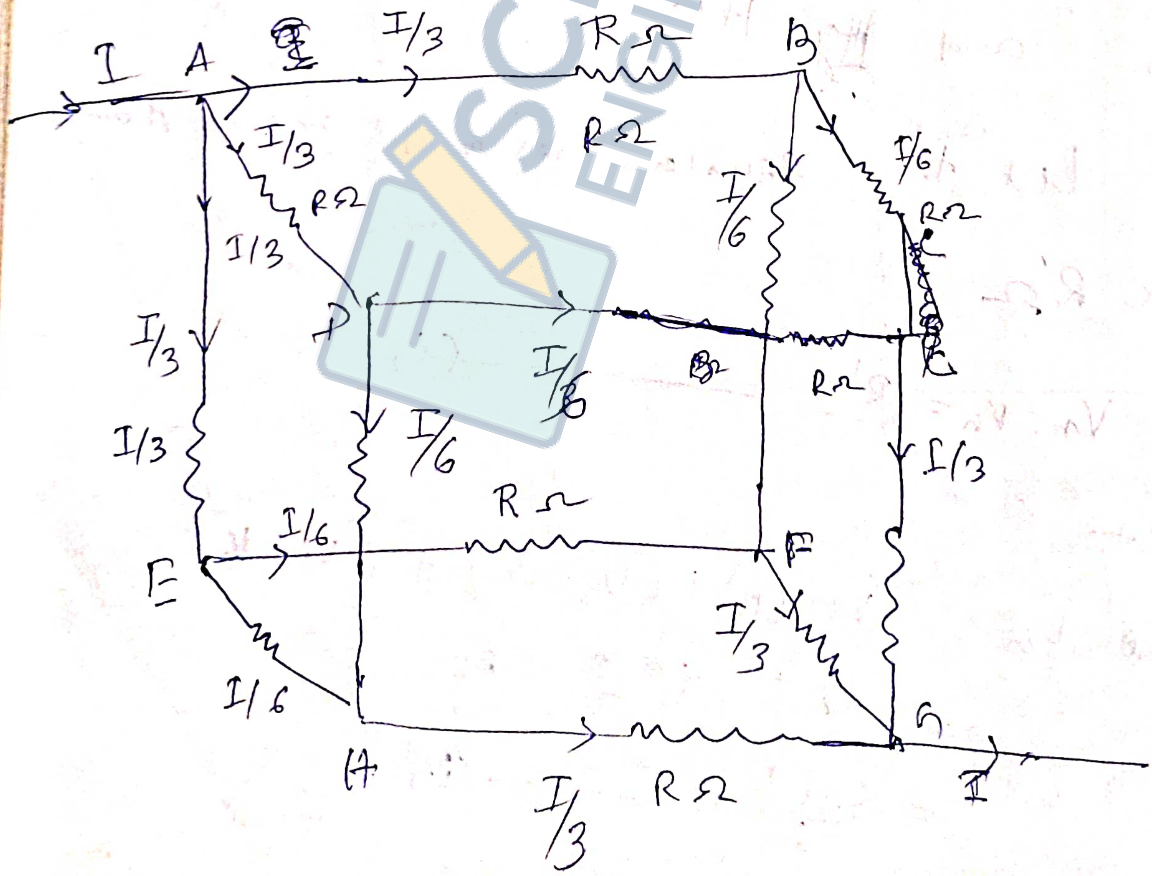
$$R'\cancel{I} = \frac{5\cancel{I}R}{6}$$

$$\boxed{R' = \frac{5R}{6}}$$

If our problem $R = 1\Omega$

$$\therefore R' = \frac{5}{6}\Omega$$

Fig :



Answers to problems

2. Copper wire has diameter $\frac{1}{12}$ inch.

$d_1 = \frac{1}{12}$ inch.

$l_1 = 8\ \Omega$ / mile.

$\sqrt{144} = 12$; $\frac{100}{440}$

$d_2 = \frac{1}{20}$ inch.

$l_2 = 1$ mile.

$r = \rho \frac{L}{A}$

$r_1 = \rho \frac{L_1}{A_1}$

$r_2 = \rho \cdot \frac{L_2}{A_2}$

$\frac{r_1}{r_2} = \frac{L_1}{A_1} \times \frac{A_2}{L_2} = \frac{L_1 \times \cancel{\pi} d_1^2 \times \cancel{4}}{\cancel{4} \times 1 \times \cancel{\pi} d_2^2} = \frac{L_1 \times \cancel{1} \times 400}{144 \times \cancel{1}}$

$\Rightarrow \frac{8}{r_2} = \frac{L_1 \times 400}{144} = \frac{\cancel{1 \times 400}\ 50}{144}$

$\Rightarrow r_2 = \frac{144}{50} =$

Again $R = \frac{\rho \cdot L_1 \times 4}{\pi d_1^2} = \frac{\rho \cdot L_1 \times 4 \times 144}{\pi \times 1}$

$\Rightarrow \frac{8\ \Omega}{\text{mile}} = \frac{\rho \cdot L_1 \times 576}{\pi}$

$\Rightarrow 1$ / mile $= \frac{8\ \Omega \times \pi}{576 \times \text{mile} \times \rho}$

For 2nd Case

$L_2 = \frac{R A}{\rho}$

$$\Rightarrow l = \frac{R \times \pi d^2}{4 \times \rho}$$

$$\Rightarrow 1\ \text{mile} = \frac{R \times \pi \times 1}{400 \times 4\rho}$$

$$l = \frac{8\Omega \times \cancel{\pi}}{576 \times \text{mile} \times \cancel{\rho}} \times \frac{\cancel{400 \times 4\rho}}{R \times \cancel{\pi}}$$

$$\frac{72}{8}$$

$$\rho = 5.72$$

② $$R_1 = \frac{\rho L}{A} = \frac{\rho \cdot L_1}{A_1} = \frac{\rho \cdot L_1 \times 4}{\pi d_1^2}$$

$$R_2 = \frac{\rho \cdot L_2 \times 4}{\pi d_2^2}$$

$$\frac{R_1}{R_2} = \frac{\cancel{\rho}\, L_1 \times \cancel{4}}{\cancel{\pi} d_1^2} \times \frac{\cancel{\pi} d_2^2}{\cancel{\rho} \cdot L_2 \times \cancel{4}} = \left(\frac{L_1}{L_2}\right) \cdot \left(\frac{d_2^2}{d_1^2}\right)$$

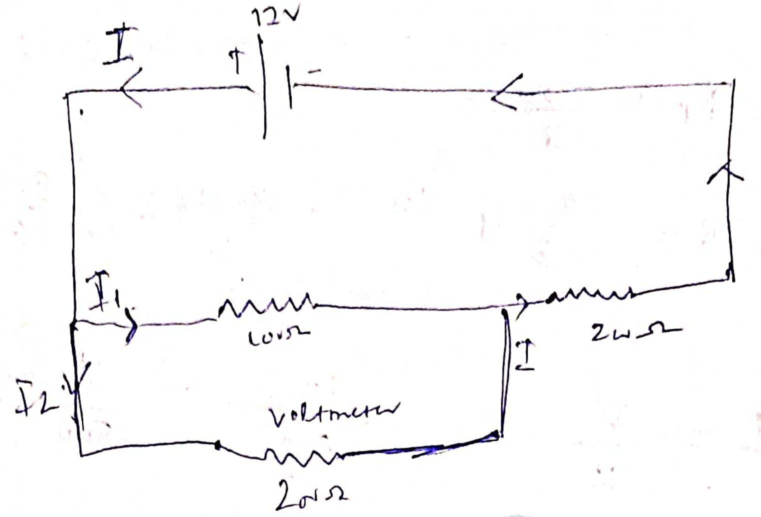
$$\Rightarrow \frac{8\Omega}{R_2} = \left(\frac{1}{9}\right)\left(\frac{1}{400} \times \frac{144}{1}\right) = \frac{72}{200}$$

$$\Rightarrow R_2 = \frac{1600}{72} = \frac{800}{36} = \frac{400}{18} = \frac{200}{9}$$

$$= 22.22\ \Omega$$

∴ The second resistance is 22.22 Ω.

3.



100Ω and 200Ω are connected in parallel.

$$\therefore \quad R_P = \frac{100 \times 200}{300} = \frac{200}{3} = 66.66\,\Omega$$

R_P and 200Ω are connected in ~~parallel~~ series.

$$R_S = 66.66 + 200 = 266.66\,\Omega$$

Total resistance $R = 266.66\,\Omega$.

Voltage = 12 V.

$$I = \frac{V}{R} = \frac{12}{266.66\,\Omega}$$

$$V_A - V_B = I \times R_P = \frac{\cancel{12}^{3}}{\cancel{266.66}_{4}} \times 66.66$$

$$\cancel{\Rightarrow \frac{12}{} = \frac{12}{266}}$$

Or

$R_p = \frac{200}{3}$

Total $R = \frac{200}{3} + 200 = \frac{200+600}{3} = \frac{800}{3}$

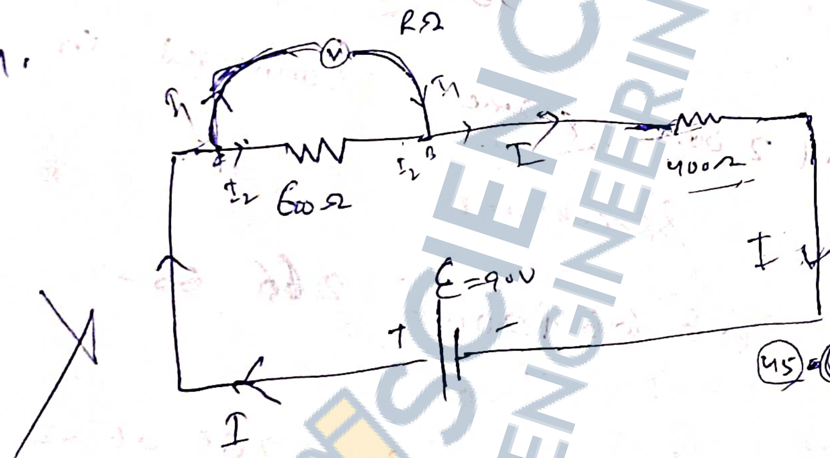
$I = \frac{V}{R} = \frac{12}{\frac{800}{3}} = \frac{36}{800}$

Voltmeter reading $= V_A - V_B = R_p \times I$

$\Rightarrow = \frac{\cancel{200}}{\cancel{3}} \times \frac{\cancel{36}\,12}{\cancel{800}\,4}$

$= 3$ volt.

4.



$R = 400\,\Omega$

$V = 45\,V$

$I = \frac{V}{R} = \boxed{\frac{45}{400}}$

$45 = I$ $\quad \frac{45}{400} = \frac{45 \times (600 R)}{600 + R}$

$600 = 2400 \cdot 4R$

$\rightarrow 720 = 200$

R = ...

because

The volt meter reading $= 45$ volt

In the 400 Ω p.d must = 45 volt

total p.d = 90 V.

$r = 400\,\Omega$, $V = 45$ volt

$I = \frac{V}{R} = \frac{45}{400}$

600 Ω and the internal resistance of Voltmeter are connected in Parallel.

net resistance = $\frac{r \times 600}{r + 600}$

Voltage = 45

$I = \frac{V}{R} = \boxed{\frac{45}{400}}$

$V = IR$

$V_A - V_B$ ~~$= I_1 \times R_V = I_2 \times 600\Omega$~~

$= I_1 \times R_V = I_2 \times 600\Omega = I \times R_{AB}$

$\Rightarrow R_V = \frac{I_2 \times 600\Omega}{I_1}$

$45 = I = I_1 + I_2 = \frac{V_1}{R_1} + \frac{V_2}{R_2}$

$\Rightarrow \frac{I}{45} = \frac{45}{R} + \frac{45}{600} = \frac{45 \times 600 + 45 R}{R(600)}$

$\Rightarrow 600R = R(600)$

$I = V/R$

Let the resistance of voltmeter be r ohm.

600Ω and r are connected in ∥.

∴ Equivalent resistance $R_P = \frac{r \times 600}{600 + r}$

Net resistance in the circuit. $400 + \frac{600r}{600+r}$

$\frac{90}{400 + \frac{600r}{600+r}} = I$ —— (i)

$V_A - V_B = I \times R_P = I \times \frac{600r}{600+r}$

$\Rightarrow 45 \times \frac{600+r}{600r} = I$ —— (ii)

Equating both sides in eqn (i) and (ii),

we get $\dfrac{90}{400 + \dfrac{600r}{600+r}} = \cancel{45}^{9} \times \dfrac{600+r}{\cancel{600r}_{\cancel{120}\,40}}$

$$\Rightarrow \frac{90\cancel{0}r\,(\cancel{600+r})}{240000 + 1000r} = \frac{3\,(\cancel{600+r})}{40r}$$

$$\Rightarrow 36000r = 720000 + 3000r$$

$$\Rightarrow \cancel{3000r}^{\,600r} = \cancel{360}^{72},00\cancel{0}0$$

$$\Rightarrow r = \cancel{\frac{36000}{300}} \quad \cancel{= 120\Omega} \quad \frac{72{,}00}{6}$$

$$= 120\Omega$$

Again → Let the voltmeter resistance be R ohm.

600 Ω resistor and R are connected in series.

∴ Equivalent resistance $= \dfrac{600R}{600+R} = R_P$

It is connected to 400 Ω resistor.

Net resistance $= 400 + \dfrac{600R}{600+R} = \dfrac{240000 + 400R + 600R}{600+R}$

$$= \frac{240000 + 1000R}{600+R}$$

$$I = \frac{V}{R} = \frac{90V \times (600+R)}{240000 + 1000R} \quad \text{—— (i)}$$

But $V_A - V_B = R_P \times I$

$45 = R_P \times I$ $\quad \Rightarrow I = \dfrac{45}{R_P}$ —— (ii)

Equating (i) and (ii), we get

$$\frac{\cancel{90}\,V \times \cancel{(600+R)}}{240000+1000R} = \frac{\cancel{45}\,\cancel{(600+R)}}{600R}$$

$\Rightarrow 1200R = 240000 + 1000R$

$\Rightarrow 200R = 24{,}0000$

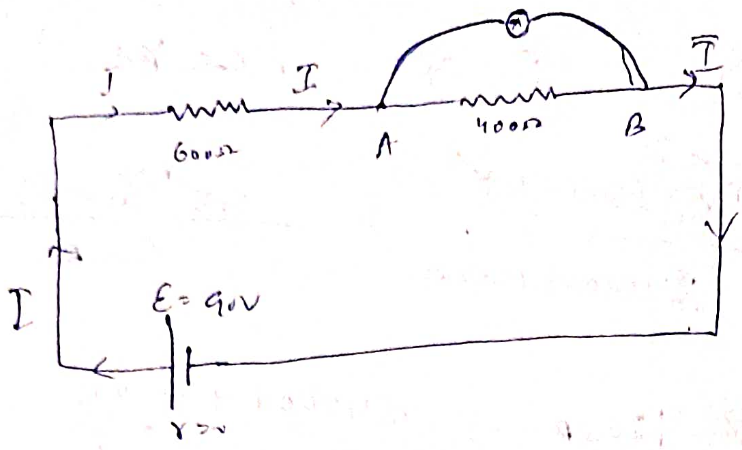
$\Rightarrow R = \frac{2400}{2} = 1200\,\Omega$ Ans

Another process

potential difference ~~about~~ across 600 Ω resistor

= 45 volt

potential difference across 400 Ω =



Net resistance = $600 + R_P = 600 + \left(\frac{400 \times r}{400 + r}\right)$

* Total Current $= I = \frac{V}{R} = \frac{90 \times (400 + r)}{2400\cancel{0} + \cancel{600r}\ 1000r}$ —— (i)

Also $V_A - V_B = I \times R_P$

$\Rightarrow \frac{V}{R_P} = I$

$\Rightarrow \frac{V(400+r)}{(400r)} = I$ —————— (ii)

Equating (i) and (ii)

$$\frac{V(400+r)}{400r} = \frac{90 \times (400+r)}{(240000+1000r)}$$

$$\Rightarrow \frac{V}{400 \times 1200} = \frac{90}{(240000 + 1000 \cdot 1200)}$$

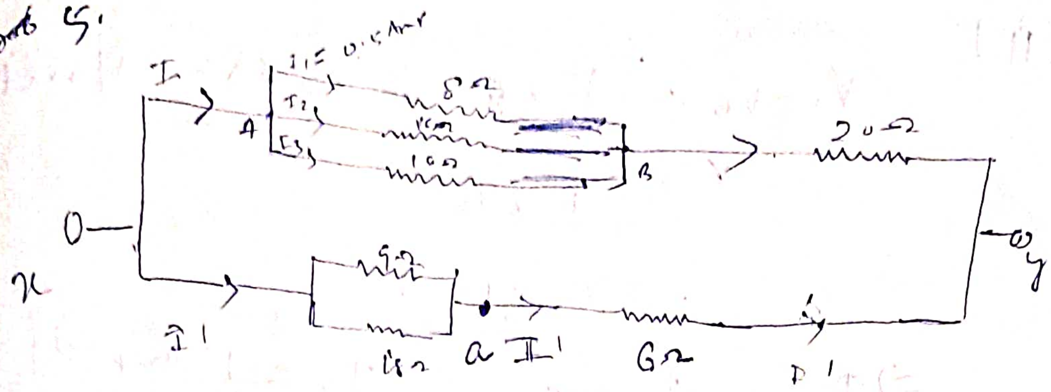
∵ The same voltmeter in connected whose $r = 1200\Omega$

$$\Rightarrow V = \frac{400 \times 1200 \times 90}{24,0000 + 1200000}$$

$$= \frac{\cancel{400} \times \cancel{1200} \times \cancel{90}\ 30}{\cancel{144}\ \cancel{0000}}$$

$= 30$ volt

Ans 5.



(8, 16, 16) Ω resistors are connected in Parallel.

$$\cancel{\frac{1}{R_p} = \frac{1}{8} + \frac{1}{16} + \frac{1}{16} = \frac{8+3+3}{48} = \frac{14}{48}}$$

$$\cancel{\Rightarrow R_p = \frac{48}{14} = \frac{24}{7}}$$

$$\frac{1}{R_p} = \frac{1}{8} + \frac{1}{16} + \frac{1}{16} = \frac{2+1+1}{16} = \frac{4}{16} = \frac{1}{4}$$

$\therefore$ $R_P = 4$,

4Ω and 20Ω are Connected in series,

$R_{S_1} = 24\,\Omega$

9Ω and 18Ω are Connected in ||,

$$\therefore R_{P_2} = \frac{9 \times 18}{9+18} = \frac{\cancel{9} \times \cancel{18}\,6}{\cancel{27}\,\cancel{3}} = 6\,\Omega$$

$R_{S_2} = 6\Omega + 6\Omega = 12\,\Omega$

R_{S_2} and R_{S_1} are Connected in ||.

$$R_{P_3} = \frac{24 \times 12}{24+12} = \frac{24 \times 12}{\cancel{36}\,3}$$

$$= 8\,\Omega$$

(ii) $V_A - V_B = I_1 \times 8 = .5 \times 8 = 4$ volt.

$= I_2 \times 16$

$= I_3 \times 16$

$\Rightarrow I_2 = \frac{1}{4}$ Amp, $I_3 = \frac{1}{4}$ Amp.

$I = I_1 + I_2 + I_3 = \frac{1}{4} + \frac{1}{2} + \frac{1}{4} = 1$ Amp.

Potential across 20Ω resistor $= I \times R = 1 \times 20 = 20$ volt.

$V_{xy} = V_A - V_B + 20 \text{ volt} = 4 + 20 = 24$ volt

$R_{xy} = 8\Omega$.

$I_{Total} = \frac{V_{xy}}{R_{xy}} = \frac{24}{8} = 3$ Amp.

$I' = I_{total} - I = 3 - 1 = 2$ Amp.

9Ω and 18Ω are in parallel connect

$R_P = 6\Omega$

$V_{xa} = R_P \times I' = 6 \times 2 = 12$ volt (Ans)

6. From the circuit diagram

R_{CD} and R_{DE} are connected in parallel.

$R_{P_1} = \frac{100 \times 25}{100 + 25} = \frac{\cancel{100} \times \cancel{25}}{\cancel{125}} = 20\Omega$,

20Ω and R_{CE} are connected in series

$\therefore R_{S_1} = 120\Omega$.

120Ω and 120Ω are connected in parallel.

$\therefore R_{P_2} = \frac{\cancel{120} \times \cancel{120}}{\cancel{240}} = 60\Omega$.

60 Ω and 100 Ω are connected in series

$R_{S2} = 100 + 60 = 160\ \Omega$.

160 Ω and 40 Ω are connected in parallel.

$\therefore R_{xy} = \dfrac{160 \times 40}{\cancel{200}_{5}} = 32\ \Omega$.

P.D between x and y = 320 Volt

Resistance " " " = 32 Ω.

Current $I = \dfrac{V}{R} = \dfrac{320}{32} = 10$ Amp.

~~Due to symmetry $I_1 = I_2 = 5$ Amp.~~

$V_{xy} = 160 \times I_2 = I_1 \times 40$

$\Rightarrow 320 = 160 I_2 = 40 I_1$

$\Rightarrow I_1 = 8$ Amp, $I_2 = 2$ Amp

I_2 again i.e 2 Amp again divided into 1 amp and 1 amp.

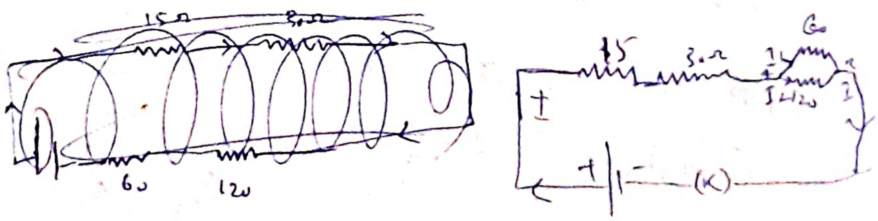
Through af = 1 Amp, through ac = 1 Amp. (I)

$R_{P_1} = 20\ \Omega$.

$V_{bc} = I_{ac} R_P = 1 \times 20 = 20$ Volt

Current Physics

31.



$V_A - V_B = I_1 \times 60 = I_2 \times 120$

$\Rightarrow I_1 = 2 I_2$

Across 15 and 30 Ω resistor of heat developed. $\frac{I^2 R_1 t}{J}$, $\frac{I^2 R_2 t}{J}$.

Their ratio = $\frac{R_1}{R_2} = \frac{15}{30} = \frac{1}{2}$.

The ratio of heat developing across 60 and 120 Ω resistor.

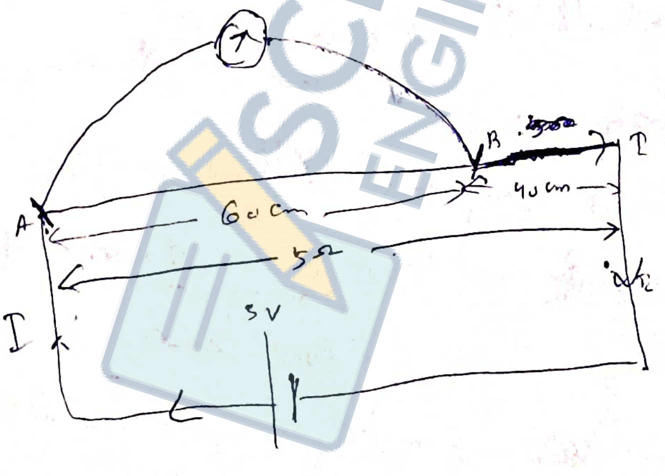
5. $\dfrac{\frac{I_1^2 R t}{J}}{\frac{I_2^2 R t}{J}}$ $= \frac{(2I_2)^2 \times 60}{I^2 \times 120\,2} = \frac{24 I_2^2}{I^2 \times 2} = 2:1$

$V = 3.00$ volt

$r = 1\Omega$

$l = 100$ cm

$R = 5.00\,\Omega$



$r = 1\Omega$

Total resistance = $5\Omega + r = 5\Omega + 1\Omega = 6\Omega$.

Potential of the battery = 3 V

Current flowing = $\frac{V}{R} = \frac{3V}{6\Omega} = \frac{1}{2}$ Amp.

100 cm wire has resistance $5\,\Omega$

1 " " " " $\frac{5}{100}\,\Omega$

60 cm " " " $= \frac{5}{100} \times 60 = 3\,\Omega$.

Voltmeter reading $V_A - V_B = I \times 1.5$

$= \frac{1}{2} \times 3\,\Omega$

$= 1.5$ volt.

If Voltmeter has resistance $150\,\Omega$.

then $150\,\Omega$ and $3\,\Omega$ are connected in ||.

$$\boxed{\frac{150 \times 3}{153} = R_P}$$

$$R_S = \frac{150}{31} + 1 = \frac{150+31}{31} = \cancel{\frac{181}{31}}$$

The Resistance of wire $5\,\Omega$ in considered as $3\,\Omega$ in parallel, $2\,\Omega$ in in series.

$$R_S = \frac{450}{153} + 1 + 2 = \frac{450+153+306}{153}$$

$$= \frac{909}{153}$$

$$I = \frac{V}{R} = \frac{3}{\frac{909}{153}} = \frac{\cancel{3} \times \cancel{153}}{\cancel{909}} = \frac{51}{101}$$

$$V_A - V_B = I \times R_P$$

$$= \frac{\cancel{51}}{101} \times \frac{150 \times \cancel{3}}{\cancel{153}}$$

$= 1.485$ volt.

Current density ($\vec{J}$)

It is a vector quantity whose magnitude is equal to the current per unit area of cross-section.

$$\therefore \quad |\vec{J}| = \frac{I}{A}$$

The direction of $\vec{J}$ is along the outward drawn normal.

$$\therefore \quad J = \frac{\frac{nAe^2\tau E}{m}}{A} = \frac{ne^2\tau E}{m}$$

or $\boxed{\vec{J} = \sigma \vec{E}}$

Derivation of Ohm's law from the relation $J = \sigma E$:

From the defn of J, we know that

$$J = \frac{I}{A} \quad \text{and} \quad E = \frac{V}{l}$$

$\therefore$ $J = \sigma E$ becomes $\frac{I}{A} = \frac{1}{\rho} \cdot \frac{V}{l}$

or $\boxed{V = \frac{\rho l}{A} I = RI}$

This is ohm's law.

Heating effect of electric current

It is experimentally found that heat is generated in the conductors where an electric current is made to flow for sometime. Joule has ~~es~~ established three laws regarding the quantity of heat produced.

① First law

Statement: The amount of heat generated in a conductor is directly proportional to the square of the current when resistance of the wire and time of passing current are kept constant.

$\therefore$ $H \propto I^2$, when R and t are kept constants.

Explanation

Suppose I amp of current be passed for 20 minutes through a resistance wire which is dipped in a liquid taken in a Calorimeter. The amount of heat generated be H_1 Cal.

$$\therefore H_1 \propto (1)^2$$

Now the resistance of the rheostat be decreased so that the current will be increased to 2 amp. Let this ~~ccbtat~~ current be allow to flow for 20 minutes and heat generated ~~by~~ be H_2 Cal.

Then $H_2 \propto (2)^2$

Hence $\frac{H_1}{H_2} = \frac{1}{4} = 0.25$ (expected).

In actual experiments, there may be loss of heat due to radiation. If $\frac{H_1}{H_2} \simeq 0.25$ be obtained then the first law will be verified.

(2) Second law

Statement: The amount of heat generated in a conductor is directly proportional to the resistance of the wire when the amount of ~~as~~ current and time of passing current are kept constants.

$\therefore H \propto R$, when I and t are kept constants.

Explanation :

Suppose 1 amp of ~~co~~ current be produced in a circuit having a battery, key, ~~xx~~ rheostat, Ammeter and a resistance wire of length l (say). By ~~Calor~~ Calorimeter device the amount of heat produced is found to be H_1 Cal in 20 minute.

$\therefore H_1 \propto R$

Now the length of the wire be made $2l$, with no change in the diameter and material. The resistance of the rheostat be decreased to maintain the current at 1 amp. The amount of heat produced in 20 min be H_2 Cal found by Calorimeter device.

$\therefore H_2 \propto 2R$

Thus $\frac{H_1}{H_2} = \frac{1}{2} = 0.5$ (expected)

In practice, if $\frac{H_1}{H_2} \simeq 0.5$ be obtained, Then the second law will be verified.

③ → <u>Third law</u>

<u>Statement</u> : The amount of heat generated in a conductor is directly proportional to to the time of passing current when the amount of current and resistance of the wire are kept constants.

$\therefore$ $H \propto t$, when I and R are kept constant.

<u>explanation</u> : Suppose 1 amp of current be produced in a circuit for 20 minutes having a battery, key, rheostat, Ammeter and a resistance wire which is dipped in a liquid taken in a calorimeter. By calorimeter device, the amount of heat produced is H_1 cal in 20 min

$\therefore$ $H_1 \propto t$

Now the time taken 40 minutes. The amount of heat produced in 40 min be H_2 cal found by calorimetric device.

$\therefore \quad H_2 \propto 2t$

Thus $\frac{H_1}{H_2} = \frac{1}{2} = 0.5$ (expect)

In practice, if $\frac{H_1}{H_2} \simeq 0.5$ be obtained then the third law will be verified.

Combining these three variations, we have

$H \propto I^2Rt$, when all the quantities vary.

$\Rightarrow H = KI^2Rt$

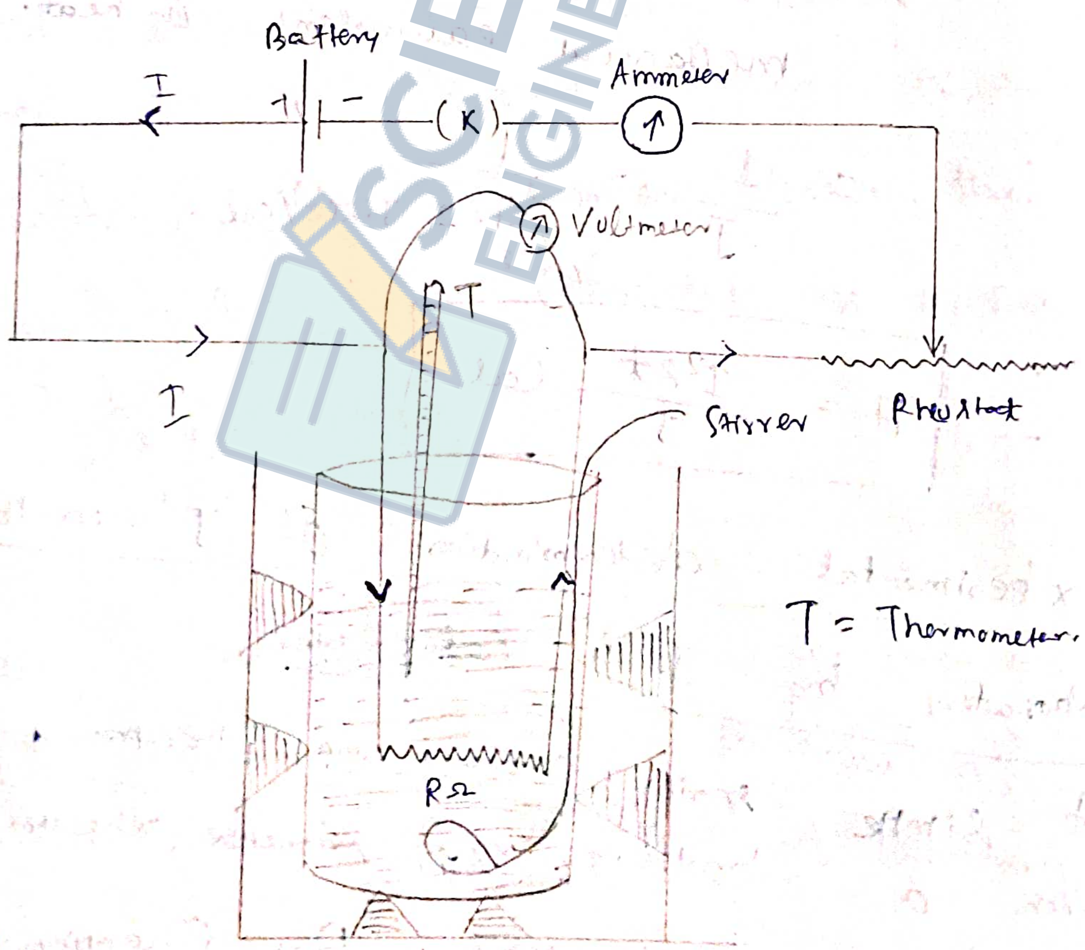
where K = a constant found to be equal to the reciprocal of the mechanical equivalent of heat.

$$= \frac{1}{J} = \frac{1}{4.2 \text{ Joule/cal}}.$$

$$\therefore \boxed{H = \frac{I^2Rt}{J} \text{ Cal}}$$

Experimental determination of 'J' in the Laboratory by Joule's Calorimeter

A simple series circuit is prepared with a battery, key, Ammeter, rheostat and a resistance wire. By changing the resistance of the rheostat, a desired current can be produced. A Voltmeter is placed across the resistance wire. From the voltmeter and ammeter reading resistance of the wire can be found out ($V = RI$). The wire is dipped in kerosene or water taken in a Calorimeter. Stirring is done to have uniform mixing of temperature. By a thermometer initial and final temperatures are found out after a specified time for which the current is passed.



T = Thermometer.

Calculation

Heat lost by electric wire

= Heat gained by the Calorimeter, stirrer and the liquid

$$\frac{I^2Rt}{J} = m_1 s_1 \Delta\theta + (m_2 - m_1) s_2 \Delta\theta$$

Where m_1 = Mass of the empty Calorimeter and stirrer in gms.

m_2 = Mass of the Calorimeter + stirrer + liquid in gms.

$\therefore m_2 - m_1$ = Mass of the liquid taken in gms.

s_1 = Specific heat of the Calorimetric substance (copper)

s_2 = Specific heat of the liquid

$\Delta\theta$ = Rise of temp in °C or °K

$$\frac{I^2Rt}{J} = \left[m_1 s_1 + (m_2 - m_1) s_2\right] \Delta\theta$$

$$\Rightarrow J = \frac{I^2Rt}{\left[m_1 s_1 + (m_2 - m_1) s_2\right] \Delta\theta} \text{ Joule/Cal.}$$

Precautions :

1. High current should not be passed, because this will make large quantity of heat lost in the process of radiation.

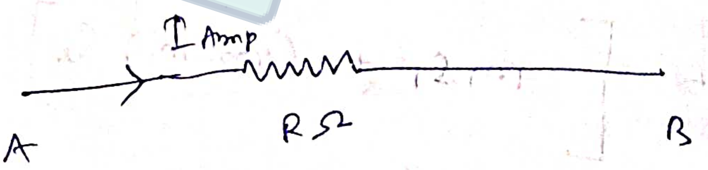
2. The current should be passed for short amount of time till the temp rises by $10^\circ C$ to $20^\circ C$

3. Radiation correction procedure should be followed to have correct temp of mixing.

4. Stirring must be ~~const~~ continuously done to have uniform temp. throughout.

Electrical work energy and power

Lets have a conductor AB of resistance R ohm. through which a current I Amp flowing for t sec.



The amount of charge flowing through it is given by $q = It$.

The amount of workdone to flow q unit of charge through the wire

$$W = q \cdot \Delta V = It \cdot RI = I^2 Rt \text{ Joule}$$

Thus, electrical workdone $= I^2 Rt$ Joule.

$$\text{Electrical power} = \frac{\text{Electrical workdone}}{\text{Time taken}}$$

$$= \frac{I^2 R t}{t}$$

$$= I^2 R \text{ watt} = IR \cdot I = V \cdot I \text{ watt}$$

$$= V \cdot \frac{V}{R} = \frac{V^2}{R} \text{ watt.}$$

The practical unit by which electrical work or energy is measured is called

KWh (Kilo watt hour).

$$1 \text{ KWh} = 10^3 \frac{\text{Joule}}{\text{sec}} \times 3600 \text{ sec}$$

$$= 36 \times 10^5 \text{ Joule.}$$

Bigger units like mega watt hour are also used.

$$1 \text{ MWh} = 10^6 \frac{\text{Joule}}{\text{sec}} \times 3600 \text{ sec}$$

$$= 36 \times 10^8 \text{ Joule.}$$

Smaller units like watt-hour are also used.

$$1 \text{ Wh} = 1 \frac{\text{Joule}}{\text{sec}} \times 3600 \text{ sec} = 3600 \text{ Joule}$$

P.T.O

4/ An electric ~~eattle~~ Kettle has two thermal coils - with current in one coil, water boils in 6 minutes and with current in the other coil it boils in 8 minutes.

When both coils are joined in

(a) series (b) parallel,

How long will it take to boil?

(Ans: 3.428 minute, 14 minute)

(Hints: $H_1 = H_2 = H_S = H_P =$ Constant, $I =$ Constant)

Ans: Let R_1 and R_2 be the resistances of the two coils.

Amount of Heat required to boil a given amount of water remains the same

$$H_1 = H_2$$

$$\frac{\cancel{I^2} R_1 t_1}{\cancel{J}} = \frac{\cancel{I^2} R_2 t_2}{\cancel{J}}$$

$$\Rightarrow R_1 \times 6\,\text{min} = R_2 \times 8\,\text{min}$$

$$\Rightarrow 3R_1 = 4R_2 \quad \text{———} (i)$$

When the two wires are joined in the series ~~&~~ let the time taken to boil the water in the kettle be t_s minute

$H_1 = H_s$ gives ~~B~~

$$\frac{\cancel{I^2} R_1 t_1}{\cancel{J}} = \frac{\cancel{I^2} R_s \cdot t_s}{\cancel{J}}$$

$$\Rightarrow R_1 \times 6\,\text{min} = (R_1 + R_2)\, t_s\,\text{min}$$

$$\Rightarrow 6R_1 = \left(R_1 + \frac{3}{4}R_1\right) t_s$$

$$= \frac{7R_1}{4} t_s$$

$$\Rightarrow t_s = \frac{6\cancel{R_1} \times 4}{7\cancel{R_1}} = \frac{24}{7} = 3.428 \text{ minute}$$

When the wires are joined in parallel let the time taken to boil the water in the kettle be t_p minute

$H_1 = H_p$ gives

$$\frac{\cancel{I^2} R_1 t_1 \,\text{min}}{\cancel{J}} = \frac{\cancel{I^2} \cdot R_p \, t_p \,\text{min}}{\cancel{J}}$$

$$\Rightarrow R_1 \cdot 6 \text{ min} = \left(\frac{R_1 R_2}{R_1+R_2}\right) t_p$$

$$\Rightarrow \cancel{R_1} \cdot 6 \text{ min} = \left(\frac{R_1 \cdot \frac{3R_1}{4}}{R_1 + \frac{3}{4}R_1}\right) t_p$$

$$= \frac{3}{\cancel{4}} \cancel{R_1^2} \times \frac{\cancel{4}}{7\cancel{R_1}} t_p$$

$$\Rightarrow t_p = \frac{\cancel{6}^{2} \times 7}{\cancel{3}} = 14 \text{ minutes}$$

(Ans)

[illegible]

5. Two lamps marked "60W, 120V" and "40W, 120V" are joined in series across a 120 volt line. What power is consumed in each lamp?

Ans: (240 Ω, 360 Ω, 9.6 watt, 14.4 watt)

6. 3 equal resistors are connected in series, when a certain P.D is applied across the combination, the total power consumed is 10W. What power would be consumed if the ~~three~~ three resistors were connected in parallel across the same P.D (Ans: 90W)

Problems on Chemical Effect of Current

1. Prove that $\frac{Z_1}{Z_2} = \frac{E_1}{E_2}$

where $Z = E.C.E$

$E = C.E$

Ans: Lets have two electrolytes placed in series in a circuit having d.c voltage.

If the masses of the ions deposited at the cathode be m_1 and m_2 respectively, then Faraday's first law gives

$$\frac{m_1}{m_2} = \frac{Z_1 I t}{Z_2 I t} = \frac{Z_1}{Z_2} \quad \text{—(i)}$$

From Faraday's second law, we know that

$$\frac{m_1}{m_2} = \frac{E_1}{E_2} \quad \text{—(ii)}$$

From eqns (i) and (ii), we get

$$\frac{Z_1}{Z_2} = \frac{E_1}{E_2}$$ (Proved).

2. A spoon having an area 20 square mm is to be coated with Ag to a thickness of 0.01 mm.

If a current of 0.15 Amp is used, calculate the time for which it must flow? (Ans. 12.52 sec)

~~Eoc of~~ E.C.E of Silver = 0.001118 gm/Coulomb

ρ of Silver = 10.5 gm/c.c.

Ans :

Area = 20 m.m² = 20×10^{-2} c.m.

Thickness = 0.01×10^{-1} = .001 cm.

$\cdot\frac{01}{100}$

volume = $20 \times 10^{-2} \times 10^{-3} = 20 \times 10^{-5}$

mass = volume $\times \rho$ = $20 \times 10^{-5} \times 10.5$

$= 21 \times 10^{-4}$ gm

We know from Faraday's law

$m = ZIt$

$\Rightarrow 21 \times 10^{-4} = .001118 \times .15 \times t$

$\Rightarrow t = \dfrac{21 \times 10^{-4}}{.15 \times .001118}$

$= \dfrac{21 \times 10^{-4} \times 10^{2} \times 10^{6}}{15 \times 1118}$

$= \dfrac{210000}{15 \times 1118}$

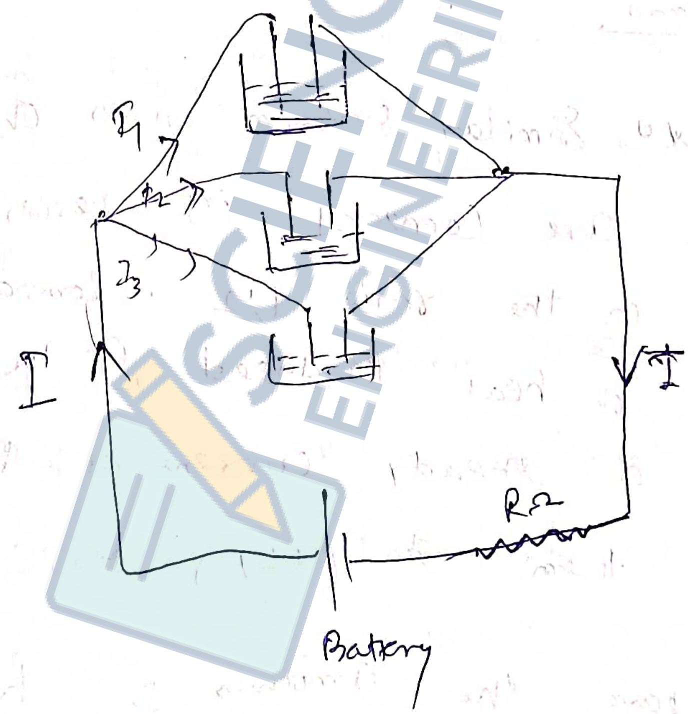
$= 12.522$

3. 3 Cu voltameters in parallel are connected to the ends of a battery with resistance. After 30 minutes the deposites are 0.763, 0.742 and 0.785 gm Find the strength of the current drawn from the battery.

(Ans: 3.867 Amp,)

E.C of Cu = 0.000329 gm/ Coulomb)

Ans :



From Faraday first law

$$m_1 = Z I_1 t$$

$$m_2 = Z I_2 t$$

$$m_3 = Z I_3 t$$

$$m_1 + m_2 + m_3 = Zt(I_1 + I_2 + I_3) = Z I t$$

$$\Rightarrow 0.763 + 0.742 + 0.785 = .000329 \times 30 \times 60 \times I$$

$\Rightarrow \dfrac{2290}{.000329 \times 30 \times 60} = I$

$\Rightarrow I = \dfrac{2.29 \times 10^{6}}{329 \times 30 \times 6}$

$= \dfrac{2290 \times 10^{}}{987 \times 6}$

$= \dfrac{229000}{5922}$

$= 3.8669$ sec

Problems

1. Two similar uniform wires of equal length are connected in series having diameters in the ratio 1:2. Compare the amount of heat produced in the wire if a steady current is passed through them. Ans (4:1)

2. Compare the amounts of heat developed in the four arm of a balanced Wheat Stone's bridge when the resistances of the arms are 10Ω, 1Ω, 30Ω, 3Ω

Ans (30 : 3 : 10 : 1)

3/ A current of 5 Amps flows through a wires of resistance 10 Ω for 2 min. If the heat produced is exclusively (assume) supplied to 100 gms of water, through how many degrees will the temp be raised. Ans: (71.4°C)

4/ An electric copper kettle weighing 1000 gms holds 1800 gms of water. If a current of 5 Amp at 200 volts passes through a kettle. Calculate the time taken by water to reach boiling point from 20°C? (Ans: 10 min 38.4 sec)

SP of Cu = 0.1

5. Calculate the time required to boil the a litre of water which is at 25.4°C, the available energy being at the rate of 1 H.P (assume)

6. Calculate the amount of heat produced in 5 min in 20 watt lamp,

(Ans: 1428.57 cal.

7. A lamp with a carbon filament works at 2.5 watt under a voltage of 20 volts. What is the resistance of the lamp (Ans: 160Ω)

8. An electric iron when hot has a resistance of 80Ω and it is used on 200 volt circuit. What will be the cost of using for 2 hrs if energy cost Rs 1/- per kwh.

9. Two points at a given difference of potential are joined by n wires of equal resistances. Prove that the heat produced when the wires are joined in parallel = n^2 times the heat generated when they are arranged in series.

10. hw K → 6 54 page 31 Mk

11. An electric bulb is marked 220 volt and 60 W. What does it mean? If such a bulb be made to work

for 5 hrs a day during the whole month of September, what should be the bill if the charge is 3 units per rupee

(Rs 3 rupee)

12. A university hostel has 360 lamps installed. The lamps consume 50 watts each and they are lighted for 6 hrs daily for 9 months. The voltage of parallel supply is 220 and the current cost $\frac{3}{8}$ = (3/8 paise per KWh)

Find the cost of the current as well as the main current way

(Ans:- 10935 RS, 81.81 Amp

13. An electric kettle whose water equivalent is 100 gms contains 1000 gms of water at 15 C. If the kettle takes 4 Amp at 230 volts.

Find

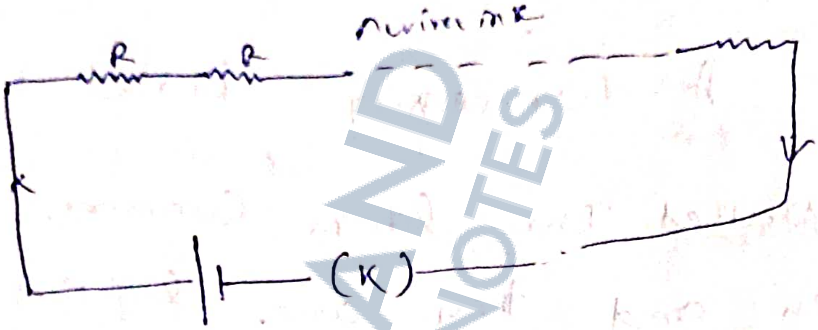
(a) The time required to boil water assuming that 10% of heat generated is lost

(b) Rate of generation of heat in ckt.

(Ans: 7 min, 54 sec, 21a cal/sec.

-.-

Ans :



Since n wires are connected in series.

$$R_s = R + R + \ldots + R_n$$

$$= nR$$

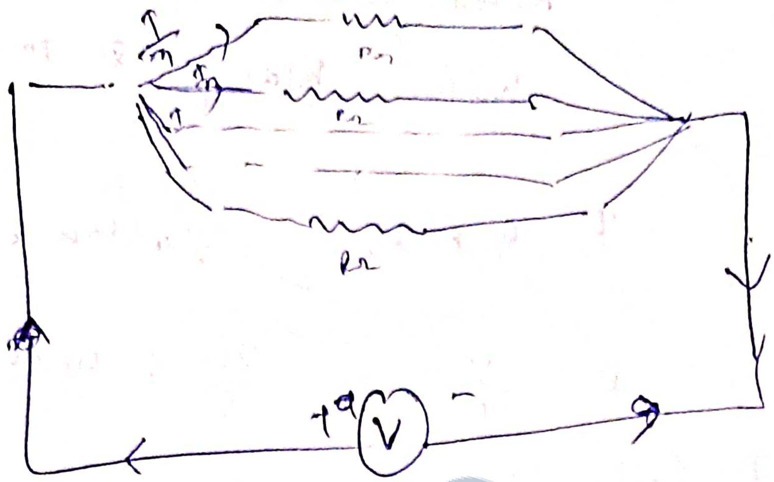
$$I = \frac{V}{R} = \frac{V}{nR}$$

Heat produced in 1 wire $\frac{I^2 R t}{J}$

Heat produced $= \frac{\left(\frac{V}{nR}\right)^2 \cdot R \cdot t}{J}$

in n wires $H_s = \frac{n \cdot \frac{V^2}{n^2 R^2} \cdot R\, t}{J}$

$$= \frac{V^2 t}{n J . R}$$



$$\frac{1}{R_p} = \frac{1}{R} + \frac{1}{R} - \cdots + \frac{1}{R}$$

$$= \frac{n}{R}$$

$$\Rightarrow R_p = \frac{R}{n}. \quad I = \frac{V}{\frac{R}{n}} = \frac{Vn}{R}$$

Heat produced in 1 wire

$$= \frac{\left(\frac{I}{n}\right)^2 R t}{J} = \frac{\frac{V^2 n^2}{\cancel{R^2}} \cdot \cancel{R}\, t}{R\, J\, n^2}$$

Heat produced in n wires

$$H_p = \frac{V^2 \cancel{n^2}\, t}{R\, J\, \cancel{n^2}} \times n$$

$$= \frac{n V^2 t}{RJ}$$

$$\frac{H_p}{H_s} = \frac{n V^2 \cancel{t}}{\cancel{R} \cancel{J}} \times \frac{n \cancel{J} \cancel{R}}{\cancel{V^2} \cancel{t}}$$

$$= n^2$$

$$\Rightarrow H_p = n^2 \cdot H_s.$$

(P) (Proved)

4. Kettle has mass = 1000 gm.

Water holds = 1800 gm.

$I = 5$ Amp, Voltage = 200 volt

$$R = \frac{V}{I} = \frac{200}{5} = 40\Omega$$

Heat produced = $\frac{I^2Rt}{J} = \frac{25 \times 40 \times t}{4.2}$ —(1)

Heat lost by kettle + water = Heat gained by ice

$= \cancel{\text{}}\, m_1 S_1 \Delta\theta_1 + m_2 S_2 \Delta\theta$

$= 1000 \times .1 \times (100-20) + 1800 \times 1 \times (100-20)$

$= 100 \times 80 + 1800 \times 80$

$= 80 (1900)$

$= 152000$

$$\Rightarrow \frac{25 \times 40 \times t}{4.2} = 152,000$$

$$\Rightarrow t = \frac{152,0\cancel{0}\cancel{0} \times 4.2}{25 \times \cancel{40}}$$

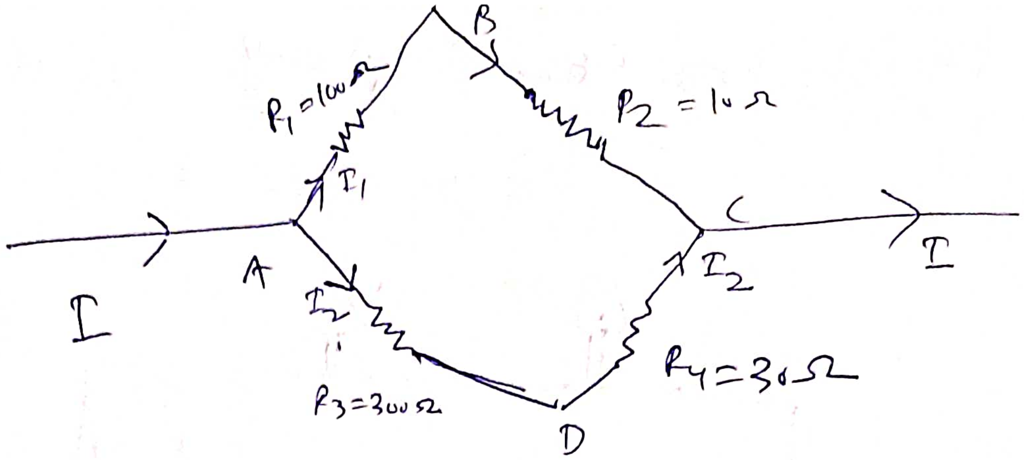
$= 638.4$ sec

$= 10.64$ min

$= 10$ min, $.64 \times 60$

$= 10$ min 38.4 sec

2.



Now $V_A - V_C = I_1 \times (100 + 10) = I_2 (300 + 30)$

$\Rightarrow 110 I_1 = 330 I_2$

$\Rightarrow I_1 = 3 I_2$

$H_1 : H_2 : H_3 : H_4$

$= \dfrac{I_1^2 \cdot 100 \cancel{t}}{\cancel{J}} : \dfrac{I_1^2 \, 10 \cancel{t}}{\cancel{J}} : \dfrac{I_2^2 \, 300 \cancel{t}}{\cancel{J}} : \dfrac{I_2^2 \, 30 \cancel{t}}{\cancel{J}}$

$= (3I_2)^2 \cdot 100 : (3I_2)^2 \, 10 : \cancel{I_2^2} \, 300 : \cancel{I_2^2} \, 30$

$= 9 \cancel{I_2^2} \cdot 100 : 9 \cdot \cancel{I_2^2} \cdot 10 : 300 : 30$

$= 900 : 90 : 300 : 30$

$= 30 : 3 : 10 : 1$

Ans

First, to Exercise Just 8 — u —

(5.) Two lamps marked '60W', '120V' '40W, 120V'

$P_1 = 60W$, $V = V_1 + V_2 = 120 \text{Volt}$

$P_2 = 40W$

We know that $P = \frac{V^2}{R}$

For the ~~P~~ first lamp $60W = \frac{(120)^2}{R}$

$\Rightarrow R = \frac{\cancel{120}^{2} \times 120}{\cancel{60}} = 240\Omega$

For the second lamp $40W = \frac{(120)^2}{R}$

$\Rightarrow R = \frac{(120)\cancel{^2} \times \cancel{120}^{3}}{\cancel{40}}$

$= 360\Omega$

Total voltage $= 120V$.

Total resistance $= (360 + 240) = 600\Omega$.

$I = \frac{V}{R} = \frac{120}{600} = \frac{1}{5}$ Amp.

(i) Power consumed by first lamp

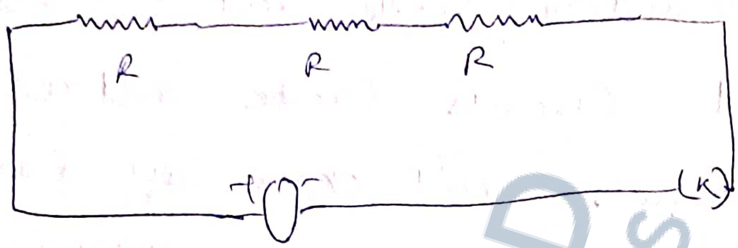
~~$= \theta V \cdot I = \frac{P \cdot x}{5}$~~

$= I^2 R$

$= \frac{1}{25} \times 240 = 9.6$ Watt.

(ii) Power Consumed by second lamp

$$I^2R = \frac{1}{25} \times 360 = 14.4 \text{ watt.}$$



The resistors are connected in series.

$$R_s = \underline{\underline{3R}}.$$

so Power Consume = 10W.

$$P = \frac{V^2}{R} = \frac{V^2}{3R}$$

$$\Rightarrow \frac{V^2}{3R} = 10\text{ W}$$

$$\Rightarrow V^2 = \underline{30R} \text{ volt}.$$

When Connected in parall

$$\frac{1}{R_P} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} = \frac{3}{R}$$

$$\Rightarrow R_P = \frac{R}{3}.$$

$$\text{Power-Consume} = \frac{V^2}{R} = \frac{30R}{\frac{R}{3}} = \frac{30\cancel{R} \times 3}{\cancel{R}} = \underline{90 \text{ Watt}}.$$

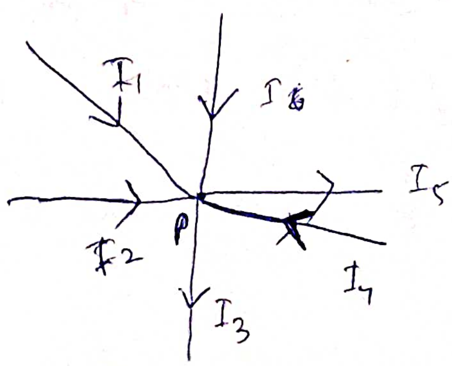
Analysis of Multiloop circuits

We have seen that ohm's law is applicable to single conductors and it can be extended to simple loop circuits. Even complicated circuits can be reduced to simple circuits. and ohms law can be applied. But, if there are many loops in a circuit which can not be reduced to simple loop circuits then then Ohm's law fails to give the values of current in such circuits. Kirchhoff's 2 laws are very helpful in solving such multiloop circuits.

1. Kirchhoff's 1st law

The algebraic sum of currents meeting at a point is zero.

$$\boxed{\Sigma I = \text{Zero}}$$



By convention currents coming towards the junction point are taken as +ve and currents going away from the junction point are taken as negative.

$\therefore \quad I_1 + I_2 + I_{\cancel{6}} - I_5 - I_3 + I_4 = 0$

$\Rightarrow I_1 + I_2 + I_4 + I_6 = I_5 + I_3$

$\Rightarrow$ Sum of currents coming towards the junction point = Sum of current going away from the junction point.

$\Rightarrow$ Charges can not be stored at any junction point.

Kirchhoff's second law

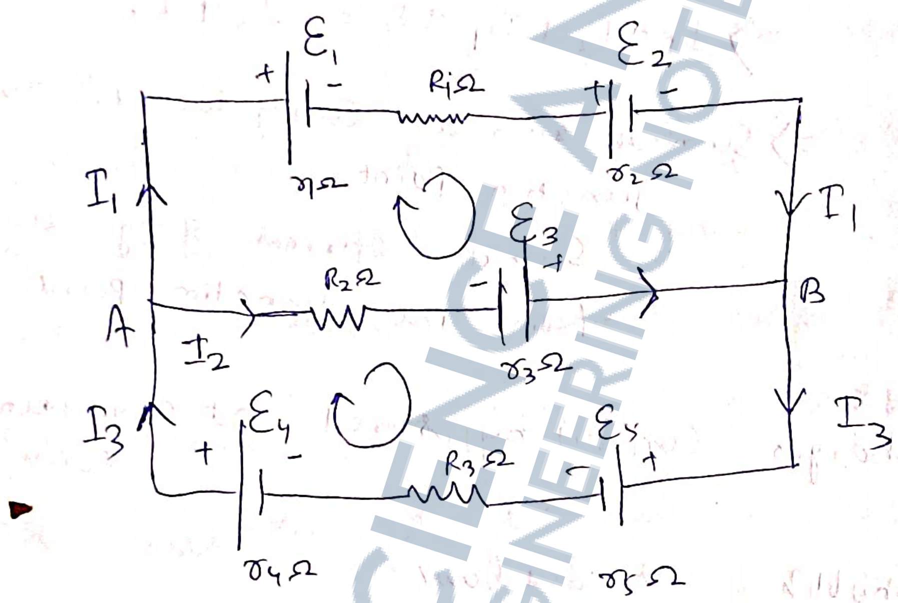
The algebraic sum of product of current and resistance of each part of a closed circuit is equal to the algebraic sum of electro motive forces present in that circuit.

$$\boxed{\sum RI = \sum \varepsilon}$$

Illustration

~~Best~~ By taking clockwise sense as +ve for currents and -ve otherwise. The e.m.f are also taken as +ve if they try to send current in the clockwise direction and -ve otherwise. 3 currents I_1, I_2, I_3 have been assumed for the three branches.

Applying Kirchhoff's second law to the upper loop, we get



$$r_1 I_1 + R_1 I_1 + r_2 I_1 - r_3 I_2 - R_2 I_2$$
$$= \varepsilon_1 - \varepsilon_2 - \varepsilon_3 \quad \text{——— (i)}$$

Applying Kirchhoff's second law to the lower loop, we get

$$R_2 I_2 + r_3 I_2 + r_5 I_3 + R_3 I_3 + r_4 I_3 = \varepsilon_3 - \varepsilon_5 + \varepsilon_4 \quad \text{——— (ii)}$$

Applying Kirchhoff's first law to the junction point A, we get

$$I_3 - I_1 - I_2 = 0 \quad \text{——— (iii)}$$

Solving these three eqⁿs, we can get the values of I_1, I_2 and I_3.

Problem

1. Two cells of e.m.f 1.5 and 2 Volt with internal resistances 1Ω and 2Ω respectively are connected in parallel to an external resistance of 5Ω. Calculate the current in each branch of the network.

(Ans: 0.029, 0.265, 0.294 Amp)

2. Two cells of e.m.f 1.5 and 2 V have internal resistances 2Ω and 1Ω respectively have their −ve terminals joined by a wire of 6Ω and +ve terminals by a wire of 4Ω resistance. A third resistance wire of 8Ω connects the midpoints of these two wires. Find the p.d at the ends of the third wire.

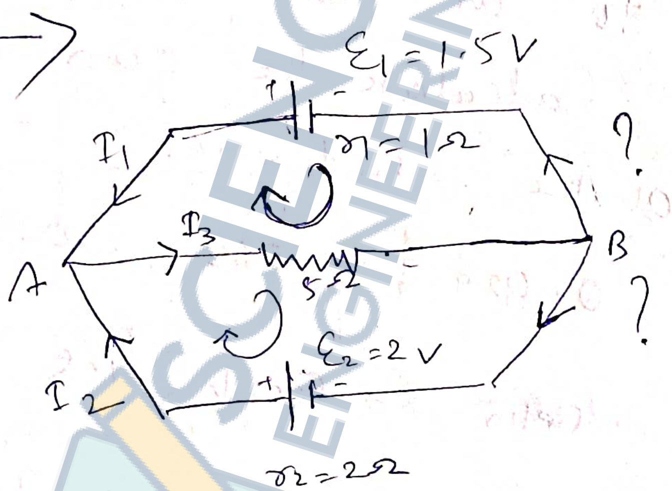
(Ans → 1.26 volt)

3. Two cells of e.m.f ε_1 and ε_2 have internal resistance r_1 and r_2 respectively. If these cells are connected in parallel to an external resistance R so as to send a current in the same direction. Show that the current through R is given by,

$$\frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 r_2 + R(r_1+r_2)}$$

Ans →

1.



Applying ~~Kirc~~ Kirchhoff's first law

At junction A

$$I_1 + I_2 - I_3 = 0 \quad \text{(i)}$$

Applying Kirchhoff's 2nd law for upper loop,

$$-I_1 \, 1\Omega - I_3 5 = -\varepsilon_1 \quad \text{(ii)}$$

$$I_1 + 5I_3 = 1.5$$

For lower loop. ⇒

$$I_3 5 + I_2 2\Omega = \varepsilon_2 \quad \text{(iii)}$$

$$5I_3 + 2I_2 = 2$$

~~From eqn (iii)~~

$$I_3 = \frac{2 - 2I_2}{5}$$

Putting this value in eqn (ii)

$$I_1 + \cancel{5}\cdot\left(\frac{2 - 2I_2}{\cancel{5}}\right) = 1.5$$

$$\Rightarrow I_1 + 2 - 2I_2 = 1.5$$

$$\Rightarrow I_1 - 2I_2 = -0.5$$

$$\Rightarrow I_1 = 2I_2 - 0.5$$

But $I_3 = I_1 + I_2$

$$= 2I_2 - 0.5 + I_2$$

$$= 3I_2 - 0.5$$

Putting the values in eqn (i)

$$I_1 + I_2 - I_3 = 0$$

$$\Rightarrow (2I_2 - 0.5) + I_2 - (3I_2 - 0.5) = 0$$

$$\Rightarrow 2I_2 + I_2$$

OR

$$I_3 = I_1 + I_2$$

Putting this value in eqn (ii)

$$I_1 + 5(I_1 + I_2) = 1.5$$

$$\Rightarrow 6I_1 + 5I_2 = 1.5 \quad \text{---------- (iv)}$$

$$5(I_1+I_2)+2I_2=2$$

$$\Rightarrow \text{or } 5I_1+7I_2=2 \qquad \text{—(V)}$$

$$30I_1+25I_2=7.5$$

$$30I_1+42I_2=12$$

$$(-)\qquad(-)\qquad(-)$$

$$-17I_2=-4.5$$

$$\Rightarrow I_2=\frac{4.5}{17}=\frac{45}{170}=\frac{9}{34}$$

$$=0.2647 \text{ Amp}$$

$$6I_1+5\left(\frac{9}{34}\right)=1.5$$

$$\Rightarrow 6I_1=1.5-\frac{45}{34}$$

$$=\frac{51-45}{34}$$

$$=\frac{6}{34}$$

$$\Rightarrow I_1=\frac{6}{34}\times\frac{1}{6}=\frac{1}{34}$$

$$=.029 \text{ Amp}$$

$$5I_3+2I_2=2$$

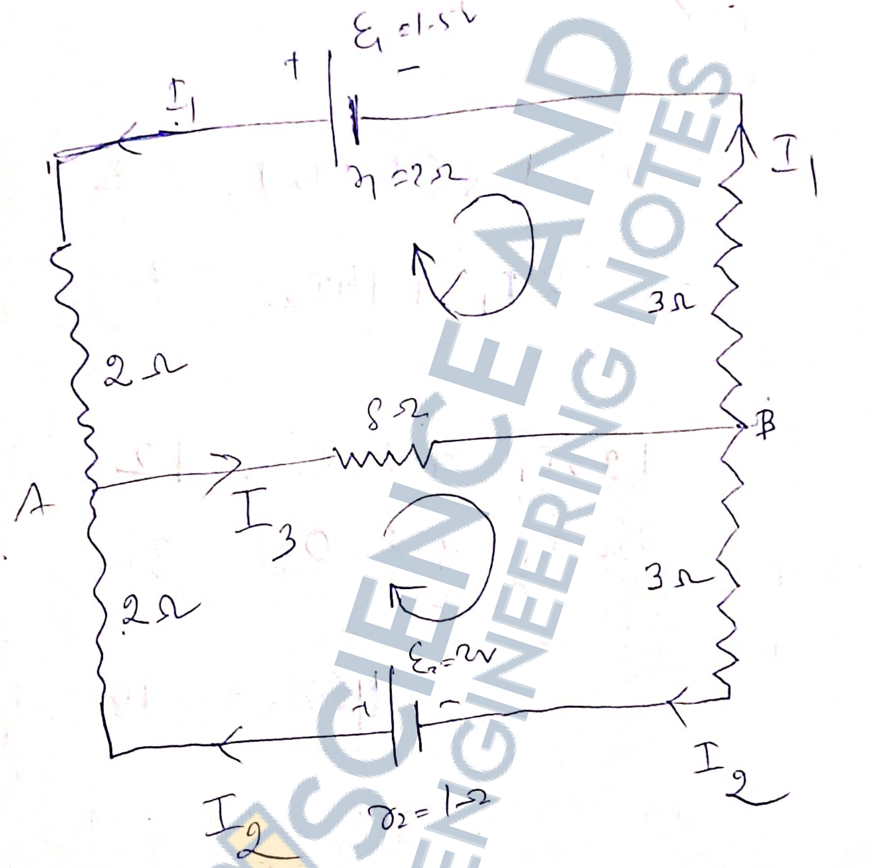
$$\Rightarrow 5\cdot I_3+2\left(\frac{9}{34}\right)=2$$

$\Rightarrow 5I_3 = 2 - \frac{9}{17} = \frac{25}{17}$

$\Rightarrow I_3 = \frac{5}{17} = .294$

$I_1 = .029, \quad I_2 = .2647, \quad I_3 = .294$

2.



Applying Kirchhoff's first law at A

$I_1 + I_2 - I_3 = 0$ —— (i)

Applying Kirchhoff's 2nd law for upper loop.

$-2I_1 - 2I_1 - 3I_1 - 8I_3 = -1.5$ —— (ii)

$\Rightarrow 7I_1 + 8I_3 = 1.5$ —— (iii)

for lower loop

$I_3 8 + I_2 3 + I_2 1 + I_2 2 = 2$

$\Rightarrow 6I_2 + 8I_3 = 2$ —— (iii)

$I_1 + I_2 = I_3$ from eqn (i)

Putting this value in eqn (ii),

$$7I_1 + 8(I_1 + I_2) = 1.5$$

$$\Rightarrow 15 I_1 + 8 I_2 = 1.5 \quad \text{—— (a)}$$

$$6I_2 + 8(I_1 + I_2) = 2$$

$$\Rightarrow 8 I_1 + 14 I_2 = 2 \quad \text{—— (b)}$$

15

$$120 I_1 + 64 I_2 = 12$$

$$120 I_1 + 210 I_2 = 30$$

$(-) \quad (-) \quad (-)$

210
64
6

$$146 I_2 = 18$$

$$\Rightarrow I_2 = \frac{18}{146} = \frac{9}{73}$$

$\Rightarrow$ —— I_1

$$6I_2 + 8I_3 = 2$$

$$\Rightarrow 6 \cdot \frac{9}{73} + 8I_3 = 2$$

$$\Rightarrow 8I_3 = 2 - \frac{54}{73} = \frac{146-54}{73}$$

$$= \frac{92}{73}$$

$$\Rightarrow I_3 = \frac{\cancel{\cancel{92}}^{\cancel{46}\,23}}{73} \times \frac{1}{\cancel{\cancel{8}}_{\cancel{4}\,2}} = \frac{23}{146}$$

Chemical effect of electric current

Electrolysis:- The process of breaking a compound in sol^n into its constituents by passing a direct current through the sol^n is called electrolysis.

Electrolyte:-

The compound in sol^n through which the current is passed is called electrolyte.

Electrode:- The two conducting metals placed in the sol^n at a separation by which current is passed from an external circuit are called electrodes. That electrode which is connected to the +ve terminal of the battery is called anode. and the other electrode which is connected to the -ve terminals of the battery is called cathode

Voltameter:- It includes the electrolyte and the electrodes.

Ex:-

(1) In a silver voltameter, there are two silver electrodes dipped in a sol^n of $AgNO_3$. When a battery is connected to these two electrodes, $AgNO_3$ breaks up into

Ag^+ and NO_3^-. The silver ions (Ag^+) moves towards the cathode and gets deposited where as the NO_3^- ion move towards the anode and brings out a silver atom and again $AgNO_3$ is formed with -ve charge given to the anode. As a result, the anode becomes lighter and the cathode becomes heavier with the passage of time.

Ex: ②

In a copper voltameter there are two copper electrodes dipped in a soln of $CuSO_4$.

$$CuSO_4 \xrightarrow{electrolysis} Cu^{++} + SO_4^{--}$$

The Cu^{++} ion moves towards the cathode and SO_4^{--} moves towards the anode. The conc of $CuSO_4$ soln remains unchanged although the cathode becomes heavier and the anode becomes lighter.

Faraday's laws on Electrolysis

Faraday has given two laws regarding the mass of ions deposited at the cathode due to passage of current through the electrolyte

$\therefore \quad m \propto Q$

or $\quad \boxed{m = ZQ}$

Where Z is called constant for a particular element in soln or electrolyte, called <u>electro chemical equivalant (E.C.E)</u>

~~Defn~~

But $I = \frac{Q}{t}$

$\therefore Q = It$

Thus $m = ZIt$

$\therefore Z = m$ when $I = $ Amp, $t = 1$ sec.

<u>Defn of Z</u>

The electro chemical equivalant may numerical defined as the amount of substance deposited when 1 amp current passed for 1 sec ~~...~~ through the electrolyte

<u>Two laws can be stated</u>

(a) $m \propto I$, when time is kept constant.

<u>Statement</u>: The mass of ions deposited at an electrode is directly proportional to the amount of current passing through the electrolyte when time of passing current is kept constant.

Explanation

By adjusting the resistance of the rheostat, let us have a current of 1 amp in the circuit which is passed for 30 min through some electrolyte. The increase of mass of the cathode gives the mass of ions deposited. (m_1 gm, say)

The current be changed to 2 Amp and again it should be passed for 3 min. The mass of ions deposited $= m_2$ gm (say)

Thus $\frac{m_1}{m_2} = \frac{1}{2}$ (expected)

(b) $m \propto t$ when current (I) is kept constant.

Statement:

The mass of ions deposited at an electrode is directly ~~prop~~ proportional to the time of passing current when current is kept constant.

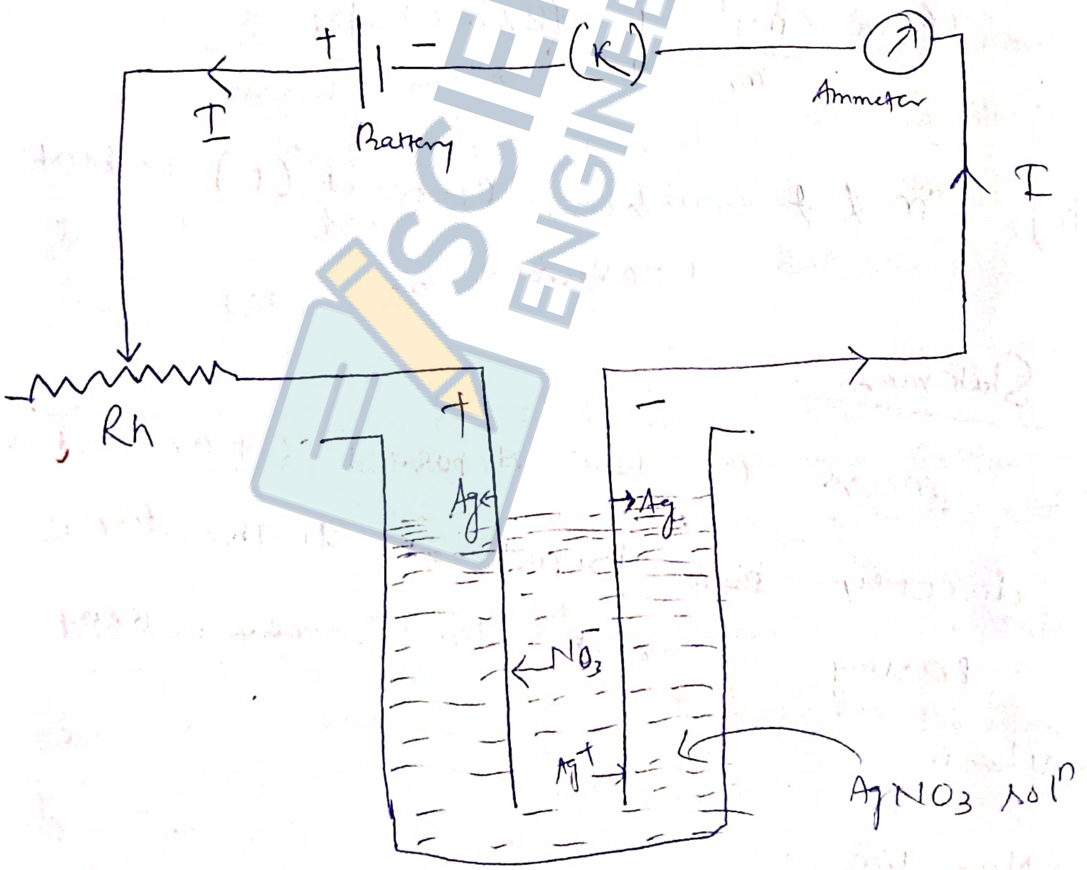
Explanation:

Let us ~~to~~ pass 1 amp of current for 30 min. through an electrolyte and the mass of ions deposited at the electrode be m_1 gm. Keeping current constant at 1 amp. let us pass it through the electrolyte for 60 min and the mass deposited at the cathode be m_3 gm.

$$\therefore \frac{m_1}{m_3} = \frac{1}{2} \quad \text{(expected)}$$

The value of Z of Ag = 0.001118 gm/Coulomb

Z for Cu = 0.000329 gm/Coulomb.



The above circuit can be used to verify Faraday's first law of electrolysis.

(2) Second law

Statement :- If the same amount of current be passed through two different electrolytes placed in series, then the mass of ions deposited at different electrodes are proportional to their respective chemical equivalents.

Chemical equivalant $= E(say) = \dfrac{\text{Atomic weight}}{\text{Valancy}}$

E = Equivalant weight.

$\therefore \quad m_1 \propto E_1$ ~~between m_2 and E_2~~

and $m_2 \propto E_2$

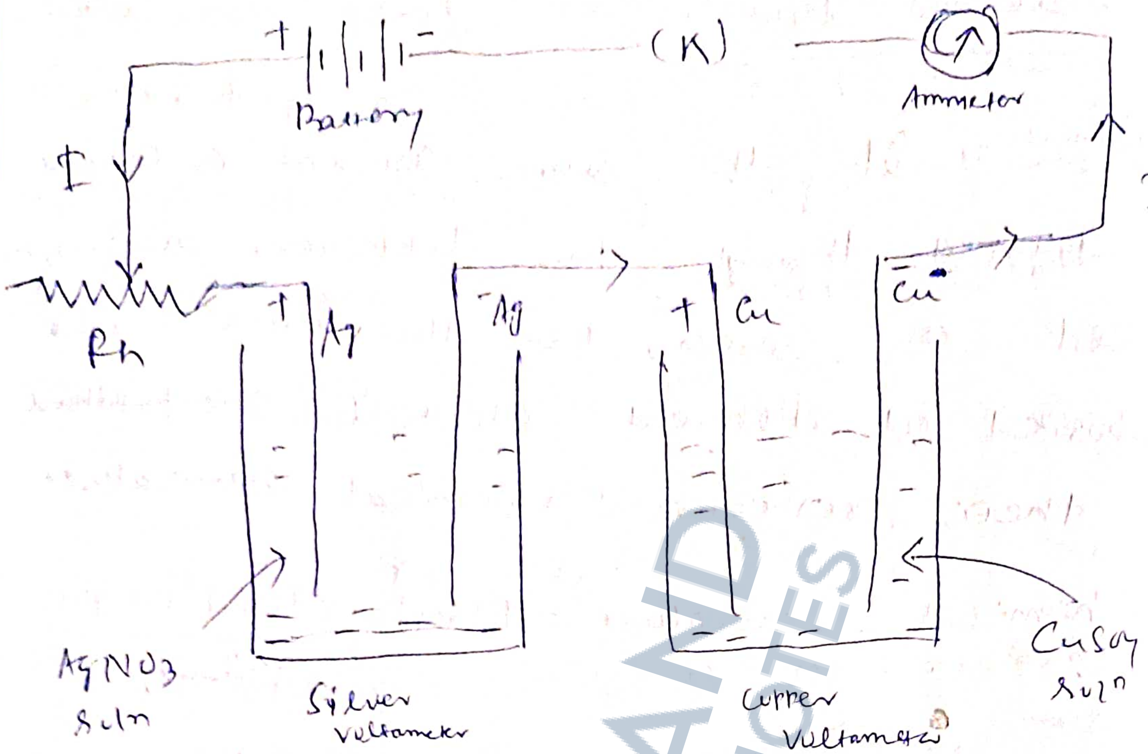
$$\frac{m_1}{m_2} = \frac{E_1}{E_2}$$

Where m_1 = Mass of the ions deposited at the cathode of the 1st electrolyte.

m_2 = Mass of the ions deposited at the cathode of 2nd electrolyte.

Experimental verification of the 2nd law

Suppose 1 Amp of current be passed for 1 hour and the masses deposited at the cathodes of the two voltameter be m_1 and m_2.



E_1 for silver $= \frac{108}{1} = 108$

E_2 for Cu $= \frac{63.5}{2} = 31.75$

Thus $\frac{m_1}{m_2} = \frac{108}{31.75}$ (expected)

$= \frac{3.4}{1}$

If the deposited of silver at the cathode be 3.4 times the mass of copper deposited at its cathode, then the 2nd law of Faraday is verified.

Faraday Unit of Charge

It is that amount of charge which can deposit 1 gm equivalent of any substance at the Cathode. The value of 1 Faraday is 96,500 Coulomb, which is calculated from Faraday's 1st law.

Ex: 1. Applying Faraday's 1st law

$m = ZQ$ for $AgNO_3$ soln, we have

107.87 gm $= 0.001118$ gm/Coulomb. Q

$\Rightarrow Q = \frac{107.87}{.001118} = 96,484.79428$ Coul.

96492.231

Ex: 2: Applying Faraday's 1st law

$m = ZQ$ for $CuSO_4$ soln, we have

$31.77 = 0.000329$ gm/Coul $\times Q$

$\Rightarrow Q = \frac{31.77}{.000329} = 96565.34954$ Coul

96604.533

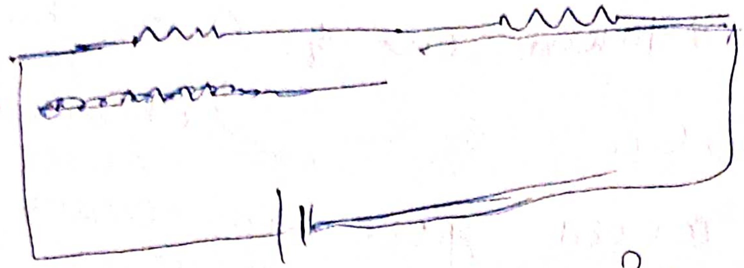
Application of electrolysis

1. Electroplating

The process of depositing a layer of some superior metals such as gold, silver, nickle etc on an object by electrolysis is called electroplating.

Answers to problems

1.



$H_1 = \frac{I^2 . R_1 . t}{J}$, $H_2 = \frac{I^2 R_2 t}{J}$

$$\frac{H_1}{H_2} = \frac{I^2 R_1 t}{J} \times \frac{J}{I^2 R_2 t} = \frac{R_1}{R_2} = \frac{\rho l}{A_1} \times \frac{A_2}{\rho l}$$

$$= \frac{\pi d_2^2}{\pi d_1^2} = \frac{4}{1}$$

$$= 4 : 1$$

G 53 pak

20. Since the wheatstone bridge is balance

Therefore no current will flow through the galvanometer. So the resistance can be omitted.

R_1 and R_2 are in series, $R_{s_1} = 27\ \Omega$

R_3 and R_4 are in series $R_{s_2} = 135\ \Omega$.

Net resistance $= \frac{27 \times 135}{27 + 135} = 22.5\ \Omega$.

$V = 2.48$

$I = \frac{V}{R} = \frac{2.48}{22.5} = 0.110222$ Amp.

But $V_{MA} = V_{MB}$

$\Rightarrow I_1 R_1 = I_2 R_3$

$\Rightarrow I_1 \times 12 = I_2 \times 60$

$\Rightarrow I_1 = 5I_2$

But $I_1 + I_2 = .1102222$ Amp.

$\Rightarrow 5I_2 + I_2 = .1102222$ Amp

$\Rightarrow I_2 = \frac{.1102222}{6}$ Amp.

$= .01837037$ Amp

$I_1 = 5 \times \underline{.0918518\cdot 7}$ Amp.

$V_{MA} = V_{MB} = I_2 \times R_3 =$ or $I_1 \times R_1$

$= 1.10$ volt

$V_{AR} = V_{BR} = I_2 \times R_4 = I_1 = I_2 \times 75$

$= 1.3777$ volt

Since Galvanometer is balanced

volt $V_{AB} = 0$ Ans.

3.

$I = 5$ Amp

$R = 10\,\Omega$

$t = (2\times 60)$ sec

$$\frac{I^2Rt}{J} = ms\cdot\Delta\theta$$

$$\Rightarrow \frac{25\times \cancel{10}\times \cancel{2}\times \cancel{60}}{\cancel{4.2}\ \cancel{2.1}\ .7} = \cancel{100}\times 1\times \Delta\theta$$

$$\Rightarrow \frac{50\times 10}{7} = \Delta\theta$$

$$\Rightarrow \frac{500}{7} = \Delta\theta$$

7) 500 (71.42
49
10
7
30
28
20
14
6

$\therefore$ Temp rises $= 71.4°C$

5. Heat required $ms\Delta\theta$

$= 1000 \cdot 1 \cdot (100 - 25.4)$

$= 1000 \times 74.6$

$= 74600$ Cal

$$\frac{\boxed{I^2Rt}}{J} = 74600 \text{ Cal}$$

$$\Rightarrow \frac{746 \text{ watt} \times t}{4.2} = 74,600 \text{ Cal}$$

$$\Rightarrow t = \frac{74,600\times 4.2}{746} = 420 \text{ sec}$$

$= 7$ min

6. $I^2R = 20$

$$H = \frac{I^2Rt}{J} = \frac{\cancel{20} \times 5 \times \cancel{60}}{\cancel{4.2}} = \frac{10000}{7} = 1428.57 \text{ Cal.}$$

$$7)\ 10000\ (1428.57$$

7. $P = 2.5 = \frac{V^2}{R} = \frac{(20)^2}{R}$

$\Rightarrow 2.5 = \frac{400}{R}$

$\Rightarrow R = \frac{400}{2.5} = \frac{4000}{25} = 160\,\Omega$

8. $r = 80\,\Omega$

$V = 200$ volt

$$I = \frac{V}{r} = \frac{200}{80} = 2.5 \text{ Amp.}$$

$$\text{Power Consumed} = I^2R = (2.5)^2 \times 80 = 500 \text{ watt}$$

It is consumed for 2 hrs ie ~~watt hour~~

$= 500\text{ watt} \times 2$

Rs 1/- per 1 Kwh

$= 1000$ watt hr

$= 10^3$ Wh $= 1$ KWh

∴ The money has to spend is 1 rupee.

9. ✓ 10. ✓

11. ~~V = 220 volt~~,

It means that when potential difference or voltage supplies 220 volts then it will consume 60 watt power.

In one day = 60 × 5 = 300 watt hr.

In 30 day = 300 × 30 = 9×10^3 watt hr
= 9 KWh hours
= 9 unit.

8 units cost = 1 rupee.
9 units cost = 3 rupee.

12. Total lamps = 360.

1 lamp consume = 50 watt.
360 " " = (360 × 50) watt.
each lamp lighted for = 6 hrs.
Total power consumed in one day = 360 × 50 × 6 hr
" " (9 × 30) = $\frac{360 \times 50 \times 6 \times 9 \times 30}{}$ watt hr / Kwh
= $29,160 \times 10^3$
= 29,160 Kwh
= 29,160 unit

It costs 1 unit = $\frac{3}{8}$ Rupee
29,160 unit = 10,935 rupee.

V = 220 volt,

Power - Each lamp Consume = 50 watt

360 lamp will Consume - 360 × 50 watt.

$P = 360 \times 50$ watt = 18000 watt

$V = 220$ volt.

$I = \frac{P}{V} = \frac{18{,}000}{220} = 81.81$ Amp.

13. Water equivalent of kettle = MS = 100 gms.

$\theta_i = 15^\circ C$.

$\theta_f = 100^\circ C$.

water has mass = 1000 gm.

~~Heat required to boil water~~

∴ Heat produced by kettle to boil water

= Heat gain by water + Heat gain by kettle.

= $1000 \times 1 \times (100-15) + 100 \times (100-15)$.

= 85000 + 8500

= 93,500 Cal

⇒ $\frac{I^2Rt}{J}$ I = 1 [illegible]

10 % heat = 93,50 Cal has lost.

Since heat is lost, So more heat in ~~[illegible]~~ required = 9,350 Cal.

this amount ~~So heated needed = 93,500~~

Total heat Consumed = 93,500 + 9,350 = 102,850 Cal.

$\therefore \frac{I^2Rt}{J} = 102{,}850$

অর্থাৎ

$$\Rightarrow \frac{V.I.t}{J} = 102,850$$

$$\Rightarrow \frac{230 \times 4 \times t}{4.2} = 102,850$$

$$\Rightarrow t = \frac{102,850 \times 4.2}{230 \times 4}$$

$$= 469.53 \text{ sec}$$

$$= 7.82 \text{ min}$$

$$= 7 \text{ min}, 49 \text{ sec}.$$

Total heat = 102850 Cal.

Total time = 469.53 sec.

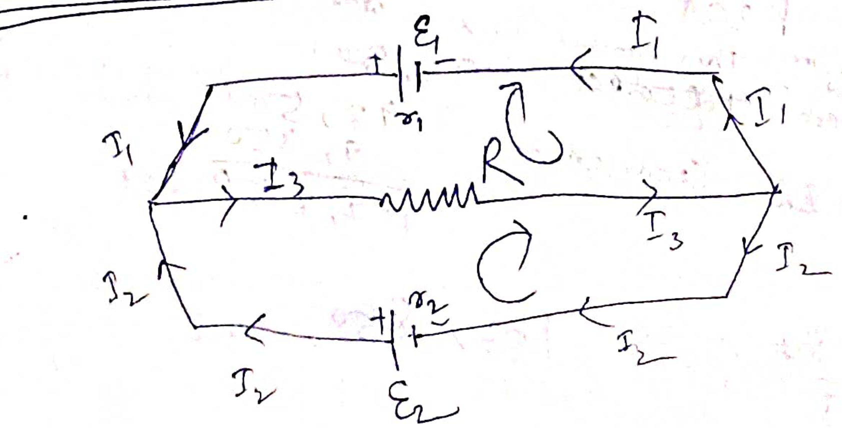
$$\text{Heat per sec} = \frac{102,850}{469.53}$$

$$= 219 \text{ Cal/sec}.$$

— v —

Problems on Kirchhoff's law

3.



Applying Kirchhoff's first law to the point A,

$$I_1 + I_2 - I_3 = 0 \quad \text{——— (i)}$$

Applying Kirchhoff's 2nd law to the upper ~~first~~ loop,

$$-I_1 . r_1 - I_3 R = -\mathcal{E}_1 \quad \text{——— (ii)}$$

$$\Rightarrow I_1 r_1 + I_3 R = \mathcal{E}_1$$

Applying Kirchhoff's 2nd law to the lower loop,

$$I_3 R + I_2 r_2 = \mathcal{E}_2 \quad \text{——— (iii)}$$

From eqn (i), $I_3 = I_1 + I_2$, Putting this value in (ii) and (iii)

$$I_1 r_1 + (I_1 + I_2) R = \mathcal{E}_1 \quad \text{——— (iv)}$$

$$\cancel{\Rightarrow I_1 r_1 + I_1 R + I_2 R = \mathcal{E}_1}$$

$$I_1 r_1 + I_1 R + I_2 R = \mathcal{E}_1$$

$$(I_1 + I_2) R + I_2 r_2 = \mathcal{E}_2 \quad \text{——— (v)}$$

$$\cancel{\Rightarrow I_1 R + I_2 R + I_2 r_2 = \mathcal{E}_2}$$

Subtracting (v) from (iv)

$$I_1 r_1 - I_2 r_2 = \mathcal{E}_1 - \mathcal{E}_2$$

$$\Rightarrow I_1 = \frac{\mathcal{E}_1 - \mathcal{E}_2 + I_2 r_2}{r_1} \quad \text{——— (vi)}$$

Putting this value in eqn (iv),

we get

$$\left(\frac{\varepsilon_1-\varepsilon_2+I_2 r_2}{\cancel{r_1}}\right)\cancel{r_1} + \left(\frac{\varepsilon_1-\varepsilon_2+I_2 r_2}{r_1}\right)R$$

$$+ I_2 R = \varepsilon_1$$

$$\Rightarrow \frac{\varepsilon_1 r_1 - \varepsilon_2 r_1 + I_2 r_2 r_1 + \varepsilon_1 R - \varepsilon_2 R + I_2 r_2 R + I_2 R r_1}{r_1} = \varepsilon_1$$

$$\Rightarrow I_2 (r_2 r_1 + r_2 R + R r_1) + (\cancel{\varepsilon_1 r_1} - \varepsilon_2 r_1 + \varepsilon_1 R - \varepsilon_2 R) = \cancel{\varepsilon_1 r_1}$$

$$\Rightarrow I_2 = \frac{-\varepsilon_1 R + \varepsilon_2 r_1 + \varepsilon_2 R}{r_1 r_2 + r_2 R + r_1 R}$$

Putting this value in eqn (v),

$$I_3 R + \left(\frac{\varepsilon_1 R - \varepsilon_2 r_1 - \varepsilon_2 R}{r_1 r_2 + r_2 R + r_1 R}\right) r_2 = \varepsilon_2$$

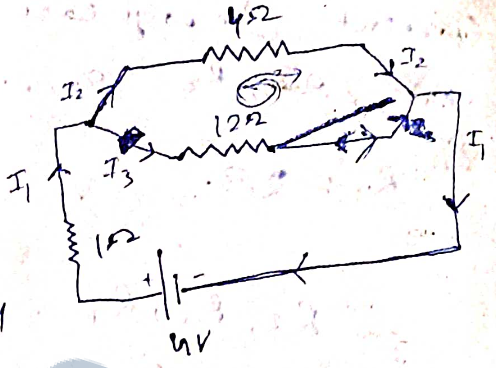
$$\Rightarrow I_3 R = \varepsilon_2 - \frac{\varepsilon_1 R r_2 - \varepsilon_2 r_1 r_2 - \varepsilon_2 R r_2}{r_1 r_2 + r_2 R + r_1 R}$$

$$\Rightarrow I_3 R = \frac{\varepsilon_2 r_1 r_2 + \varepsilon_2 r_2 R + \varepsilon_2 r_1 R - \varepsilon_1 R r_2 + \varepsilon_2 r_1 r_2 + \varepsilon_2 R r_2}{r_1 r_2 + r_2 R + r_1 R}$$

$$\Rightarrow I_3 = \frac{1}{R}\left(\frac{\qquad}{r_1 r_2 + R(r_1 + r_2)}\right)$$

Problems on Kirchhoff's law

1.



4Ω and 12Ω are connected in parallel

$$R_P = \frac{12 \times 4}{16} = 3\Omega$$

3Ω and 1Ω are connected in series.

$$R_{S_1} = 4\Omega \qquad V = 4 \text{ volt}$$

$$I_1 = \frac{V}{R} = \frac{4}{4} = 1 \text{ Amp}$$

Let current through 3Ω, 4Ω, 12Ω resistors be I_1, I_2 and I_3

Applying Kirchhoff' first law

$$I_1 - I_2 - I_3 = 0 \quad \text{——— (i)}$$

$$\Rightarrow I_1 = I_2 + I_3$$

$$\Rightarrow 1 = I_2 + I_3$$

Applying 2nd law to loop consisting 4Ω and 12Ω

$$4I_2 - 12I_3 = 0 \quad \text{——— (ii)}$$

$$\Rightarrow 4(1 - I_3) - 12I_3 = 0$$

$$\Rightarrow 4 - 16I_3 = 0$$

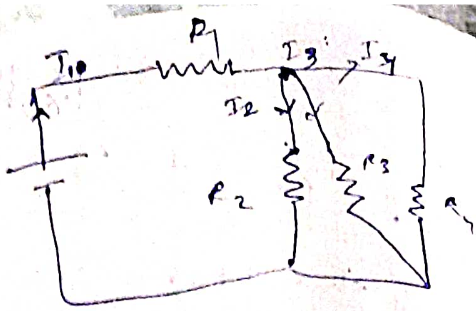
$$\Rightarrow I_3 = \frac{4}{16} = \frac{1}{4} \text{ Amp.}$$

$$I_2 = 1 - I_3 = 1 - \frac{1}{4} = \frac{3}{4} \text{ Amp.} \quad \boxed{\text{Ans}}$$

Voltage across 4Ω resistor

$$= I_2 \times R = \frac{3}{4} \times 4 = 3 \text{ volt} \quad \boxed{\text{Ans}}$$

2. Calculate the current through each resistor. $R_1 = 2\Omega$, $R_2 = 3\Omega$, $R_3 = 6\Omega$, $R_4 = 2\Omega$, $V = 6$ volt



R_2, R_3, R_4 are in parallel and R_1 with series.

$$\therefore R = R_1 + \left(\frac{R_2 R_3 R_4}{R_3 R_4 + R_2 R_4 + R_2 R_3} \right)$$

$$= 2 + \left(\frac{3 \cdot 6 \cdot 2}{12 + 6 + 18} \right)$$

$$= 2 + \left(\frac{36}{36} \right)$$

$$= 2 + 1$$

$$= 3\Omega.$$

$V = 6$ volt

$$I_1 = \frac{V}{R} = \frac{6}{3} = 2\Omega$$

Applying Kirchhoff's 2nd law in

$$I_4 R_4 - I_3 R_3 = 0$$

$$\Rightarrow I_4 \cdot 2 - I_3 \cdot 6 = 0$$

$$\Rightarrow 2 I_4 = 6 I_3$$

$$\Rightarrow I_4 = 3 I_3$$

$$I_3 R_3 - I_2 R_2 = 0$$

$$\Rightarrow I_3 \cdot \cancel{6}^{2} = I_2 \cdot \cancel{3}$$

$$\Rightarrow I_2 = 2 I_3$$

Ans → $A_1 \to 2$, $A_3 \to \frac{1}{3}$
$A_2 \to \frac{2}{3}$, $A_4 : 1$

~~Applying Kirchhoff's law~~,

But
$I_2 + I_3 + I_4 = I_1$

$\Rightarrow I_2 + I_3 + I_4 = 2$

$\Rightarrow 2I_3 + I_3 + 3I_3 = 2$

$\Rightarrow 6I_3 = 2$

$\Rightarrow I_3 = \frac{2}{6} = \frac{1}{3}$

$I_2 = 2 \cdot \frac{1}{3} = \frac{2}{3}$

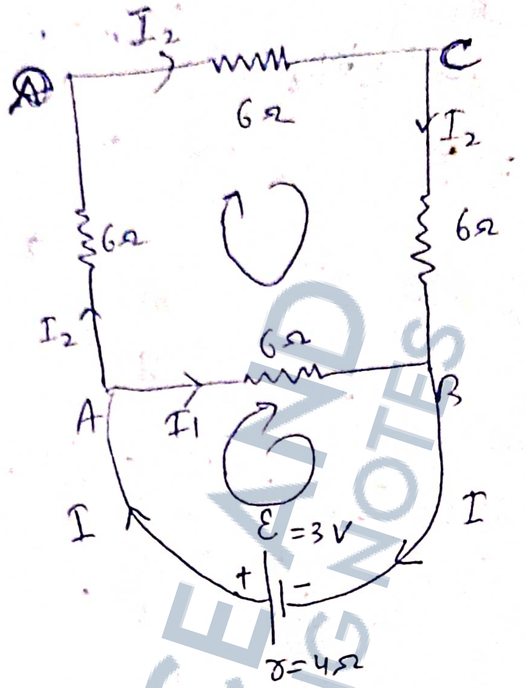
$I_4 = 3 \cdot \frac{1}{3} = 1$

$\therefore I_1 = 2$ Amp, $I_2 = \frac{2}{3}$, $I_3 = \frac{1}{3}$, $I_4 = 1$ Amp

5. A uniform wire 4 metre long and of resistance 6 Ω per meter in bent into the form of a square ABCD. The adjacent corners A and B are connected to a battery of e.m.f 3 volt. and internal resistance 4 Ω. Find the current along AB.

(Ans : $\frac{9}{34}$ Amp)

Soln



Method - 1

AD, CD and CB resistors each is equal to 6Ω are connected in series.

Equivalent resistance

$R_s = 18\ \Omega$.

R_s and AB are connected in parallel.

$$R_p = \frac{18 \times \cancel{6}}{\cancel{24}\ 4} = \frac{18}{4}\ \Omega.$$

Total resistance of the circuit

$$= \frac{18}{4}\Omega + 4\Omega$$

$$= \frac{18 + 16}{4}\Omega$$

$$= \frac{34}{4}\Omega$$

$$= \frac{17}{2}\Omega.$$

$\mathcal{E} = 3V$ volt

$$\text{current}(I) = \frac{V}{R} = \frac{3}{\frac{17}{2}} = \frac{6}{17}$$

$$V_A - V_B = I \times R_P = I_2 \times 18 = I_1 \times 6$$

$$\Rightarrow \frac{6}{17} \times \frac{18}{4} = I_1 \times 6$$

$$\Rightarrow I_1 = \frac{6}{17} \times \frac{\cancel{18}^{9}}{\cancel{4}_{2}} \times \frac{1}{6} = \frac{9}{34}\text{ Amp.}$$

$$I_2 = \frac{\cancel{6}^{3}}{17} \times \frac{\cancel{18}}{\cancel{4}_{2}} \times \frac{1}{\cancel{18}} = \frac{3}{34}\text{ Amp.}$$

<u>Method-2</u>

Applying Kirchhoff's 2nd law for the upper loop,

$$I_2 \cdot 6 + I_2 6 + I_2 6 - I_1 6 = 0$$

$$\Rightarrow 18 I_2 - I_1 6 = 0$$

$$\Rightarrow 3I_2 - I_1 = 0$$

$$\Rightarrow I_1 = 3I_2$$

For the lower loop,

$$I_1 \cdot 6 + I \cdot 4 = 3 \quad \text{—— (ii)}$$

For the junction point A,

$$I - I_1 - I_2 = 0$$

$$\Rightarrow I = I_1 + I_2$$

Putting this in eqn (ii),

$$I_1 6 + (I_1 + I_2) 4 = 3$$

$$\Rightarrow I_1 6 + 4I_1 + 4I_2 = 3$$

$$\Rightarrow 10 I_1 + 4 I_2 = 3 \quad \text{—— (iii)}$$

$$\Rightarrow 10(3I_2) + 4I_2 = 3$$

$$\Rightarrow 30I_2 + 4I_2 = 3$$

$$\Rightarrow 34 I_2 = 3.$$

$$\Rightarrow I_2 = \frac{3}{34} \text{ Ans.}$$

$$I_1 = 3 I_2 = 3 \cdot \frac{3}{34} = \frac{9}{34} \text{ Ans.}$$

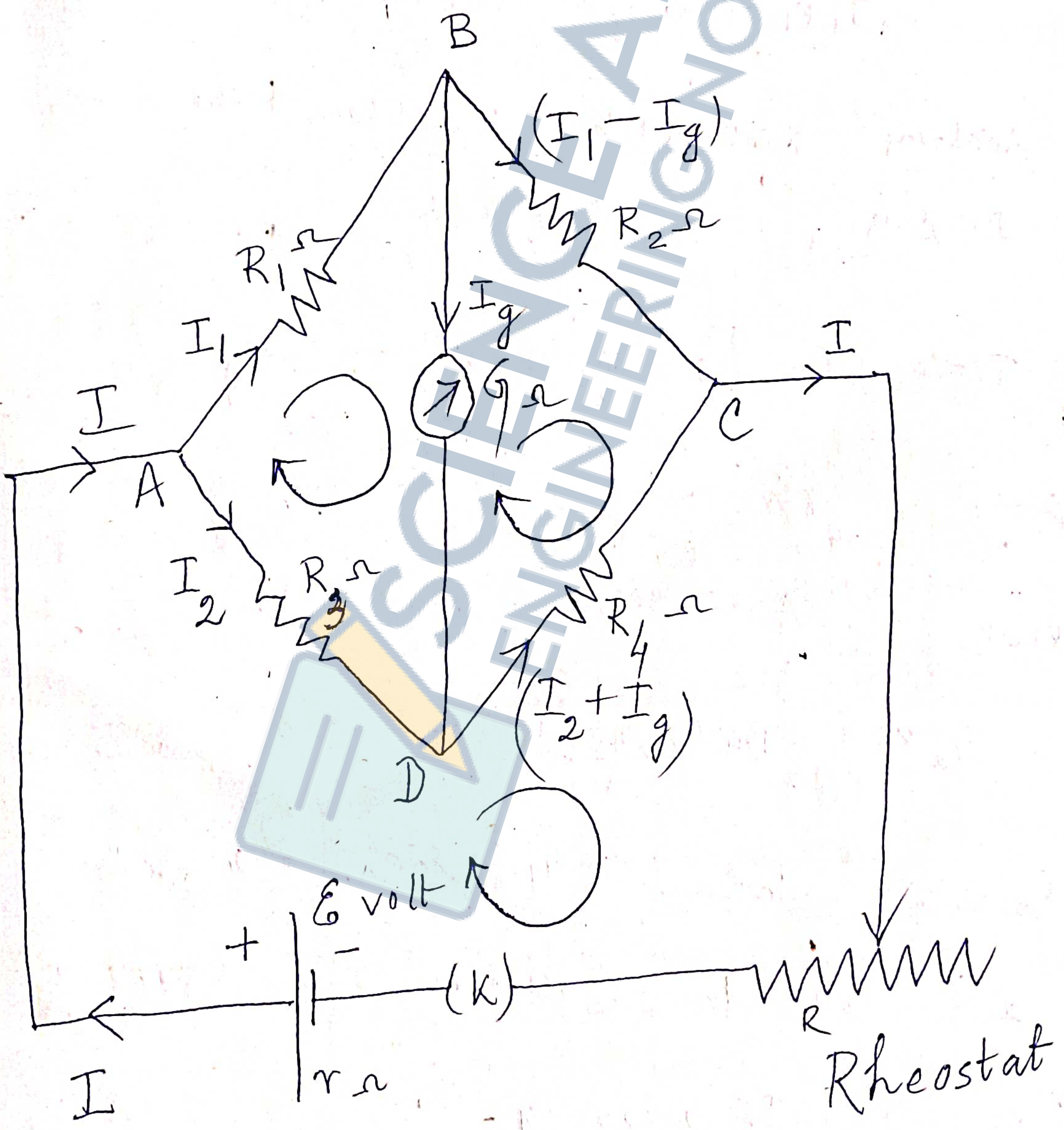
Current across $AB = \frac{9}{34}$ Ans.

Branch change করলে

Current এ change হবে,

2.0 Wheat-stone's bridge. (unbalanced)

This is a typical arrangement of 4 resistances forming the four sides of a quadrilateral such that the galvanometer is connected to the opposite corner while the battery is connected to the other two opposite corners. ~~of the quadrilateral~~.



In general, there will be some current flowing through the galvanometer and we call such a bridge as unbalanced

Wheatstone's bridge.

Applying Kirchhoff's first law to the junction point A, we get

$$I - I_1 - I_2 = 0 \quad \text{———(i)}$$

Applying Kirchhoff's second law to the loop ABDA, we get

$$I_1 R_1 + I_g G - I_2 R_3 = 0 \quad \text{———(ii)}$$

Applying Kirchhoff's second law to the loop BCDB, we get

$$(I_1 - I_g) R_2 - R_4 (I_2 + I_g) - G I_g = 0 \quad \text{———(iii)}$$

Applying Kirchhoff's second law to the loop ADCKA, we get

$$I_2 R_3 + R_4 (I_2 + I_g) + R I + r I = \mathcal{E} \quad \text{—(iv)}$$

Solving these 4 eqns, one can get the values of currents like I, I_1, I_2, I_g.

Balanced Wheat Stone's Bridge

This is a typical arrangement of 4 resistances forming the four sides of a quadrilateral. A galvanometer is connected to any two opposite corners where as a battery is connected to the other two opposite corners. By adjusting the values of the resistances, it is possible to have no current through the galvanometer.

i.e $I_g = 0$

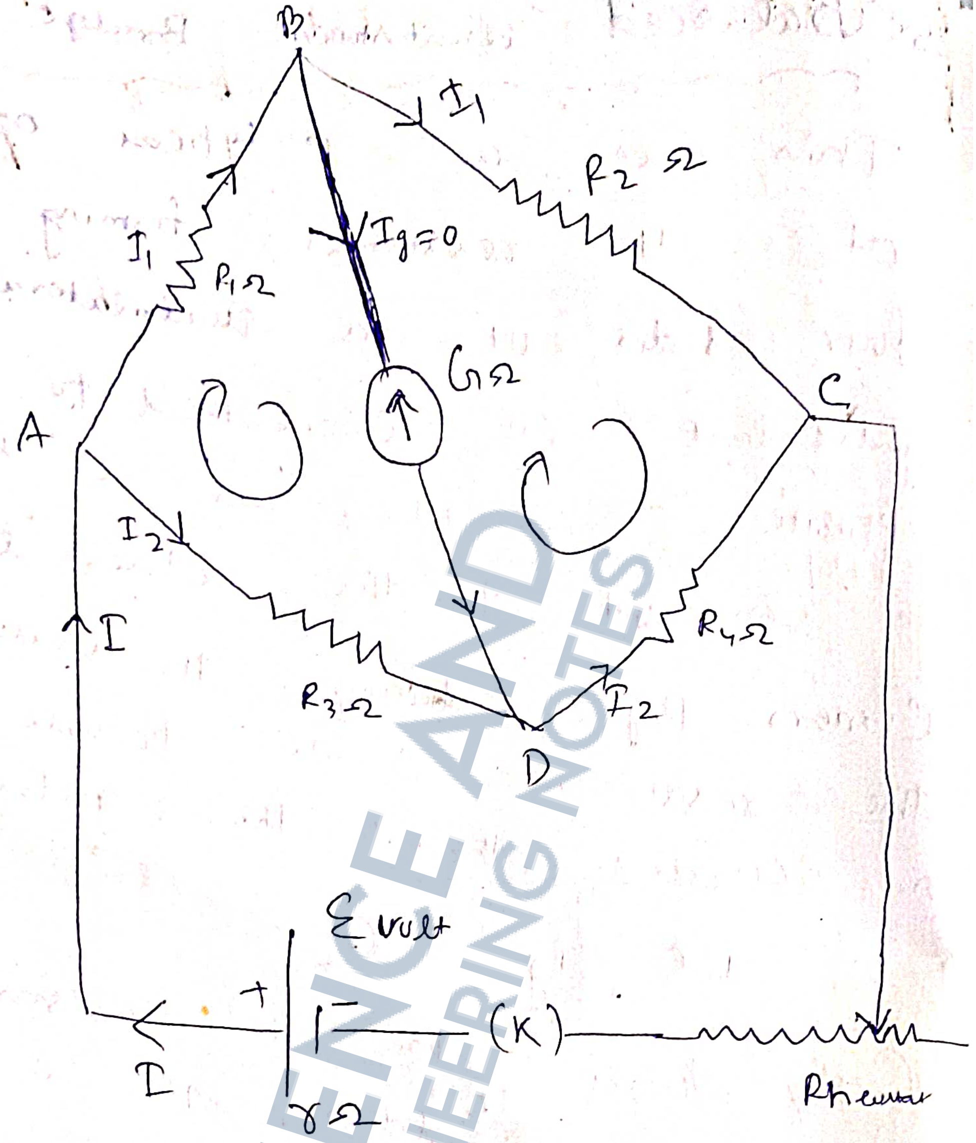
Only when the 4 resistances satisfy a condition, it is possible to have no-deflection in the galvanometer.

Let's try to derive the condition of balanced of the wheatstone's bridge using Kirchhoff's laws. to the loops ABDA and BCDB

Applying Kirchhoff's second law to the loop ABDA, $\Sigma RI = \Sigma E$

$$I_1 R_1 + G.0 - I_2 R_3 = 0$$

$$\Rightarrow I_1 R_1 = I_2 R_3 \quad \text{---(1)}$$



Applying Kirchhoff's law to the loop

BCDB $\quad \sum IR = \sum \varepsilon$

$$R_2 I_1 - R_4 I_2 - G \cdot \cancel{I_g}^{\,0} = 0$$

$$\Rightarrow \quad I_1 R_2 = I_2 R_4 \quad \text{———} \quad (ii)$$

Dividing eqn (i) by eqn (ii),

$$\boxed{\frac{R_1}{R_2} = \frac{R_3}{R_4}}$$

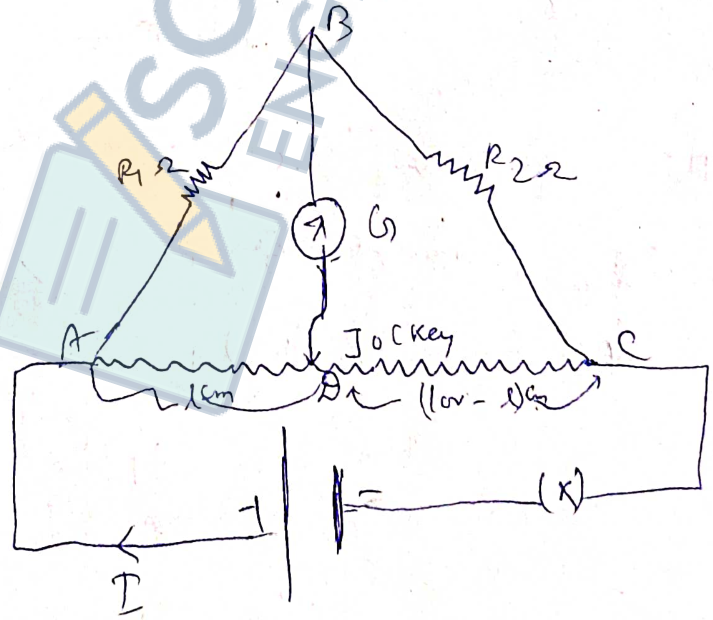
or $\quad \boxed{\frac{R_1}{R_3} = \frac{R_2}{R_4}} \quad \Rightarrow \; = \frac{I_2}{I_1}$

This is the condition of balance of a wheatstones bridge.

This principle is applied to instruments like meter bridge and post office box to find the un-known resistance of a wire.

Application :- (Meter bridge)

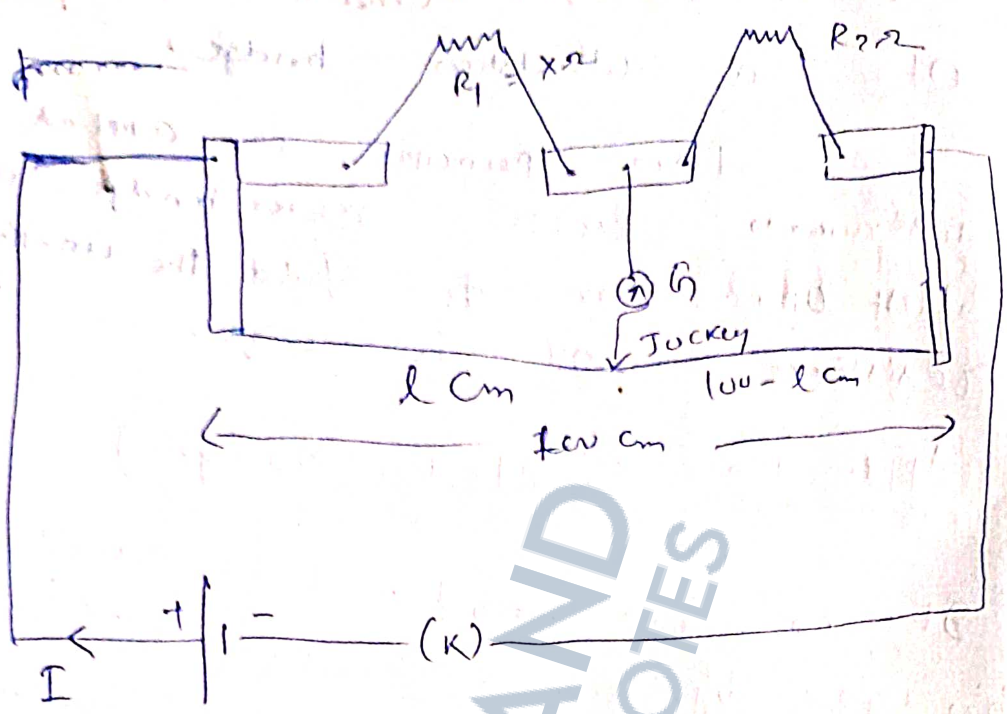
It is a modification of wheatstone's bridge by which resistance of a wire can be determined. Here the two resistance R_3 and R_4 have been replaced by a uniform wire of length 100 cm. There is a contact maker called jockey which ~~ded~~ divides the wire into two parts.



$$R_3 = l\rho$$

$$R_4 = (100 - l)\rho$$

where ρ = resistance per unit length.



For no current through the galvanometer

$$\frac{X}{R_2} = \frac{R_3}{R_4} = \frac{l f}{(100-l)f}$$

or $$X = R_2 \cdot \frac{l}{100-l}$$

If the unknown resistance be interchanged with R_2, then $l'f$ be R_3 and $R_4 = (100-l')f$

$$\frac{R_2}{X} = \frac{l'f}{(100-l')f} = \frac{l'}{100-l'}$$

$$\frac{X}{R_2} = \frac{(100-l')}{l'}$$

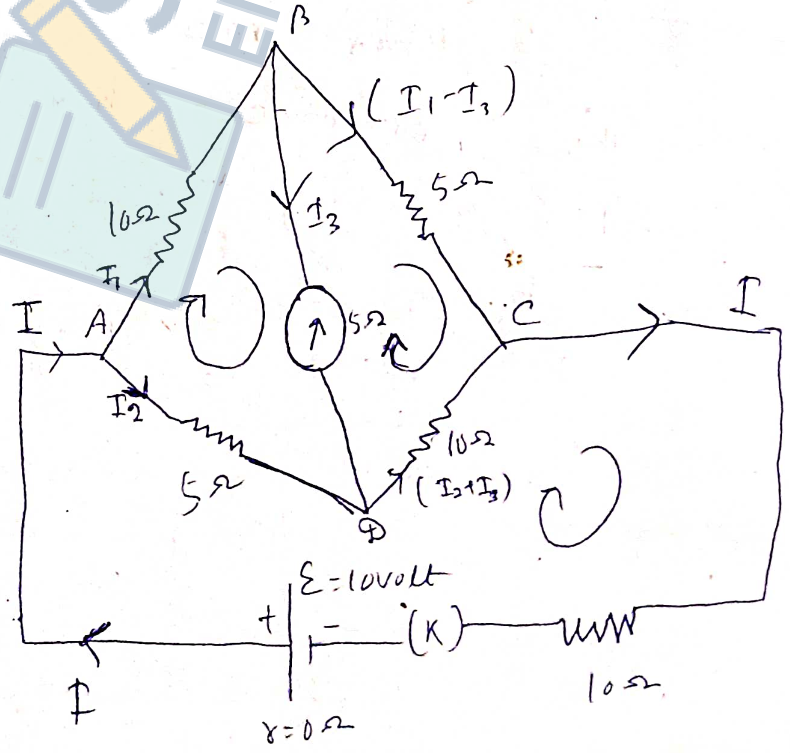
$$\Rightarrow X = \frac{R_2(100-l')}{l'}$$

Mean of these two values of X be taken

(6) ABCD is a quadrilateral of which the arms have resistances AB = 1 Ω, BC = 2 Ω, CD = 3 Ω, DA = 4 Ω. A galvanometer of resistance 5 Ω is placed across BD. If a current of 1 Amp is passed into A and leaves at C, calculate the current in the galvanometer. (Ans:- $\frac{1}{15}$ Amp)

(7) A current of 0.1 Amp enters a wheatstone bridge consisting of 3 arms of 10 Ω each and one of 11 Ω. Find the current through the galvanometer whose resistance is 100 Ω. (Ans:- $\frac{1}{4520}$ Amp)

(8) Determine the current in each branch of the following network.



Ans:-
Current along
AB = $\frac{4}{17}$ Amp
BC = $\frac{6}{17}$ Amp,
CD = $\frac{-4}{17}$ Amp
DA = $\frac{6}{17}$ Amp
BD = $\frac{-2}{17}$ Amp
Main current I = $\frac{10}{17}$ Amp

Problems on Chemical effect of current:

4. A series circuit is completed with a battery of negligible resistance, a Cu voltameter and a resistance box. With 5Ω from the box, the mass of Cu deposited is 0.36 gm in 10 minute. With 10Ω from the box, the mass of Cu deposited is 0.48 gm. in 20 min. Find the internal resistance of the voltameter. (Ans = 5Ω)

Ans: If the internal resistance of the voltameter is $r\,\Omega$,

when 5Ω is included in the circuit current will be given by $I_1 = \dfrac{\varepsilon}{5+r}$

Proble ... → (4)

when 10Ω is taken out from the resistance box, 10Ω is included in the circuit and the current becomes $I_2 = \dfrac{\varepsilon}{10+r}$

$$\therefore \frac{I_1}{I_2} = \frac{10+r}{5+r}$$

From Faraday's first law

$$m_1 = Z I_1 t_1$$

and $m_2 = Z I_2 t_2$

$\therefore \frac{m_1}{m_2} = \frac{I_1 t_1}{I_2 t_2}$

$\Rightarrow \frac{.36\,gm}{.48\,gm} = \frac{10+r}{5+r} \cdot \frac{18\,min}{24\,min}$

$\Rightarrow \frac{3}{4} = \frac{10+r}{10+2r}$

$\Rightarrow 30 + 6r = 40 + 4r$

$\Rightarrow 2r = 10$

$\Rightarrow r = 5\Omega$

(5.) In the electrolysis of water, 83.7 C.C of hydrogen were collected at 25°C at a pressure of 68 cm of mercury when a current of 0.5 Amp had been passed for 20 minutes. Calculate the E.C.E of Cu. (Ans: 0.000 3216 gm/Coul)

Given → At wt of Cu = 63.57
At wt of H = 1.008
Density of hydrogen at N.T.P. .0898 gm/lt

Hints → Using combined gas law volume of hydrogen at N.T.P be found out.

$m = Volume \times d = Z_H I t$, $\frac{Z_1}{Z_2} = \frac{E_1}{E_2}$, $\frac{m_1}{m_2} = \frac{E_1}{E_2}$

6. A tangent Galvanometer has a current passed through it when the deflection becomes 45°. The same current passes through a copper voltameter where it deposites 0.3 gm of Cu in 30 minute. If the E.C.E of Cu is 0.00033 gm/Coul, Find the value of the current. (Ans :- 0.505 Amp)

Hints :- For a tangent galvanometer,

$I = K \tan\theta$

7. An electric circuit contains a T.G which gives deflection of 45°. When an additional resistance of 5 Ω is put in the circuit, the deflection reduces to 30°. Calculate the total resistance in the first case.

Ans :- $\frac{5}{2}(\sqrt{3}+1)\,\Omega$

$I_1 = \frac{\varepsilon}{r}$ $\frac{I_1}{I_2}$

$I_2 = \frac{\varepsilon}{r+5}$

8. A battery of internal resistance B is connected with a T.G in series and resistance R. The deflection being α. When R is replaced by R', the deflection is β. Prove that the internal resistance of galvanometer is

$$\left(\frac{R'\tan\beta - R\tan\alpha}{\tan\alpha - \tan\beta}\right) - B$$

Ans: I_1 = Current in the first case

$$= \frac{\varepsilon}{R+r+B}$$

I_2 = Current in the second case

$$= \frac{\varepsilon}{R'+r+B}$$

$$\therefore \frac{I_1}{I_2} = \frac{R'+r+B}{R+r+B} \quad \text{———} (i)$$

For a T.G we know that

$$I_1 = 10K\tan\alpha$$

$$I_2 = 10K\tan\beta$$

$$\therefore \frac{I_1}{I_2} = \frac{\tan\alpha}{\tan\beta} \quad \text{———} (ii)$$

Equating the R.H.S of (i) and (ii)

$$\frac{R' + \gamma + B}{R + \gamma + B} = \frac{\tan\alpha'}{\tan\beta}$$

$\Rightarrow R'\tan\beta + \gamma\tan\beta + B\tan\beta = R\tan\alpha + \gamma\tan\alpha + B\tan\alpha$

$\Rightarrow \gamma(\tan\beta - \tan\alpha) = R\tan\alpha - B\tan\alpha - R'\tan\beta - B\tan\beta$

$= -B(\tan\alpha + \tan\beta) - R'\tan\beta + R\tan\alpha$

$$\Rightarrow \gamma = \frac{R\tan\alpha - B(\tan\alpha + \tan\beta) - R'\tan\beta}{(\tan\beta - \tan\alpha)}$$

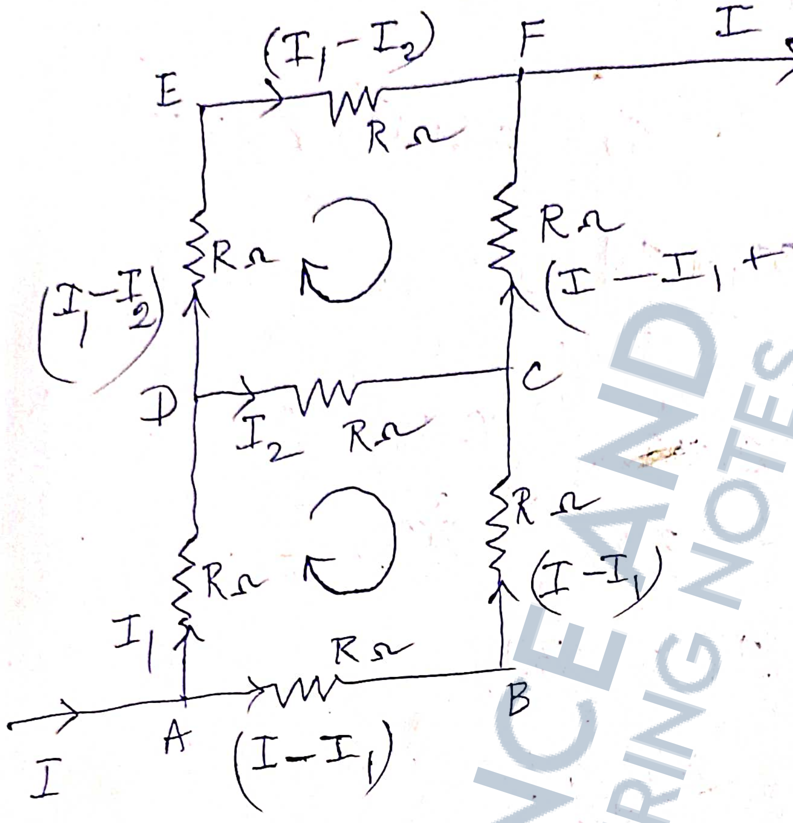
$= R'\tan\beta - R\tan\alpha + B(\tan\alpha + \tan\beta)$

$\Rightarrow R'\tan\beta + B\tan\beta - R\tan\alpha - B\tan\alpha = \gamma(\tan\alpha - \tan\beta)$

$$\Rightarrow \frac{R'\tan\beta - B(\tan\alpha - \tan\beta) - R\tan\alpha}{(\tan\alpha - \tan\beta)} = \gamma$$

$$\Rightarrow \frac{R'\tan\beta - R\tan\alpha}{(\tan\alpha - \tan\beta)} - B = \gamma$$

Q(4) Find the equivalent resistance between A and F. Ans = $\frac{7R}{5}\,\Omega$



Express I_1 & I_2 in terms of I.

$V_A - V_F = R' I$

$= V_A - V_B$

$+ V_B - V_C$

$+ V_C - V_F$

Applying Kirchhoff's 2nd law for the loop ADCBA, we get.

$I_1 R + I_2 R - (I - I_1)R - (I - I_1)R = 0$

$\Rightarrow I_1 R + I_2 R - IR + I_1 R - IR + I_1 R = 0$

$\Rightarrow 3 I_1 R + I_2 R - 2IR = 0$

$\Rightarrow 3I_1 + I_2 = 2I \Rightarrow I = \frac{3I_1 + I_2}{2}$ —(i)

Applying Kirchhoff's 2nd law for the loop DEFCD, we get

$(I_1 - I_2)R + (I_1 - I_2)R - (I - I_1 + I_2)R - I_2 R = 0$

$\Rightarrow I_1 R - I_2 R + I_1 R - I_2 R - IR + I_1 R - I_2 R - I_2 R = 0$

$\Rightarrow 3I_1R - 4I_2R = IR$

$\Rightarrow 9I_1 - 4I_2 = I$ — (ii)

Equating (i) and (ii), we get

$$\frac{3I_1 + I_2}{2} = 3I_1 - 4I_2$$

$\Rightarrow 3I_1 + I_2 = 6I_1 - 8I_2$

$\Rightarrow \cancel{3}I_1 = \overset{3}{\cancel{9}}I_2$

$\Rightarrow I_1 = 3I_2$

From (ii),

$3 \cdot (3I_2) - 4I_2 = I$

$\Rightarrow 9I_2 - 4I_2 = I$

$\Rightarrow 5I_2 = I$

$\Rightarrow I_2 = \frac{I}{5}$

$I_1 = 3 \times \frac{I}{5} = \frac{3I}{5}$

$V_A - V_f = R'I = V_A - V_B + V_B - V_C + V_C - V_f$

$$\Rightarrow R' = \frac{R(I - I_1) + R(I - I_1) + R(I - I_1 + I_2)}{I}$$

$$= \frac{R(3I - 3I_1 + I_2)}{I} = \frac{R\left(3I - 3\cdot\frac{3I}{5} + \frac{I}{5}\right)}{I} = \frac{R \times 7\cancel{I}}{5 \cdot \cancel{I}} = \frac{7R}{5}$$

∴ Equivalent resistance $\frac{7R}{5}\ \Omega$. (Ans)

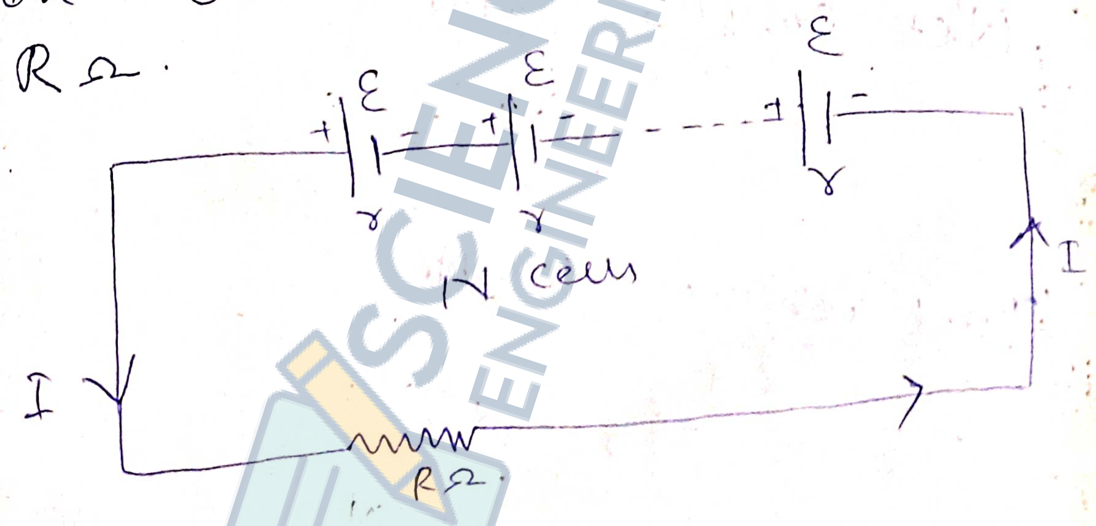
30.07.2k1

Grouping of cells.

Suppose we are provided with N number of cells, each of e.m.f $\mathcal{E}$ volt and internal resistance r ohm.

(I) Cells in series

Cells are said to connected in series when the −ve terminal of one cell is connected to the +ve terminal of the other cell and the ~~traces~~ free ends are connected to an external resistance $R\,\Omega$.



Net e.m.f $= N.\mathcal{E}$

because all the cells try to push the charges in the same direction.

Total resistance $= R + N.r$

Current $= \dfrac{\text{Net e.m.f}}{\text{Total resistance}}$

R should be high

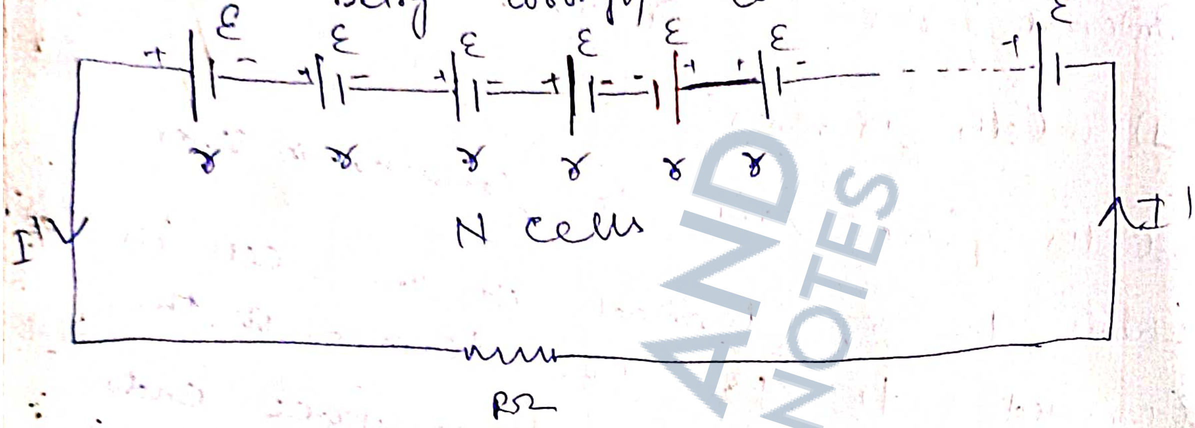
$$I = \frac{N\varepsilon}{R + Nr}$$

Case-I: If $R << Nr$, then $I = \frac{N\varepsilon}{Nr} = \frac{\varepsilon}{r}$

current is independent of n. There is no increase in current providing more and more cells. So this connection is not useful.

Case-II: If $R >> Nr$, $I = \frac{N\varepsilon}{R}$. So current increases with number of cells. So series connection is useful if external resistance is very very higher than internal resistance of cell.

② Cells in series with one of the cells being wrongly connected



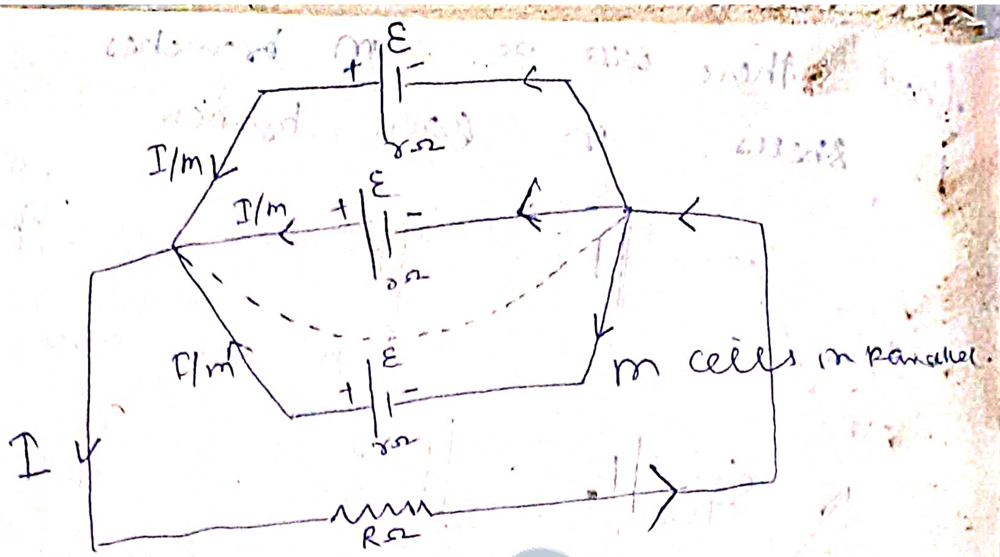
$$\text{Net emf} = (N-1)\varepsilon - \varepsilon$$
$$= (N-2)\varepsilon$$

Total resistance $= R + Nr$

$$\text{Current} = I' = \frac{(N-2)\varepsilon}{R + Nr}$$

③ Cells in parallel

Cells are said to be connected in parallel when all the +ve terminal are connected to one point and all the −ve terminals are connected to another point. These two points can be connected to an



external resistance $R\,\Omega$.

Net e.m.f = ε

Total resistance = $R + r_p$

where r_p equivalent resistance of all the cells which are connected in parallel.

$\therefore \quad \frac{1}{r_p} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r}$ ------ up to m term.

$= \frac{m}{r}$

$\Rightarrow r_p = \frac{r}{m}$

Current (Main) = $\frac{\text{Net emf}}{\text{Total resistance}}$

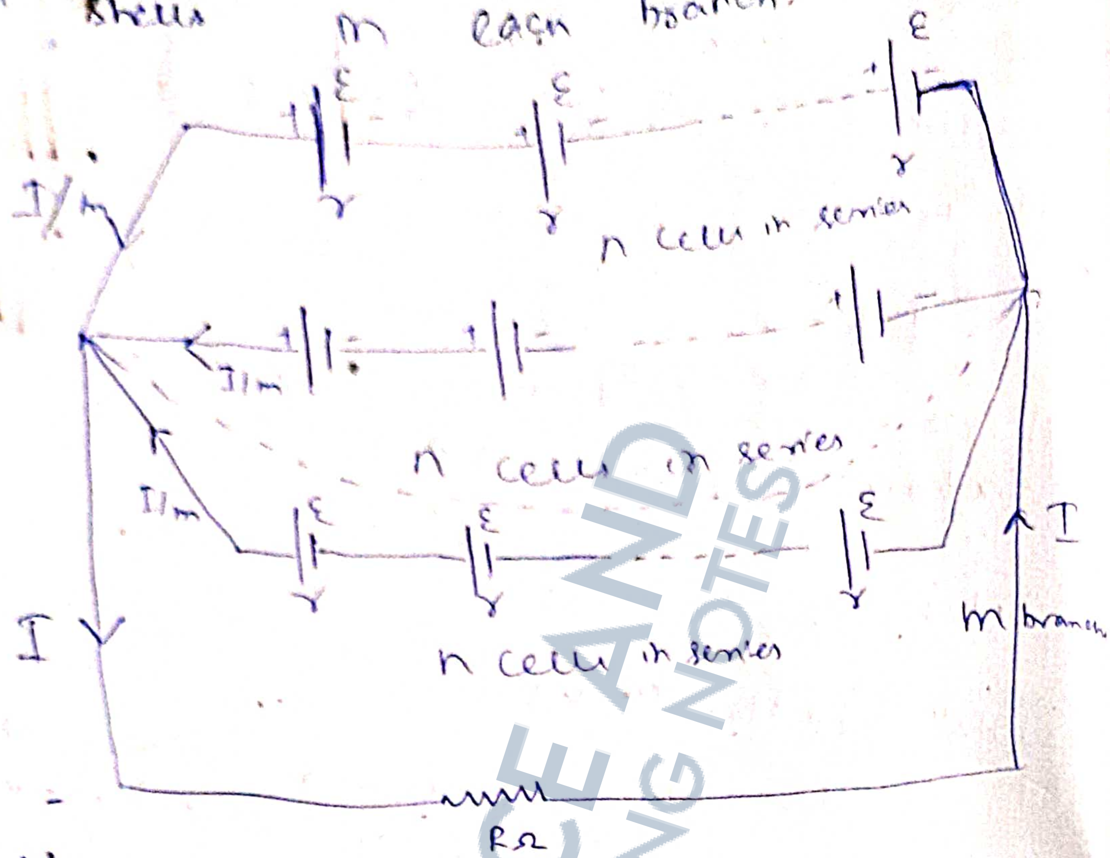
$\Rightarrow I = \frac{\varepsilon}{R + \frac{r}{m}} = \frac{m\varepsilon}{mR + r}$

> Case-I
> $R >> \frac{r}{m}$
> $I = \frac{\varepsilon}{R}$, so not useful in increasing No. of cells.
> Case-II $R \leq \frac{r}{m}$,
> $I = m \times \frac{\varepsilon}{r}$, so it is useful.
> So external resistance should be very low

(4) Mixed grouping of Cells

Let's make a combination of cells such

that there will be m branches with n shells in each branch.



Net e.m.f = e.m.f of each branch

$= n\varepsilon$

Total resistance of the circuit = $R + r_p$

where r_p = Equivalent resistance of all the cells

$\therefore \frac{1}{r_p} = \frac{1}{nr} + \frac{1}{nr} + \text{---} \text{ upto m term}$

$= \frac{m}{nr}$

$\Rightarrow r_p = \frac{nr}{m}$

$\therefore$ Current through the external resistance $= \frac{\text{Net e.m.f}}{\text{Total resistance}}$

$$\boxed{I = \frac{n\varepsilon}{R + \frac{nr}{m}} = \frac{mn\varepsilon}{mR + nr} = \frac{N\varepsilon}{mR + nr}}$$

(5) Condition to have max^m current out of a given number of cells

Suppose $N = 24 = mn$

Possible Combinations are,

$m = 2, n = 12$

$m = 12, n = 2$

$m = 3, n = 8$

$m = 8, n = 3$

$m = 4, n = 6$

$m = 6, n = 4$

To know the right Combination to have max^m current, we see from the expression $I = \frac{N\varepsilon}{mR + nr}$ That The numerator is a constant and the denominator can be change if the d.r be made a min^m then I will be max^m

$$\therefore mR + nr = \left(\sqrt{mR}\right)^2 + \left(\sqrt{nr}\right)^2$$

$$= \left(\sqrt{mR} - \sqrt{nr}\right)^2 + 2\sqrt{mR}\cdot\sqrt{nr}$$

$$= (\sqrt{MR} - \sqrt{nr})^2 + 2\sqrt{MnRr}$$

The second term is a constant quantity and the d.r can be made a min^m only when the squared quantity becomes 0. (Min^n)

$$\therefore \sqrt{MR} = \sqrt{nr}$$

$$\Rightarrow MR = nr$$

$$\Rightarrow \boxed{R = \frac{nr}{m}} = r_p$$

Thus the current will be max^m when the external resistance will be equal to the effective internal resistance of all the ~~small~~ cells put together.

Problem :-

1. 24 cells, each of e.m.f 1.4 volt and internal resistance 2 Ω. are to be connected so as to produce max^m current through a wire of resistance 12 Ω.

(i) How you will connect them?

(ii) Find the strength of the current through each cell.

(c) Find the p.d across the external resistance.

Ans:

Let there be m branches with n cells in each branch.

$\therefore mn = 24$ ——— (i)

The condition for maxm current out of a given number of cell is

$$R = \frac{nr}{m}$$

$$\Rightarrow 1.2 = \frac{n \cdot 2}{m}$$

$$\Rightarrow \frac{n}{m} = 6$$ ——— (ii)

multiplying (i) and (ii)

$$n^2 = 144$$

$$\Rightarrow n = 12$$

$$m = \frac{24}{12} = 2$$

i.e there will be two branches with 12 cells in each branch.

(ii) $I = \dfrac{NE}{mR + nr} = \dfrac{24 \cdot (1.4)}{2 \cdot 12 + 12 \cdot 2} = \dfrac{24 \times 1.4}{48}$

$= 0.7$ Amps.

Current flowing from each branch

$= \frac{0.7}{2} = 0.35$ Amp.

= Current through cell

Q11,

$V = \frac{RI}{3} = 12 \times 0.7$

$= 8.4$ ~~Amp~~ volt

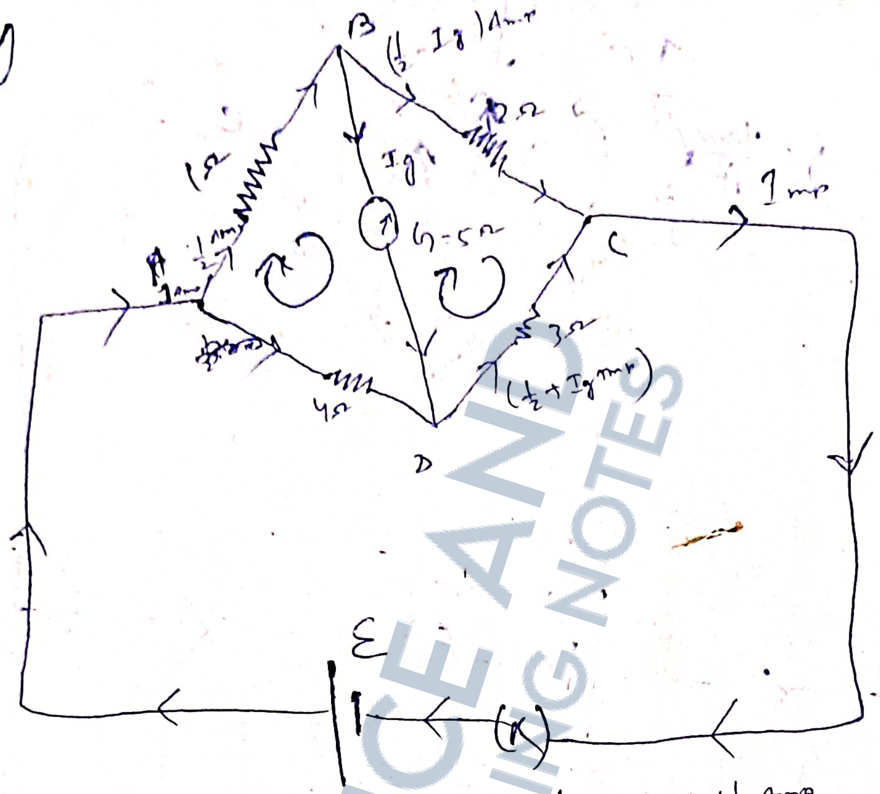
G57,

Cell - 38, $\rightarrow$ 1.87, 2.066 volt

⑦ $\rightarrow$ 19.1 Ω . 114.3 volt.

Answers to problems

6.



At A, 1 Amp current divides into $\frac{1}{2}$ Amp and $\frac{1}{2}$ Amp.

Applying Kirchhoff's law, for the loop ABDA, we get

$$\frac{1}{2}\cdot 1 + I_g\cdot 5 - \frac{1}{2}\cdot 4 = 0$$

---

6. Applying Kirchhoff's first law at the junction point A, we get

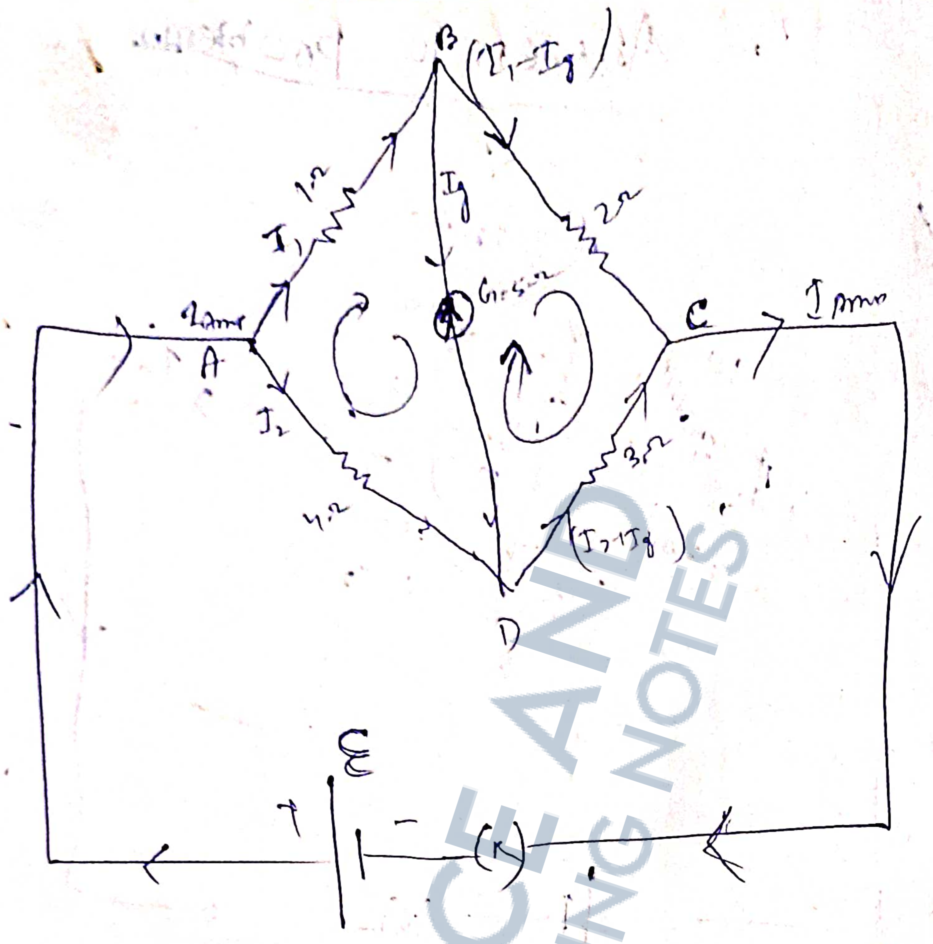
$$I_1 + I_2 = 1 \text{ ~~Amp~~} \quad \text{——— (i)}$$

Applying Kirchhoff's second law for the loop ABDA, we get

$$I_1 + I_g\cdot 5 - I_2\,4 = 0 \quad \text{——— (ii)}$$

For the loop BCDA, $(I_1 - I_g)\cdot 2 - (I_2 + I_g)3 - I_g\cdot 5 = 0$ (iii)

$\boxed{\text{For ADCKA, } I_2\cdot 4 + (I_2+I_g)3 = \mathcal{E} \quad \text{——— (iv)}}$



From

Eqn (ii)

$$\frac{I_1 - 4I_2}{5} = -I_g$$

$$\Rightarrow I_g = \frac{4I_2 - I_1}{5}$$

From eqn (iii)

$$2I_1 - 2I_g - 3I_2 - 3I_g - 5I_g = 0$$

$$\Rightarrow 2I_1 - 3I_2 - 10I_g = 0$$

$$\Rightarrow 2I_1 - 3I_2 - \cancel{10}^{2}\left(\frac{4I_2 - I_1}{\cancel{5}}\right) = 0$$

$$\Rightarrow 2I_1 - 3I_2 - 8I_2 + 2I_1 = 0$$

$\Rightarrow 4I_1 - 11I_2 = 0$

$\Rightarrow 4(1 - I_2) - 11I_2 = 0$

$\Rightarrow 4 - 4I_2 - 11I_2 = 0$

$\Rightarrow 4 = 15I_2$

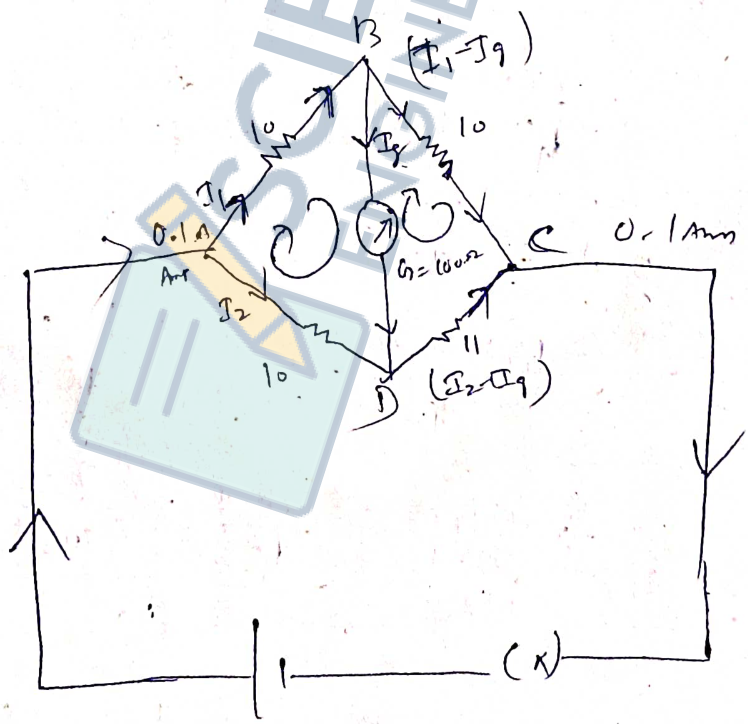
$\Rightarrow I_2 = \frac{4}{15}$

$I_1 = 1 - \frac{4}{15} = \frac{11}{15}$

$I_g = \frac{4I_2 - I_1}{5} = \frac{4\left(\frac{4}{15}\right) - \frac{11}{15}}{5}$

$= \frac{(16-11)}{15 \times 5} = \frac{5}{15 \times 5} = \frac{1}{15}$ Amp

7.



$I_1 + I_2 = 0.1$ —(i)

$I_1(10) + I_g \cdot 100 - 10I_2 = 0$ —(ii)

$(I_1 - I_g)10 - (I_2 + I_g)11 - I_g\,100 = 0$ —(iii)

$$I_g = \frac{10I_2 - 10I_1}{100} = \frac{I_2 - I_1}{10}$$

From eqn (iii)

$$10I_1 - 10I_g - 11I_2 - 11I_g - 100I_g = 0$$

$$\Rightarrow 10I_1 - 11I_2 - 121I_g = 0$$

$$\Rightarrow 10I_1 - 11I_2 - 121\left(\frac{I_2 - I_1}{10}\right) = 0$$

$$\Rightarrow 100I_1 - 110I_2 - 121I_2 + 121I_1 = 0$$

$$\Rightarrow 221I_1 - 231I_2 = 0$$

$$\Rightarrow 221(0.1 - I_2) - 231I_2 = 0$$

$$\Rightarrow 22.1 - 221I_2 - 231I_2 = 0$$

$$\Rightarrow I_2 = \frac{22.1}{452}$$

$$I_1 = 0.1 - \frac{22.1}{452} = \frac{45.2 - 22.1}{452} = \frac{23.1}{452}$$

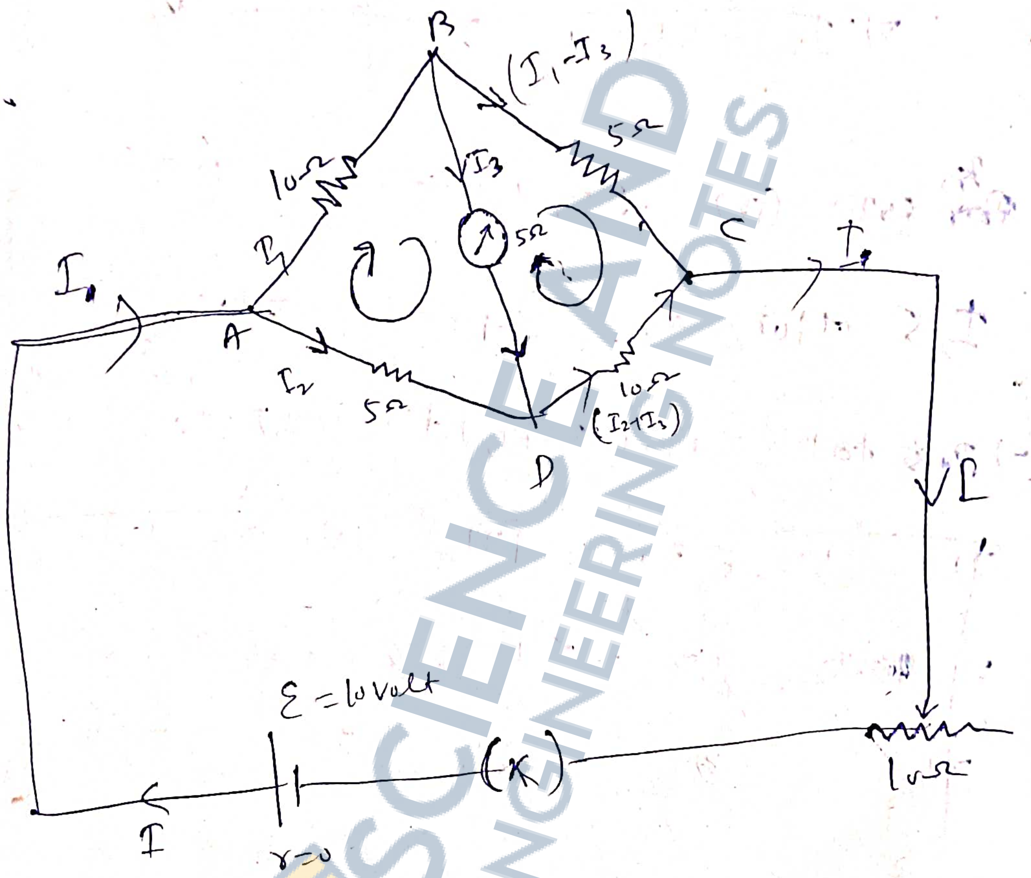
$$I_g = \frac{I_2 - I_1}{10} = \frac{\frac{22.1}{452} - \frac{23.1}{452}}{10}$$

$$= \frac{-1}{4520} \text{ Amp.}$$

We have assumed that current

flows from B to D. But the -ve sign show that current flows from D to B. ∴ The galvanometer current is $\frac{1}{452}$ Amp

8.



$I = I_1 + I_2$ ——— (i)

$10I_1 + I_3 5 - I_2 5 = 0$ ——— (ii)

$(I_1 - I_3)5 - (I_2+I_3)10 - I_3 5 = 0$ ——— (iii)

$I_2 5 + (I_2+I_3)10 + I.10 = 10$ (iv)

From (ii), $\frac{10I_1 - 5I_2}{5} = -I_3 \Rightarrow I_3 = -2I_1 + I_2$

From (iii) $5I_1 - 5I_3 - 10I_2 - 10I_3 - I_3 5 = 0$

$\Rightarrow 5I_1 - 10I_2 - 20I_3 = 0 \Rightarrow I_1 - 2I_2 - 4I_3 = 0$

$\Rightarrow I_1 - 2I_2 - 8(-2I_1 + I_2) = 0$

$\Rightarrow I_1 - 2I_2 + 8I_1 - 4I_2 = 0$

$\Rightarrow 9I_1 - 6I_2 = 0$

$\Rightarrow \cancel{3I_1 - I_2 = 0}$ $\Rightarrow 3I_1 - 2I_2 = 0$

$\Rightarrow 3I_1 = 2I_2$ — (V)

$\Rightarrow \cancel{I_2 - 5I_1 = 0}$

In eqn (IV), putting the value of R from eqn 6,

$I_2 5 + 10I_2 + 10I_3 + 10I = 10$

$\Rightarrow 15I_2 + 10(-2I_1 + I_2) + 10(I_1 + I_2) = 10$

$\Rightarrow 15I_2 - 20I_1 + 10I_2 - 10I_1 - 10I_2 = 10$

$\Rightarrow -5I_2 + 10I_1 = 10$

$\Rightarrow -I_2 + 2I_1 = 2$ — (VI')

$\Rightarrow -(5I_1) + 2I_1 = 2$

$\Rightarrow -3I_1 = 2$

$\Rightarrow I_1 = -\frac{2}{3}$

$\Rightarrow 15I_2 - 20I_1 + 10I_2 + 10I_1 + 10I_2 = 10$

$\Rightarrow 35I_2 - 10I_1 = 10$

$\Rightarrow 35\left(\frac{3}{2}I_1\right) - 10I_1 = 10$

$\Rightarrow \frac{105I_1 - 20I_1}{2} = 10$

$\Rightarrow 85 I_1 = 20$

$\Rightarrow I_1 = \frac{20}{85} = \frac{4}{17}$ Amp.

$I_2 = \frac{3}{2} I_1 = \frac{3}{2} \times \frac{4}{17} = \frac{6}{17}$

$I_3 = I_2 - 2I_1$

$= \frac{6}{17} - 2 \cdot \frac{4}{17} = \frac{-2}{17}$ Amp.

$I = I_1 + I_2 = \frac{10}{17}$ Amp.

Along AB $= I_1 = \frac{4}{17}$

Along BC $= I_1 - I_3 = \frac{4}{17} + \frac{2}{17} = \frac{6}{17}$

Along CD $= I_2 + I_3 = \frac{6}{17} - \frac{2}{17} = \frac{4}{17}$

Along AD $= I_2 = \frac{6}{17}$

Along BD $= I_3 = \frac{-2}{17}$

Max^m current $I = \frac{10}{17}$ Amp.

Chemical effect:

Q, We know from Combined gas eq,

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\Rightarrow \frac{76 \times V_1}{273} = \frac{68 \times 83.7}{298}$$

$\Rightarrow V_1 = \dfrac{\cancel{27.3} \times \cancel{68} \times \cancel{83.7}\ \ 76.1}{\cancel{76} \times 298}$

$= \cancel{27.3} = 68.606$ ml.

$I = 0.5$ Amp

$t = 20 \times 60 = 1200$ sec.

Mass of H_2 = 68.606 ml × density

density = $\dfrac{.0898 \text{ gm}}{lt} = \dfrac{.0898 \text{ gm}}{1000 \text{ ml}}$

$= .0000898$

$= 68.606 \times .0000898$

$= 6.1608188 \times 10^{-3}$

$\Rightarrow Z \cdot (.5) \cdot (1200 \text{ sec}) = "$

$\dfrac{Z_{Cu}}{Z_2} = \dfrac{E_1}{E_2}$

$\Rightarrow Z = \dfrac{6.1608188 \times 10^{-3}}{600}$

$= 6.102 \times 10^{-5}$

$\Rightarrow \dfrac{Z_{Cu}}{1.02 \times 10^{-5}} = \dfrac{31.78}{1.008}$

$\Rightarrow Z_{Cu} = \dfrac{1.02 \times 31.78 \times 10^{-5}}{1.008}$

$= 32.1583 \times 10^{-5}$

$= .000321583 \simeq .000321$ g

Coulomb

6.

31.77 gm Cu is deposited by 96,500 Coul.

1 " " " " $\frac{96,500}{31.77}$ Coul.

.3 " " " " $\frac{96,500}{31.77} \times (0.3)$ Coul

$$Q = Z I t$$

$$\Rightarrow \frac{96500 \times (.3)}{317.7} = .00033 . I \times (30 \times 60)$$

$$\Rightarrow I = \frac{965 \times 3}{317.7 \times .00033 \times 18}$$

$$= \frac{96500 \times .3 \times 1}{317.7 \times 1800}$$

$$\frac{965 \times 10^5}{317.7 \times 6 \times 33}$$

$$= \frac{15300 \times 10^3}{317.7 \times 39.6}$$

$$= 0.0506 \text{ Amp}$$

or

$$m = Z . I t$$

$$\Rightarrow 0.3 = .00033 \times I \times (30 \times 60)$$

$$\Rightarrow I = \frac{.3 \times 10^5 \times 10^2}{33 \times 18 \times 10^2}$$

$$= \frac{300}{594}$$

$$= .505 \text{ Amp.}$$

7. Let R be the resistance of the circuit

$$I_1 = \frac{\mathcal{E}}{R} = 10 K \tan 45^\circ$$

when 5Ω is connected

$$I_2 = \frac{\mathcal{E}}{5+R} = 10 K \tan 30$$

$$\therefore \frac{I_1}{I_2} = \frac{\mathcal{E}}{R} \times \frac{R+15}{\mathcal{E}} = \frac{R+15}{R} = \frac{\tan 60^\circ}{\tan 30^\circ}$$

$$\Rightarrow \frac{R+15}{R} = \frac{1}{\frac{1}{\sqrt{3}}} \cdot \sqrt{3}$$

$$\Rightarrow R+15 = \sqrt{3}R$$

$$\Rightarrow \cancel{R(\sqrt{3}+1) = 5}$$

$$\Rightarrow R(\sqrt{3}-1) = 5$$

$$\Rightarrow R = \frac{5}{\sqrt{3}-1} = \frac{5(\sqrt{3}+1)}{3-1} = \frac{5}{2}(\sqrt{3}+1)\ \Omega$$

Gujrat

38.

Let the current flow in the ~~current~~ circuit I.

They are in helping series means +ve end is connected to −ve end & −ve end is connected to +ve end of battery.

$$\text{Current } I = \frac{\mathcal{E}}{R+(r_1+r_2)} = \frac{2+4}{2.7+(.1+.2)}$$

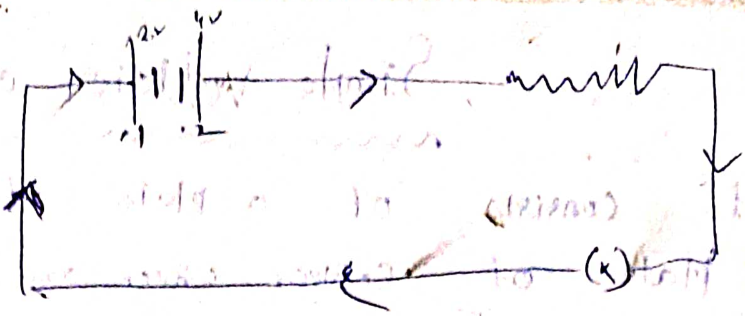
$$= \frac{6}{2.7+.3} = \frac{6}{3} = 2\ \text{Amp.}$$

When they are connected in helping series potential drop across 2V battery Ir

$= 2 \times .1 = .2$

Terminal Potential $= 2 - .2 = 1.8$ volt

3.



In the opposing series, the current send by the 4V battery is opposed by 2V battery.

Net E.m.f = $(4-2) = 2$ volt.

$I = \frac{\varepsilon}{R+r} = \frac{2}{2.7+.3} = \frac{2}{3} = 0.6666$ Amp

Potential drop $= Ir = (0.6666) \times (.1) = .06666$

Terminal Potential across 2V battery $= \varepsilon + Ir$

$= 2 + .06666$

$= 2.06666$ volt.

7. $r = 0.5\,\Omega$

$I = 5.00$ Amp.

$\varepsilon = 12$

Net E.m.f $= 110 - 12$

$= 98V$

$\varepsilon = I(R+r) = 5(R+0.5)$

$\Rightarrow \cancel{12}\,98 = 5R + 2.5$

$\Rightarrow 5R = 98 - 2.5 = 95.5$

$\Rightarrow R = \frac{95.5}{5} = 19.1\,\Omega$

~~Terminal potential $= V + Ir$~~

~~$= 12 + (5 \times .5)$~~

~~$= 14.5$ volt~~

$V = \varepsilon + Ir$

$= 12 + 5 \times .5$

$= 14.5$

Helping Series

$V = \varepsilon_2 - Ir_2$

$= 2 - 2 \times 0.1$

$= 1.8$ volt

Opposing Series

I' is $-$ve for smaller battery

$\therefore V = \varepsilon_2 + I'r_2$

$= 2 + \frac{2}{3} \times 0.1$

$= 2.066$ volt

Simple voltaic cell

It consists of a plate of Zinc and a plate of copper which are dipped in a dilute H_2SO_4 such that 3/4 (nearly) of the plates are immersed.

At the beginning, H_2SO_4 molecule breaks up into $2H^+$ ion and SO_4^{--} ion.

The ionic reaction is

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{--}$$

Copper has the affinity towards positive ions and Zinc has the affinity towards negative ions.

Hence the +ve ions move towards the copper plate and become H_2 gas.

$$2H^+ + Cu \rightarrow H_2\uparrow + Cu^{++}$$

This process continues till the copper plate acquires a voltage of 0.46 volts. Any further movement of $2H^+$ ion towards it is not possible because of strong repulsion.

The -ve ions move towards the Zinc plate and combine with Zinc atoms forming $ZnSO_4$ and the Zinc plates gradually becomes -vely charged. This process will continue till the Zinc plate acquires a potential of −0.62 volts.

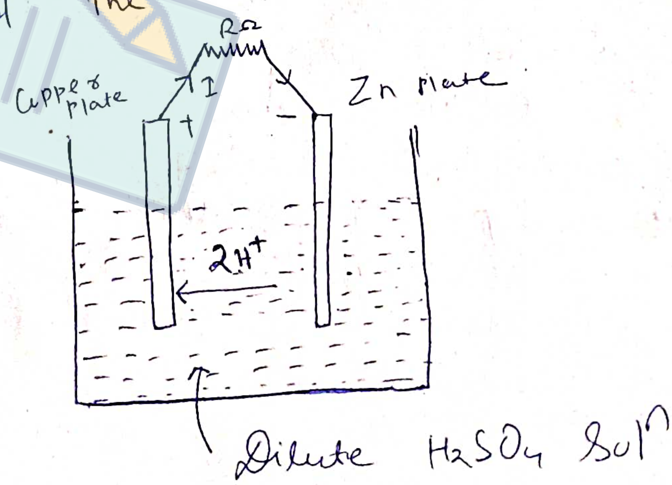
Thus, the potential difference between Cu and Zn plates

$= 0.46 - (-0.62)$

$= 1.08$ volts.

If the terminals of the Cu and Zn plate be connected by means of a conducting wire, then some of the -ve charges from the Zn plate will flow towards the Cu plate and get neutralised. Then the Zn plate and the Cu plate receive more ions.

The electrons will flow from the Zn plate towards Cu plate through the outer connecting wire. Hence current direction is from the copper plate towards the Zn plate through the outer connecting wire. This current also proceeds inside the liquid and the circuit gets completed.



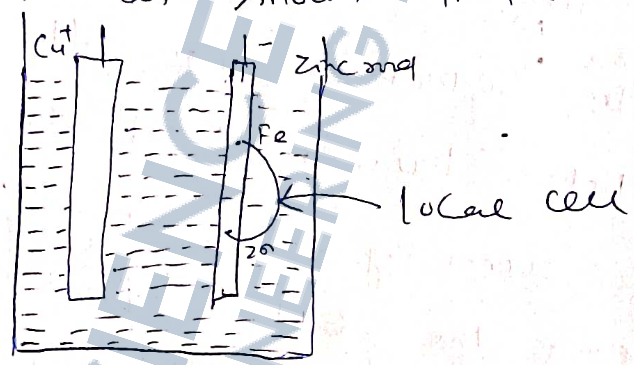
Defects of a simple voltaic cell:

A voltaic cell has two common defects

1. Local action, 2. Polarisation...

1. Local action :

The commercial Zinc contains many impurities like Carbon, arsenic, lead and iron. These impurites are electro+ve with respect to Zinc. As ~~a result~~ a result, small cells are formed between Zinc and impurity atoms via the solution as shown in the diagram.



Then smaller currents are produced and the Zinc rod gets heated. This current can n't be utilised for any useful purpose.

Remedy (ઉકેલ)

The Zinc plate should be amalgamated. When Zinc plate is amalgamated with mercury, the impurity atoms remains inside ~~the~~ and the pure atoms of Zinc comes outside. Hence the acid cannot come in contact with impurity atoms.

~~[illegible]~~ Thus, the reaction is possible only between Cu and Zn through the soln.

2. Polarisation :

Due to formation of a layer of hydrogen bubbles, the current through the cells falls and finally it may stop altogether. This is called <u>Polarisation</u>.

<u>Remedy</u>

1. Mechanical method :

The positive plate (Cu), may be made rough and constantly shaken or brushed to remove hydrogen bubbles. But this method is inefficient.

(2). Chemical method :

Here the hydrogen is oxidised into water by oxidising agents like MnO_2, as in the Leclanche cell and $K_2Cr_2O_7$ as in the bichromate cell.

$$2MnO_2 + H_2 \rightarrow Mn_2O_3 + H_2O$$

(3.) <u>Electro-Chemical method</u> :

In this method, hydrogen is electrochemically substituted by some less trouble some element.

For example, in a Daniell cell, we use $CuSO_4$ soln as depolarisor and hydrogen is substituted by copper which does not produce any back emf.

$$\therefore Zn + H_2SO_4 \rightarrow ZnSO_4 + 2H^+$$

$$CuSO_4 + 2H^+ \rightarrow H_2SO_4 + Cu^{++}$$

Relation between emf and potential difference

Electro motive force (em.f) is not a force and it is defined as the amount of work done to move 1 Coul of charge throughout the circuit including the cell.

$\therefore$

$\mathcal{E} = \Delta W$ in the outer circuit $+ \Delta W$ in the inner circuit

$= q \cdot \Delta V$ in the outer circuit $+ q \cdot \Delta V$ in the inner circuit

$= 1$ Coul. RI volt $+ 1$ Coul. rI volt where r = Internal resistance of the cell which depends on

1. Separation of plates in the cell.
2. ~~Connection~~ Concentration of the soln.
3. Temperature 4. Nature of liquid.

Thus $\mathcal{E} = RI + rI$

$$\boxed{\mathcal{E} = V + rI}$$

where V is called terminal potential difference (T.P.D)

$r.I$ is called lost volt. Because this much of voltage is not available for useful work.

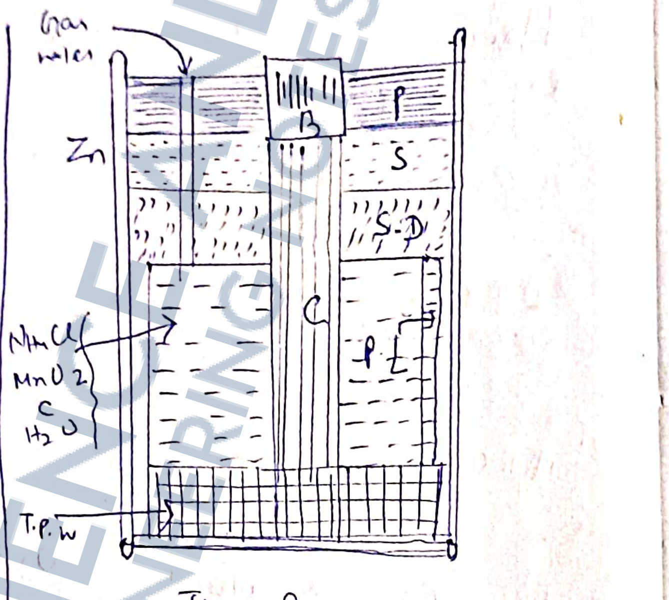
Thus $\mathcal{E} = I(r+R)$

or $\boxed{I = \dfrac{\mathcal{E}}{r+R}}$

i.e Current = $\dfrac{\text{Net emf}}{\text{Total resistance}}$

The Dry cell :

These cells are the modified form of Leclanche's cell made portable by dispencing with liquids. The -ve plate (Zn) is a hollow cylinder of Zn which form the walls and bottom of the cell. The +ve plate is a Carbon rod (C) placed in the centre of the cylinder. The Carbon rod is fitted with a brass cap (B) which forms the terminal of the +ve pole.



The Dry cell

A paste of NH_4Cl, MnO_2, C (Coke or graphite) and a little water is used on between the Carbon rod and Zinc cylinder. A paper lining (P.L) seporates the paste from the wall of the cylinder and NH_4Cl acts through this. The Carbon rod is insulated from the bottom of the cylinder by means of a tar paper wather (T-P-W). The top of the cell is filled up with a layer of sawdust (S.D), followed by a layer of sand (S), then by a layer of pitch or wax (P) to prevent loss of water by evaporation and short-circuiting of the poles. There is a pinhole in the pitch through which the gases escape. The $ZnCl_2$ formed by the action of Zn on NH_4Cl absorbs the NH_3 gas. The coke or graphite reduces the internal resistance. The e.m.f of the cell is about 1.5 volts. On continued use it may polarise, but recover its e.m.f if allowed to remain on open circuit for a while.

The dry cell are indispensible for electric torches, portable testing sets and for high tension supply of radio sets.

The Leclanche's cell :-

This cell consists of an amalgamated zinc rod (Z) immersed in a strong soln of NH_4Cl contained in an outer glass vessel. In this vessel a porous pot is placed with a gas-carbon rod C

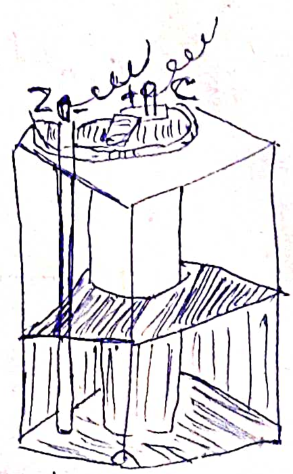
Q4 The centre surrounded by a mixture of broken carbon and ~~powdered~~ powdered manganese dioxide (MnO_2)

This zinc rod acts as the -ve plate, carbon rod as the +ve plate, NH_4Cl as exciting liquid and MnO_2 as depolariser. The charcoal powder is mixed up to make the depoliser an electrical conductor. By the action of zinc on NH_4Cl, NH_3 is liberated which escapes through the mixture while the hydrogen ion liberated is oxidised by the MnO_2 into H_2O according to the following chemical reaction.

$$Zn^{++} + 2NH_4Cl = ZnCl_2 + 2NH_3 + 2H^+$$

$$2H^+ + 2MnO_2 \rightarrow Mn_2O_3 + H_2O$$

Here MnO_2 is the oxidising agent, but as it is solid, its action is slow, so if the cells acts for some



Leclanche's cell

time. polarisation sets in, and the current falls off. This is an obvious disadvantage with this cell. If, however, the cell is given rest for some time, it regains its strength. So the cell is suitable for intermittent work e.g for telephone, telegraph, electric bell etc. ② E.M.F is about 1.5 volts. This cell last for a very long time.

— o —

1) Find the resistance of the following ladder made out of 1 Ω resistances. If a 12 volt battery be connected between A and B, find the current if the internal resistance of the battery is 0.5 Ω.

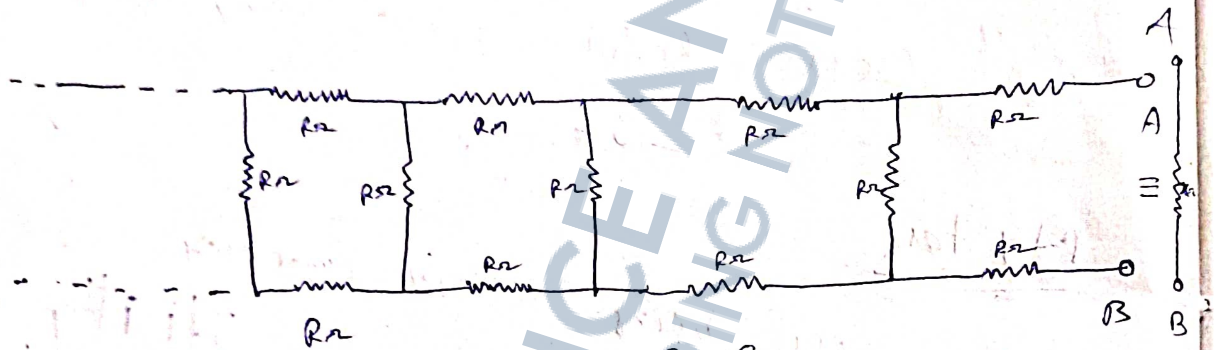


Fig (i)

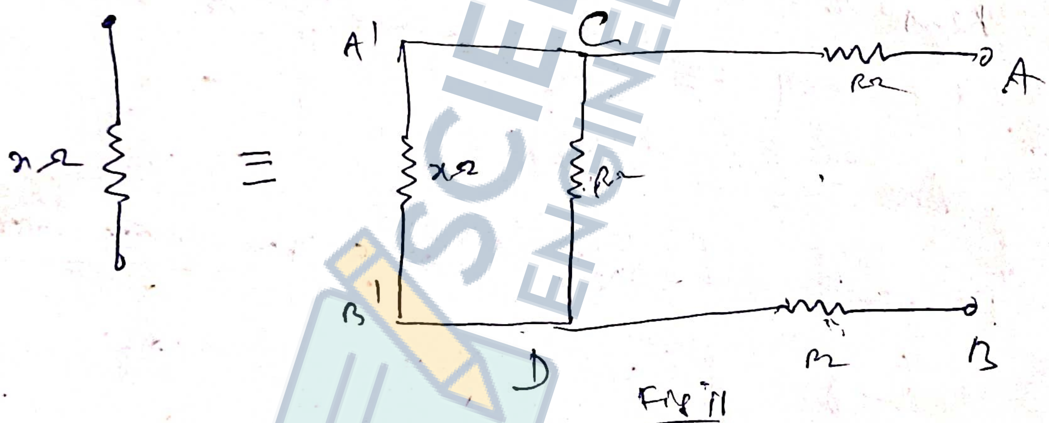


Fig (ii)

Let R_p be the equivalent resistance between the points C and D of fig (ii)

$$\frac{1}{R_p} = \frac{1}{x} + \frac{1}{R} = \frac{R+x}{xR}$$

$$\Rightarrow R_p = \frac{xR}{R+x}$$

$\therefore \quad R_{AB} = R_{BD} + R_{DC} + R_{CA}$

$$= R + \frac{xR}{R+x} + R$$

$$\cancel{R+x}$$

From fig (ii), we see that

$$R_{AB} = x$$

$$\Rightarrow R + \frac{xR}{R+x} + R = x$$

$$\Rightarrow 2R + \frac{xR}{R+x} = x$$

$$\Rightarrow \frac{2R^2 + 2Rx + Rx}{R+x} = x$$

$$\Rightarrow 2R^2 + 3Rx = xR + x^2$$

$$\Rightarrow x^2 - 2Rx - 2R^2 = 0$$

$$\Rightarrow x = \frac{2R \pm \sqrt{4R^2 - 4.(1).(-2R^2)}}{2.(1)}$$

$$= \frac{2R \pm 2\sqrt{3}\,R}{2}$$

$$= (1 \pm \sqrt{3})R$$

Since resistance is always +ve, we -ve value of resistance can not accepted.

$\therefore \quad x = (1+\sqrt{3})R = 2.732R$

Here, $R = 1\Omega$

$x = 2.372\ \Omega$.

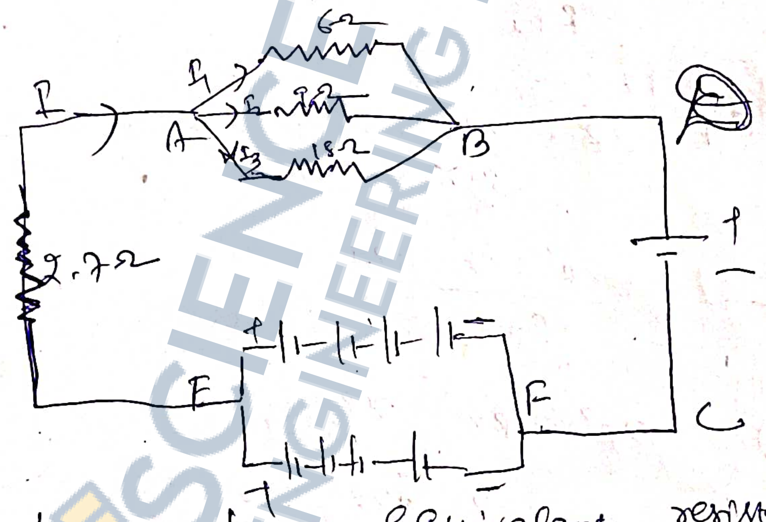
$$\mathcal{E} = V + Ir$$

$$= IR + Ir = I(R + r)$$

$$12 = I(2.732 + .5)$$

$$\Rightarrow I = \frac{12}{3.232} = 3.7128\ \text{Amp.}$$

33.



Soln: Let the equivalant resistance between A and B $r_p\ \Omega$.

$$\therefore \frac{1}{r_p} = \frac{1}{6} + \frac{1}{9} + \frac{1}{18}$$

$$= \frac{3+2+1}{18}$$

$$= \frac{6}{18}$$

$$r_p = 3\Omega$$

Let the equivalant resistance between the points E and F be $r_p\ \Omega$

$\therefore \frac{1}{r_p} = \frac{1}{4r} + \frac{1}{4r} = \cancel{\frac{2}{4r}} = \frac{1}{2r}$

$\Rightarrow r_p = 2r \quad = 2 \times (.1) \quad = 0.2\,\Omega$

$\therefore$ Total resistance of the circuit

$= \cancel{R_{AB}\ R_{AB}}$

$= R_p + R_{CD} + R_{EF} + \cancel{B}\,2.7$

$= 3 + \cancel{4}(.1) + (2) + 2.7$

$= 6\,\Omega$

$V_E - V_F = 4\mathcal{E}$

Net Emf $= 4\mathcal{E} - \mathcal{E}$

$= 3\mathcal{E}$

$= 3 \times 1.5$

$= 4.5$

($\because$ CD cell is connected in opposite sense)

(a) $I = \dfrac{\text{Net Emf}}{\text{Total resistance}} = \dfrac{4.5}{6}$

$= \dfrac{45}{60} = \dfrac{3}{4} = .75$ Amp

(Ans)

(b) To find the current along the $9\,\Omega$ resistor.

We can write

$V_A - V_B = R_1 I_1 = R_2 I = R_3 I_3 = I \cdot R_P$

$\Rightarrow R_2 I_2 = I R_P$

$\Rightarrow 9 \times I_2 = \frac{3}{4} \times \cancel{3}$

$\Rightarrow I_2 = \frac{1}{4} = .25$ Amp.

Heat produced in 15 minutes along the 9Ω resistor

$$= \frac{I_2^2 \cdot R_2 \cdot t}{J} \text{ Cal}$$

$$= \frac{(\frac{1}{4})^2 \cdot (9) \cdot (15 \times 60)}{4.2} \text{ Cal}$$

$$= \frac{9 \times 15 \times \cancel{60}\,15}{\cancel{16}\,4 \times 4.2}$$

$= 120.53$ Cal.

(e) Turning from $V_{(1)}$, we see that the current is −ve for the cell

$\therefore V = \varepsilon + Ir$

$= 1.5 + \frac{\cancel{3}}{\cancel{4}}(0.75) \cdot (0.1)$

$= 1.5 + 0.075$

$= 1.575$ Volt

7) Electrical energy converted into chemical energy in 1 hour.

$$W = \mathcal{E} I t$$
$$= (1.5) \times \left(\frac{3}{4}\right) \times \left(\frac{900}{3600}\right) \text{ Joule}$$

$$= \frac{1.5 \times 3 \times 900}{3600} \text{ watt hour}$$

$$= 1.125 \text{ watt hour}$$

8. The relation between e.m.f and T.P.D. is known to be

$$\mathcal{E} = V + Ir$$

For a point on the Y-axis, the x-co-ordinate is zero.

$$\therefore I = 0$$

Hence $\mathcal{E} = V = 1.1$ volt

For a point on the x-axis the y-coordinate is zero.

$$\therefore V = 0$$

$$\therefore \mathcal{E} = 0 + I_{max}$$

where I_{max} = Max^m value of current obtained

When there is a short circuit current.

From the graph, we find

$I_{max} = 0.265$ Amp

$\therefore$ 1.1 volt $= r \cdot (0.265$ Amp.$)$

$\Rightarrow r = \dfrac{1.1}{0.265} = 4.15\ \Omega$

— o —

Magnetic effect of electric current

Oersted was the first scientist to show that a current carrying conductor produces a magnetic field around it. Laplace gave a formula for the magnetic induction developed around the conductor.

He didnot give the direction of magnetic field intensity. Thus, Laplace's formula is only quantitative.

Biot and Savart gave an expression for the magnetic induction in vector form. Thus, magnitude and direction