1.2 Electric Current

Flow of free electrons is called **electric current**. A copper strip has a large number of free electrons. When electric pressure or voltage is applied to it, free electrons, being negatively charged, will start moving towards the positive terminal round the circuit as shown in Fig. 1.1.This directed flow of electrons is called electric current. The actual direction of current (i.e., flow of electrons) is from the negative terminal to the positive terminal through the part of the circuit external to the cell. However, prior to the electron theory, it was assumed that current flowed from the positive terminal to the negative terminal of the cell via the circuit. This convention is so firmly established that it is still in use. This assumed current is now called *conventional current*.

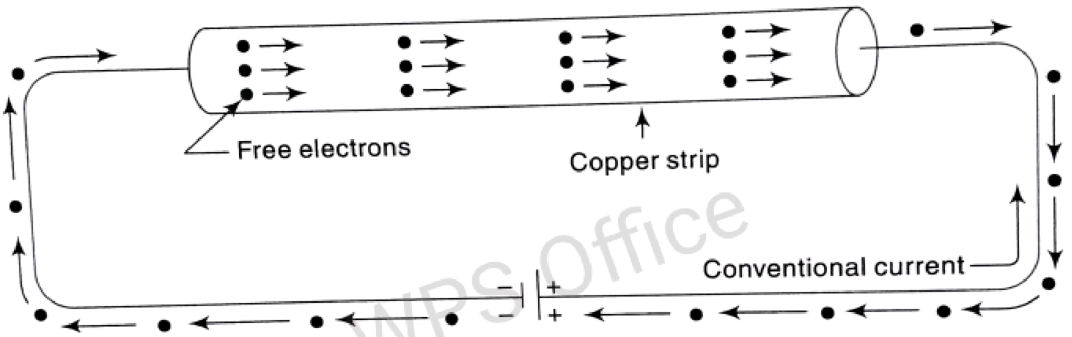

Fig. 1.1 Flow of electric current

The substances that have large number of free electrons will permit the flow of current easily. Such substances are called *conductors*, e.g., copper, zinc, silver, aluminium. On the other hand, atoms of some substances have valence electrons that are tightly held to their nuclei, i.e., they have few free electrons. Such substances will not permit the flow of electric current and are called *bad conductors* or *insulators*, e.g., glass, mica, porcelain.

The strength of electric current I is the rate of flow of electrons, i.e., charge flowing per second.

So, Current, $I = \dfrac{Q}{t}$

The charge Q is measured in coulomb and time t in second. Therefore, the unit of electric current will be *coulomb/sec*, also known as *ampere* (A). If $Q = 1$ C, $t = 1$ sec, then $I = 1/1 = 1$ A.

One ampere of current is said to flow through a wire if at any section one coulomb of charge flows in one second.

1.3 Electric Potential

Electric Potential

removing the electrons from it or by supplying the electrons to it. Work is done in this process because electrons have to be removed or supplied against the opposing forces. This work done is stored in the body in the form of potential energy. The charged body has the capacity to do work by moving other charges either by attraction or by repulsion. This ability of the charged body to do work is called electric potential.

Thus, the capacity of a charged body to do work is called **electric potential.**

The greater the capacity of a charged body to do work, the greater is its electric potential. Obviously, the work done to charge a body to 1 C will be a measure of its electric potential, i.e.,

$$\text{Electric potential, } V = \frac{\text{Work done}}{\text{Charge}} = \frac{W}{Q}$$

The work done is measured in joule and the charge is measured in coulomb. Therefore, the unit of electric potential will be *joule/coulomb*, also known as *volt* (V). If $W = 1$ J, $Q = 1$ C, then $V = 1/1 = 1$ V.

Thus, when we say that a body has an electric potential of 5 V, it means that every coulomb on a charge possesses an energy of 5 J.

1.4 Potential Difference

The difference in the potentials of two charged bodies is called **potential difference.** or voltage

If two bodies have different electric potentials, a potential difference exists between the bodies. Consider two bodies A and B having potentials of 5 V and 3 V respectively as shown in Fig. 1.2(a). Each coulomb of charge on body A has energy of 5 J while each coulomb of charge on body B has energy of 3 J. Clearly, body A is at higher potential than body B.

(a) (b)

Fig. 1.2 Potential difference and flow of current

If the bodies A and B are joined through a conductor [see Fig. 1.2(b)], then electrons will flow from body B to body A. When the two bodies attain the same potential, the flow of current stops. Therefore, we arrive at a very important conclusion that current will flow in a circuit only if potential difference exists. No current will flow if there is no potential difference. It may be noted that potential difference is sometimes called voltage.

A device that maintains potential difference between two points is said to develop **electromotive force (emf).** A simple example is that of a cell or dc generator. Thus, potential difference causes current to flow while an emf maintains the potential difference.

1.6 Ohm's Law

The relationship between voltage (V), current (I) and resistance (R) in a dc circuit was first discovered by German scientist George Simon Ohm. This relationship is called Ohm's law and may be stated as under:

The ratio of the potential difference (V) between the ends of a conductor to the current (I) flowing between them is constant, provided the physical conditions (e.g., temperature) do not change, i.e.,

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

where R is the resistance of the conductor between the two points considered.

For example, if the voltage between two points A and B is V volt and the current flowing between them is I ampere (Fig. 1.4), then V/I will be constant and equal to R, the resistance between the points A and B. If the voltage is doubled,

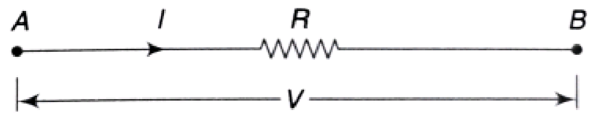

Fig. 1.4 Illustration of Ohm's law

the current will also double so that the ratio V/I remains constant. It may be noted here that if voltage is measured in volt and current in ampere, then resistance will be in ohm. The following points may be noted about Ohm's law:

(i) Ohm's law is true for dc circuits. However, it is not, in general, valid for ac circuits.

(ii) Strictly speaking, Ohm's law is true for metal conductors at constant temperature. If the temperature changes, Ohm's law is not applicable.

(iii) There are many conductors (e.g., silicon carbide) to which Ohm's law is not applicable even if the temperature is constant. It is because such materials have the property of changing their resistance as the current through them is changed.

(iv) Ohm's law can be expressed in three forms, viz.

$$I = V/R, \qquad V = IR, \qquad R = V/I$$

These formulae can be applied to any part of a dc circuit or to a complete circuit.

1.7 Electric Power

The rate at which work is done in an electric circuit is called **electric power**, i.e.,

$$\text{Electric power} = \frac{\text{Work done in electric circuit}}{\text{Time}}$$

When voltage is applied to a circuit, it causes current (i.e., free electrons) to flow through it. Clearly, work is being done in moving the electrons in the circuit. This work done in moving the electrons in unit time is called the electric power. Thus, referring to the part AB of the circuit (see Fig. 1.5),

V = Potential difference (PD) across AB in V

I = Current in A

R = Resistance of AB in Ω

t = Time in sec for which the current flows

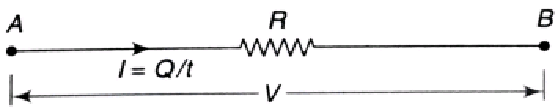

Fig. 1.5 Power dissipated in resistance

The total charge that flows in t second is $Q = I \times t$ coulomb and by definition (see Section 1.3),

$$V = \frac{\text{Work done}}{Q}$$

or $\qquad \text{Work done} = VQ$

$$= VIt \qquad (\because Q = It)$$

So, Electric power, $P = \dfrac{\text{Work done}}{t}$

$$= \frac{VIt}{t} = VI \text{ joule/sec or watt}$$

So, $P = VI$ (i)

Using $V = IR$,

$$P = I^2R \quad \text{(ii)}$$

Similarly, using $I = V/R$

$$P = \frac{V^2}{R} \quad \text{(iii)}$$

The above three formulae are equally valid for calculation of electric power in a dc circuit. The formula to be used depends simply on the quantities known or most easily determined.

The basic unit of electric power is *joule/sec* or *watt* (W). The power consumed in a circuit is 1 watt if a PD of 1V causes 1A current to flow through the circuit. So,

Power in watt = Voltage in volt × Current in ampere

The bigger units of electric power are kilowatt (kW) and megawatt (MW).

1 kW = 1000 W

1 MW = 10^6 W or 10^3 kW

1.8 Electrical Energy

The total work done in an electric circuit is called **electrical energy**, i.e.,

$$\text{Electrical energy} = \text{Electrical power} \times \text{time}$$
$$= V\,I\,t$$
$$= I^2 R\,t$$
$$= \frac{V^2}{R} t$$

The formulae for electrical energy can be readily derived by multiplying the electric power by 't', the time for which the current flows. The unit of electrical energy will depend upon the units of electric power and time as follows:

(i) If power is taken in watt and time in second, then the unit of electrical energy will be watt-sec, i.e.,
Energy in watt-sec = Power in watt × Time in sec

(ii) If power is expressed in watt and time in hour, then the unit of electrical energy will be watt-hour, i.e.,
Energy in watt-hour = Power in watt × Time in h

(iii) If power is expressed in kilowatt and time in hour, then the unit of electrical energy will be kilowatt-hour (kW-h), i.e.,
Energy in kW-h = Power in kW × Time in h

It may be pointed out here that in practice, electrical energy is measured in kilowatt-hour (kW-h). **One kilowatt-hour (kW-h)** of electrical energy is expended in a circuit if 1 kW (1000 W) of power is supplied for 1 h.

1.9 DC Circuit

The essential parts of an electric circuit are (i) the source of power (e.g., battery, generator), (ii) the conductors used to carry the current, and (iii) the load (e.g., lamps, heater, motor). The source supplies electrical energy to the load, which converts it into heat or other forms of energy. Thus, conversion of electrical energy into other forms of energy is possible only with the help of suitable circuits.

The closed path followed by a direct current (dc) is called a **dc circuit**. Figure 1.6 shows a torch bulb connected to a battery through conducting wires. The direct current starts from the positive terminal of the battery and comes back to the starting point via the load. The direct current follows the path *ABCDA*, and *ABCDA* is a dc circuit. The load for a dc circuit is usually a resistance. In a dc circuit, loads (i.e., resistances) may be connected in series, parallel, or series-parallel. Accordingly, dc circuits can be classified as:

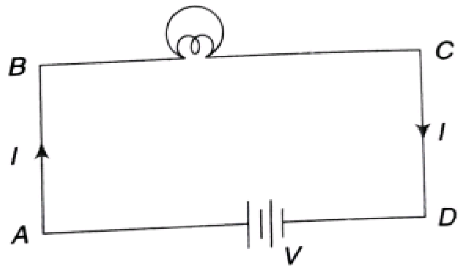

Fig. 1.6 A dc circuit

(i) Series circuits
(ii) Parallel circuits
(iii) Series-parallel circuits

1.9.1 Series Circuit

The circuit in which resistances are connected end to end so that there is only one path for the current to flow is called a **series circuit.**

Consider three resistances of R_1, R_2, and R_3 ohm connected in series across a battery of V volt as shown in Fig. 1.7(a). Obviously, there is only one path for the current I, i.e., current is same throughout the circuit.

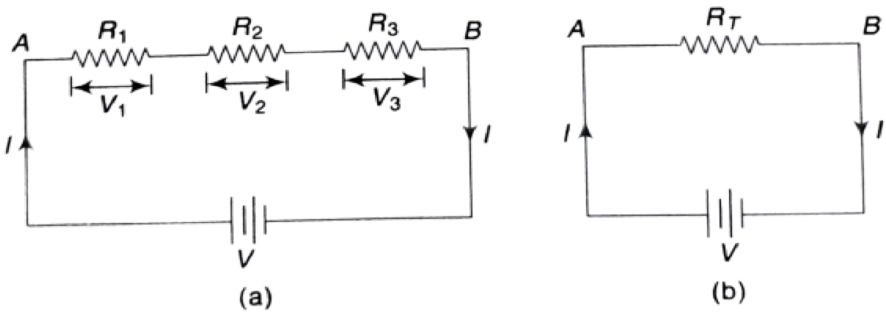

Fig. 1.7 A series circuit

By Ohm's law,

Voltage drop across the resistance R_1, $V_1 = I\,R_1$
Voltage drop across the resistance R_2, $V_2 = I\,R_2$
Voltage drop across the resistance R_3, $V_3 = I\,R_3$

Now, for a series circuit, sum of voltage drops is equal to the applied voltage. So,

$$V = V_1 + V_2 + V_3$$
$$= I R_1 + I R_2 + I R_3$$
$$= I(R_1 + R_2 + R_3)$$

or $$\frac{V}{I} = R_1 + R_2 + R_3$$

But V/I is the total resistance R_T between the points A and B [Fig. 1.7(b)]. R_T is called the total or equivalent resistance of the three resistances. So,

$$R_T = R_1 + R_2 + R_3$$

Hence, when a number of resistances are connected in series, the total resistance is equal to the sum of the individual resistances.

The following points may be noted about a series circuit:

(i) The current flowing through each resistance is same.
(ii) The applied voltage equals the sum of different voltage drops.
(iii) The total power consumed in the circuit is equal to the sum of the powers consumed by the individual resistances.
(iv) Every resistor of the circuit has its own voltage drop.

Voltage divider rule

It may be observed that the source voltage in the circuit shown in Fig. 1.7(a) divides among the resistors R_1, R_2, and R_3. The voltage drop across the resistances can be obtained as

$$V_1 = IR_1 = \frac{V}{R_T} R_1 \qquad \left(\because I = \frac{V}{R_T}\right)$$

Similarly, $$V_2 = IR_2 = \frac{V}{R_T} R_2$$

$$V_3 = IR_3 = \frac{V}{R_T} R_3$$

That is, the voltage drop across each resistor in a series circuit is directly proportional to the ratio of its resistance to the total series resistance of the circuit. By using the voltage divider rule, the proportion in which the voltage drops are distributed around a circuit can be determined.

1.9.2 Parallel Circuit

The circuit in which one end of each resistance is joined to a common point and the other end of each resistance is joined to another common point, so that there are as many paths for current flow as the number of resistances, is called a parallel circuit.

Consider three resistances of R_1, R_2, and R_3 ohm connected in parallel across a battery of V volt as shown in Fig. 1.8(a). The total current I divides into three parts: I_1 flowing through R_1, I_2 flowing through R_2 and I_3 flowing through R_3. Obviously, the voltage across each resistance is the same (i.e., V volt in this case) and there are as many current paths as the number of resistances.

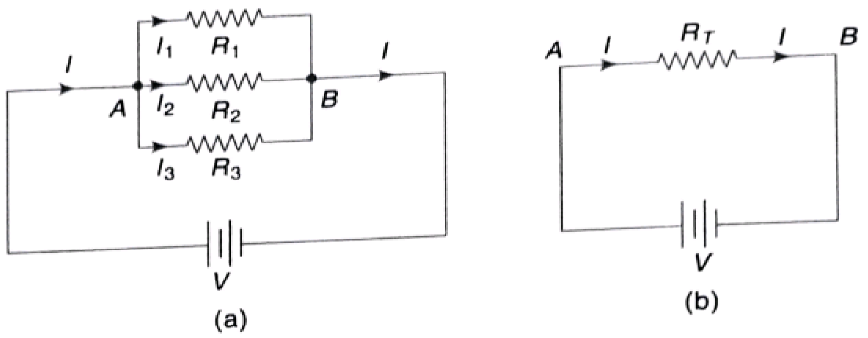

Fig. 1.8 A parallel circuit

By Ohm's law,

Current through the resistance R_1, $I_1 = \dfrac{V}{R_1}$

Current through the resistance R_2, $I_2 = \dfrac{V}{R_2}$

Current through the resistance R_3, $I_3 = \dfrac{V}{R_3}$

Now, for a parallel circuit, sum of the branch currents is equal to the total current. So,

$$I = I_1 + I_2 + I_3$$

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

$$= V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

or $$\frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

But V/I is the total resistance R_T of the parallel resistances [see Fig. 1.8(b)] so that $I/V = 1/R_T$.

Hence, $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Hence, when a number of resistances are connected in parallel, the reciprocal of the total resistance is equal to the sum of reciprocals of the individual resistances.

The following points may be noted about a parallel circuit:

(i) The voltage drop across each resistance is same.

(ii) The total current equals the sum of the branch currents.

(iii) The total power consumed in the circuit is equal to the sum of the powers consumed by the individual resistances.

(iv) Every resistor has its own current.

Current divider rule

Consider a parallel circuit of Fig. 1.9. Two resistances R_1 and R_2 connected in parallel across a battery of V volt. The total current I divides into two parts: I_1 flowing through R_1 and I_2 flowing through R_2.

The total resistance or equivalent resistance can be obtained as

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

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

So, $$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

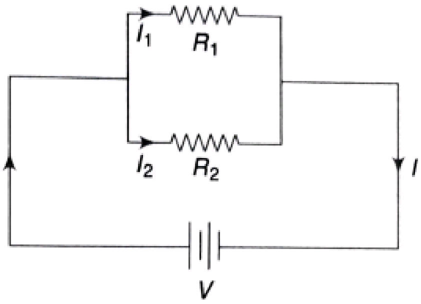

Fig. 1.9 Illustration of current divider rule

Hence, the total value of two resistances connected in parallel is equal to the product of the individual resistances divided by their sum.

The branch currents can be obtained as

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

So, $$V = IR_T = I\frac{R_1 R_2}{R_1 + R_2}$$

Current through R_1,

$$I_1 = \frac{V}{R_1}$$

$$= \frac{I\dfrac{R_1 R_2}{R_1 + R_2}}{R_1} \qquad \left(\because V = I\frac{R_1 R_2}{R_1 + R_2}\right)$$

or $$I_1 = I\frac{R_2}{R_1 + R_2}$$

Current through R_2,

$$I_2 = \frac{V}{R_2}$$

or $$I_2 = I\frac{R_1}{R_1 + R_2} \qquad \left(\because V = I\frac{R_1 R_2}{R_1 + R_2}\right)$$

Hence, in a parallel circuit of two resistances, the current through one resistance is the line current (i.e., the total current) times the opposite resistance divided by the sum of the two resistances.

Example 1.8 Determine the current through and the voltages across three resistances, of ohmic values 5 Ω, 7 Ω, and 8 Ω, connected in series and across a 100 V source.

Solution

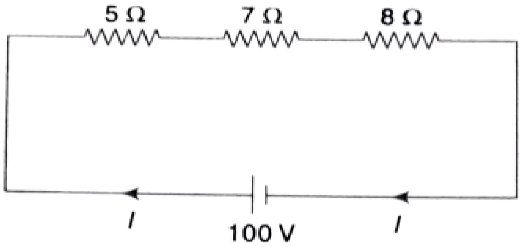

Fig. 1.10

Total resistance = R_{eq} = 5 + 7 + 8 = 20 Ω

Total circuit current = $I = \dfrac{V}{R_{eq}} = \dfrac{100}{20} = 5$ A

Voltage across the 5 Ω resistance = 5 I = 25 V
Voltage across the 7 Ω resistance = 7 I = 35 V
Voltage across the 8 Ω resistance = 8 I = 40 V

Example 1.9 Determine the currents through and the voltage across three resistances, of ohmic values 5 Ω, 10 Ω, and 20 Ω, all connected in parallel and across a 100 V source. Also find the current and the power drawn from the source.

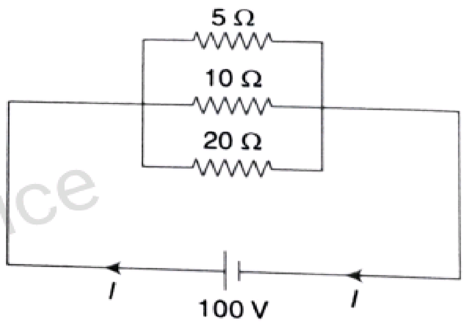

Fig. 1.11

Solution

Current through the 5 Ω resistance $= \dfrac{100}{5} = 20$ A

Current through the 10 Ω resistance $= \dfrac{100}{10} = 10$ A

Current through the 20 Ω resistance $= \dfrac{100}{20} = 5$A

Total current drawn from the source = 20 + 10 + 5 = 35 A
Power drawn from the source = VI = 100 × 35 = 3500 W

Example 1.10 Four resistances, of ohmic values 5 Ω, 10 Ω, 15 Ω, and 20 Ω, are connected in series across a 100 V source. How is this voltage divided among the various resistors?

Solution

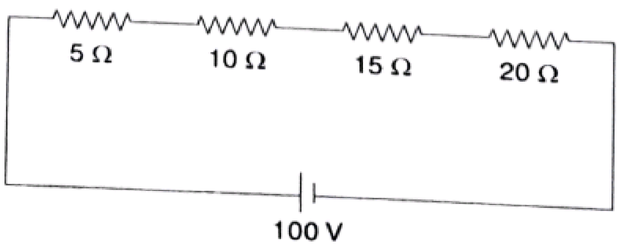

Fig. 1.12

Using the voltage division rule, we have

$$V_{5\,\Omega} = \left[\frac{5}{5+10+15+20}\right]100 = 10\text{ V}$$

$$V_{10\,\Omega} = \left[\frac{10}{5+10+15+20}\right]100 = 20\text{ V}$$

$$V_{15\,\Omega} = \left[\frac{15}{5+10+15+20}\right]100 = 30\text{ V}$$

$$V_{20\,\Omega} = \left[\frac{20}{5+10+15+20}\right]100 = 40\text{ V}$$

Example 1.11 Three resistances, of ohmic values 4 Ω, 12 Ω, and 6 Ω, are connected in parallel. If the total current is 12 A, how is this current divided among the various resistors?

Solution

Total or equivalent resistance,

$$\frac{1}{R_{eq}} = \frac{1}{4} + \frac{1}{12} + \frac{1}{6} = \frac{6}{12}$$

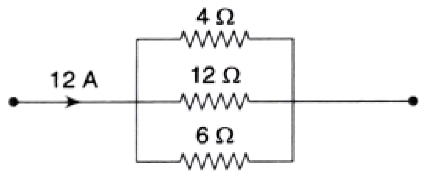

Fig. 1.13

Hence $R_{eq} = \frac{12}{6} = 2\ \Omega$

PD across the parallel circuit = $IR_{eq} = 12 \times 2 = 24$ V

Current through 4 Ω resistance $= \frac{24}{4} = 6$ A

Current through 12 Ω resistance $= \frac{24}{12} = 2$ A

Current through 6 Ω resistance $= \frac{24}{6} = 4$ A

Example 1.12 Two resistors R_1 and R_2 are connected in parallel to a certain supply. The current taken from the supply is 5 A. Calculate the value of R_1 if $R_2 = 6\ \Omega$ and the current through R_1 is 2 A. Also find the total power absorbed by the circuit.

Solution

Figure 1.14 shows the circuit arrangement.

Current through $R_2 = I_2 = 5 - 2 = 3$ A

Supply voltage $= I_2R_2 = 3 \times 6 = 18$ V

So, $R_1 = \frac{V}{I_1} = \frac{18}{2} = 9\ \Omega$

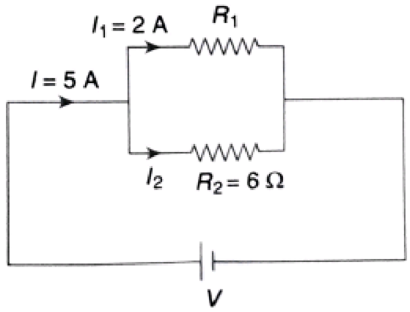

Fig. 1.14

Power absorbed by the circuit

$$= I_1^2 R_1 + I_2^2 R_2$$
$$= (2)^2 \times 9 + (3)^2 \times 6$$
$$= 36 + 54$$
$$= 90\text{ W}$$

Example 1.13 Calculate the effective resistance of the circuit of Fig. 1.15 and the current through 8 Ω resistance, when potential difference of 60 V is applied between the points *A* and *B*.

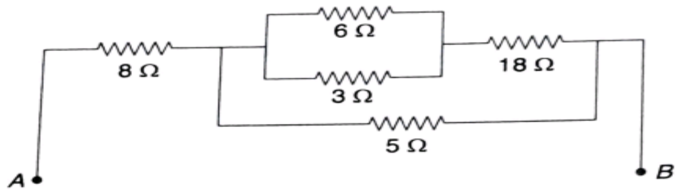

Fig. 1.15

Solution

Potential difference of 60 V is applied between the points *A* and *B*. Let the current delivered by the source is *I* A.

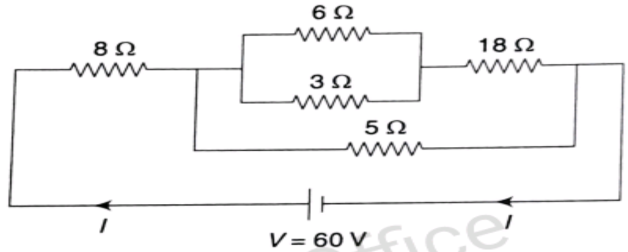

Fig. 1.16

In Fig. 1.16, the resistors 6 Ω and 3 Ω, are in parallel. $\therefore 6 \parallel 3 = 2\ \Omega$.

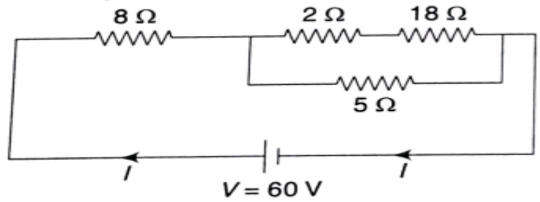

Fig. 1.17

In Fig. 1.17, resistors 2 Ω and 18 Ω are in series. $\therefore 2 + 18 = 20\ \Omega$.

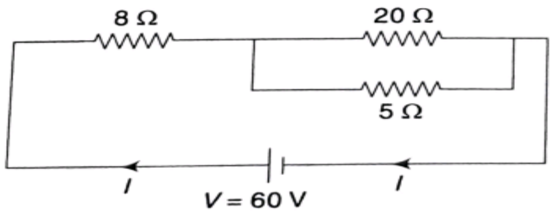

Fig. 1.18

In Fig. 1.18, resistors 20 Ω and 5 Ω are in parallel. $\therefore 20 \parallel 5 = 4\ \Omega$

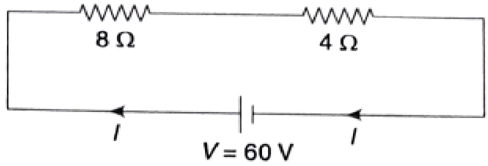

Fig. 1.19

In Fig. 1.19, resistors 8 Ω and 4 Ω are in series. $\therefore 8 + 4 = 12\ \Omega$

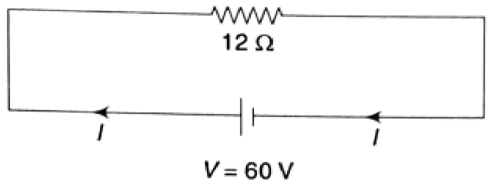

Fig. 1.20

By Ohm's law, circuit current, $I = \dfrac{60}{12} = 5$ A

Hence, current through 8 Ω resistor, $I_{8\,\Omega} = 5$ A (→)

Example 1.14 What is reading of the ammeter shown in the circuit of Fig. 1.21?

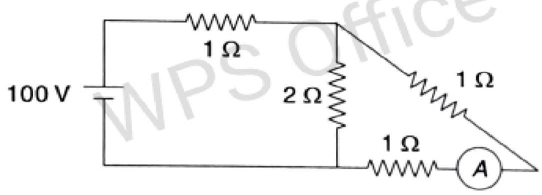

Fig. 1.21

Solution

Let the source current is I A.

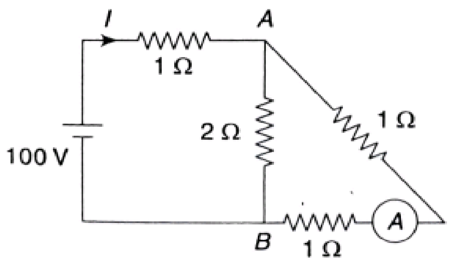

Fig. 1.22

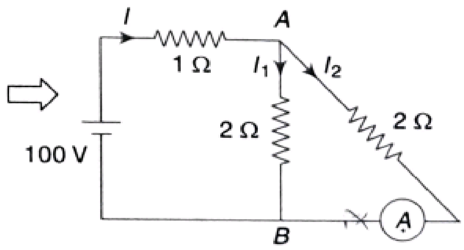

Fig. 1.23

The source current divides at node A. In Fig. 1.23, branch current I_2 flows through ammeter. For the calculation of branch current, source current is required. Equivalent resistance across the battery can be calculated as

$$R_{eq} = 1 + (2||2) = 2\ \Omega$$

By Ohm's law,

total current, $I = \dfrac{V}{R_{eq}} = \dfrac{100}{2} = 50$ A

By current division rule, $I_2 = 50 \times \dfrac{2}{2+2} = 25$ A

Hence, the ammeter reading is 25 A (the ammeter resistance is neglected).

Example 1.15 Calculate the effective resistance between the points A and B in the circuit shown in Fig. 1.24.

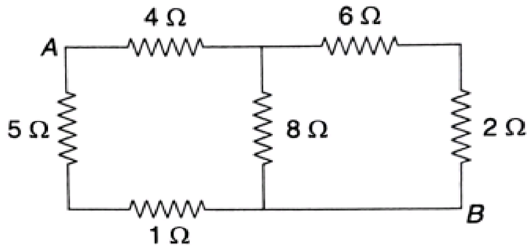

Fig. 1.24

Solution

Marking the different nodes, we get the following figure:

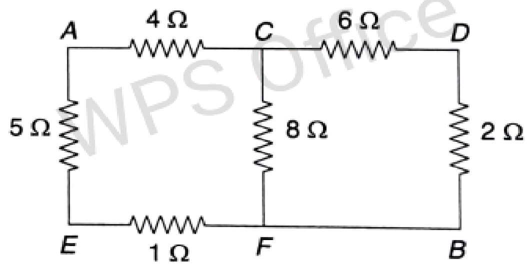

Fig. 1.25

In Fig. 1.25, resistors 5 Ω and 1 Ω are in series. Also resistors 6 Ω and 2 Ω are in series.

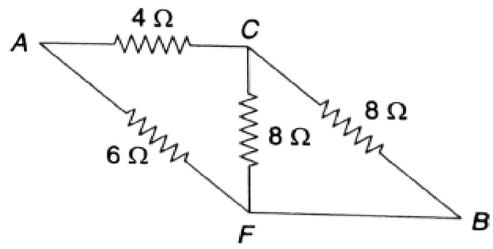

Fig. 1.26

It may be noted that series resistances can be clubbed (added) together and after adding the series resistances, common nodes vanish, i.e., in Fig. 1.25, node E and node D vanish. In Fig. 1.26, node F and node B are same and by joining them, we get the following figures:

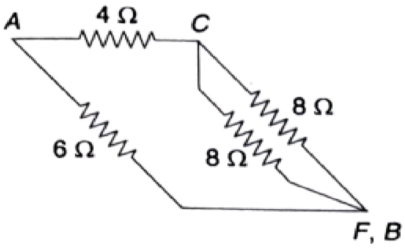

Fig. 1.27

⇒

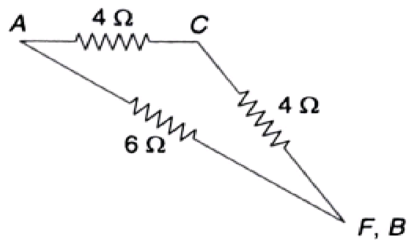

Fig. 1.28

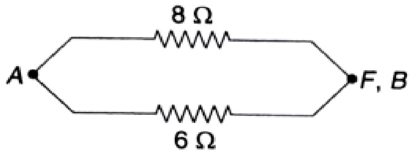

Fig. 1.29

⇒

Fig. 1.30

Thus, the equivalent resistance between the terminals A and B, $R_{AB} = 3.43\ \Omega$.

Example 1.16 Calculate battery current and the effective resistance of the network of Fig. 1.31.

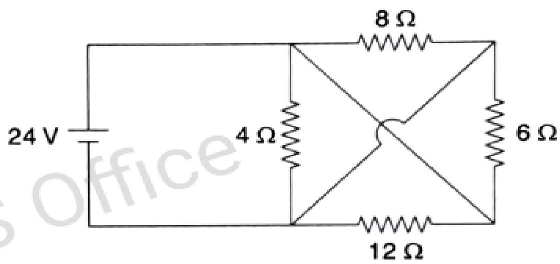

Fig. 1.31

Solution

By marking the different nodes and assuming the battery current I A, we get the circuit as shown in Fig. 1.32.

By taking the link CE from outside, the cross connection can be avoided. Thus, the circuit of Fig. 1.32 can be simplified as shown in Fig. 1.33.

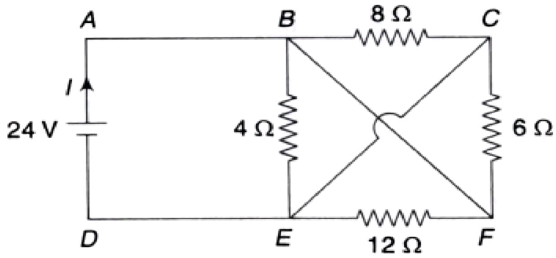

Fig. 1.32

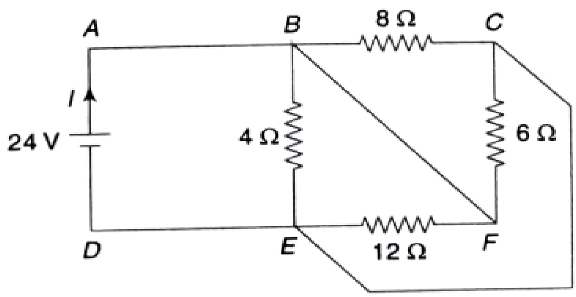

Fig. 1.33

In Fig. 1.33, node B and node F are same and by joining them, the circuit can be simplified as follows:

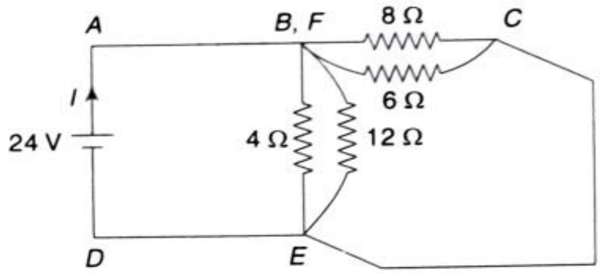

Fig. 1.34

In Fig. 1.34, resistors 6 Ω and 8 Ω are in parallel. Also resistors 4 Ω and 12 Ω are in parallel.

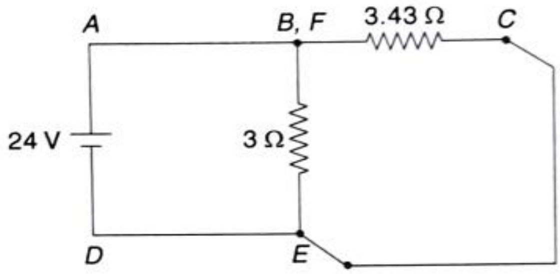

Fig. 1.35

In Fig. 1.35, resistors 3 Ω and 3.43 Ω are in parallel.

By Ohm's law, battery current, $I = \dfrac{24}{1.6} = 15\text{A}$.

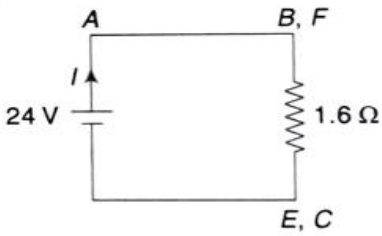

Fig. 1.36

Example 1.17 Calculate battery current of the network of Fig. 1.37.

Solution

By marking the different nodes and assuming the battery current I A, we get the circuit as shown in Fig. 1.38.

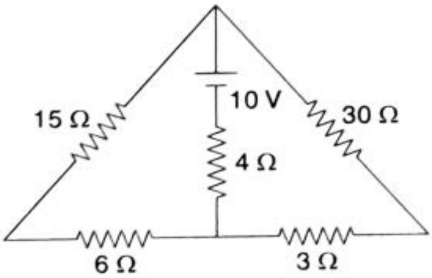

Fig. 1.37

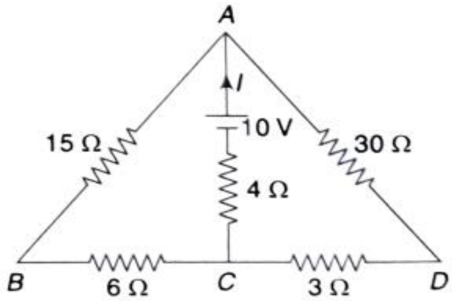

Fig. 1.38

Battery current can be calculated as $I = \dfrac{10}{R_{eq}}$. First we have to calculate R_{eq}.

In Fig. 1.38, resistors 6 Ω and 15 Ω are in series. Also resistors 30 Ω and 3 Ω are in series.
In Fig. 1.39, resistors 21 Ω and 33 Ω are in parallel across the terminals A and C.
In Fig. 1.40, 4 Ω and 12.83 Ω are in series.
By Ohm's law, battery current

$$I = \frac{10}{16.83} = 0.59 \text{ A}$$

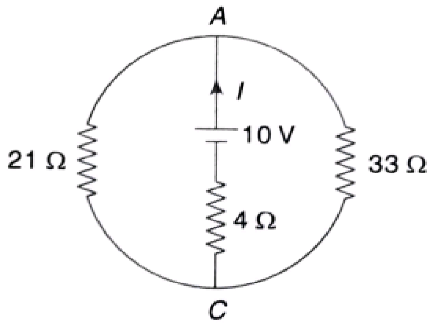

Fig. 1.39

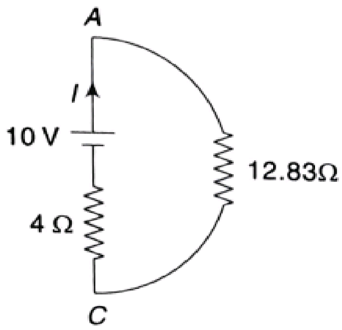

Fig. 1.40

⇒

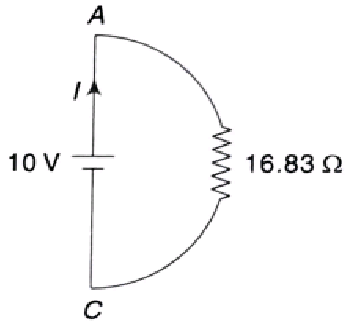

Fig. 1.41

Example 1.18 Calculate the effective resistance R_{AB} of network of Fig. 1.42.

Solution

In Fig. 1.42, node C and node E are same, and by joining them, the circuit of Fig. 1.42 can be simplified as shown in Fig. 1.43.

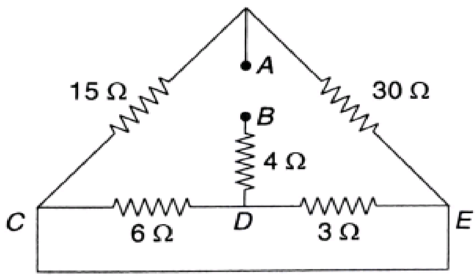

Fig. 1.42

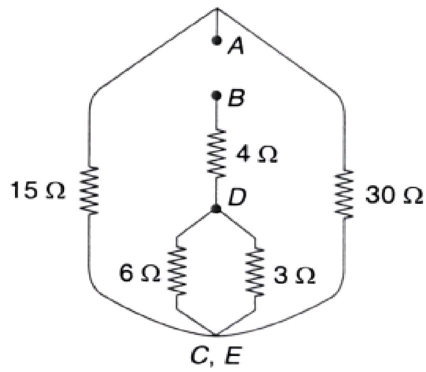

Fig. 1.43

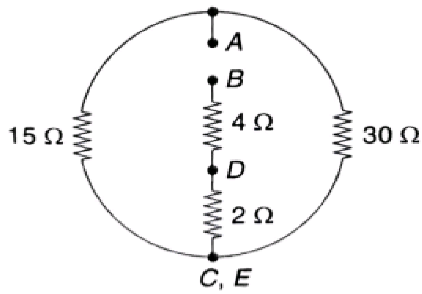

Fig. 1.44

⇒

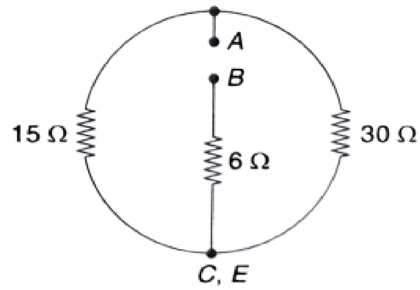

Fig. 1.45

In Fig. 1.43, resistors 6 Ω and 3 Ω are in parallel.
In Fig. 1.44, resistors 4 Ω and 2 Ω are in series.
In Fig. 1.45, resistors 15 Ω and 30 Ω are in parallel.

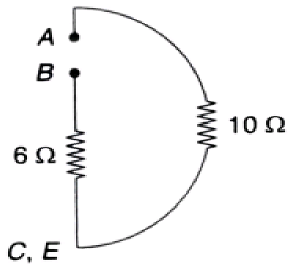

Fig. 1.46

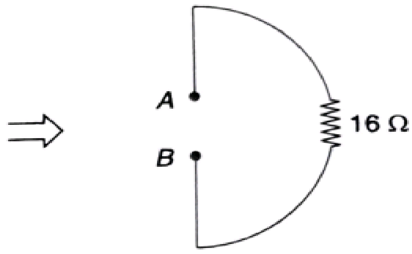

Fig. 1.47

Thus, the equivalent resistance between the terminals A and B, $R_{AB} = 16\ \Omega$.

Example 1.19 Calculate battery current of the network of Fig. 1.48.

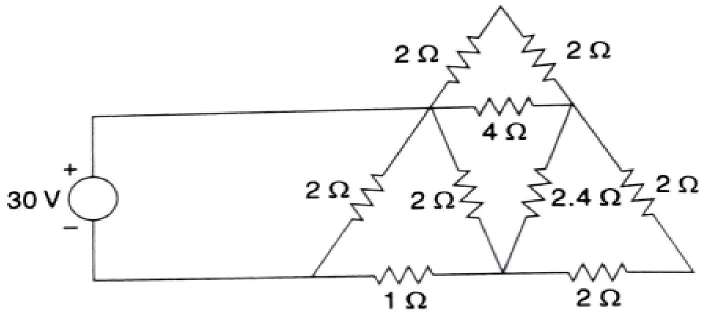

Fig. 1.48

Solution

Marking the different nodes and assuming the current delivered by the source as I A, we get the following figure:

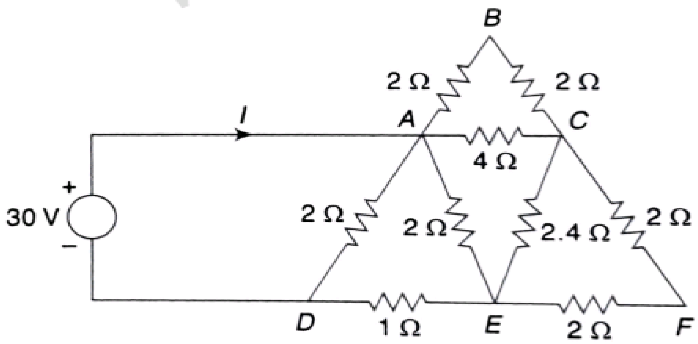

Fig. 1.49

By reducing the circuit across the battery, the equivalent resistance can be calculated.

By Ohm's law, battery current,

$$I = \frac{30}{1.06} = 28.3\ \text{A}$$

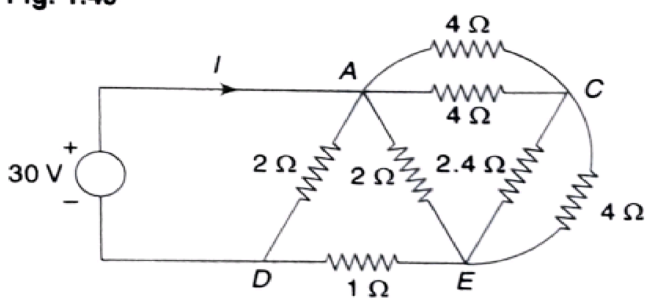

Fig. 1.50

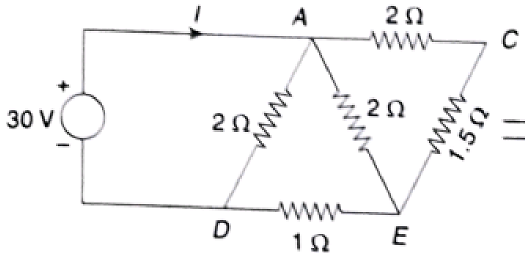

Fig. 1.51

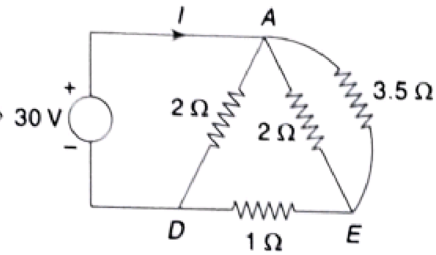

Fig. 1.52

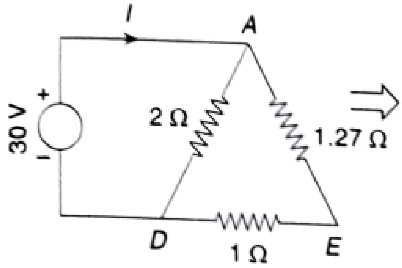

Fig. 1.53

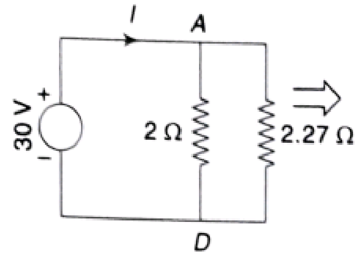

Fig. 1.54

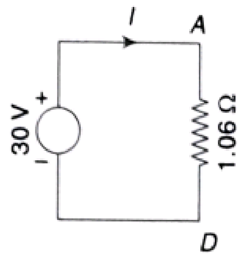

Fig. 1.55

Example 1.20 Calculate the effective resistance R_{AB} of the network shown in Fig. 1.56.

Solution

In Fig. 1.56, by taking the 8 Ω resistor from outside, the cross connection can be avoided. Thus, the circuit of Fig. 1.56 can be simplified as shown in Fig. 1.57.

In Fig. 1.57, node D and node F are same and by joining them, the circuit of Fig. 1.57 can be further simplified as shown in Fig. 1.58.

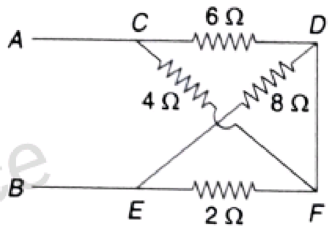

Fig. 1.56

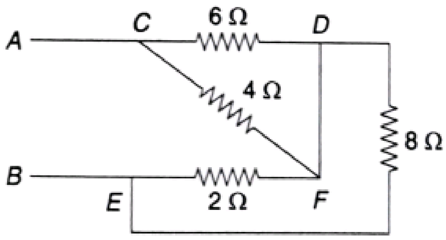

Fig. 1.57

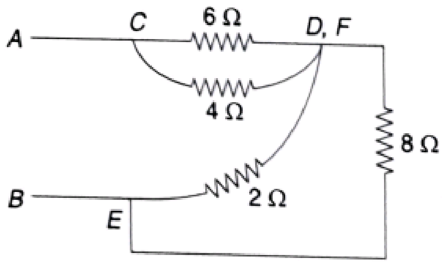

Fig. 1.58

In Fig. 1.58, resistors 6 Ω and 4 Ω are in parallel. Also resistors 2 Ω and 8 Ω are in parallel.

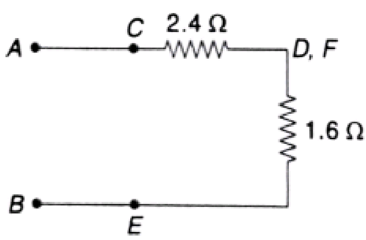

Fig. 1.59

Fig. 1.60

Thus, equivalent resistance between the terminals A and B, $R_{AB} = 4\ \Omega$.

Example 1.21 Calculate the effective resistance R_{AB} of network shown in Fig. 1.61. (All resistances are in ohm.)

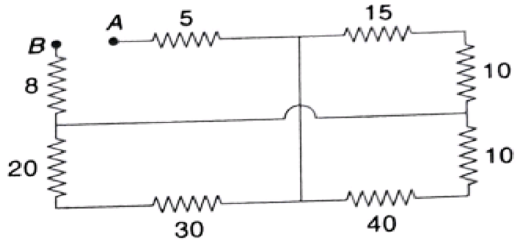

Fig. 1.61

Solution

Marking the different nodes in the circuit of Fig. 1.61, we get circuits as shown in Figs 1.62 and 1.63.

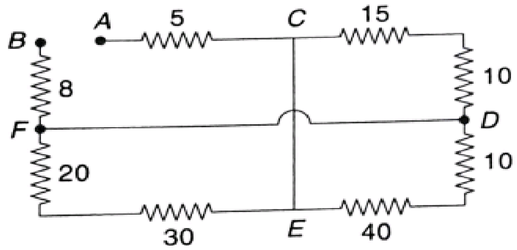

Fig. 1.62

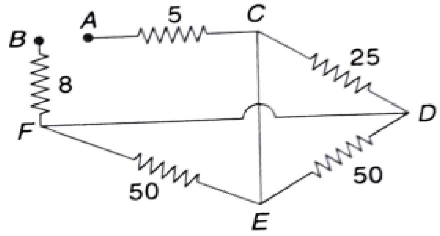

Fig. 1.63

In Fig. 1.63, by taking the link CE from outside, the cross connection can be avoided. Thus, the circuit of Fig. 1.63 can be simplified as shown below:

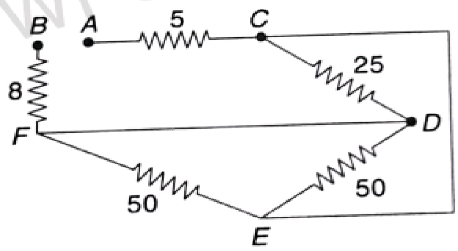

Fig. 1.64

In Fig. 1.64, node F and node D are same and by joining them, the circuit of Fig. 1.64 can be further simplified as shown below:

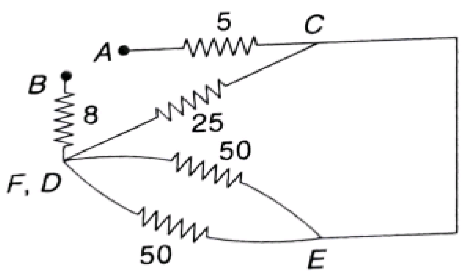

Fig. 1.65

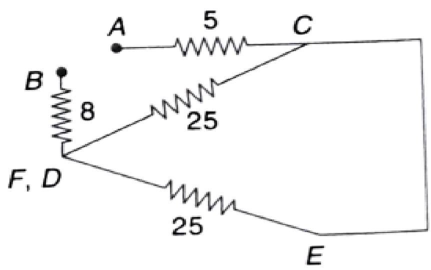

Fig. 1.66

In Fig. 1.66, node C and node E are same and by joining them, the circuit of Fig. 1.66 can be further simplified as shown in Figs 1.67, 1.68, and 1.69. Thus, the equivalent resistance between the terminals A and B, $R_{AB} = 25.5\ \Omega$.

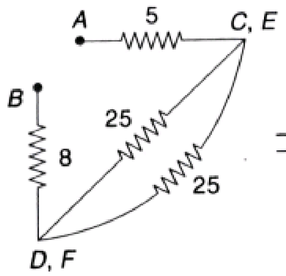

Fig. 1.67

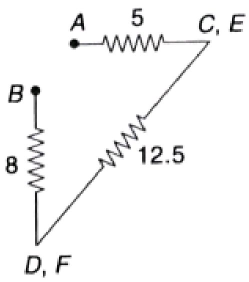

Fig. 1.68

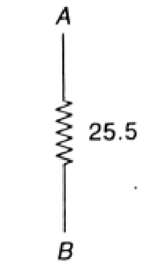

Fig. 1.69

Example 1.22 Find the current I through the lamp when the switch S is closed in the circuit shown in Fig. 1.70.

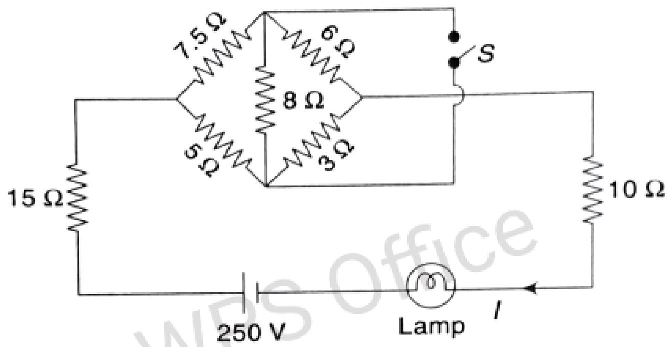

Fig. 1.70

Solution

Marking the different nodes in the circuit of Fig. 1.70, we get the circuit as shown in Fig. 1.71.

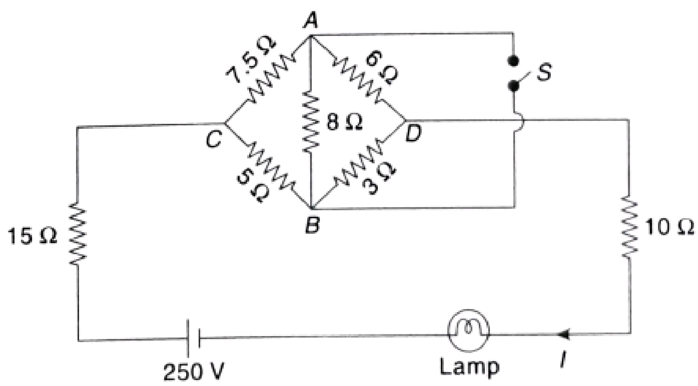

Fig. 1.71

After closing the switch S (refer Fig. 1.72), the resistor 8 Ω will be shorted and circuit gets modified as shown in Fig. 1.73.

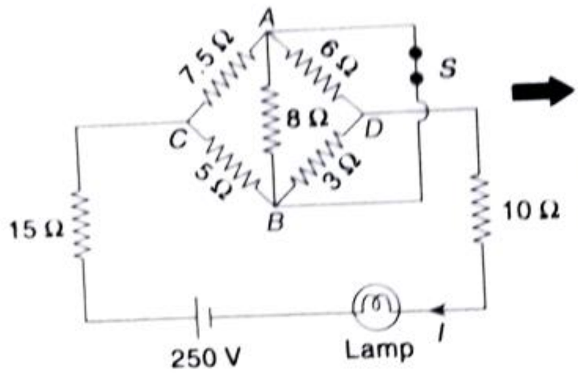

Fig. 1.72

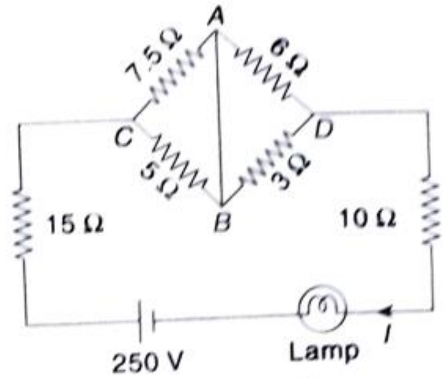

Fig. 1.73

In Fig. 1.73, nodes A and B are same and by joining them, the circuit of Fig. 1.73 can be further simplified as shown below:

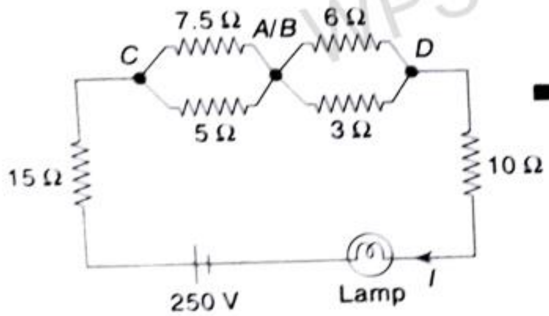

Fig. 1.74

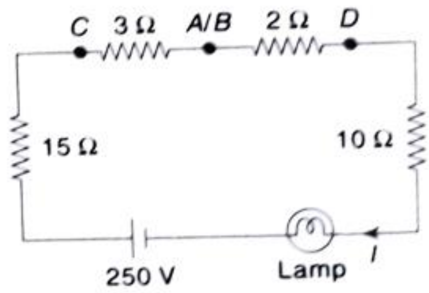

Fig. 1.75

From Fig. 1.75, current I through the lamp can be calculated as:

$$I = \frac{250}{15 + 3 + 2 + 10} = 8.33 \text{ A}$$

Example 1.24 A resistance of 10 Ω is connected in series with two resistances each of 15 Ω arranged in parallel. What resistance must be shunted across the parallel combination so that the total current taken shall be 1.5 A with 20 V applied.

Solution
The circuit connections are shown in Fig. 1.77.

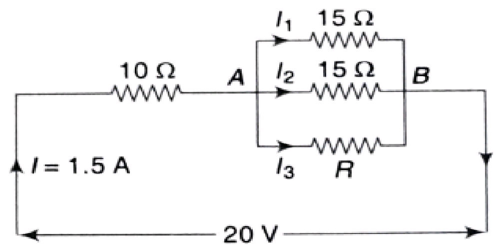

Fig. 1.77

Voltage drop across 10 Ω resistor = 1.5 × 10 = 15 V
Voltage drop across parallel combination, $V_{AB} = 20 - 15 = 5$ V
Voltage across each parallel resistor is 5 V.

Hence, $I_1 = \frac{5}{15} = \frac{1}{3}$ A and $I_2 = \frac{5}{15} = \frac{1}{3}$ A

Now, $I_3 = I - (I_1 + I_2)$

So, $I_3 = 1.5 - \left(\frac{1}{3} + \frac{1}{3}\right) = \frac{5}{6}$ A

Now, $I_3 R = 5$

So, $\left(\frac{5}{6}\right) R = 5$

Hence, $R = 6\ \Omega$

Example 1.25 In the circuit shown below, find the value of resistance R, when power consumed by the 12 Ω resistor is 36 W.

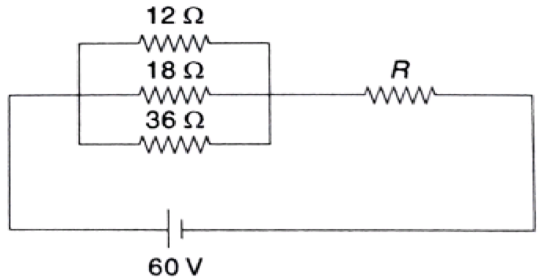

Fig. 1.78

Solution
The circuit connections are shown in Fig. 1.79.

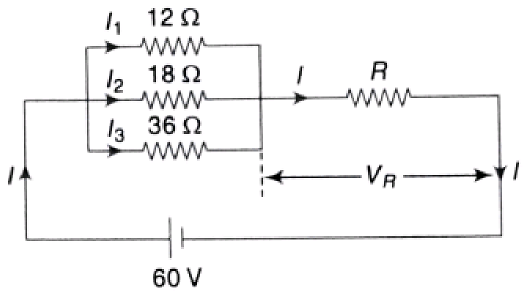

Fig. 1.79

Power in 12 Ω resistor = $I_1^2 \times 12 = 36$ $\therefore I_1 = 1.732$ A

Hence, voltage across 12 Ω resistor = 1.732 × 12 = 20.784 V

and voltage across R, $V_R = 60 - 20.784 = 39.216$ V

Hence, $I_2 = 20.784/18 = 1.155$ A

and $I_3 = 20.784/36 = 0.577$ A

Then $I = I_1 + I_2 + I_3 = 1.732 + 1.155 + 0.577 = 3.464$ A

Hence, value of unknown resistance, $R = V_R/I = 39.216/3.464 = 11.321\ \Omega$

Example 1.26 Find (i) current in 15 Ω resistor, (ii) voltage across 18 Ω resistor, and (iii) power dissipated in 7 Ω resistor of the circuit given in Fig. 1.80.

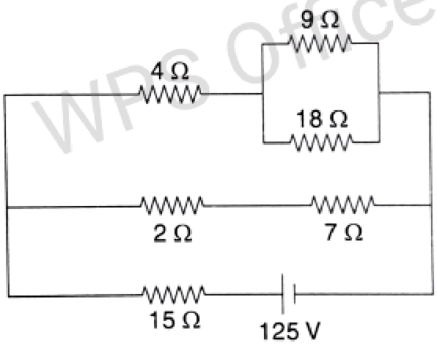

Fig. 1.80

Solution

Assuming the different currents, we get the following circuits:

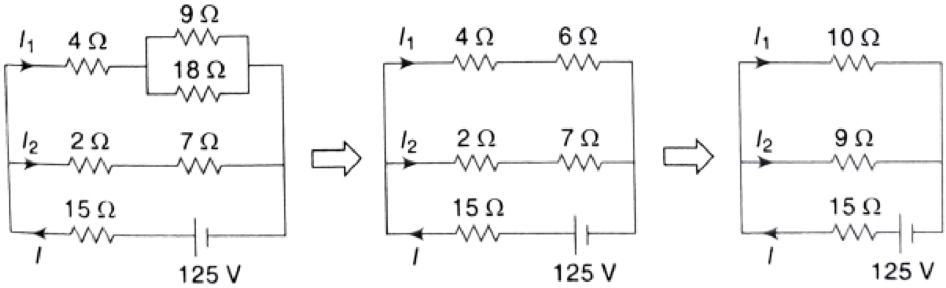

Fig. 1.81 **Fig. 1.82** **Fig. 1.83**

Equivalent resistance across the battery, $R_{eq} = 15 + (10 \parallel 9) = 19.736\ \Omega$

(i) Current in 15 Ω resistor, $I = \dfrac{V}{R_{eq}} = \dfrac{125}{19.736} = 6.33$ A

(ii) Applying the current rule to circuit of Fig. 1.83, branch current I_1 can be calculated as

$$I_1 = I\frac{9}{9+10} = \frac{6.33 \times 9}{19} = 3 \text{ A}$$

Hence, current in 18 Ω resistor $= \dfrac{I_1 \times 9}{9+18} = \dfrac{3 \times 9}{27} = 1$ A

and voltage across 18 Ω resistor = 18 × 1 = 18 V

(iii) Current in 7 Ω resistor, $I_2 = I - I_1 = 6.33 - 3 = 3.33$ A

Hence, power dissipated in 7 Ω resistor $= I_2^2 \times 7 = (3.33)^2 \times 7 = 77.6$ W

Example 1.27 In the circuit shown below, find the value of resistance R.

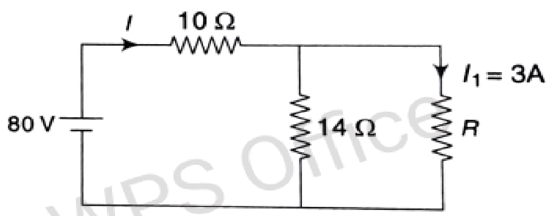

Fig. 1.84

Solution

Total circuit current, $I = \dfrac{80}{10 + (14 \parallel R)} = \dfrac{80}{10 + \dfrac{14R}{14+R}} = \dfrac{80(14+R)}{140+24R}$ (i)

By current division rule, I_1 can be calculated as

$$I_1 = I\frac{14}{14+R}$$

or $3 = I\dfrac{14}{14+R}$ $(\because I_1 = 3)$

Hence, $I = \dfrac{3(14+R)}{14}$ (ii)

From (i) and (ii), we get $R = 9.722\ \Omega$