(iii) Potential of point B w.r.t. point A is -12 V (though it is at zero potential w.r.t. ground).

(iv) Since it is electrically connected to the ground by means of the conductor BC, point B is at ground potential *i.e.*, it is at **0 V.**

Example 1.2. *In Fig. 1.11 (b), mid-point C of the 6 Ω resistor has been grounded. Calculate*

(i) potential of point A w.r.t. ground

(ii) potential of point B w.r.t. ground

(iii) p.d. between A and B

(iv) current flowing through portion CB and its direction.

Solution. (*i*) Since R_{AC} equals half the total circuit resistance, drop across it is also half the applied voltage *i.e.*, 12/2 = 6 V. Hence, potential of point A w.r.t. point C (*i.e.*, ground) is **+6 V**

(*ii*) For similar reasons, potential of point B w.r.t. point C (*i.e.*, ground) is **–6V**

(*iii*) P.D. between A and B = 6 V – (– 6 V) = **+12 V**

(*iv*) Since, $R_{CB} = 3\Omega$ and $V_{CB} = 6$ V, $I_{CB} = 6/3 =$ **2 A**

This current must flow from higher to lower potential. Since point C is at 0 V and B is at – 6 V, current flows along CB.

1.8. Work and Power

Work and energy are the same thing but power is different because it is defined as the rate of doing work. Suppose, a battery of V volts drives a current of I amperes through a resistance of R ohms for t seconds. Then, total work done by the battery to maintain this current is

$$\begin{aligned} \text{W.D.} &= VIt \text{ joules} \\ &= I^2 R t \text{ joules} && \text{—eliminating } V \\ &= V^2 t / R \text{ joules} && \text{—eliminating } I \\ &= Wt \text{ joules} && \text{—putting } W = VI \end{aligned}$$

Unit of Work

1. The commonly-used unit of work is joule (J) which may be defined in the following two ways :

(*a*) It is equal to the work done when a force of 1 newton (N) moves a body through a distance of 1 metre (m) in its direction of application.

or

(*b*) It is equal to the work done when a charge of 1 coulomb (C) is moved between two points having a potential difference of 1 V.

$$\begin{aligned} 1 \text{ joule} &= 1 \text{ metre-newton} \\ &= 1 \text{ volt-coulomb} \end{aligned}$$

2. Another unit often employed in Semiconductor Physics is electron-volt (eV).

It is equal to the amount of work needed to move an electron between two points having a potential difference of one volt.

Since, there are 6.24×10^{18} electrons in one coulomb

$$\therefore \quad 1 \text{ J} = 6.24 \times 10^{10} \text{ eV}$$

$$1 \text{ eV} = 1/6.24 \times 10^{18} = 1.6 \times 10\times^{19} \text{ J}$$

Power. The electric power required to maintain this current is

$$P = \frac{\text{W.D.}}{t} \text{ watts} = \frac{VI\,t}{t} = VI \text{ watts}$$

$$= \frac{V^2 t}{Rt} = \frac{V^2}{R} \text{ watts} = \frac{I^2 Rt}{t} = I^2 R \text{ watts}$$

The bigger units are :

$$1 \text{ kilowatt (kW)} = 1000 \text{ W} = 10^3 \text{ W}$$

$$1 \text{ megawatt (MW)} = 1{,}000{,}000 \text{ W} = 10^6 \text{ W}$$

Example 1.3. *A 100 Ω resistor is required to be used in a circuit carrying a current of 0.15 A. What should be the power rating of the resistor?*

Solution. $P = I^2 R = 0.15^2 \times 100 = 2.25$ W

In order to prevent overheating of such a resistor, its power or wattage rating should be nearly twice of that calculated above. Hence, a resistor of 5 W power rating would be most suitable.

1.9. Cells in Series and Parallel

Electric cells may be connected either in series or in parallel, to form *batteries*. Each of these combinations has a different value of the total voltage and current-delivering capacity.

1. Series Connection

In Fig. 1.12, four dry cells each of 1.5 V have been connected in series *i.e.*, from end-to-end.

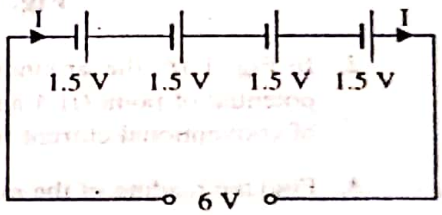
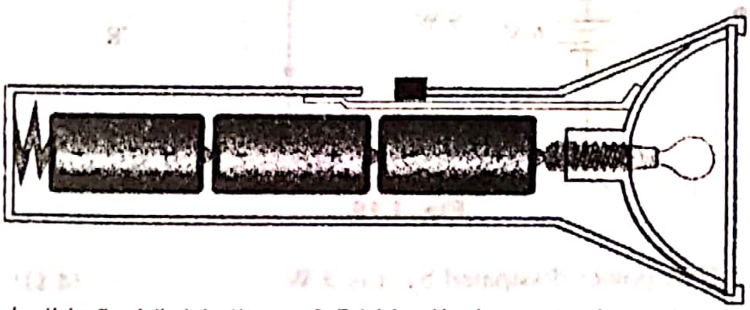


Fig. 1.12

The total voltage is 4 times the voltage of a single cell *i.e.*, 4 × 1.5 = 6 V. However, the current-delivering capacity of the series combination *does not exceed that of the single cell.* In case, cells of different emf's are connected in series, the current delivering capacity of such a combination is equal to that of the single cell which has the lowest current-delivering capacity.



In this flashlight, three 1.5 V batteries are placed in series to produce a larger voltage.

Hence, series combination of cells is employed when higher *voltages* (non-currents) are required.

2. Parallel Connection

Such a combination is used when the purpose is to obtain more current than is available from a single unit. As shown in Fig. 1.13, total voltage available across output terminals *A* and *B* is equal to the voltage of a single cell. However, output current *I* is equal to the sum of four cell currents *i.e.*, $I = i_1 + i_2 + i_3 + i_4$. Normally, only those cells having identical emf's are connected in parallel.

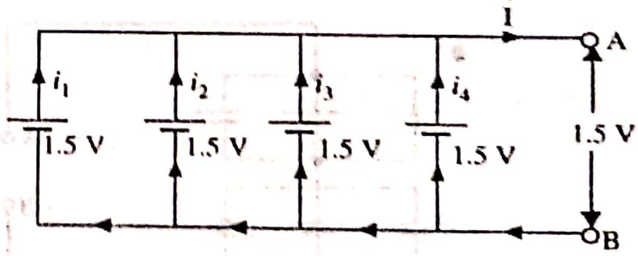


Fig. 1.13

Hence, parallel combination of cells is employed, where increased *current* (rather than voltage) is the main requirement.

However, series-parallel combination (Fig. 1.14) is employed where both higher voltage and increased current are required *i.e.*, greater power is required. Such connections are frequently found in many circuits including those in radio and television receivers.

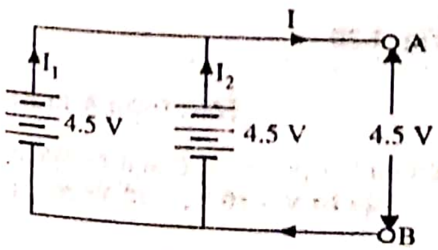
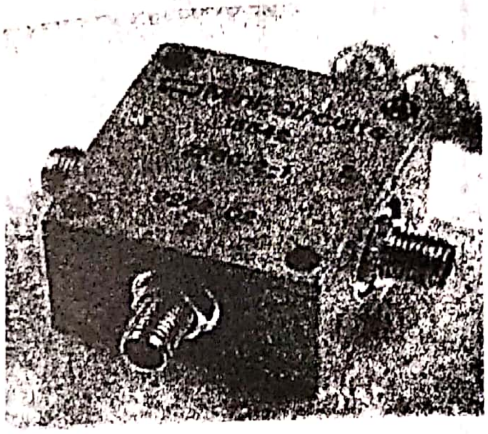


Fig. 1.14

CHAPTER 2

Resistive Circuits



2.1. Series Circuit

When components in a circuit are connected end-to-end (Fig. 2.1) so that all the circuit current passes through each component, they form a series circuit. The three resistors R_1, R_2 and R_3 are in series with each other and the battery. The result is only one path for current flow. Hence, current I is the *same in all the three resistors*. Due to this current flow, voltage drops V_1, V_2, and V_3 occur across R_1, R_2 and R_3 respectively. Obviously,

$$V_1 = I R_1,\ V_2 = I R_2 \text{ and } V_3 = I R_3$$

The sum of these three voltage drops must equal the applied voltage.

$$\therefore\ V = V_1 + V_2 + V_3$$

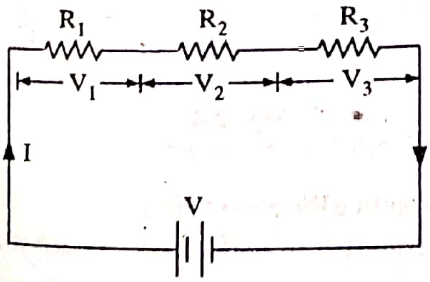


Fig. 2.1

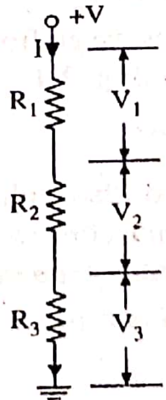


Fig. 2.2

Incidentally, circuit of Fig. 2.1 may be redrawn as shown in Fig. 2.2. In this diagram, the negative battery terminal has been grounded (even though we could ground the positive terminal as well).

2.2. Characteristics of a Series Circuit

A series resistive network has the following characteristics :

1. ***Total resistance equals the sum of all series resistances.***

In the Fig. 2.3 are shown a few resistors connected in series across a voltage source.

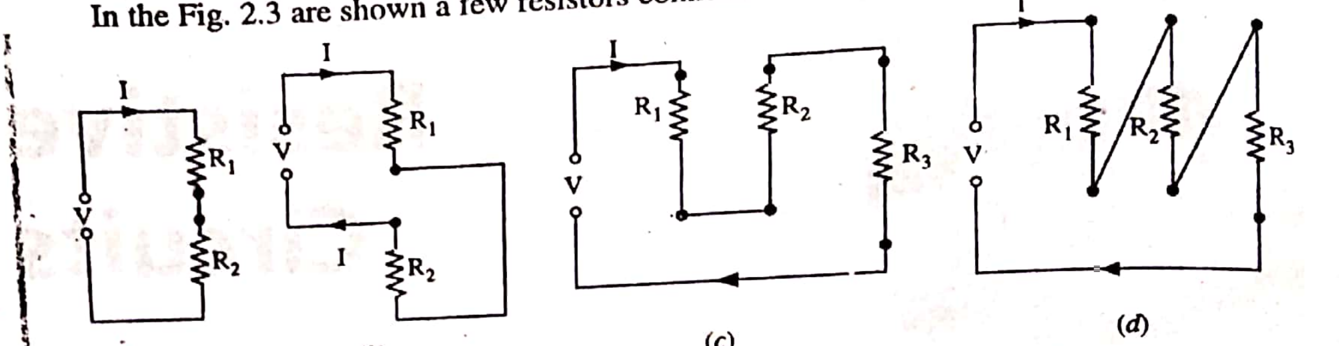


Fig. 2.3

In Fig. 2.3 (*a*) $R = R_1 + R_2$

In Fig. 2.3 (*b*) $R = R_1 + R_2$

In Fig. 2.3 (*c*) $R = R_1 + R_2 + R_3$

In Fig. 2.3 (*d*) $R = R_1 + R_2 + R_3$

Talking in terms of conductances, we have in Fig. 2.3 (*c*)

$$\frac{1}{G} = \frac{1}{G_1} + \frac{1}{G_2} + \frac{1}{G_3}$$

2. ***Current through all resistors is the same.***

The value of circuit current is given by

$$I = \frac{\text{applied voltage}}{\text{total resistance}} = \frac{V}{R}$$

3. ***The sum of individual IR drops equals the applied voltage.***

As seen from Fig. 2.1,

$$V = V_1 + V_2 + V_3$$

4. There is a stepped fall in voltage as we go from one end the battery to the other as shown in Fig. 2.4.

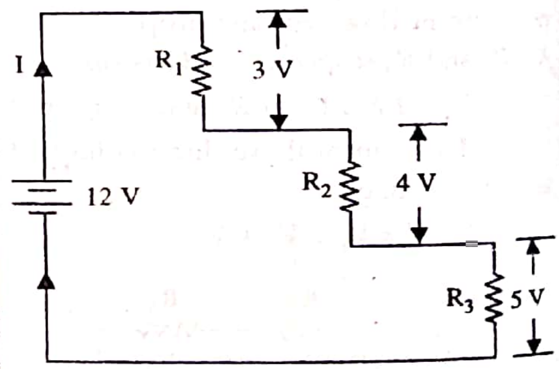


Fig. 2.4

2.3. The Case of Zero IR Drop

It is obvious that drop '*IR*' will be zero when either *I* is zero or *R* is zero. Now, for copper connecting wires, *R* is practically zero. Hence, there is no voltage drop across such interconnecting wires even though they may carry their normal current.

Similarly, there is no *IR* drop when *I* is zero *i.e.*, when applied voltage has been disconnected or there is an open in the circuit.

2.4. Polarity of IR Drops

The study of voltage polarities, whether positive or negative, is of extreme importance in transistor and semiconductor circuits. When voltage drop exists across a resistor, its one end must be more positive than the other. Otherwise, without a potential difference, no current could flow through the resistance to produce the *IR* drop. The polarity of this drop can be associated with the direction of current flow. If current enters a resistor at point *A* and goes out from point *B*, then *A* must be at a higher potential than *B*. In other words, *A* must be positive with respect to *B*.

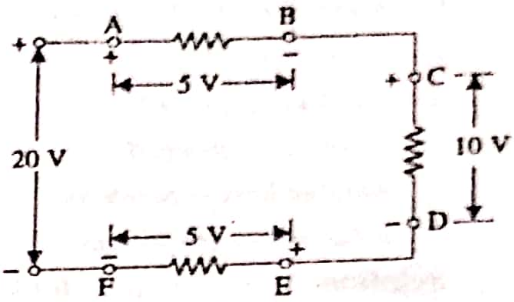


Fig. 2.5

It should be clearly understood that '+' and '–' polarities marked in Fig. 2.5 *relate to voltage drops across resistors only*. Otherwise, points *B* and *C* and, similarly, points *D* and *E* cannot be at different potentials because they are connected by a piece of conductor wire of zero resistance.

2.5. Total Power

The power needed to drive current through different resistors appears in the form of heat. Hence, total power supplied by the energy source must be equal to the sum of individual powers dissipated in different resistors.

$\therefore$ $$P = P_1 + P_2 + P_3 \text{......etc.}$$

2.6. Series-Aiding and Series-Opposing Voltages

In series-aiding combination, the voltage sources (cells or batteries) are connected in series such that positive terminal of one is joined to the negative terminal of the next. In this case, the total voltage across the circuit is the sum of all voltages or battery emf's as shown in Fig. 2 6 (*a*). Here, voltage applied across $AB = 6 + 6 = 12$ V and $I = \dfrac{12}{6} = 2$ A.

In series-opposing combination, positive terminal of one voltage source is connected to the positive terminal of the other source as shown in Fig. 2.6 (*b*). In this case, the net voltage is the difference of the two voltages and has the same polarity as the larger of the two voltages.

For example, in Fig. 2.6 (*b*), net voltage across *AB* is $12 - 6 = -6$ V. Hence, $I = 6/6 = 1$ A.

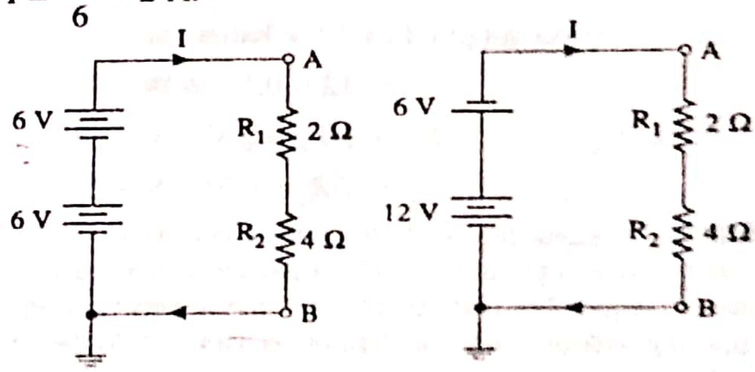


Fig. 2.6

Example. 2.1. *In Fig. 2.7, compute*

1. *total circuit resistance*
2. *circuit current*
3. *p.d. between A and E*
4. *potential of point E*
5. *power supplied by the battery.*

Solution. 1. $R = R_1 + R_2 + R_3 = 2 + 3 + 1 = 6\ \Omega$

2. $I = V/R = 12/6 = 2$ **A**

3. $R_{AE} = 2 + 3 = 5\ \Omega$

$V_{AE} = IR_{AE} = 2 \times 5$

$= \mathbf{10\ V}$

4. $V_E = 1 \times 2 = \mathbf{+2\ V}$

— above ground

5. $P = VI = 12 \times 2 = \mathbf{24\ W}$

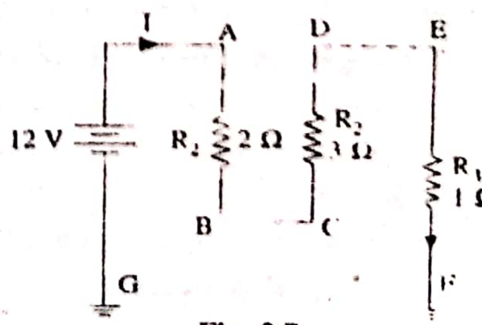


Fig. 2.7

or $60 = 20 + P_B$

$\therefore$ $P_B = 40$ mW

3. Now, $V = V_A + V_B$

$\therefore 12 = 4 + V_B \quad \therefore V_B = 8$ V

Alternatively, $P_B = V_B \times I$

or $40 = V_B \times 5$

$\therefore$ $V_B = 8$ V

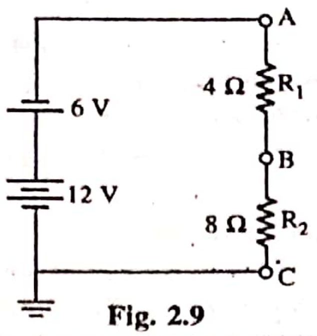


Fig. 2.9

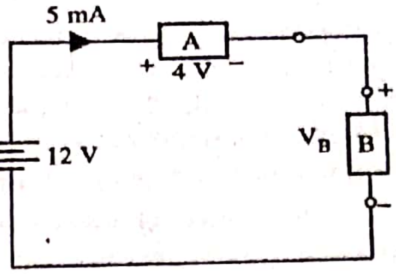


Fig. 2.10

2.7. Proportional Voltage Formula in a Series Circuit.

In a series circuit, voltage drop varies directly with resistance. Hence, a simple relation can be found to calculate individual voltage drops without first finding the circuit current.

In Fig. 2.11 (*a*) is shown a 24 V battery connected across a series combination of three resistors, R_1, R_2 and R_3. Fig. 2.11 (*b*) shows a more popular way of drawing the same circuit.

Now, total resistance $R = R_1 + R_2 + R_3 = 12$ K.

According to Proportional Voltage Formula, various drops are

$$V_1 = V \times \frac{R_1}{R} = 24 \times \frac{2}{12} = 4 \text{ V}$$

$$V_2 = V \times \frac{R_2}{R} = 24 \times \frac{4}{12} = 8 \text{ V}$$

$$V_3 = V \times \frac{R_3}{R} = 24 \times \frac{6}{12} = 12 \text{ V}$$

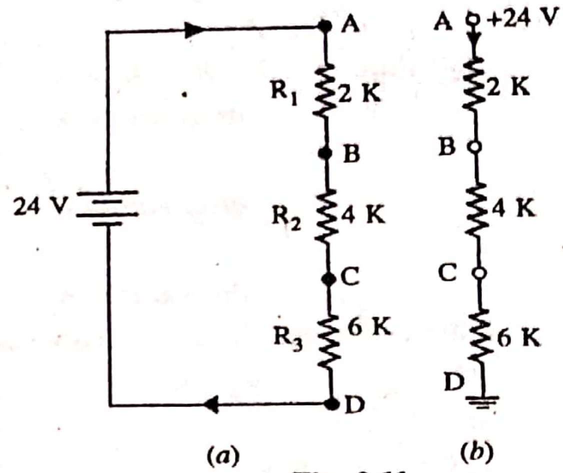


Fig. 2.11

2.8. Series Voltage Dividers

A simple series voltage divider consists of two or more resistors connected in series across a voltage source, say, a battery, as shown in Fig. 2.12. Current flowing through the resistors gives rise to voltage drops proportional to their resistances. These voltages can be used for loads needing voltages less than the battery voltage. In fact, such voltage-divider circuits are used when it is necessary to obtain different values of voltage from a single energy source. A typical example is when we use a single power supply V_{CC} to provide collector voltage and bias voltage for transistor bias circuit as shown in Fig. 2.13.

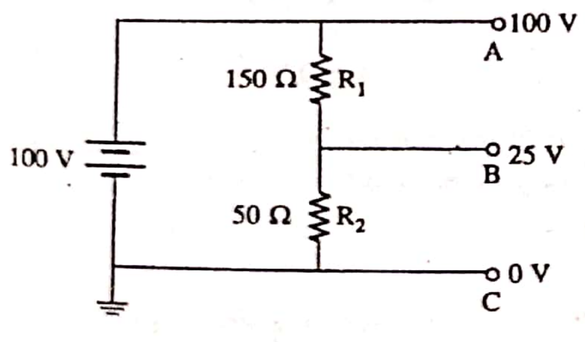


Fig. 2.12

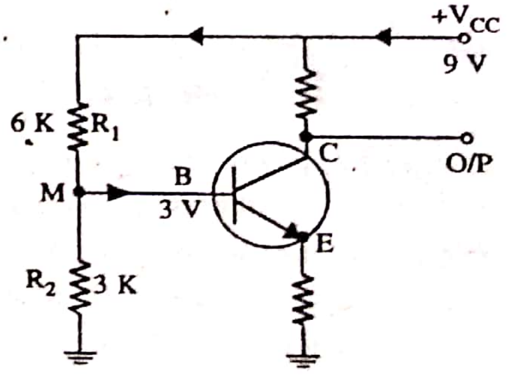
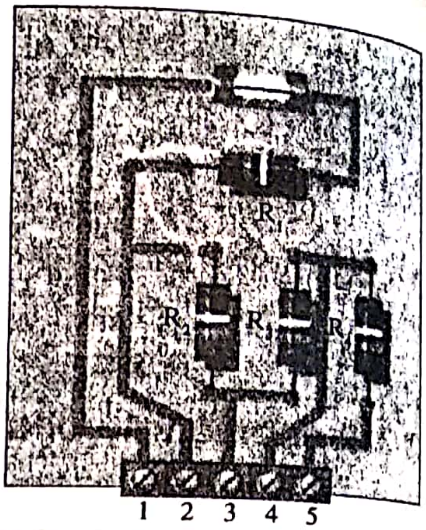


Fig. 2.13

In Fig. 2.12, two resistors of 150 Ω and 50 Ω are connected in series across a 100 V source. Voltage drop across $R_1 = 100 \times 150/200 = 75$ V. Similarly, drop across $R_2 = 100 \times 50/200 = 25$ V. As seen, point A is at 100 V whereas potential of point $B = 100 - 75 = 25$ V. Now, we have a choice of three voltages : 100 V, 75 V and 25 V. If we want 75 V, the pick off points are A and B. If we need 25 V, it is available between points B and C. Of course, 100 V is available between points A and C.



Voltage divider circuit board.

Now, take the transistor biasing circuit of Fig. 2.13. Here, collector voltage required is 9 V but base bias voltage required is 3 V. A simple series voltage divider network $R_1 - R_2$ is added to supply the two required voltages from a single source. As seen, total voltage across $R_1 - R_2$ is 9 V. Drop across $R_2 = 9 \times 3/9 = 3$ V. Hence, base B of the transistor is at + 3 V.

Example 2.5. *Find the values of different voltages that can be obtained from a 12 V battery with the help of voltage divider circuit of Fig. 2.14.*

Solution. $R = R_1 + R_2 + R_3 = 4 + 3 + 1 = 8\ \Omega$

drop across $R_1 = 12 \times 4/8 = 6$ V

$\therefore$ $V_B = 12 - 6 = 6$ V

drop across $R_2 = 12 \times 3/8 = 4.5$ V

$\therefore$ $V_C = V_B - 4.5 = 6 - 4.5 = 1.5$ V

drop across $R_3 = 12 \times 1/8 = 1.5$ V

Different load voltages available are :

(*i*) $V_{AB} = V_A - V_B =$ **6 V**

(*ii*) $V_{AC} = 12 - 1.5 =$ **10.5 V**

(*iii*) $V_{AD} = 12$ V

(*iv*) $V_{BC} = 6 - 1.5 =$ **4.5 V**

(*v*) $V_{CD} =$ **1.5 V**

Hence, there is a choice of five different voltages.

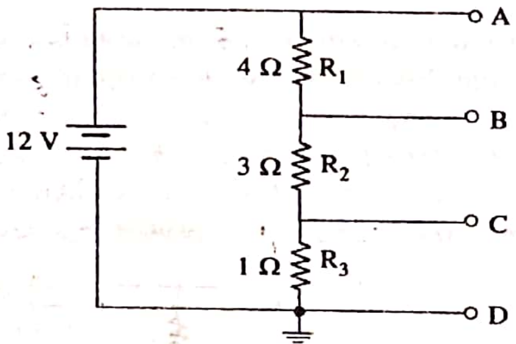


Fig. 2.14

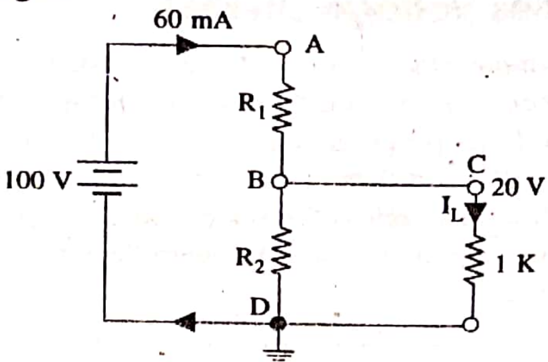


Fig. 2.15

Example 2.6. *In Fig. 2.15, find values of R_1 and R_2 if the voltage applied across load resistor of 1 K is to be 20 V. The maximum current which the battery can supply is 60 mA.*

Solution. Load current $I_L = 20/1\text{ K} = 20$ mA

Current through $R_2 = 60 - 20 = 40$ mA

Voltage across $R_2 = 20$ V — same as across the load

$R_2 = 20/40\text{ mA} =$ **500 Ω**

Drop through $R_1 = 100 - 20 = 80$ V

Current through $R_1 = 60$ mA

$R_1 = 80 / 60\text{ mA} =$ **1333.3 Ω**

2.9. 'Opens' in a Series Circuit

In a normal series circuit like the one shown in Fig. 2.16 (*a*), there is a current flow and voltage drops across different resistors are proportional to their resistances. If the circuit becomes open anywhere as shown in Fig. 2.16 (*b*), following two effects would be produced :

1. First, the 'open' will offer an infinite resistance. Hence, circuit current will become zero. Consequently, there would be no voltage drops across R_1 and R_2.

2. Second, *whole of the applied voltage would be felt across the 'open'*. The reason for this is that resistances R_1 and R_2 become negligible as compared to the infinite resistance of the 'open' which has practically whole of the applied voltage dropped across it (as per Proportional Voltage Formula).

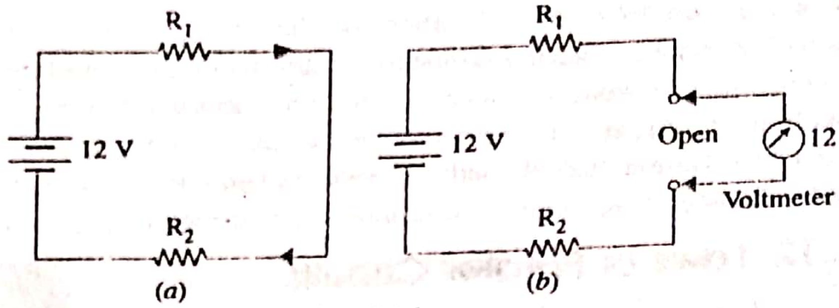
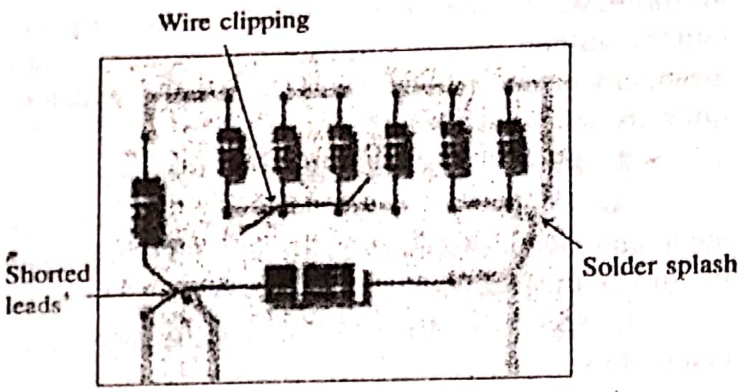


Fig. 2.16

2.10. 'Shorts' in a Series Circuit

A 'short' has practically zero resistance. Hence, it causes the problem of excessive current which, in turn, causes power to increase many times and circuit components to burn out.



Examples of shorts on a PC board.

In Fig. 2.17 (*a*) is presented the normal series circuit where $V = 12$ V, $R = 6\ \Omega$, $I = 12/6 = 2$ A, $P = I^2R = 2^2 \times 6 = 24$ W.

In Fig. 2.17 (*b*), the 3 Ω resistance has been shorted out by a resistanceless copper wire. Now, total circuit resistance is $R = 1 + 2 + 0 = 3\ \Omega$. Hence, $I = 12/3 = 4$ A and power increases to $4^2 \times 3 = 48$ W.

Fig. 2.17 (*c*) shows the situation where both 2 Ω and 3 Ω resistances have been shorted out of the circuit. In this case, $R = 1\ \Omega$. $I = 12/1 = 12$ A, $P = 12^2 \times 1 = 144$ W.

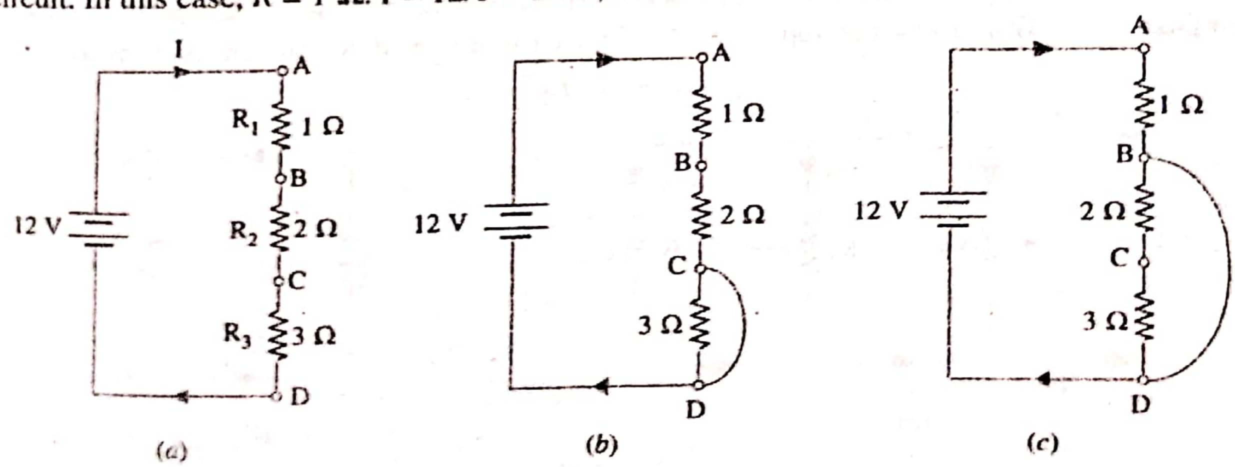


Fig. 2.17

Because of this excessive current (6 times the normal value) wires and other circuit components can become hot enough to ignite and burn. Hence, there should be a fuse which should open if there is too much current in the circuit.