1.3.1 Network Terminologies

While discussing network theorems, laws, and electrical and electronic circuits, one often comes across the following terms.

i) **Circuit:** A conducting path through which an electric current either flows or is intended to flow is called a circuit.

ii) **Electric network:** A combination of various circuit elements, connected in any manner, is called an electric network.

iii) **Linear circuit:** The circuit whose parameters are constant, i.e., they do not change with application of voltage or current is called a linear circuit.

iv) **Non linear circuit:** The circuit whose parameters change with the application of voltage or current is called a non-linear circuit.

v) **Circuit parameters**: The various elements of an electric circuit are called its parameters, like resistance, inductance, and capacitance.

vi) **Bilateral circuit:** A bilateral circuit is one whose properties or characteristics are the same in either direction, e.g. transmission line.

vii) **Unilateral circuit:** A unilateral circuit is one whose properties or characteristics change with the direction of its operation, e.g. diode rectifier.

viii) **Active network:** An active network is one which containts one or more sources of EMF.

ix) **Passive network:** A passive network is one which does not contain any source of EMF.

x) **Node:** A node is a junction in a circuit where two or more circuit elements are connected together.

xi) **Branch:** The part of a network which lies between two junctions is called a branch.

xii) **Loop:** A loop is a closed path in a network formed by a number of connected branches.

xiii) **Mesh:** Any path which contains no other paths within it is called a mesh. Thus, a loop contains meshes but a mesh does not contain a loop.

xiv) **Lumped circuit:** The circuits in which circuit elements can be represented mutually independent and not interconnected.

For convenience, the nodes are labelled by letters.
For example, in Fig. 1.2,

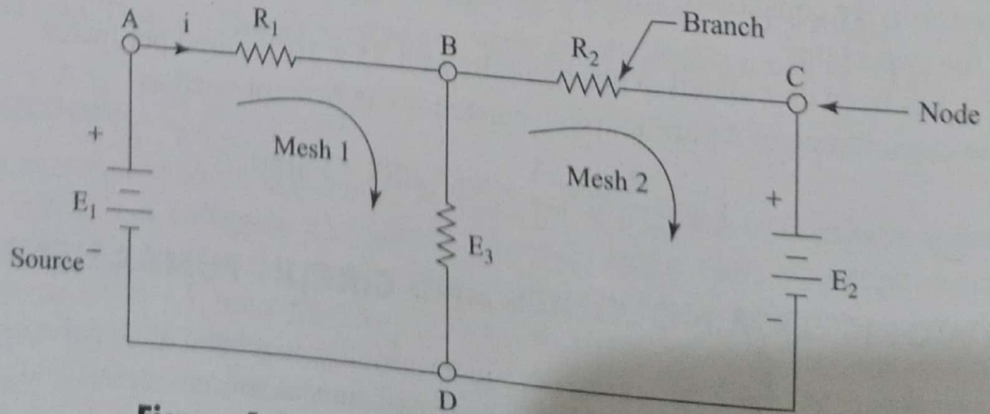


Figure 1.2 Different parts of an electric circuit

No. of nodes, N = 4 (i.e., A, B, C, D)
No. of branches, B = 5 (i.e., AB, BC, BD, CD, AD)
Independent meshes, M = B – N + 1

$$= 5 - 4 + 1 = 2 \text{ (i.e., ABDA, BCDB)}$$

No. of loops = 3 (i.e., ABDA, BCDB and ABCDA). It is seen that a loop ABCDA encloses two meshes, i.e., mesh 1 and mesh 2.

1.3.2 Voltage and Current Sources

A source is a device which converts mechanical, thermal, chemical or some other form of energy into electrical energy. There are two types of sources: voltage sources and current sources.

Voltage source

Voltage sources are further categorized as ideal voltage source and practical voltage source. Examples of voltage sources are batteries, dynamos, alternators, etc. Ideal voltage source is defined as the energy source which gives constant voltage across its terminals irrespective of current drawn through its terminals. The symbol of ideal voltage source is shown in Fig. 1.3 (a). In an ideal voltage source the terminal voltage is independent of the value of the load resistance, R_L connected. Whatever is the voltage of the source, the same voltage is available across the load terminals of R_L, i.e., $V_L = V_S$ under loading condition as shown in Fig. 1.3 (b). There is no drop of voltage in the source supplying current to the load. The internal resistance of the source is therefore, zero.

In a practical voltage source, voltage across the load will be less than the source voltage due to voltage drop in the resistance of the source itself when a load is connected as shown in Fig. 1.3 (c).

Current source

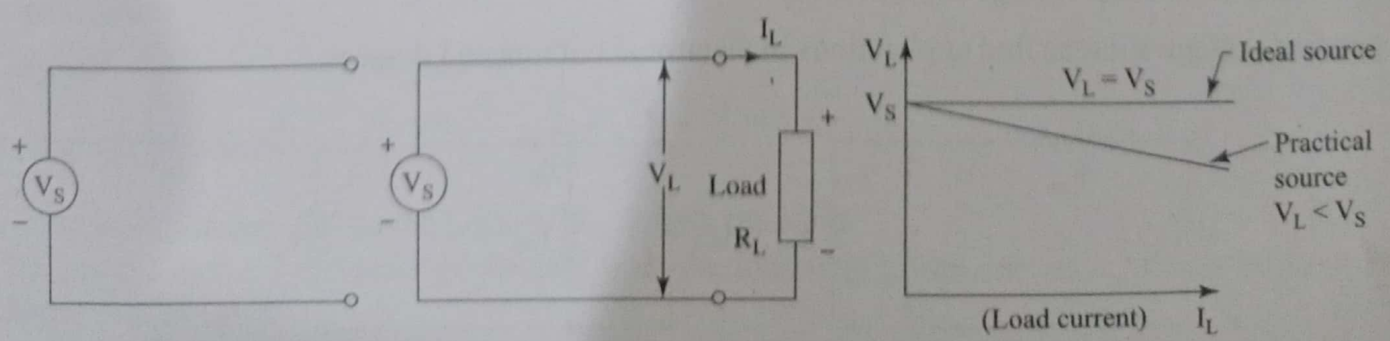
In certain applications a constant current flow through the circuit is required. When the load resistance is connected between the output terminals, a constant current I_L will flow through the load.

The examples of current sources are photo electric cells, collector current in transistors, etc. The symbol of current source is shown in Fig. 1.4.

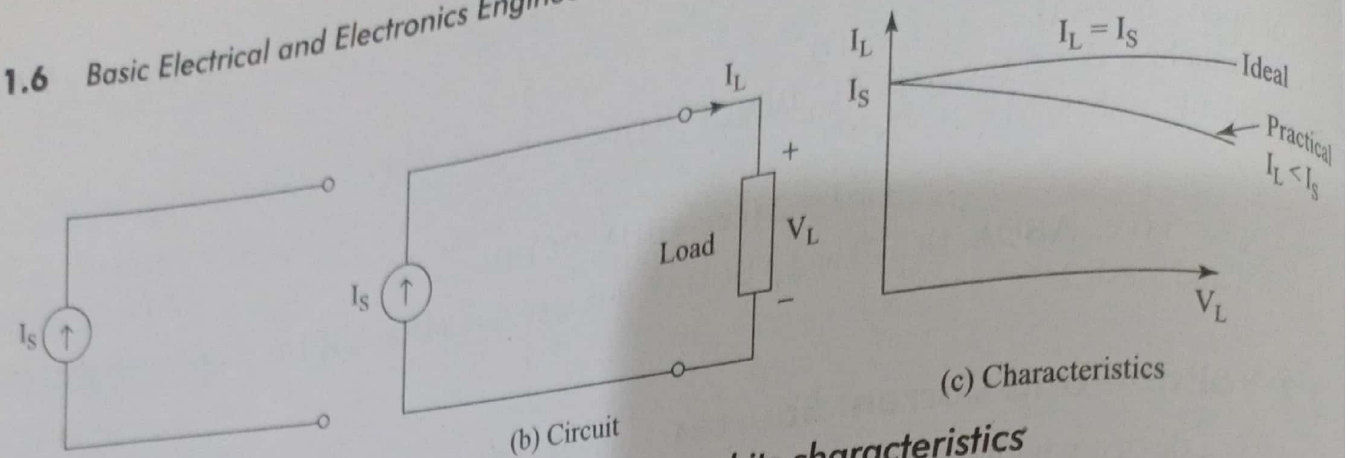
Practical voltage and current sources

A practical voltage source like a battery has the drooping load characteristics due to some internal resistance. A voltage source has small internal resistance in series while a current source has some high internal *resistance* in parallel.

For ideal voltage source $R_{se} = 0$
For ideal current source $R_{sh} = \infty$



(a) Symbol (b) Circuit (c) Load characteristics



(a) Symbol (b) Circuit (c) Characteristics

Figure 1.4 *Current source and its characteristics*

A practical voltage source is shown as an ideal voltage source in series with a resistance. This resistance is called the internal resistance of the source as has been shown in Fig. 1.5 (a). A practical current source is shown as an ideal current source in parallel with its internal resistance as shown in Fig. 1.5 (b).

From Fig. 1.5 (a), we can write

V_L (open circuit), i.e., V_L (OC) = V_S that is, when the load R_L is removed, the circuit becomes an open circuit and the voltage across the source becomes the same as the voltage across the load terminals.

When the load is short circuited, the short-circuit current, I_L (SC) = V_S/R_{se}

In the same way, from Fig. 1.5 (b), we can write

$$V_L(OC) = I_{Sh}\, R_{Sh}$$

and

$$I_L\,(SC) = I_S$$

In source transformation as discussed in Section 1.3.3, we shall use the equivalence of open-circuit voltage and short-circuit current.

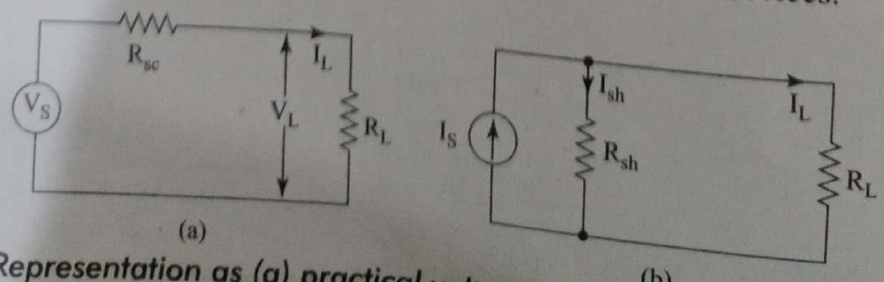
Independent and dependent sources

The magnitude of an independent source does not depend upon the current in the circuit or voltage across any other element in the circuit. The magnitude of a dependent source gets changed due to some other current or voltage in the circuit. An independent source is represented by a circle while a dependent source is represented by a diamond-shaped symbol. Dependent voltage sources are also called controlled sources.

There are four kinds of dependent sources:

- voltage-controlled voltage source (vcvs)
- current-controlled current source (cccs)
- voltage-controlled current source (vccs)
- current-controlled voltage source (ccvs)

Dependent voltage sources find applications in electronic circuits and devices.



(a) (b)

Figure 1.5 *Representation as (a) practical voltage source (b)*

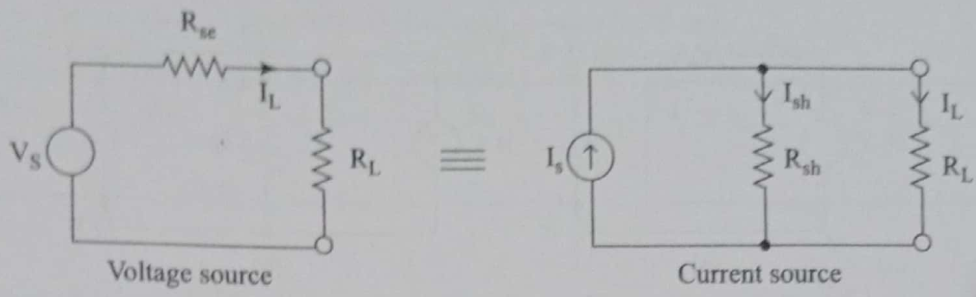


Figure 1.6 *Equivalent current source*

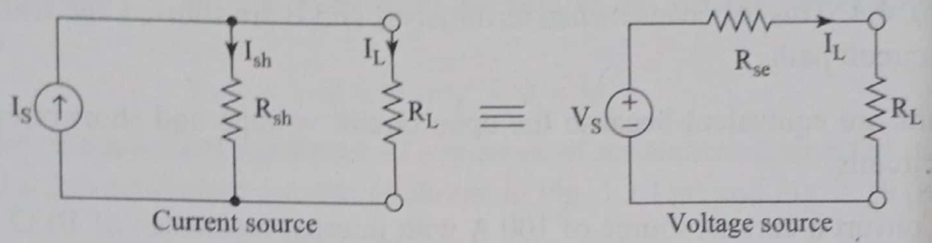


Figure 1.7 *Equivalent voltage source*

1.3.3 Source Transformation

A voltage source can be represented as a current source. Similarly a current source can be represented as a voltage source. This often helps the solutions of circuit problems.

Voltage source into current source and current source into voltage source

A voltage source is equivalent to a current source and vice-versa if they produce equal values of I_L and V_L when connected to the load R_L. They should also provide the same open-circuit voltage and short-circuit current.

If voltage source is converted into current source as in Fig. 1.6, we consider the short circuit current equivalence then $I_s = \dfrac{V_s}{R_{se}}$. [Short circuit current in the two equivalent circuits are respectively V_S/R_{Se} and I_S]

If current source converted into voltage source, as in Fig. 1.7, we consider the open-circuit voltage equivalence, then, $V_s = I_s R_{sh}$

A few examples will further clarify this concept.

Example 1.1 Convert a voltage source of 20 volts with internal resistance of 5 Ω into an equivalent current source.

Solution: Given $V_s = 20$ V, $R_{se} = 5\ \Omega$

The short circuit current, $$I_s = \frac{V_s}{R_{se}} = \frac{20}{5} = 4\text{ A}$$

The internal resistance will be the same as R_{se} in both the cases.

The condition for equivalence is checked from the following conditions viz v_{oc} should be same and I_{sc} should also be same.

In Fig. 1.8 (a), $V_{oc} = 20$ V.
In Fig. 1.8 (b), $V_{oc} = 4\text{ A} \times 5\ \Omega = 20$ V.

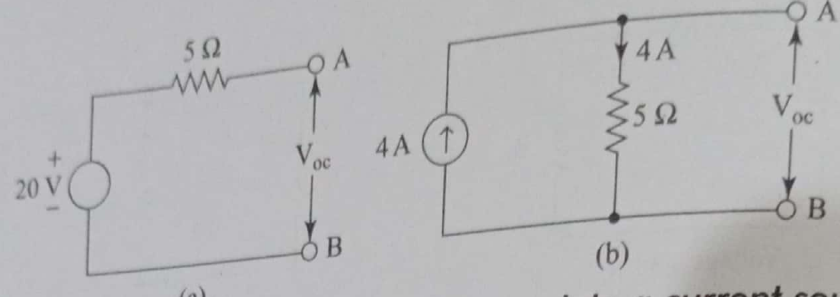


Figure 1.8 Conversion of a voltage source into a current source

I_{sc} in Fig. 1.8 (a), 4 A. This is because $I_{sc} = 20/5 = 4$ A

I_{sc} in Fig. 1.8 (b), 4 A. This is because when terminals A and B are shorted, the whole of 4 A will flo through the short circuit path.

This two circuits are equivalent because the open circuit voltage and short circuit current are th same in both the circuits.

Example 1.2 Convert a current source of 100 A with internal resistance of 10 Ω into an equivalen voltage source.

Solution:

Here $$I = 100 \text{ A}, R_{sh} = 10\ \Omega$$

For an equivalent voltage source

$$V = I \times R_{sh} = 100 \times 10 = 1000 \text{ V}$$

$$R_{sh} = R_{se} = 10\ \Omega \text{ in series}$$

The open circuit voltage and short circuit current are the same in the two equivalent circuits as shown in Fig. 1.9 (a) and 1.9 (b), respectively.

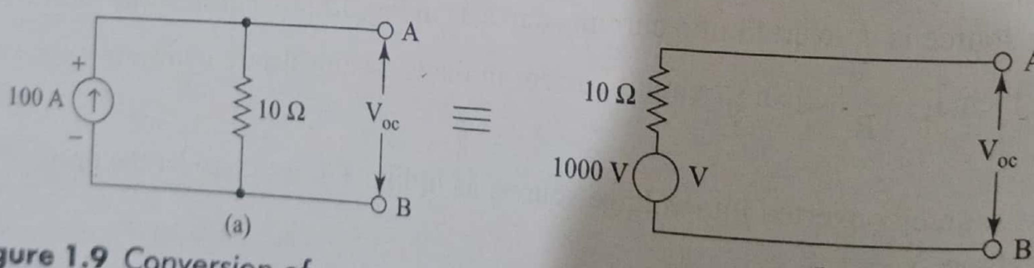


Figure 1.9 Conversion of a current source into an equivalent voltage source

1.3.4 Series–Parallel Circuits

Resistances, capacitances, and inductances are often connected in series, in parallel, or a combination of series and parallel. We need to calculate the division of voltage and currents in such circuits

Series circuits

When a number of resistances are connected end to end across a source of supply, there will be only one path for the current to flow as shown in Fig. 1.10. The circuit is called a series circuit.

The voltage drops across the resistances are V_1, V_2, V_3, and V_4, respectively. Since the same current is flowing through all the resistances, we can write

$$V_1 = IR_1,\ V_2 = IR_2,\ V_3 = IR_3, \text{ and } V_4 = IR$$

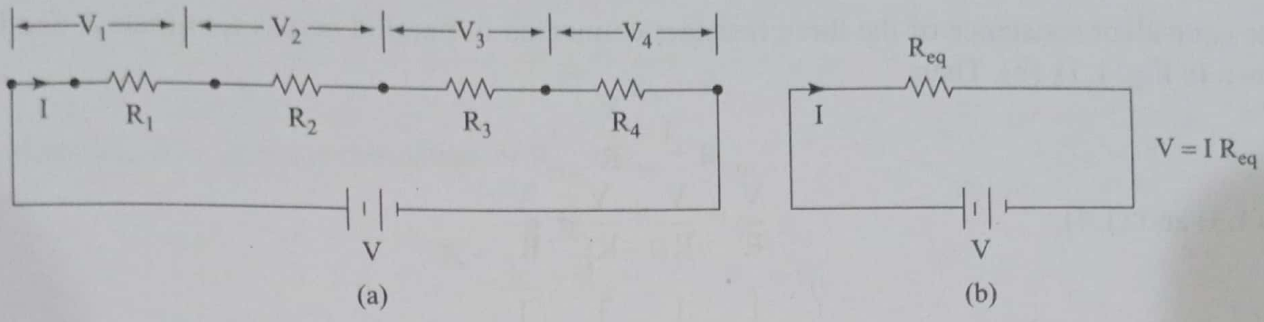


Figure 1.10 *DC series circuit*

Again, the total voltage, V applied is equal to the sum of the voltage drops across the resistances, Thus we can write

$$V = V_1 + V_2 + V_3 + V_4$$

To find the value of equivalent resistance of a number of resistances connected in series, we equate the voltage, V of the two equivalent circuits as shown in Fig. 1.10 (a) and Fig. 1.10 (b) as

or, $$I R_{eq} = IR_1 + IR_2 + IR_3 + IR_4$$

or, $$R_{eq} = R_1 + R_2 + R_3 + R_4$$

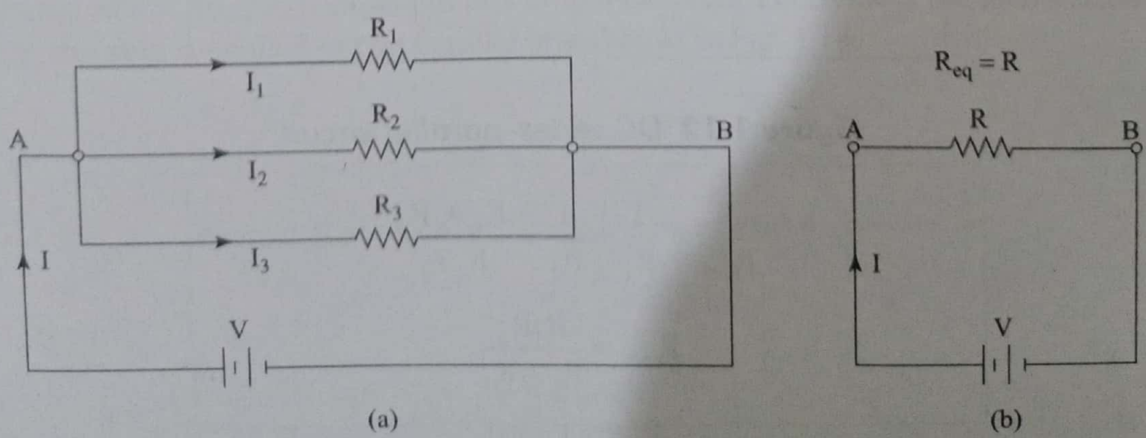
Assuming R_{eq} as equal to R, $R = R_1 + R_2 + R_3 + R_4$. (1.2)

Thus, when resistances are connected in series, the total equivalent resistance appearing across the supply can be taken as equal to the sum of the individual resistances.

Parallel circuits

When a number of resistors are connected in such a way that both the ends of individual resistors are connected together and two terminals are brought out for connection to other parts of a circuit, then the resistors are called connected in parallel as shown in Fig. 1.11. Voltage V is connected across the three resistors R_1, R_2, R_3 connected in parallel. The total current drawn from the battery is I. This current gets divided into I_1, I_2, I_3 such that $I = I_1 + I_2 + I_3$. As voltage V is appearing across each of these three resistors, applying Ohm's law we write

$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \tag{1.3}$$



Let the equivalent resistance of the three resistors connected in parallel across terminals A and B as shown in Fig. 1.11 (b). Then,

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

From (1.3) and (1.4),

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

or,

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

In general, if there are n resistors connected in parallel, the equivalent resistance R is expressed as

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

Series–parallel circuits

Figure 1.12 shows a number of resistors connected in series–parallel combinations. Here, two parallel branches and one resistance, all connected in series have been shown. To determine the equivalent resistance across the end terminals of the entire circuit, we first calculate the equivalent resistance of parallel branches and then put them in series along with any individual resistance already connected in series.

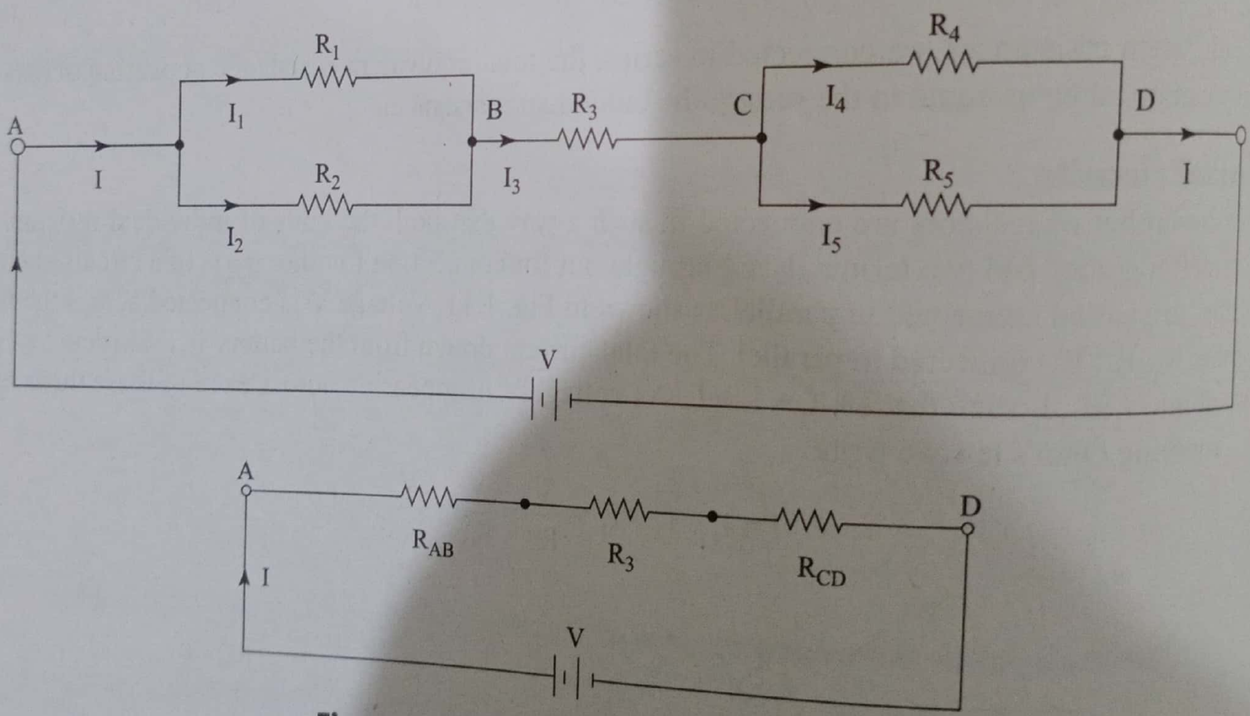


Figure 1.12 *DC series–parallel circuit*

$$\frac{1}{R_{AB}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2 + R_1}{R_1 R_2}$$

or,

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

and

$$\frac{1}{R_{CD}} = \frac{1}{R_4} + \frac{1}{R_5}$$

$$R_{CD} = \frac{R_4 R_5}{R_4 + R_5}$$

Total resistance, R = Series combination of $R_{AB} + R_{BC} + R_{CD}$

$$R = \frac{R_1 R_2}{R_1 + R_2} + R_3 + \frac{R_4 R_5}{R_4 + R_5}$$

In any electrical circuit we will find a number of such resistances connected in series–parallel combinations.

1.3.5 Voltage and Current Divider Rules

Voltage divider rule

For easy calculation of voltage drop across resistors in a series circuit, a voltage divider rule is used which is illustrated in Fig. 1.13.

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

$$V_1 = I R_1 = \frac{V}{R_1 + R_2 + R_3} \times R_1 = \frac{V}{R_T} \times R_1$$

where $R_T = R(\text{Total}) = R_1 + R_2 + R_3$

Similarly,

$$V_2 = I R_2 = \frac{V}{R_T} \times R_2$$

and

$$V_3 = I R_3 = \frac{V}{R_T} \times R_3$$

Thus, the voltage divider rule states that voltage drop across any resistor in a series circuit is proportional to the ratio of its resistance to the total resistance of the series circuit.

Current divider rule

Current divider rule is used in parallel circuits to find the branch currents if the total current is known. To illustrate, this rule is applied to two parallel branches as in Fig. 1.14.

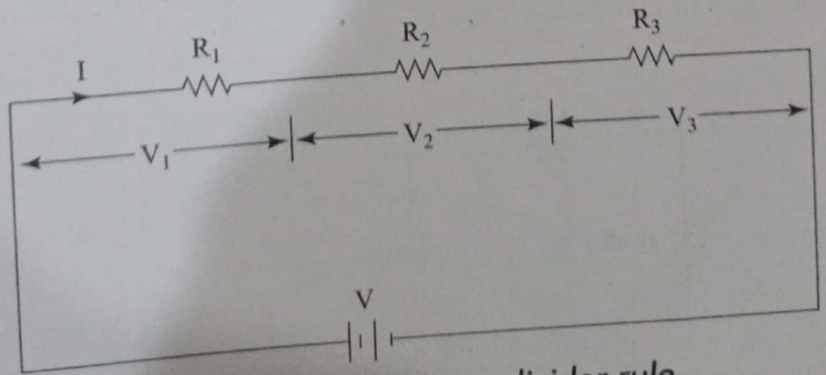


Figure 1.13 *Voltage divider rule*

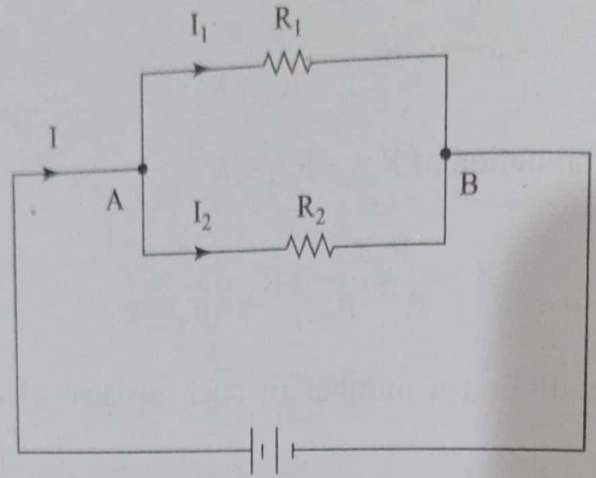


Figure 1.14 *Current divider rule*

$$V_{AB} = I_1R_1 = I_2R_2$$

and

$$I = I_1 + I_2$$

$$I_1R_1 = (I - I_1)R_2$$

or,

$$I_1(R_1 + R_2) = IR_2$$

or,

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

And,

$$I_2 = I - I_1 = I - I\frac{R_2}{R_1 + R_2}$$

$$= I\left[1 - \frac{R_2}{R_1 + R_2}\right]$$

or,

$$I_2 = I\frac{R_1}{R_1 + R_2}$$

Thus, in a parallel circuit of two resistances, current through one branch is equal to line current mul plied by the ratio of resistance of the other branch divided by the total resistance as have been shown (1.6) and (1.7).

Example 1.3 Calculate the current flowing through the various resistances in the circuit shown Fig. 1.15.

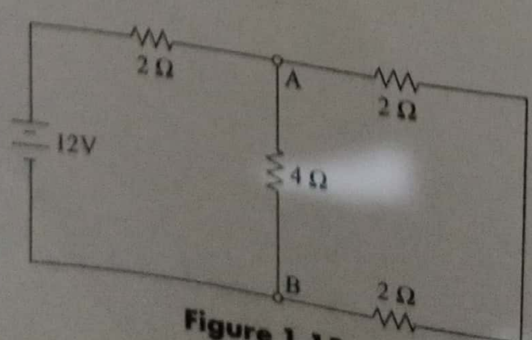


Figure 1.15