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FUNDAMENTALS OF ELELCTRICAL ENGINEERING(FEE) [22212]

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CH.2 DC CIRCUITS

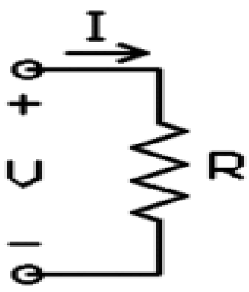
Contents:(12/70)

- Ohm's Law, Internal resistance of source, internal voltage drop, Terminal Voltage.
- Resistance in Series, Resistance in Parallel.
- Active, Passive, Linear, Non-linear Circuit, Unilateral Circuit and Bi-lateral Circuit, Passive and Active Network, Node, Branch, Loop, Mesh.
- Kirchhoff's Current Law, Kirchhoff's Voltage Law.

Ohm's Law

- "Current(I) flowing through a conductor is directly proportional to the potential difference(V) and inversely proportional to the resistance(R) if other physical condition remains unchanged. "
- $i \propto V$ $\qquad \frac{V}{i} = R$ $\qquad V = iR$ $\qquad i = \frac{V}{R}$
- ohm's law can use for AC and DC but for only linear circuits
- Limitation's of ohm's law:

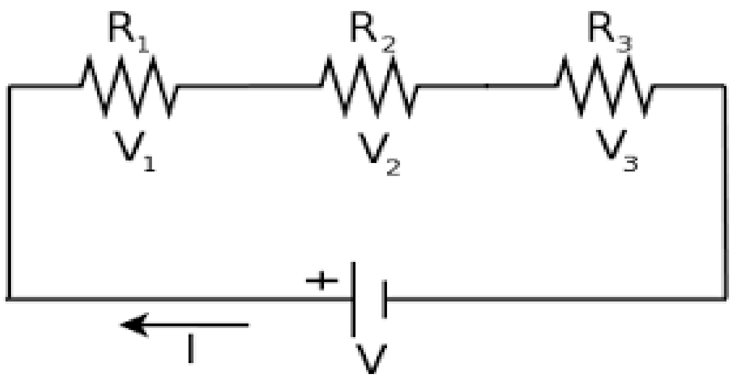
Ohm's law is not applicable to non- linear device such as diode transistor.



- Power =P= VI= I^2R= V^2/R

Resistance in Series

- Circuit diagram



- All resistance carries the same current in series.
- The voltage across each depends on its resistance. The sum of the voltage drops across the resistors equals the battery voltage.

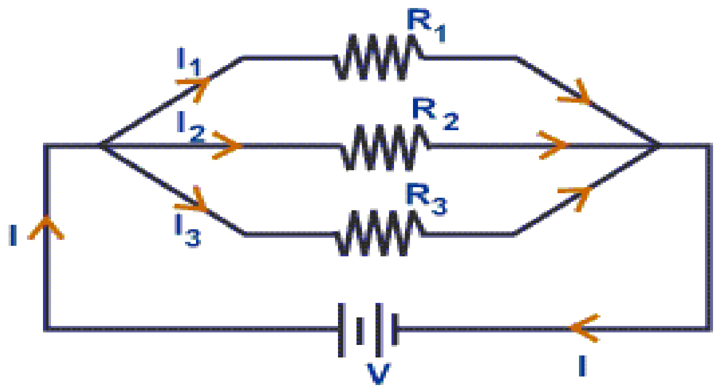
$$V=V_1+V_2+V_3$$

$$IR_t=IR_1+IR_2+IR_3$$

$$\mathbf{R_t=R_1+R_2+R_3}$$

Resistance in Parallel

- Circuit diagram:



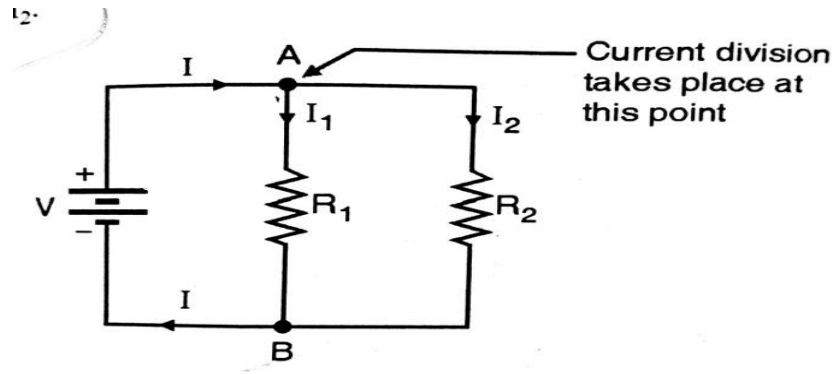
- Voltage across each resistance connected in parallel is same.
- The total current is the sum of the currents flowing through each resistor. The Voltage across each is the same.
- Total current

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{Rt} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}, \qquad \frac{\mathbf{1}}{\boldsymbol{Rt}} = \frac{\mathbf{1}}{\boldsymbol{R1}} + \frac{\mathbf{1}}{\boldsymbol{R2}} + \frac{\mathbf{1}}{\boldsymbol{R3}}$$

Division Of Current In Parallel Branches:

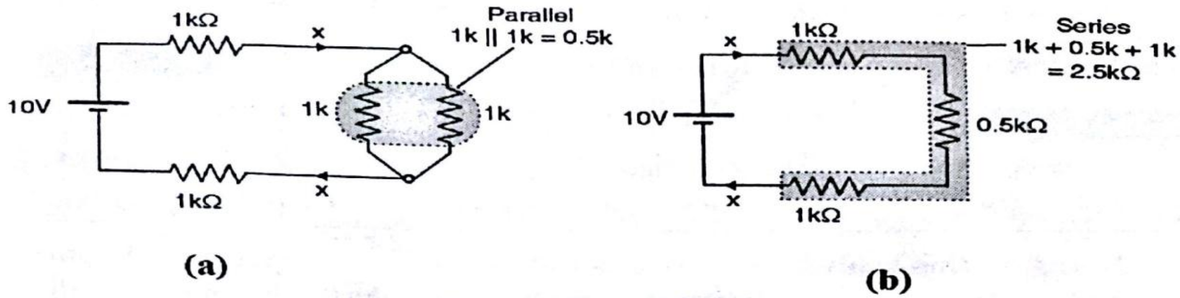
- Division of current among parallel resistors



- Fig. shows the two resistors R_1 and R_2connected in parallel with each other. A voltage source of voltage V is connected across the parallel combination and the total current supplied is I amperes. Let the current flowing through R_1 be I_1 and that through R_2 be I_2.
- $i1 = \frac{R2}{(R1+R2)} i$
- $i2 = \frac{R1}{(R1+R2)} i$

Soln. :

Step 1 : Calculate current x :



(A-2814) **Fig. P. 2.8.1**

From Fig. P. 2.8.1(b),

$$R_T = 2.5\ k\Omega$$

$$\therefore \text{ Current } x = 10\ V / R_T = 10 / 2.5\ k\Omega = 4\ mA \quad ...(1)$$

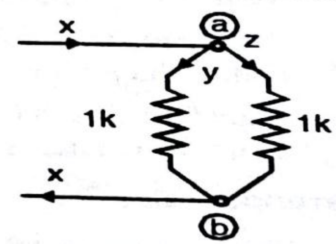
Step 2 : Calculate currents y and z :

- Refer Fig. P. 2.8.1(c) and use principle of current division between parallel resistors to write,

$$y = \frac{1\ k}{1\ k + 1\ k} \cdot x = \frac{x}{2} = 2\ mA \quad ...(2)$$

- Similarly

$$z = \frac{1\ k}{1\ k + 1\ k} \cdot x = \frac{x}{2} = 2\ mA \quad ...(3)$$



(A-2815) **Fig. P. 2.8.1(c)**

Step 3 : Verification of KCL :

At node (a) :

Current entering = x = 4 mA

Current leaving = y + z = 2 mA + 2 mA = 4 mA

Current entering x = Total current leaving (y + z).

Thus KCL is verified at node (a).

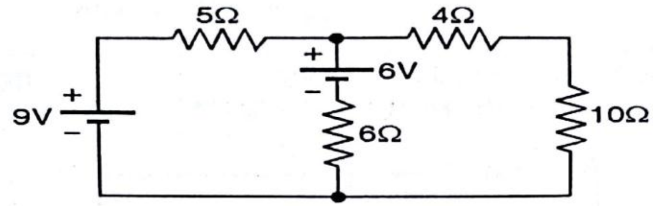
At node (b) :

Similarly at node (b),

Total current entering = y + z = 2 + 2 = 4 mA

and

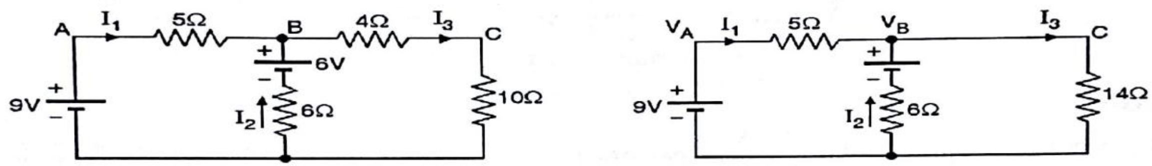
Ex. 2.8.4 : Find current through 10Ω resistor by nodal analysis. Refer Fig. P. 2.8.4. **W-10, 4 Marks**



(A-2860) **Fig. P. 2.8.4**

Soln. :

Step 1 : Mark nodes A, B and C (as shown in Fig. P. 2.8.4(a)) :



(a) (b)

(A-2861) **Fig. P. 2.8.4**

Step 2 : Find V_B :

Apply KCL at node B, $I_3 = I_1 + I_2$

But $I_3 = \frac{V_B}{14}$, $I_1 = \frac{9 - V_B}{5}$ & $I_2 = \frac{6 - V_B}{6}$

$$\therefore \frac{V_B}{14} = \frac{(9 - V_B)}{5} + \frac{(6 - V_B)}{6}$$

$$\therefore \frac{V_B}{14} = \frac{6\,(9 - V_B) + 5\,(6 - V_B)}{30}$$

$$\therefore \frac{V_B}{14} = \frac{54 - 6V_B + 30 - 5V_B}{30}$$

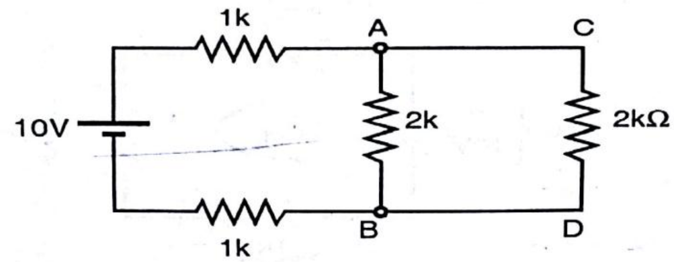
$$\therefore \frac{V_B}{14} = \frac{84 - 11V_B}{30}$$

$$\therefore 30V_B = 14\,(84 - 11\,V_B)$$

$$\therefore 30\,V_B = 1176 - 154\,V_B$$

$$\therefore V_B = 6.4 \text{ Volts}$$

Ex. 2.8.6 : Verify KVL for circuit as shown in Fig. P. 2.8.6.

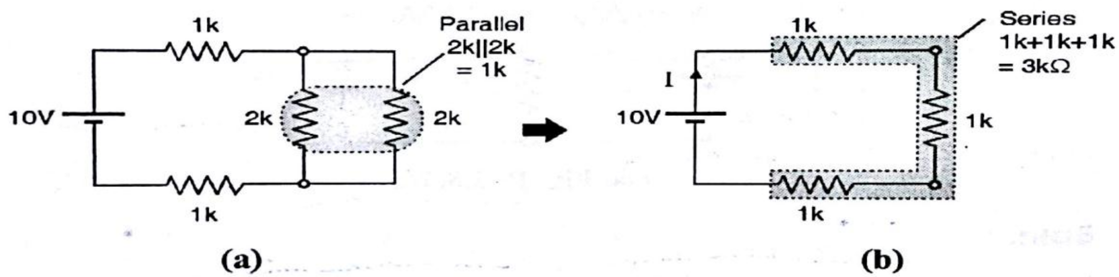


(A-214) **Fig. P. 2.8.6**

Soln. :

We will prove that the algebraic sum of voltages around a closed loop is zero.

Step 1 : Simplify the circuit and calculate R_T :



(A-215) **Fig. P. 2.8.6**

From Fig. P. 2.8.6(b)

$$R_T = 3\ k\Omega$$

Step 2 : Calculate I :

$$I = 10\ V / R_T = 10 / 3\ k\Omega = 3.33\ mA$$

Step 3 : Verify the KVL :

Consider the loop of Fig. P. 2.8.6(c). Potential Rise = 10 V

Total potential drops= $IR_1 + IR_2 + IR_3$

$$= 3.33\ mA\ (1k + 1k + 1k) = 10\ V$$

∴ Potential Rise = Potential Drop

Thus KVL is verified.

Example 2.4. *What is the voltage V_s across the open switch in the circuit of Fig. 2.7 ?*

Solution. We will apply *KVL* to find V_s. Starting from point *A* in the clockwise direction and using the sign convention given in Art. 2.3, we have

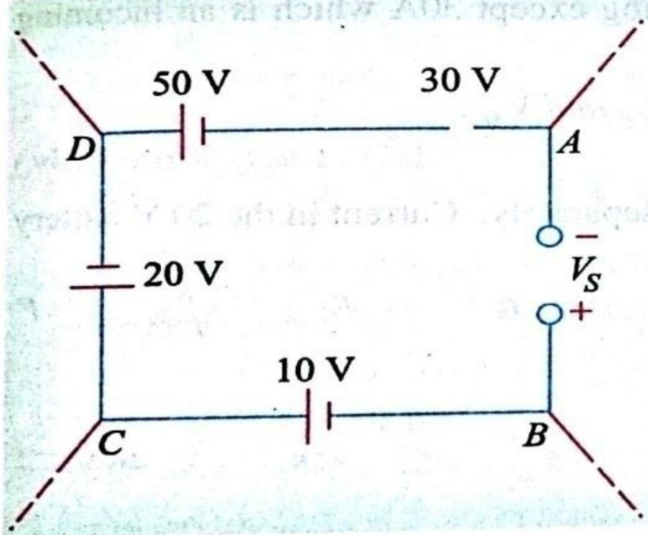


Fig. 2.7

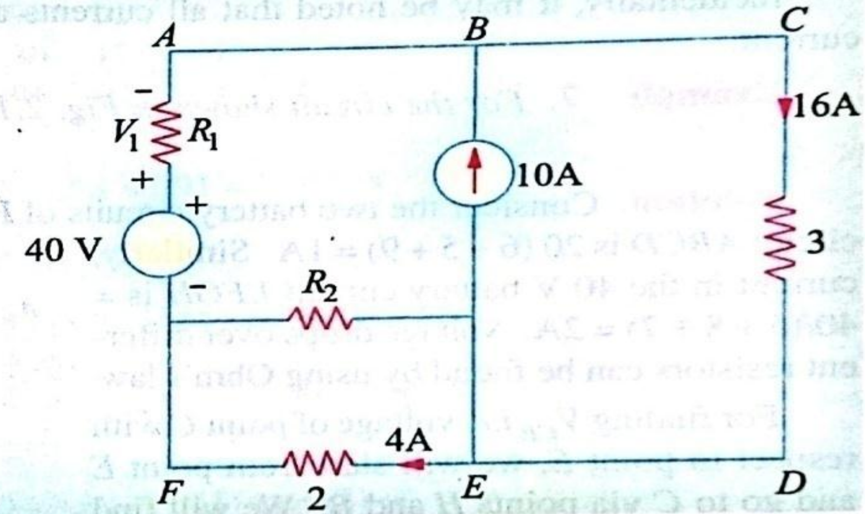


Fig. 2.8

$$+V_s + 10 - 20 - 50 + 30 = 0 \quad \therefore \quad V_s = \mathbf{30\ V}$$

Example 2.5. *Find the unknown voltage V_1 in the circuit of Fig. 2.8.*

Solution. Initially, one may not be clear regarding the solution of this question. One may think of Kirchhoff's laws or mesh analysis etc. But a little thought will show that the question can be solved by the simple application of Kirchhoff's voltage law. Taking the outer closed loop ***ABCDEFA*** and applying ***KVL*** to it, we get

$$-16 \times 3 - 4 \times 2 + 40 - V_1 = 0 ; \quad \therefore \quad V_1 = \mathbf{-16\ V}$$

The negative sign shows there is a fall in potential.

... and Ohm's Law, find the magnitude and polarity

Example 2.7. *For the circuit shown in Fig. 2.10, find* V_{CE} *and* V_{AG}.

(F.Y. Engg. Pune Univ.)

Solution. Consider the two battery circuits of Fig. 2.10 separately. Current in the 20 V battery circuit *ABCD* is 20 (6 + 5 + 9) = 1A. Similarly, current in the 40 V battery curcuit *EFGH* is = 40/(5 + 8 + 7) = 2A. Voltage drops over different resistors can be found by using Ohm's law.

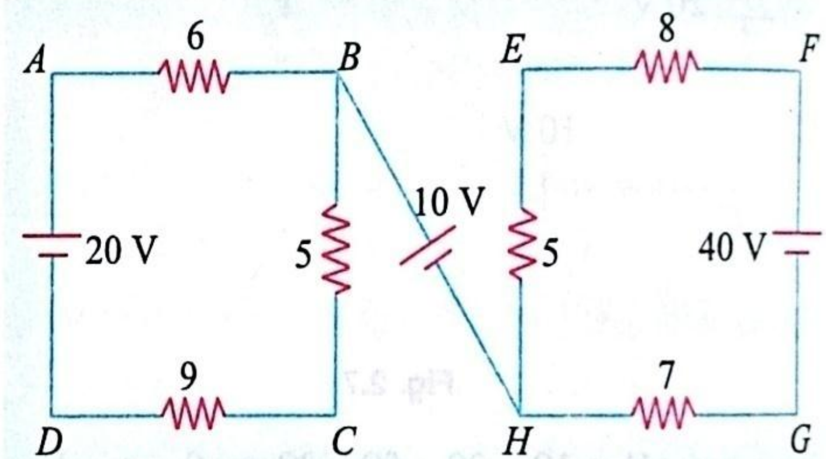


Fig. 2.10

For finding V_{CE} *i.e.* voltage of point *C* with respect to point *E*, we will start from point *E* and go to *C* via points *H* and *B*. We will find the algebraic sum of the voltage drops met on the way from point *E* to *C*. Sign convention of the voltage drops and battery e.m.fs. would be the same as discussed in Art. 2.3.

$$\therefore \quad V_{CE} = (-5 \times 2) + (10) - (5 \times 1) = -5\text{V}$$

The negative sign shows that point *C* is negative with respect to point *E*.

$$V_{AG} = (7 \times 2) + (10) + (6 \times 1) = 30 \text{ V}.$$

The positive sign shows that point *A* is at a positive potential of 30 V with respect to point *G*.

Example 2.11. *Two batteries A and B are connected in parallel and load of 10 Ω is connected across their terminals. A has an e.m.f. of 12 V and an internal resistance of 2 Ω ; B has an e.m.f. of 8 V and an internal resistance of 1 Ω. Use Kirchhoff's laws to determine the values and directions of the currents flowing in each of the batteries and in the external resistance. Also determine the potential difference across the external resistance.*

(F.Y. Engg. Pune Univ.)

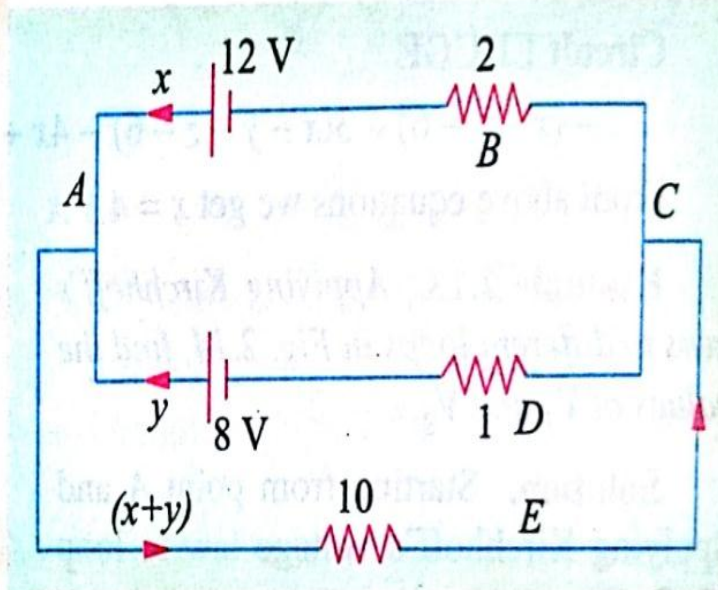


Fig. 2.13

Solution. Applying KVL to the closed circuit *ABCDA* of Fig. 2.13, we get

$$-12 + 2x - 1y + 8 = 0 \quad \text{or} \quad 2x - y = 4 \qquad ...(i)$$

Similarly, from the closed circuit *ADCEA*, we get

$$-8 + 1y + 10(x + y) = 0 \quad \text{or} \quad 10x + 11y = 8 \qquad ...(ii)$$

From Eq. (*i*) and (*ii*), we get

$x = 1.625$ A and $y = -0.75$ A

The negative sign of *y* shows that the current is flowing into the 8-V battery and not out of it. In other words, it is a charging current and not a discharging current.

ILLUSTRATIVE EXAMPLES

Example 1 : A 500 W discharge lamp takes a current of 4 A at unity p.f. Calculate :

(i) Resistance of the lamp

(ii) Voltage drop across lamp (Oct. 90)

Solution : Unity p.f. means Cos $\Phi = 1$

In such case use the formula for power as

$$P = VI \text{ watts} \quad \text{or} \quad I^2R \text{ watts.}$$

(i) Now power rating of the lamp = 500 W

Current taken by the lamp = 4 A

We have

$$I^2R = P$$

$$\therefore \quad R = \frac{P}{I^2} = \frac{500}{(4)^2} = 31.25 \ \Omega \qquad \text{(Ans.)}$$

(ii) Voltage drop across the lamp = Current × Resistance

$$V = IR$$

$$V = 4 \times 31.25$$

$$V = 125 \text{ Volts} \qquad \text{(Ans.)}$$

Example 2 : Four resistances each of one ohm are available. How will you combine them to obtain an equivalent resistance of 0.75 ohm ? This combination is connected across a 1.5 volts supply. Calculate -

(i) Current through each resistance .

(ii) Power consumed by the combination . (May 90)

Solution : The equivalent resistance of the circuit is given by

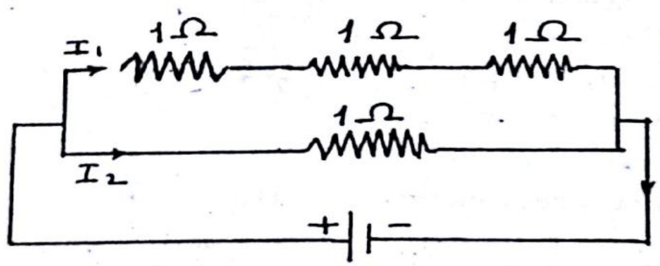


Fig. 1.28

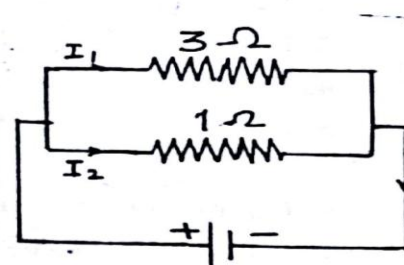


Fig. 1.29

$$R = 0.75\ \Omega \quad \text{or}$$

$$R = \frac{3}{4}\ \Omega$$

Now $$R = \frac{\textit{Product of two resistors}}{\textit{Sum of two resistors}}$$

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

arranging the resistances as following we will get

$$R = \frac{3}{4}\ \Omega$$

i.e. three resistances of each one ohm are connected in series with parallel combination of 1 ohm resistor gives total equivalent resistance as $\frac{3}{4}\ \Omega$

Now, total current in the circuit.

$$I = \frac{V}{R} = \frac{1.5}{0.75} = 2\ A$$

(i) $$I_1 = 2 \times \frac{1}{3+1} = 0.5\ A$$

$$I_2 = 2 \times \frac{3}{3+1} = 1.5\ A$$

Alternatively :

$$I_1 = \frac{V}{R_1} = \frac{1.5}{3} = 0.5\ A \qquad \text{(Ans)}$$

$$I_2 = \frac{V}{R_2} = \frac{1.5}{1} = 1.5\ A \qquad \text{(Ans.)}$$

(ii) Power Consumed $= V\,I$ watts

$= 1.5 \times 2$

$= 3$ watts (Ans.)

Example 3 : If 100 resistors each of value 47 ohms are connected in parallel, find its equivalent resistance . (Nov 89)

Solution :

Each resistance $= 47\ \Omega$

total no of resistors $= 100$

All are connected in parallel

$$\frac{1}{R} = \frac{1}{47} + \frac{1}{47} + \dots + \frac{1}{47} \cdots \quad \text{100 times}$$

$$\frac{1}{R} = \frac{100}{47} \quad \text{and} \quad R = \frac{47}{100} = 0.47 \quad \Omega \qquad \text{(Ans.)}$$

Example 4 : A resistance R is connected in series with a parallel circuit comprising two resistances 15 ohm and 10 ohms respectively. The total power consumed by this circuit is 125 watts when the applied voltage is 50 volts. Calculate the value of resistance R and current through each resistance. **(Nov. 89)**

Solution :

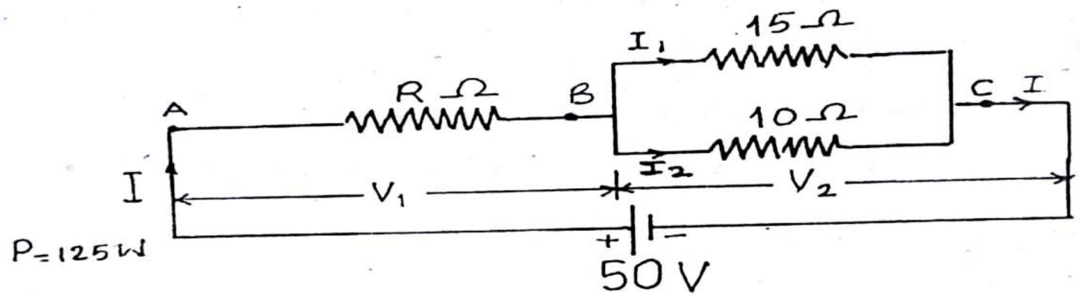


Fig. 1.30

Power P VI Watts

$$\therefore \qquad I = \frac{P}{V} = \frac{125}{50} = 2.5 \text{ Amp.}$$

Now equivalent resistance between B and C is given by

$$R_{BC} = \frac{15 \times 10}{15 + 10} = \frac{150}{25} = 6 \quad \Omega$$

$\therefore$ Voltage drop across BC,

$$V_2 = I\,R$$

$$= 2.5 \times 6 = 15 \text{ Volts}$$

Now, voltage drop across AB,

$$V_1 = V - V_{BC}$$

$$= 50 - 15$$

$$= 35 \text{ Volts.}$$

Now unknown resistance $R = \dfrac{\textit{Voltage drop across R}}{\textit{current in R}}$

$$= \frac{35}{2.5} = 14 \ \Omega \qquad \text{(Ans.)}$$

Current through 14 Ω resistor = 2.5 A (Ans)

Current through 15 Ω resistor $= \dfrac{15}{15} = 1$ A (Ans.)

Current through 10 Ω resistor $= \dfrac{15}{10} = 1.5$ A (Ans.)

Example 5 : A resistor R is connected in series with aparallel circuit comprising two resistors of 12 Ω and 8 Ω respectively. The total power dissipated in the circuit is 70 watts when the applied voltage is 20 volts (d.c.) .Calculate the resistance of resistor R

(Nov. 87)

Solution :

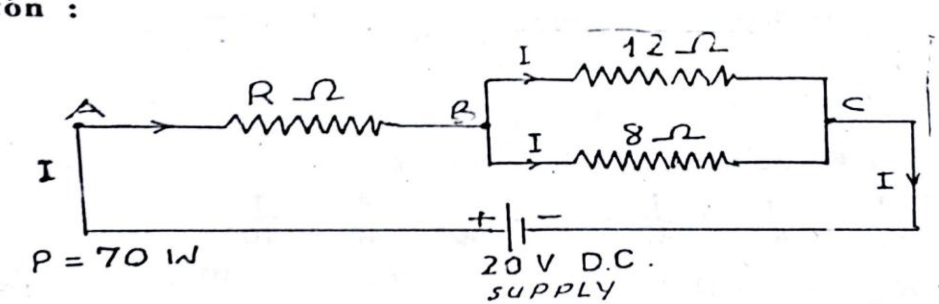


Fig. 1.31

$$P = V I$$

$$\therefore \quad I = \frac{P}{V} = \frac{70}{20} = 3.5 \text{ A}$$

$$R_{BC} = \frac{12 \times 8}{12 + 8} = \frac{96}{20} = 4.8 \ \Omega$$

$$\therefore \quad V_{BC} = I \times R_{BC} = 3.5 \times 4.8 = 16.8 \text{ Volts}$$

$$\text{and} \quad V_{AB} = V - V_{BC} = 20 - 16.8 = 3.2 \text{ Volts}$$

$$\therefore \quad R = \frac{V_{AB}}{I} = \frac{\textit{Voltage across R}}{\textit{Current through R}}$$

$$= \frac{3.2}{3.5} = 0.914 \ \Omega \qquad \text{(Ans.)}$$

Example 6 : Four resistances each of 40 ohm are connected in parallel and this combination is connected in series with a 40 ohm resistance. The combined circuit is connected across 200 volts supply. Find
(i) Total resistance (ii) Total current (iii) Total power
(iv) Voltage across each resistance (June 88)

Solution :

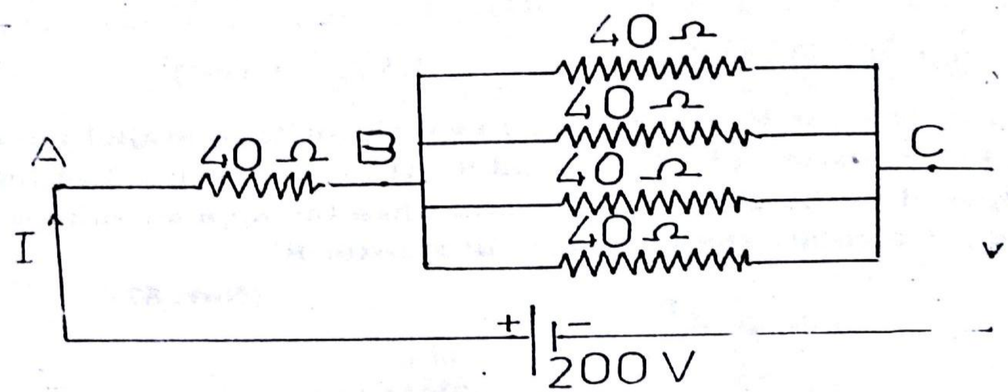


Fig. 1.32

(i) Resistance between BC will be given by

$$\frac{1}{R_{BC}} = \frac{1}{40} + \frac{1}{40} + \frac{1}{40} + \frac{1}{40} = \frac{4}{40} = \frac{1}{10}$$

$$\therefore \quad R_{BC} = 10\ \Omega$$

total resistance of the circuit

$$R = R_{AB} + R_{BC}$$

$$= 40 + 10 = 50\ \Omega \qquad \text{(Ans.)}$$

(ii) Total current $I = \frac{V}{R} = \frac{200}{50} = 4\ A$ (Ans.)

(iii) Total power $= V\,I$ watts

$= 200 \times 4$

$= 800$ watts (Ans.)

(iv) Voltage across series resistor $= 4 \times 40 = 160$ V

Voltage across each of parallel resistor $= 4 \times 10 = 40$ V

Total voltage $= 200$ V

Example 7 : Two lamps (A) of 100 watts 250 volts and (B) of 200 watts, 250 volts are connected across a 250 volts A. C. supply. Find

(i) Current taken by each lamp ,

(ii) Total current ,

(iii) Total power ,

(iv) Resistance of lamp A .

Solution :

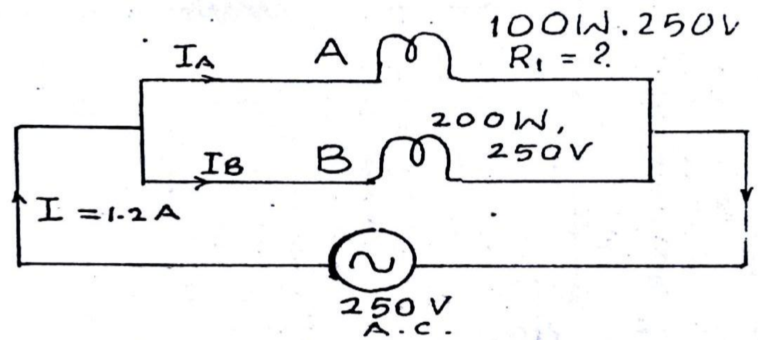


Fig. 1.33

(i) For first lamp, $P = V I_A$

$$\therefore \quad I_A = \frac{P}{V} = \frac{100}{250} = 0.4 \text{ A} \qquad \text{(Ans.)}$$

Similarly for second lamp, $I_B = \frac{P}{V} = \frac{200}{250} = 0.8$ A (Ans.)

(ii) Total current = Sum of two currents

$= 0.4 + 0.8 = 1.2$ A (Ans.)

(iii) Total power P = V I

$= 250 \times 1.2$

$= 300$ watts (Ans.)

(iv) Resistance of lamp A $= \dfrac{\textit{Voltage across lamp A}}{\textit{Current taken by lamp A}}$

$$= \frac{250}{0.4} = 625 \ \Omega$$

Example 8 : For the given figure find the value of resistance R so that power consumed by the heater remains to be 62.5 watts. (May 89)

Solution : From the rating of a heater we can calculate the resistance of heating coil.

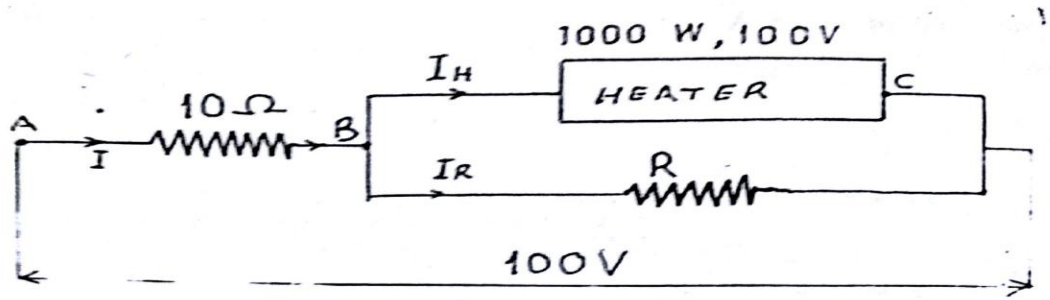


Fig. 1.34

We have,

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

$$\therefore \quad R = \frac{V^2}{P} = \frac{(100)^2}{1000} = 10 \quad \Omega$$

Let current taken by the heater $= \dot{I}_H$

Now power taken by the heater in working condition = 62.5 watts, (given)

$$\therefore \quad P = I_H^2 R$$

$$\therefore \quad I_H^2 = \frac{P}{R} = \frac{62.5}{10} = 6.25$$

$$I_H = 2.5 \text{ Amp}$$

Now current taken by the heater = 2.5 A

Voltage across heater and R $= I_H \times 10$

$= 2.5 \times 10$

$= 25$ Volts

Voltage across 10 Ω resistor $= 100 - 25$

$= 75$ Volts

❖ Linear:

If the characteristics, parameters of a network remain constant irrespective of changes in temperature, time, voltage etc then the network is called as a network.

❖ Non-linear Circuit:

If the characteristics, parameters of a network changes with the change in temperature, time, voltage etc then the network is called as a network.

- **Active network:** Active network is one which contains at least one source of e.m.f. or energy, is called active network.

- **Passive network:** Passive network is one which does not contain any source of e.m.f. or energy in it, is called passive network.

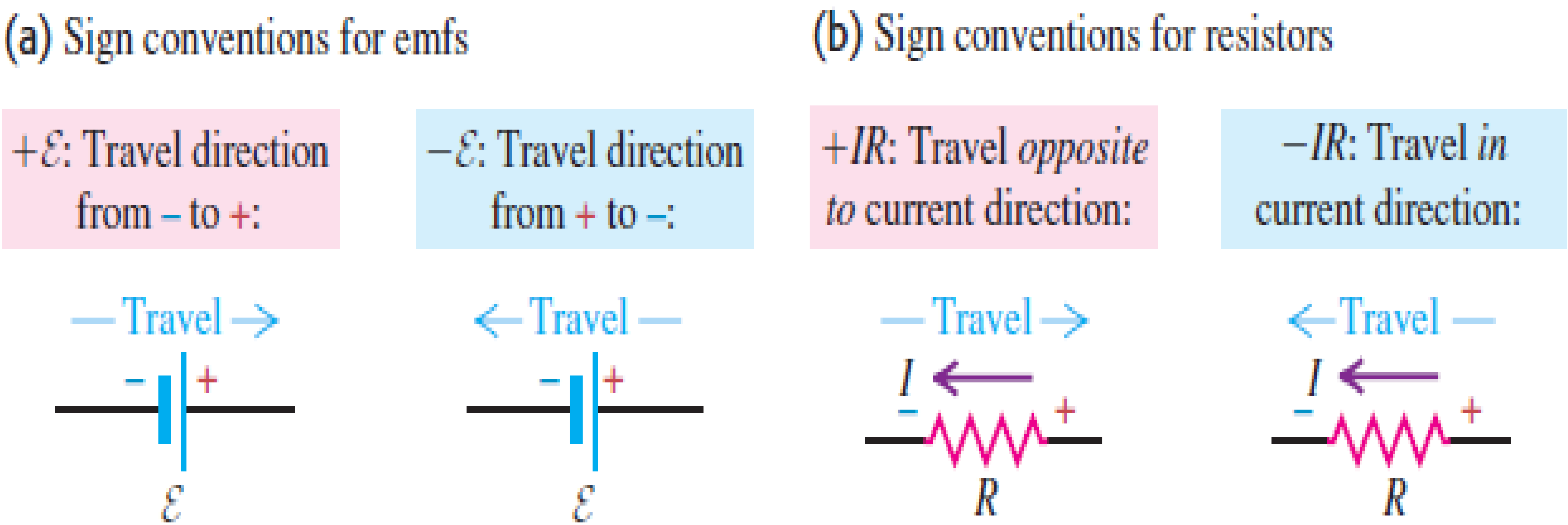
- **Unilateral network:** If the characteristic (response or behavior) of network dependents on the direction of flow of current through its elements, then the network is called as a unilateral network. Ex. Diodes, transistors etc.

- **Bilateral Network:** If the characteristic (response or behavior) of network is independent of the direction of current through its elements, then the network is called as a bilateral network. Ex. Resistive

- **Node:** A point in an electric circuit at which different branches meet.
- **Branch:** A part of an electric network which lies between two junctions or nodes.
- **Loop:** A closed path for flow of current in an electrical circuit is called loop.
- **Mesh:** A set of branches forming a closed path for electric current in an electric circuit. Also mesh can be defined as A loop that does not contain any other loop.

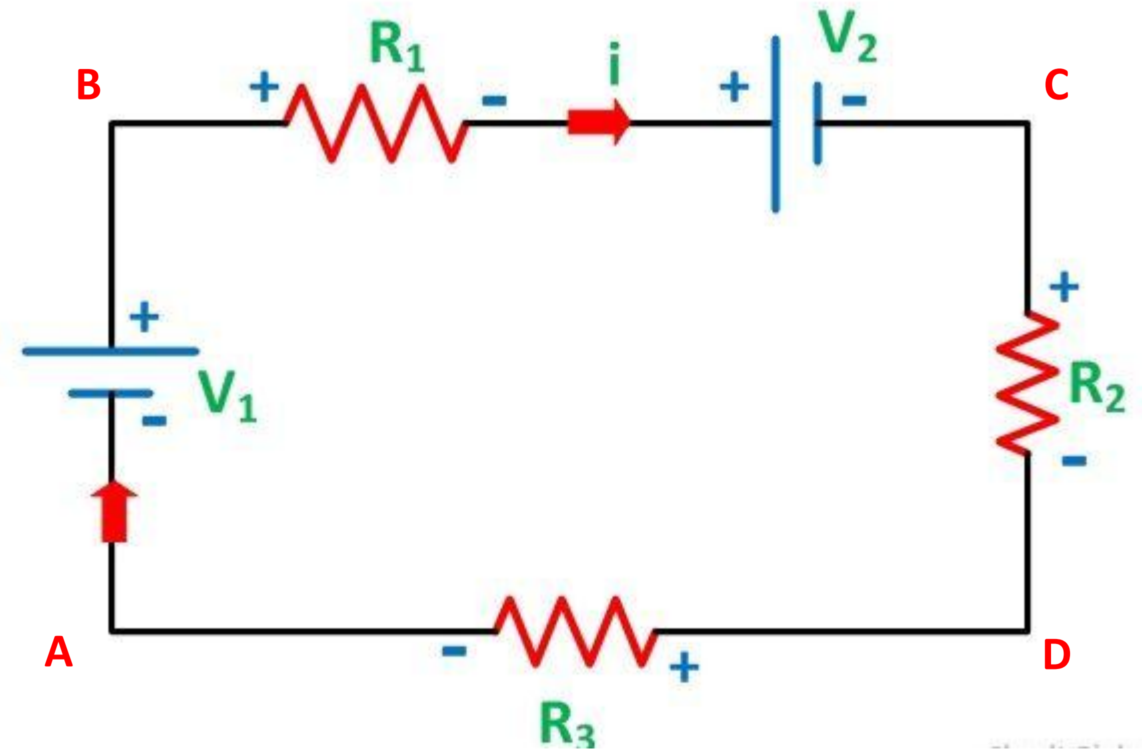
Kirchhoff's voltage Law

- **KVL** states that *the **algebraic sum of the voltages in any closed loop is zero***
- or in other words, in a closed circuit, the algebraic sum of all the EMFs + the algebraic sum of all the voltage drops (product of current (I) and resistance (R)) is zero.
- **Σ E + Σ V = 0**



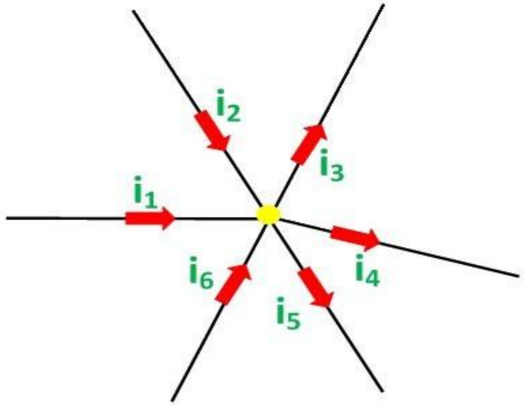
- Applying KVL to ABCD Loop

$$V1 - iR1 - V2 - iR2 - iR3 = 0$$



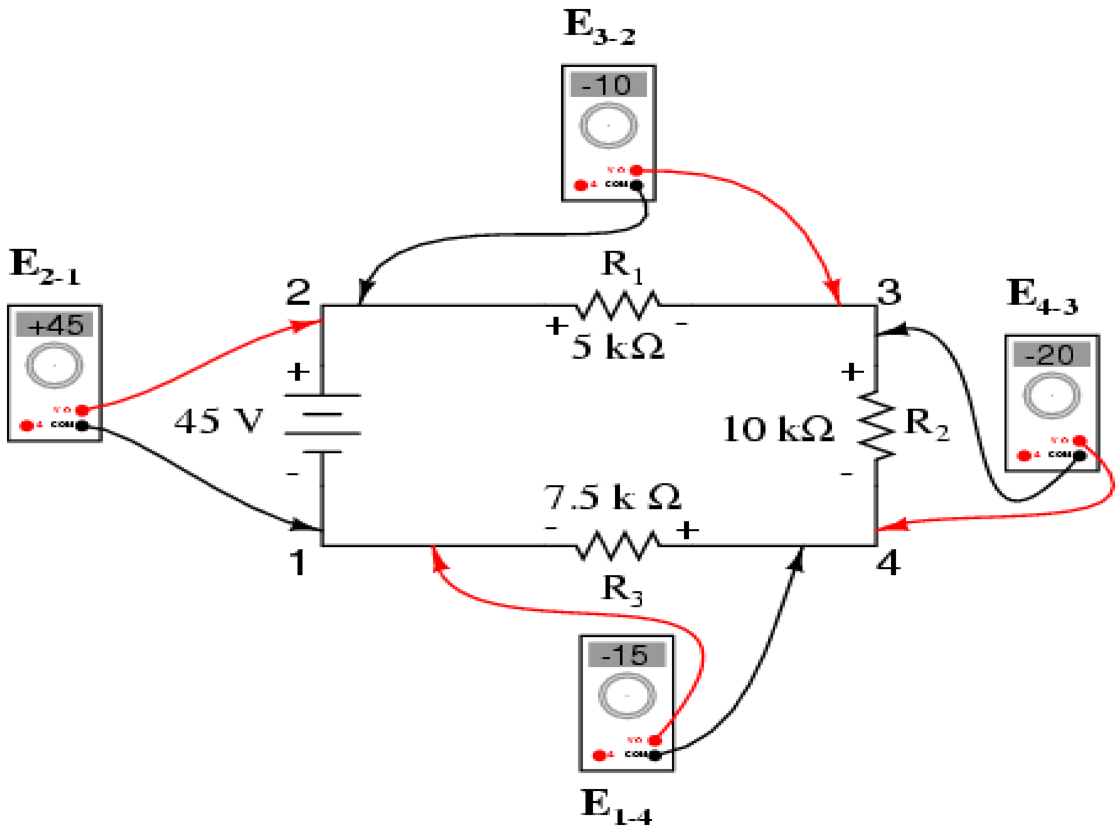
Kirchhoff's Current Law

- **KCL** states that" ***the algebraic sum of all the currents at any node point or a junction of a circuit is zero".***
- $\Sigma I = 0$
- $\mathbf{i_1 + i_2 - i_3 - i_4 - i_5 + i_6 = 0}$



- The direction of incoming currents to a node is taken as positive while the outgoing currents is taken as negative. i.e. incoming current as negative or outgoing as positive.
- KCL can also be written as
- $\mathbf{i_1 + i_2 + i_6 = i_3 + i_4 + i_5}$
- Sum of incoming currents = Sum of outgoing currents

- Applying kvl
- +45 – i R1 – i R2 – i R3 = 0
- +45 – 10 – 20 – 15= 0



Assignments-2

1) Define active circuit and passive circuit
2) State Ohm's law for electric circuit.
3) Two resistance of 6 Ω each are connected in parallel. Find equivalent resistance.
4) Derive the expression for equivalent resistance when three resistances are connected in series.
5) Define the following terms related to circuit: (i) Bilateral Network (ii) Node (iii) Loop (iv) Branch
6) Compare series & parallel circuit in terms of voltage and current.
7) State and explain KVL and KCL law
8) Find equivalent resistance between terminal A and B shown in Figure No.1

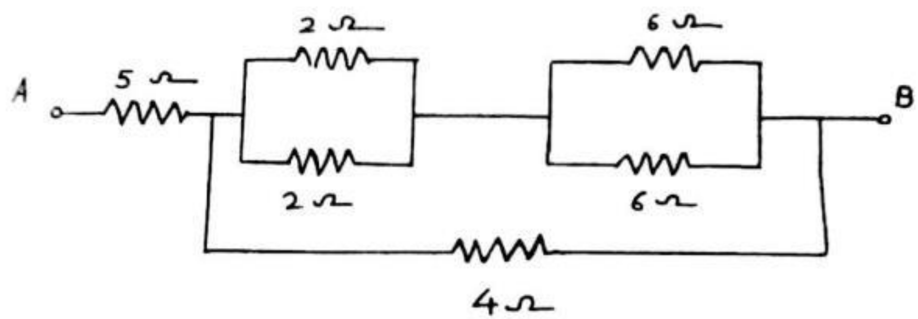


Fig. No. 1

Assignments-2

1) Find current flowing through 10 Ω resistance shown in Fig. no. 5 using Kirchhoff's law.

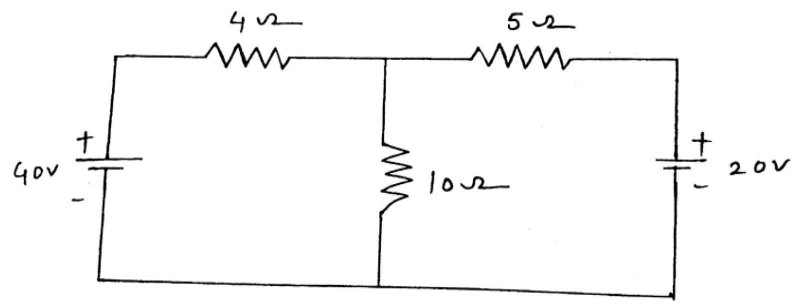
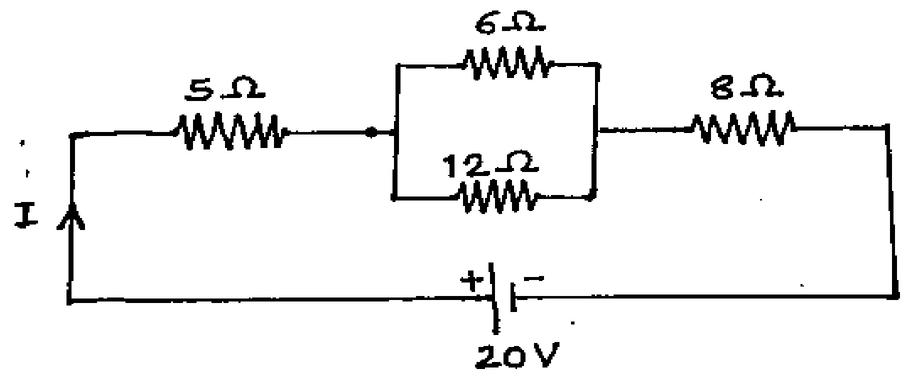


Fig. No. 5

2) Calculate: (i) Total equivale



3) Using Kirchhoff's laws calculate current through 10 ohm.