Ohm's law - simple electrical circuits and problems

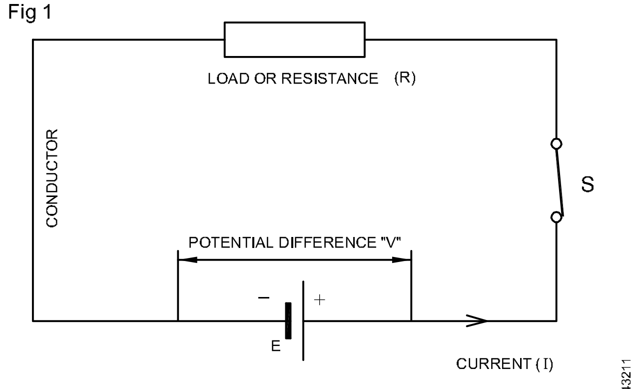
Objectives: At the end of this lesson you shall be able to
- **describe the essential factors in an electrical circuit**
- **state the relation between circuit factors through Ohm's law**
- **apply Ohm's law in an electric circuit.**
- **define electrical power and energy and calculate related problems**

Simple electric circuit

In the simple electric circuit shown in Fig 1, the current completes its path from the positive terminal of the battery via the switch and the load back to the negative terminal of the battery.

The circuit shown in Fig 1 is a closed circuit. In order to make a circuit to function normally the following three factors are essential.

Fig 1



SIMPLE ELECTRICAL CIRCUIT

- Electromotive force (EMF) to drive the electrons through the circuit.
- Current (I), the flow of electrons.
- Resistance (R) - the opposition to limit the flow of electrons.

Ohm's law

In 1826 George Simon Ohm discoverd that for metallic conductor, there is a substantially constant ratio of the potential difference between the ends of the conductor

Ohm's law gives the relation between the voltage, current and resistance of a circuit.

Ohm's law states that the ratio of the voltage (V) across any two points of a circuit to the current (I) flowing through is constant provided physical conditions, namely temperature etc. remain constant. This constant is denoted as resistance (R) of the circuit.

(or)

In simple,

Ohm's law states that in any electrical closed circuit, the current (I) is directly proportional to the voltage (V), and it is inversely proportional to the resistance 'R' at constant temperature.

(ie) $I \alpha V$ (When 'R' is kept constant)

$I \alpha R$ (When 'V' is kept constant)

$I \alpha V/R$ (Relation between I,V and R)

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

It means I = V/R

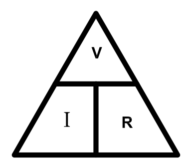
V = Voltage applied to the circuit in 'Volt'

I = Current flowing through the circuit in 'Amp'

R = Resistance of the circuit in Ohm (Ω)

The above relationship can be referred to in a **triangle** as shown in Fig 2. In this triangle whatever the value you want to find out, place the thumb on it then the position of the other factors will give you the required value.

Fig 2



Ohm's Law Triangle

For example for finding 'V' close the value 'V' then readable values are IR, so V = IR.

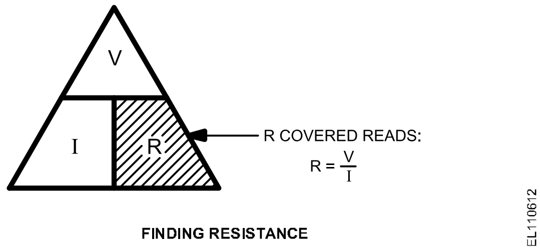
Again for finding 'R', close the value R, then readable values are V/I so R = V/I, like that $= \frac{V}{R}$.

Written as a mathetical expression, Ohm's Law is

$$\text{Resistance} = \frac{\text{Voltage (V)}}{\text{Current (I)}} \text{ (Refer Fig 3)}$$

$$\text{(or) } R = \frac{V}{I} \text{ (Refer Fig 3)}$$

Fig 3

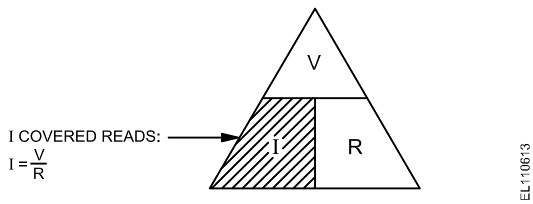


Of course, the above equation can be rearranged as:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

$$\text{(or) } I = \frac{V}{R} \text{ (Refer Fig 4)}$$

Fig 4

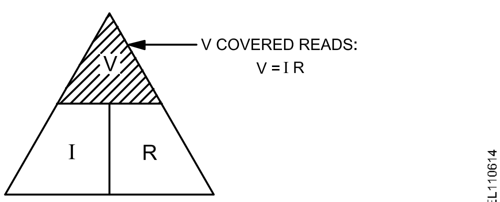


In the same way, 'V' can be found by covering 'V'

Voltage (V) = Current (I) x Resistance (R)

or V - IR (Refer Fig 5)

Fig 5

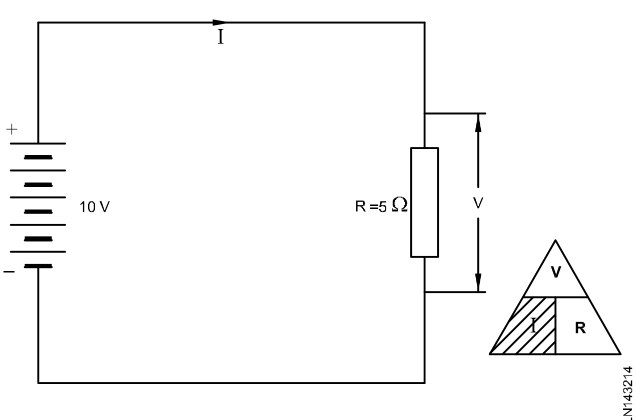


Application of Ohm's law in circuits

Example 1

Let us take a circuit shown in Fig 6 having a source of 10V battery and a load of 5 Ohms resistance. Now we can find out the current through the conductor.

Fig 6



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

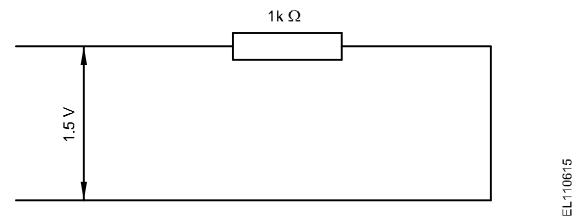
$$I = \frac{V}{R}$$

$$I = \frac{10}{5} = 2 \text{ amp}$$

Example 2

How much current (I) flows in the circuit shown in Fig 7

Fig 7



Given:

Voltage (V) = 1.5 Volts

Resistance (R) = 1 kOhm

= 1000 Ohms

Find : Current (I)

Known

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

Solution:

$$I = \frac{1.5 \text{ V}}{1000 \text{ Ohms}} = 0.0015 \text{ amp}$$

Answer:

The current in the circuit is 0.0015 A

or

the current in the circuit is 1.5 milliampere (mA)

(1000 milliamps = 1 ampere)

Problem

Find the value of voltage across a 10 Ohms resistor in the circuit shown in Fig 8. When the current of 2 Amps flows through the 10 Ohm resistor

Solution

Voltage across 10 Ohm

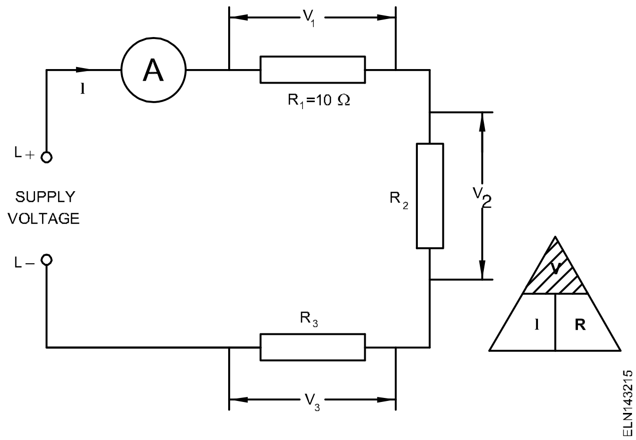
V= I x R

= 2 x 10

= 20 Volt

Similarly if the value of the other resistance is known we can find the voltage drop across them.

Fig 8



Extreme circuit conditions

Two important extreme conditions can occur in a circuit.

Open circuit

In an open circuit, there is an infinitely high resistance in the circuit. This condition can happen in a circuit when the switch is open. Therefore, no current of flow.

For example, a generator is said to be in an open circuit when the switch is open and running without supplying current to the circuit. A wall socket, too, is an open circuit if the control switch of the wall socket is ‘OFF’or 'ON' position provided there is no appliance plugged to the wall socket.

Short circuit

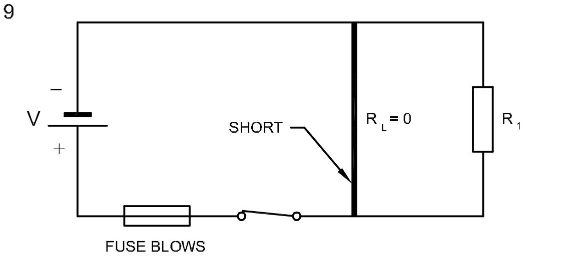
The other important extreme condition is the short circuit. A short circuit will occur, for example, when the two terminals of a cell are joined (Fig 9). A short circuit may also occur if the insulation between the two cores of a cable is defective.

The resulting negligible resistance will cause large currents which can become a hazard. A fuse, if provided in the circuit as shown in Fig 9, could then blow and automatically open the circuit.

Practical application

The knowledge gained by this exercise can be applied to calculate the current drawn by a particular load resistance when the supply voltage is known. This will enable the technician to select a proper size of cable for the circuit.

Fig 9



Electrical Power (P) & Energy (E)

The product of voltage (V) and current (I) is called electrical power. Electrical power (P) = Voltage x Current P=V x I

The unit of Electrical power is 'Watt' It is denoted by the letter 'P' It is measured by Watt meter. The following formulae can also be derived from formula of power (P) as

(i) $P = V \times I$

$= IR \times I$

$P = I^2 R$

(ii) $P = V \times I$

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

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

Electrical Energy (E)

The product of power (P) and time (t) is called as electrical energy (E)

Electrical Energy (E) = Power x time

$E = P \times t$

$= (V \times I) \times t$

$E = V \times I \times t$

The unit of electrical energy is "Watt hour" (Wh)

The commercial unit of Electrical energy is "Kilo watt hour" (KWH) or unit

B.O.T (Board of Trade) unit / KWH/Unit

One B.O.T (Board of Trade) unit is defined as that one thousand watt lamp is used for one hour time, it consumes energy of one kilowatt hour (1kWH). It is also called as **"unit"**

Energy = 1000W x 1Hr = 1000WH (or) 1kWH

Example - 1

How much electrical energy is consumed in an electric iron rated as 750W/250V used for 90 Minutes

Given:

Power (P) = 750W

Voltage (V) = 250V

Time = 90min (or) 1.5Hr

Find:

Electrical Energy (E) = ?

Solution:

Electrical Energy (E) = P x t

=750 w x 1.5Hr

= 1125 WH (or)

E = 1.125 kWH

Example 2

Calculate the power of a lamp, which takes a current of 0.42 Amp at 240 V supply

Given:

Voltage (V) = 240 V

Current (I) = 0.5 A

Find:

Power(P) = ?

Solution:

P = V X I

= 240 x 0.42

= 100.8W

Hence, Power (P) = 100 W (approx)

Example 3:

Calculate the hot resistance (R) of the 200W/250V rated bulb?

Given:

Power (P) = 200 W

Voltage (V) = 250 V

Find:

Resistance (R) = ?

Solution:

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

$$R = \frac{V^2}{P} = \frac{250 \ X \ 250}{200}$$

(R) Resistance = 312.5 Ohm (Ω)

Example 4

In a house, the following electrical loads are daily used:-

(i) 5 Nos of 40W Tube Lights used for 5 hours/day

(ii) 4 Nos of 80W fans used for 8 hours/day

(iii) 1 No of 120W T.V. receiver used for 5 hours/day

(iv) 4 No of 60W lamps used for 4 hours/day

Calculate the total energy consumed in unit's per day and also the cost of electric bill for the month of January If the cost of energy is 1.50/unit

Given

Load details per day

Electric Device		Power		Numbers		Time in hours
(i) Tube light	-	40W	-	5	-	5 hr/day
(ii) Fans	-	80W	-	4	-	8 hr/day
(iii) T.V.	-	120W	-	1	-	6 hr/day
(iv) Lamps	-	60W	-	4	-	4 hr/day

cost of energy - Rs.1.50/unit

Find:

(i) Energy consumption in unit per day = ?

(ii) Cost of energy for the month of January = ?

Solution

Energy consumption/day

1. Tube light = 40W x 5 x 5 hr /day

$$= \frac{1000 \text{ wh}}{1000} = 1\text{Kwh/day}$$

2. Fans = 80W x 4x8 hr/day

$$= \frac{2560}{1000} = 2.56\text{Kwh/day}$$

3. T.V. = 120W x 1x6 hr/day

$$= \frac{720 \text{ wh}}{1000} = 0.72\text{Kwh/day}$$

4.Lamp = 60W x 4x4 hr/day

$$= \frac{960}{1000} = \text{Kwh} = \frac{0.96\text{kwh/day}}{5.24\text{kwh/day}}$$

(i) Total energy consumption in unit per day = 5.24 unit

(ii) Total energy consumption for the month of January (i.e 31 days) = 5.24 x 31 = 162.44 units

Cost of energy = Rs. 1.50/unit

Total electric bill for the month of January = 162.44 x 1.50 = Rs.243.66

Electricity Bill for the month = Rs. 244/-

Assignment :

> **Note : The instructor may ask the trainees to prepare electric bill for the current month for his house (or) any building.**

Work, Power and Energy

Work is said to be done, when a force (F) displaces a body from one distance (s) to another (or)

Work done = Force x distance moved

w.d = F x S

It is generally denoted as "W"

The unit of work done is

(i) In Foot Pound Second (F.P.S) System is "Foot Pound (lb.ft)"

(ii) In Centimetre Gram Second (C.G.S) System "Gram Centimetre (gm.cm)"

or

1 gm.cm = 1 dyne

1 dyne = 10^7 ergs

The smallest unit of work done is **"Erg"**

(iii) In Metre - Kilogram - Second (M.K.S.) System is "Kilogram Metre (Kg-M)'

1 Kilogram = 9.81Newton

(iv) In system of international unit (S.I. Unit) is 'Joule'

1 Joule = 1 Newton Metre (Nw-M)

Power (P)

The rate of doing work is called as Power (P)

Power (P) = work done / time taken

$$P = \frac{F \text{ x } S}{t}$$

It's unit is Lb.ft/sec in FPS system

gm-cm/sec is in C.G.S. System

(or)

Dyne/sec

(or)

Kg-M/sec in M.K.S System (or) NW - M/ sec

(1kg = 9.81 Newton)

Joule/sec in (S.I)

1 Joule/Sec = 1 watt

Electrical Power = VI Watt

The unit of Mechanical power is "Horse Power" (H.P)

Horse Power (HP) further classified into two:

They are:-

Indicated Horse Power - (IHP)

Brake Horse Power - (BHP)

Indicated Horse Power (IHP)

The power developed inside the engine (or) pump (or) motor is called Indicated Horse Power (IHP)

Brake Horse Power (BHP)

The useful Horse Power which is available at the shaft of the engine/motor/pump is called Brake Horse Power (BHP)

So, IHP is always greater than

BHP due to friction losses

IHP > BHP

The relation between Mechanical and Electrical Power

(ie) 1 HP (British) = 746 Watt

1 HP (Metric) = 735.5 Watt

One HP (Metric)

The amount of Mechanical Power required to move/displace a body/substance by force of 75 Kg to one metre distance in one second is called as one HP (metric)

HP (Metric) = 75kg - M/Sec

One HP (British)

The amount of Mechanical power required to move/displace a body/substance of force 550lb to one foot (ft) distance in one second is called as one HP (British)

1 HP (British) = 550 lb.ft/sec

Energy

The capacity for doing work is called as electrical Energy

(or)

The product of power and time is known as Electrical energy

(ie) Energy = Power x time

$$t = \frac{\text{workdone}}{\text{time}} \text{xtime}$$

Electric - energy = Power x time

= VI x t

S.I unit of energy is "Joule"

(ie) Energy = (Joule/sec) x sec

$$= \frac{\text{Joulle}}{\text{Sec}} \times \text{Sec} = \text{joule}$$

(ie) The S.I of unit of work done and energy is same (Joule)

The energy can be divided into two main categories (ie)

(i) Potential Energy (eg. Loaded gun, energy (stored in spring etc)

(ii) Kinetic Energy (eg. Moving of car, raining etc).

Kirchhoff's law and its applications

Objectives: At the end of this lesson you shall be able to
- **state Kirchhoff's first law**
- **apply Kirchhoff's first law to find the circuit current**
- **state Kirchhoff's second law and apply the same to find the voltage drop in branches**
- **solve problems by applying Kirchhoff's laws.**

Kirchoff's laws are used in determinig the equivalent resistance of a complex network and the current flowing in the various conductors.

Kirchhoff's laws

Kirchhoff's first law: At each junction of currents, the sum of the incoming currents is equal to the sum of the outgoing currents. (Figs 1 & 2) (or) The algebric sum of all branch currents meeting at a point/node is zero

Fig 1

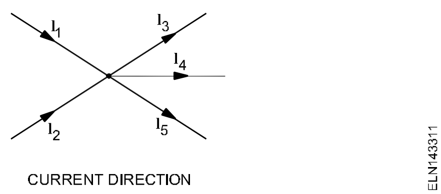
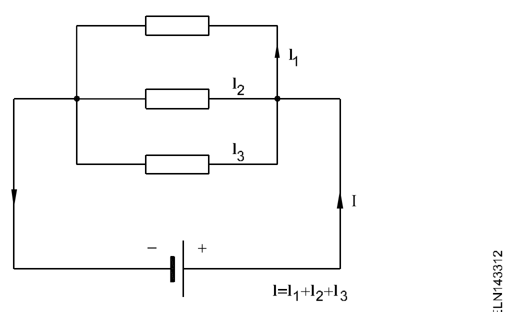


Fig 2



If all inflowing currents have positive signs and all outflowing currents have negative signs, then we can state that

$$I_1 + I_2 = I_3 + I_4 + I_5$$

$$+ I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

In the above example the sum of all the currents flowing at the junction (node) is equal to zero.

$$\Sigma I = 0$$

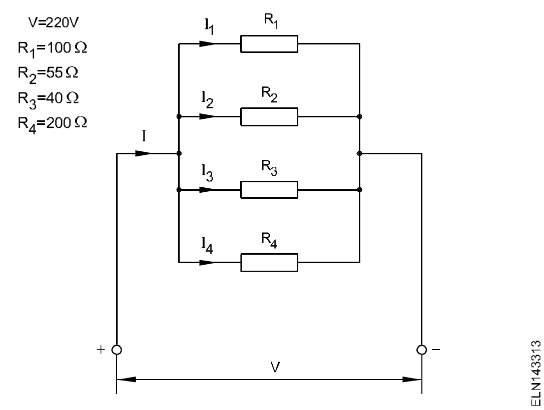
$$I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ldots\ldots\ldots$$

Example: Apply Kirchhoff's First Law to find the current shown in circuit Fig 3.

Find current

$$I, I_1, I_2, I_3, I_4$$

Fig 3



Solution

$$I_1 = \frac{V}{R_1} = \frac{220\text{ V}}{100\text{ ohms}} = 2.2\text{A}$$

$$I_2 = \frac{V}{R_2} = \frac{220\text{ V}}{55\text{ ohms}} = 4\text{A}$$

$$I_3 = \frac{V}{R_3} = \frac{220\text{ V}}{40\text{ ohms}} = 5.5\text{A}$$

$$I_4 = \frac{V}{R_4} = \frac{220\text{ V}}{200\text{ ohms}} = 1.1\text{A}$$

$$I = I_1 + I_2 + I_3 + I_4$$

$$= 2.2\text{A} + 4\text{A} + 5.5\text{A} + 1.1\text{A} = 12.8\text{A}$$

Checking the calculation

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{100} + \frac{1}{55} + \frac{1}{40} + \frac{1}{200}$$

$$= \frac{22 + 40 + 55 + 11}{2200} = \frac{128}{2200} = \frac{16}{275}$$

$$\frac{1}{R_{TOT}} = \frac{16}{275}$$

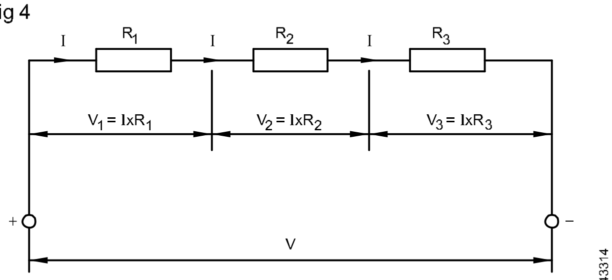
$R_{TOT} = 17.19$ ohms

$$I = \frac{V}{R_{TOT}} = \frac{220V}{17.19 \text{ ohms}} = 12.798 \text{ A}$$

Kirchhoff's second law

A simple case: In closed circuits, the applied terminal voltage V is equal to the sum of the voltage drops V_1+V_2 and so forth. (Fig 4)

Fig 4



SERIES CIRCUIT

If all the generated voltages are taken as positive, and all the consumed voltages are taken as negative, then it can be stated that:

in each closed circuit the sum of all voltages is equal to zero.

$$\Sigma V = 0$$

Example

Given

$V = 220V$
$R_1 = 36$ ohms
$R_2 = 40$ ohms
$R_3 = 60$ ohms
$R_4 = 50$ ohms

Find

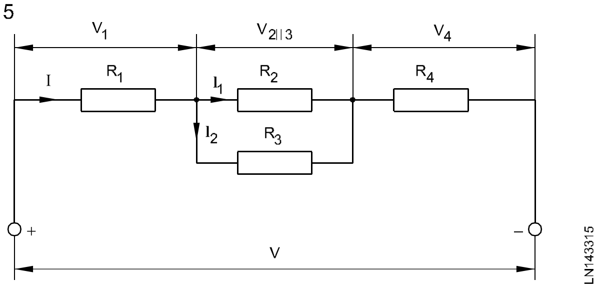
$R, I, I_1, I_2,$

$V_1, V_{2\parallel 3}, V_4$

Solution

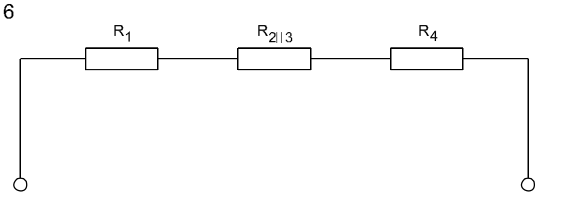
Apply Kirchhoff's First Law to find the voltage drops in the branches (Fig 5).

Fig 5



Calculate the total resistance R of the series circuit according to Kirchhoff's Second Law. (Fig 6)

Fig 6



First simplify by calculating the equivalent resistance for R_2, R_3 according to Kirchhoff's First Law.

$$R_{2\parallel 3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{40 \text{ ohms} \times 60 \text{ ohms}}{(40 + 60) \text{ ohms}}$$

$= 24$ ohms

$R_{TOT} = R_1 + R_{2\parallel 3} + R_4$

$= 36$ ohms $+ 24$ ohms $+ 50$ ohms

$= 110$ ohms

The total current I can now be calculated by means of Ohm's Law:

$$I = \frac{V}{R_{TOT}} = \frac{220 \text{ V}}{110 \text{ ohms}} = 2A$$

The partial voltages are accordingly:

$V_1 = I \times R_1 = 2A \times 36$ ohms $= 72$ V

$V_{2\parallel 3} = I \times R_{2\parallel 3} = 2A \times 24$ ohms $= 48$ V

$V_4 = I \times R_4 = 2A \times 50$ ohms $= 100$ V

Checking the calculation

$V = V_1 + V_{2\parallel 3} + V_4$

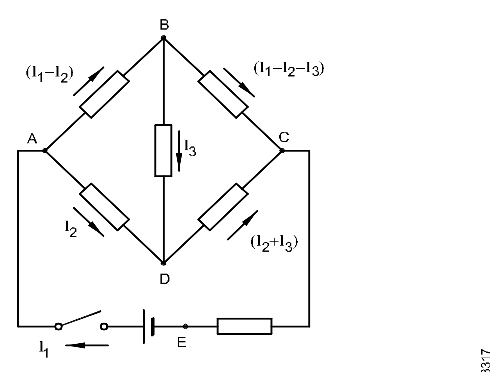
220 V $= 72V + 48V + 100$ V

220 V $= 220$ V

Suggested steps for the application of Kirchhoff's Laws to solve problems.

1 Mark the nodes (junction points) in the given network.
2 Mark the current direction over each element (resistor) in the circuit. The current direction is arbitrary. But it is often convenient to use a direction that goes from –ve to +ve through an emf.
3 Indicate the loop currents with I_1, I_2, I_3 etc. Apply Kirchhoff's First Law to the junction nearer to it. (Fig 7)

Fig 7

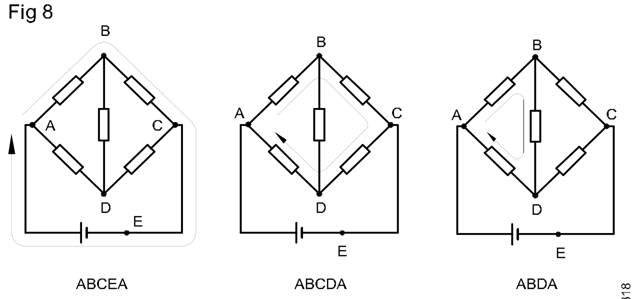


BRIDGE CIRCUIT

4 Once the current and its direction are marked over an element, keep it the same until the problem is solved.

5 Select the windows, (closed loops) in the circuit and name the window. eg. Fig 8.

Fig 8



CLOSED LOOPS

6 Each element should be included atleast once in any one of the closed loops selected in the above step.

7 Raise in potential is considered as +ve. A drop (fall) in potential is considered as –ve.

8 Trace around each loop and write Kirchhoff's Voltage Law equation. For such tracing to be complete, one should return to the starting point.

9 While tracing, the direction of movement is important.

For the source of emf

A **raise in potential** occurs when moving from the –ve to the +ve terminal of a source. Therefore the value is positive.

A **drop in potential** occurs when moving from a +ve to a –ve terminal of a source. Therefore the value is negative.

The current direction is not considered to fix the potential-raise or potential-drop across a source of emf.

For the resistors

A drop in potential occurs when moving across the resistor in the same direction as that of the current through the resistor. Therefore the value is negative.

A raise in potential occur when moving across the resistor in the opposite direction to that of the current through the resistor. Therefore, the value is positive.

The direction of movement while tracing the loop and related current direction in each element is important. The polarity of the source of emf is not considered to fix the potential raise or drop across a resistor.

10 Solve the equations to determine the current through each element.

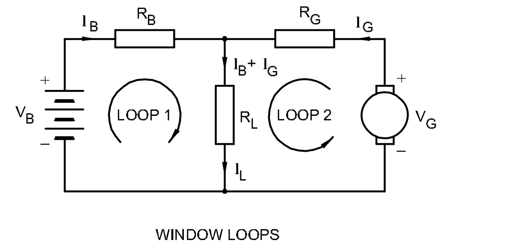
Example 1: A battery of open-circuit voltage V_B and internal resistance R_B is connected in parallel with a generator of open-circuit voltage V_G and internal resistance RG. This combination feeds load resistance R_L. For the following values find the battery current, generator current, load current and load voltage.

V_B = 13.2 V, V_G = 14.5 V, $_{RB}$ = 0.5 Ω and R_L = 2 Ω, R_G = 0.1 - 2 Ω

Solution

1 Draw a circuit diagram. (Fig 9)

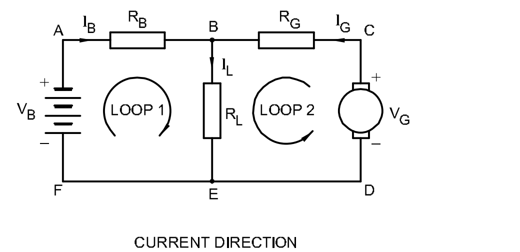
Fig 9



WINDOW LOOPS

2 It can be seen from Fig 9 that there are two `windows' loops in the circuit. this means that we must show two currents, one in each loop, in any arbitrary direction. (We shall show currents I_B and I_G in the direction we think the current might flow). (Fig 10)

Fig 10



CURRENT DIRECTION

3 Using Kirchoff's Current Law, we can identify the current through the load resistor as

$I_L = I_B + I_G$.

Indicate this current in Fig 10.

4 Show the polarity signs of the voltage drops across each resistor using the assumed directions of the current. (Fig 10)

5 Indicate, in each window, a current loop that goes around a complete circuit. The direction is arbitrary, but it is often convenient to use a direction that goes from - to + through an emf. (See loops 1 and 2 in Fig 8).

6 Trace around each loop, writing Kirchhoff's Voltage Law equation by applying the following basic principles

- If you encounter - V_G of the voltage source first then the +ve of the source while tracing through a loop take the source as +ve.
- If you encounter positive of the source first and then negative of the source while tracing through a loop take the source is negative.
- When you trace a voltage drop in the same direction of current take the voltage drop as negative.
- When you trace a voltage drop in the opposite direction of current take the voltage drop as positive.
- Form clear loops denoting the line of tracing starting with alphabet `A' then after completing the path end with `A'.

Refer Fig 10. Let us start from first loop starting with A and ending with A.

i.e. ABEFA

Applying the above principles

A to B = – $I_B R_B$ (Voltage drop alongwith current direction)

B to E = – $I_L R_L$ -do-

E to F = 0

F to A = $+V_B$ (First negative and then positive of the source in the direction of current)

Hence for first loop, we have

$-I_B R_b - I_L R_L + V_B = 0$ .... Eqn. (1)

OR

$= I_B R_B + (I_B + I_G) R_L$ .... Eqn. (2)

For loop 2 we have C B E D C

$-I_G R_G - I_L R_L + V_G = 0$ .... Eqn. (3)

$-I_G R_G - (I_B + I_G) R_L + V_G = 0$

$VG = I_G R_G + (I_B + I_G) R_L$ .... Eqn. (4)

Insert in eqn. (2) and (4) the numerical values we have

$13.2 = 0.5I_B + 2(I_B + I_G)$ .... Eqn. (5)

$14.5 = 0.1I_B + 2(I_B + I_G)$ ... Eqn.(6)

Collect together like terms and solve for I_G I_B

$13.2 = 2.5I_B + 2I_G$ .... Eqn. (7)

$14.5 = 2I_B + 2.1I_G$ .... Eqn.(8)

Multiply eqn.(7) by 2 and eqn. (8) by 2.5 we have

$26.4 = 5I_B + 4I_G$ ..... Eqn.(9)

$36.25 = 5I_B + 5.25I_G$ .....Eqn.(10)

Subtract eqn.(9) from eqn. (10) we have

$36.25 = 5I_B + 5.25I_G$

$26.4 = 5I_B + 4I_G$

$9.85 = 1.25 I_G$

$$I_G = \frac{9.85}{1.25} = 7.88 \text{ amps}$$

Substituting the value $I_G = 7.88$ in eqn. (9) we have

$26.4 = 5I_B + 4 \times 7.88$

$= 5I_B + 31.52$

$26.4 - 31.52 = 5I_B$

$-5.12 = 5 I_B$

$$I_B = \frac{-5.12}{5}$$

$= -1.024$ amps

Minus sign in the answer indicates that the battery is not sending any current but receives a charging current of 1.024 amps.

Accordingly current supplied by the generator

$I_G = 7.88$ amps

Current taken by the battery I_B (Battery in getting charged) = 1.024 amps

Load current $I_L = I_B + I_G$

where $I_B = -1.024$ amps

$I_G = +7.88$

$I_L = (-1.024 + 7.88)$

$= 6.856$ amps

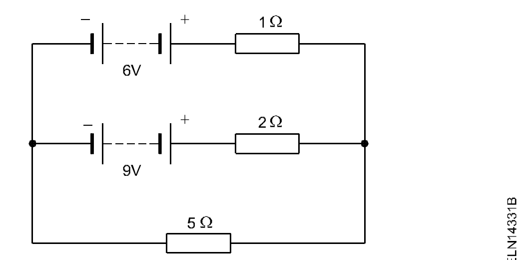
Voltage across the load $= I_L R_L$

$= 6.856 \times 2$

$= 13.712$ volts

Example 2: For the given circuit in Fig 11, determine the following

Fig 11



1 Mark the nodes and name the closed loops.

2 Name and mark the direction of current in the element following Kirchhoff's First Law.

3 Trace around each loop and write Kirchhoff's 2nd law.

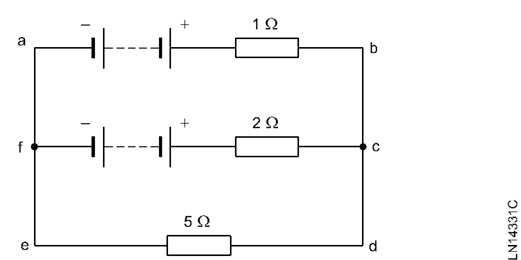
4 Solve the problem using simultaneous equation to find the current delivered or received by the battery 6 V and 9 V.

5 Find the current passing through the 5 ohm resistor.

6 Cross check your calculation.

i The nodes are marked and the closed loops are named (Fig 12)

Fig 12

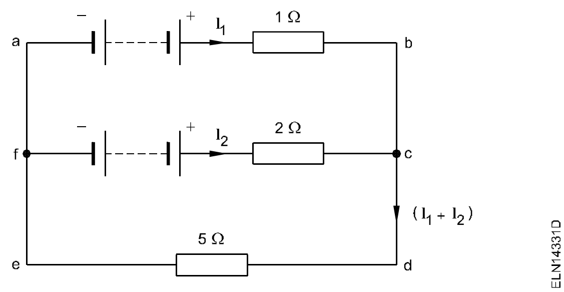


Loop 1 = a b c d e f a

Loop2 = f c d e f

ii Direction of current is marked (Fig 13)

Fig 13



Loop 1 – a b c d e f a

$+6 - 1I_1 - 5(I_1 + I_2) = 0$

$+6 - I_1 - 5I_1 - 5I_2 = 0$

$+6 - 6I_1 - 5I_2 = 0$

$6I_1 + 5I_2 = 6$ .... Eqn.(1)

Loop 2- f c d e f

$+9 - 2I_2 - 5(I_1 + I_2) = 0$

$9 - 2I_2 - 5I_1 - 5I_2 = 0$

$9 - 5I_1 - 7I_2 = 0$

$5I_1 + 7I_2 = 9$ .... Eqn. (2)

iv Multiplying eqn. (2) by 6 and eqn. (1) by 5 we have

$5I_1 + 7I_2 = 9 \times 6$

$6I_1 + 5I_2 = 6 \times 5$

$30I_1 + 42 I_2 = 54$ .... Eqn. (3)

$30I_1 + 25I_2 = 30$ .... Eqn. (4)

Substracting equation 4 from eqn.3 we have

$17I_2 = 24$

$I_2 = \frac{24}{17} = 1.41$ amps

Substituting I_2 = 1.41 in eqn. 1 we have

$6I_1 + 5(1.41) = 6$

$6I_2 + 7.05 = 6$

$6I_1 = 6 - 7.05 = -1.05$

$I_1 = -0.175$ amps.

As the current value of I_1 is minus sign the current is assumed to flow in opposite direction to the asumed direction

Only the 9V battery delivers current
while the current received by the 6 V battery
= 0.175 amps.

Current delivered by 9 V battery = 1.41 amps

Current passing through 5 ohms resistor

$I_1 + I_2 = -0.175 + 1.41$

= 1.235 amps

PD across 5 ohm resistor = 1.235 x 5 = 6.175 V.

Cross check

Taking loop 3 a b c f a

$+6 - I_1 + 2 I_2 - 9 = 0$

$6-(-0.175)+2.82-9=0$

$8.995 - 9 = 0$

As the values are more or less the same verified by cross checking and found to be corre.

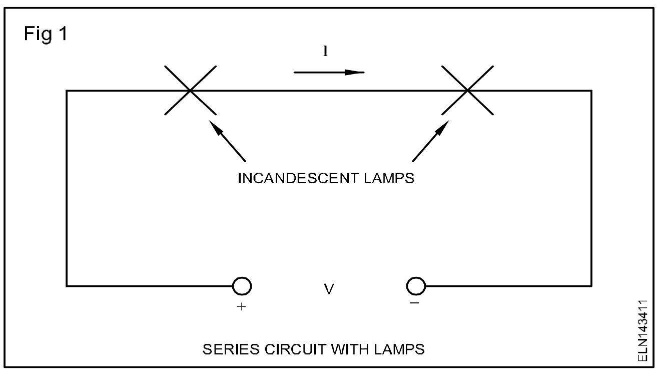
DC series and parallel circuits

Objectives: At the end of this lesson you shall be able to
- **state the characteristics of series circuit and determine the current and voltage across each resistors**
- **determine the total voltage sources in series circuit**
- **state the relation between EMF potential difference and terminal voltage**
- **determine the polarity of voltage drops with respect to ground**

The series circuit

If more than one resistors are connected one by one like a chain and if the current has only one path is called as series circuit. It is possible to connect two incandescent lamps in the way shown in Fig 1. This connection is called a series connection, in which the same current flows in the two lamps.

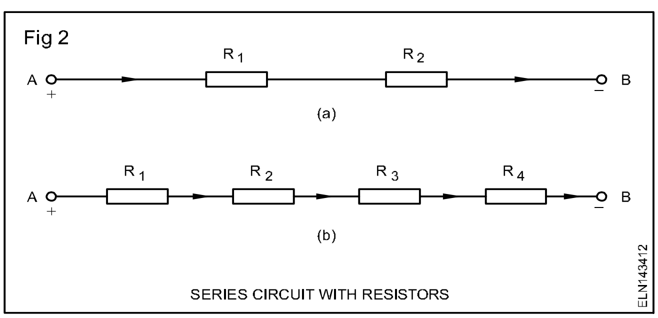
Fig 1



SERIES CIRCUIT WITH LAMPS

The lamps are replaced by resistors in Fig 2. Fig 2 (a) shows two resistors are connected in series between point A and point B. Fig 2(b) shows four resistors are in series. Of course, there can be any number of resistors in a series connection. Such connection provides only one path for the current to flow.

Fig 2



SERIES CIRCUIT WITH RESISTORS

Identifying series connections

In an actual circuit diagram, a series connection may not always be as easy to identify as those in the figure. For example, Fig 3(a), 3(b), 3(c) & 3(d) shows series resistors drawn in different ways. In all the above circuits we find there is only one path for the current to flow.

Current in series circuits

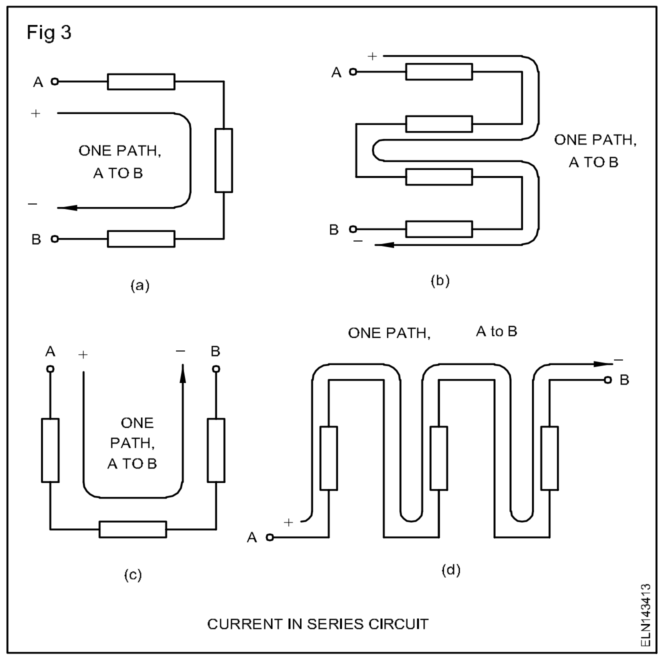
The current will be the same at any point of the series circuit. This can be verified by measuring the current in any two points of a given circuit as shown in Figs 4(a) and 4(b). The ammeters will show the same reading.

The current relationship in a series circuit is

$$I = I_{R1} = I_{R2} = I_{R3}.$$ (Refer Fig 4a & 4b)

We can conclude that there is only one path for the current to flow in a series circuit. Hence, the current is the same throughout the circuit.

Fig 3



CURRENT IN SERIES CIRCUIT

Total resistance in series circuit

You know how to calculate the current in a circuit, by Ohm's law, if resistance and voltage are known. In a circuit consisting of two resistors R_1 and R_2 we know that the resistor R_1 offers some opposition to the current flow. As the same current should flow through R_2 in series it has to overcome the opposition offered by R_2 also.

If there are a number of resistors in series, they all oppose the flow of current through them.

The 2nd characteristic of a DC series circuit could be written as follows (R).

The total resistance in a series circuit is equal to the sum of the individual resistances around the series circuit. This statement can be written as

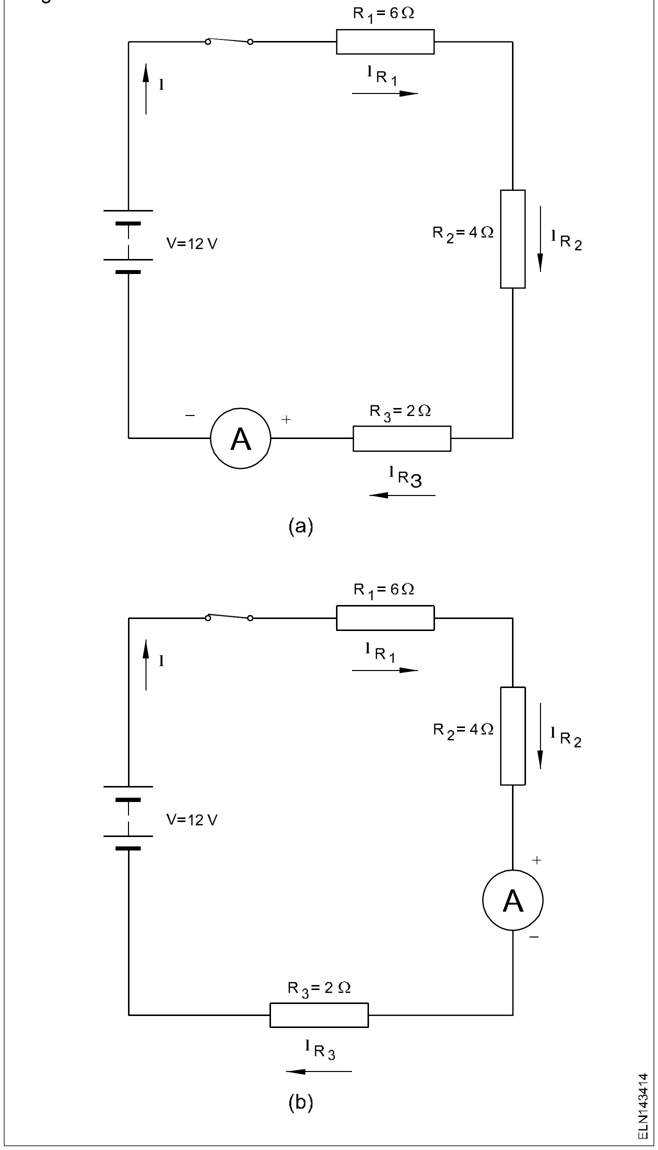
$$R = R_1 + R_2 + R_3 + ...R_n$$

where R is the total resistance

$R_1, R_2, R_3, ...R_n$ are the resistors connected in series.

When a circuit has more than one resistor of the same value in series, the total resistance is $R = r \times N$

Fig 4



where 'r' is the value of each resistor and N is the number of resistors in series.

Voltage in series circuits

In DC circuit voltage divides up across the load resistors, depending upon the value of the resistor so that the sum of the individual load voltages equals the source voltage.

The 3rd characteristic of a DC circuit can be written as follows.

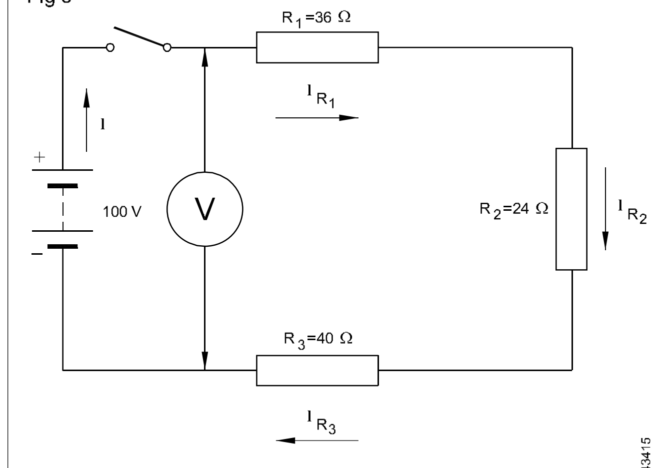
As the source voltage divides/drops across the series resistance depending upon the value of the resistances

$$V = V_{R1} + V_{R2} + V_{R3} + ...V_{RH}$$

the total voltage of a series circuit must be measured across the voltage source, as shown in Fig 5.

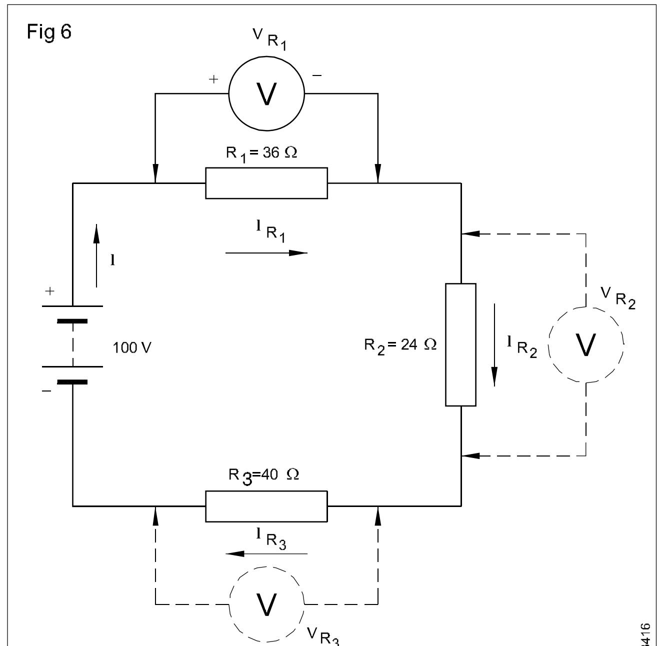
Voltages across the series resistors could be measured using one voltmeter at different positions as illustrated in Fig 6.

Fig 5



MEASURIING THE TOTAL VOLTAGE OF SERIES CIRCUIT

Fig 6



VOLTAGE DROP IN A SERIES CIRCUIT

When Ohm's law is applied to the complete circuit having an applied voltage V, and total resistance R, we have the current in the circuit as

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

Application of Ohm's law to DC series circuits

Applying to Ohm's law to the series circuit, the relation between various currents could be stated as below

$$I = I_{R1} = I_{R2} = I_{R3}$$

This could be stated as $\frac{V}{R} = \frac{V_{R1}}{R_1} = \frac{V_{R2}}{R_2} = \frac{V_{R3}}{R_3}$

You can use any of the above formulae to calculate current in a series circuit.

We know the total supply voltage

$V = V_{R1} + V_{R2} + V_{R3}$

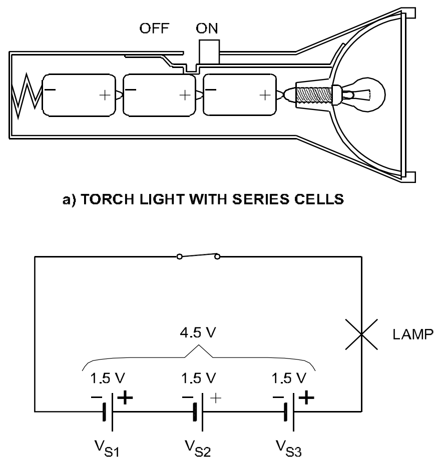
i.e. $IR = R_1 I_{R1} + R_2 I_{R2} + R_3 I_{R3}$

and Total resistance $R = R_1 + R_2 + R_3$.

Voltage sources in series

When cells are placed in a torch light, they are connected in series to produce a higher voltage as shown in Fig 7.

Fig 7



a) TORCH LIGHT WITH SERIES CELLS

b) SCHEMATIC DIAGRAM OF THE TORCH LIGHT CIRCUIT

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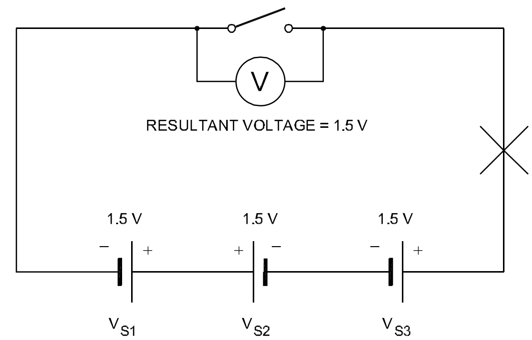
Series voltage sources are added when their polarities are in the same direction and or subtracted when their polarities are in the opposite direction. For example, if one of the ends of the cell, say V_{S2} in a torch light is wrongly placed in polarity as indicated in the schematic of Fig 8 its voltage to be subtracted as follows.

Fig 8



OPPOSITE POLARITIES SUBTRACT

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$V_{Total} = V_{S1} - V_{S2} + V_{S3}$

$= 1.5\text{ V} - 1.5\text{ V} + 1.5\text{ V}$

$= 1.5\text{ V}$

Use of series connection

1 Cells in torch light, car batteries, etc.

2 Cluster of mini-lamps used for decoration purposes.

3 Fuse in circuit.

4 Overload coil in motor starters.

5 Multiplier resistance of a voltmeter.

Polarity of IR voltage drops

Definitions

Electromotive force (emf)

We have seen that the electromotive force (emf) of a cell is the open circuit voltage, and the potential difference (PD) is the voltage across the cell when it delivers a current. The potential difference is always less than the emf.

Potential difference

PD = emf – voltage drop in the cell

Potential difference can also be called by another term, the terminal voltage, as explained below.

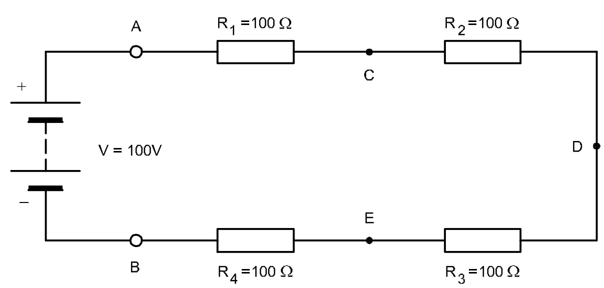
Terminal voltage

It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt. It is given by the emf minus the voltage drop in the source of supply,

i.e. $V_T = \text{emf} - IR$

where I is the current and R the resistance of the source.

Fig 1



VOLTAGE DROP ACROSS RESISTORS

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Voltage drop (IR drop)

The voltage lost by resistance in a circuit is called the Voltage drop or IR drop.

Example 1

The resistances and applied voltage are known. (Fig 1)

The voltage drops across the resistors

The total resistance of the circuit in Fig 1 would be equal to $R_T = 100 + 100 + 100 + 100 = 400$ ohms.

The current flowing through the circuit would be

$I = (100/400) = 0.25$ amps.

But point A has a potential of 100 volts and point B has zero. Somewhere along the circuit between A and B, the 100 volts have been lost.

To find the voltage drop for each resistor is easy. First find the current, which we have calculated as 0.25 amps, then

$V_{R1} = 0.25 \times 100 = 25$ V

$V_{R2} = 0.25 \times 100 = 25$ V

$V_{R3} = 0.25 \times 100 = 25$ V

$V_{R4} = 0.25 \times 100 = 25$ V.

Add up all the voltage drops and they will total 100 volts which is the applied voltage of the circuit.

$25 + 25 + 25 + 25 = 100$ volts.

The sum of the voltage drops in a circuit must be equal to the applied voltage.

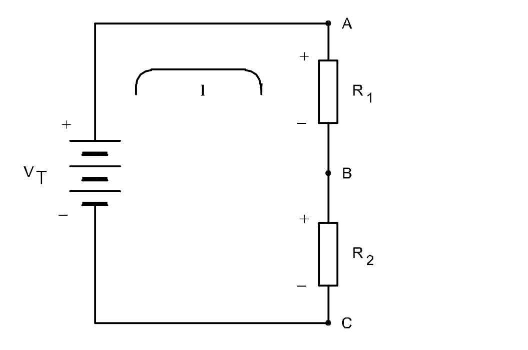
$V_{Total} = V_{R1} + V_{R2} + V_{R3} + V_{R4}$.

Polarity of voltage drops

When there is a voltage drop across a resistance, one end must be more positive or more negative than the other end. The polarity of the voltage drop is determined by the direction of conventional current. In Figure 2, the current direction is through R_1 from point A to B.

Therefore, the terminal of R_1 connected to point A has a more positive potential than point B. We say that the voltage across R_1 is such that point A is more positive than point B. Similarly the voltage of point B is more positive than point C.

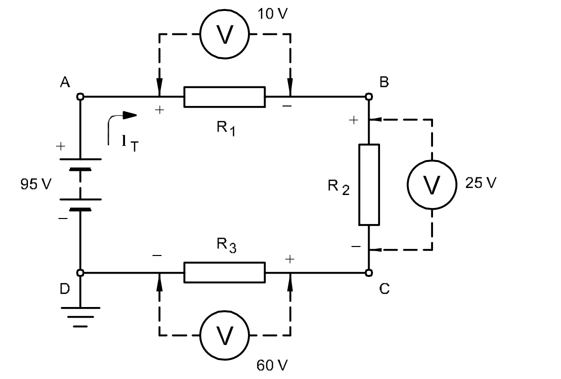
Fig 2



POLARITY OF VOLTAGE SOURCE

Another way to look at polarity between any two points is that the one nearer to the positive terminal of the voltage source is more positive; also, the point nearer to the negative terminal of the applied voltage is more negative. Therefore, point A is more positive than B, while C is more negative than B. (Fig 2)

Fig 3



VOLTAGE DROP AT SERIES CIRCUIT

Example 2

Find the voltage at the points A,B, C and D with respect to ground.

Mark the polarity of voltage drops in the circuit (Fig 3) and find the voltage values at points A, B, C and D with respect to ground.

Trace the complete circuit in the direction of current from the + terminal of the battery to A, A to B, B to C, C to D, and D to the negative terminal. Mark plus (+) where the current enters each resistor and minus (–) where the current leaves each resistor.

The voltage drops indicate (Fig 3) Point A is the nearest point to the positive side of the terminal; so voltage at A with respect to ground is

$V_A = +95$ V.

There is a voltage drop of 10 V across R_1; so voltage at B is

$V_B = 95 - 10 = +85$ V.

There is a voltage drop of 25 V across R_2; so voltage at C is

$V_C = 85 - 25 = +60$ V.

There is a voltage drop of 60V across R_3; so voltage at D is

$V_D = 60 - 60 = 0$ V.

Since the circuit is grounded at D, V_D must equal 0 V.

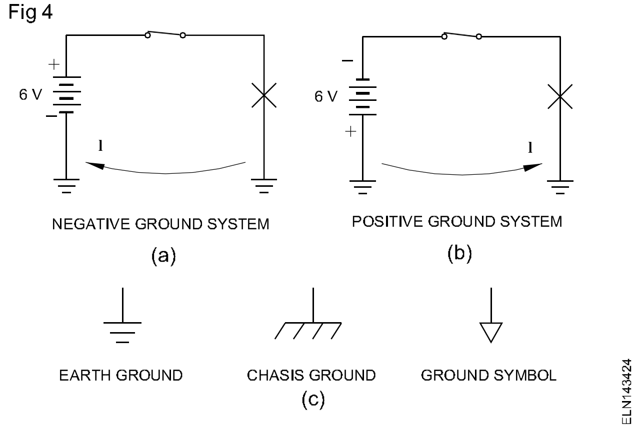
Positive and Negative grounds

In the electrical system of automobiles it is customary to connect one side of the battery to the metal chassis and call it the ground side. In this way metal chassis can be used as the **return path** for any circuit without providing an extra wire.

While most cars have 'negative grounds,' some (European) vehicles have a 'positive-ground' system. In the positive ground system reduced corrosion problems are claimed. Fig 4 shows both the systems.

In the negative ground system all wiring is at a positive potential with respect to the chassis, (as shown in Fig 4a)

Fig 4



whereas in a positive ground system (Fig 4b), all potentials are negative. Current flows in opposite directions in the two systems. But in both systems, the metal chassis is used as a common reference point to state the value of voltage at any point in the system.

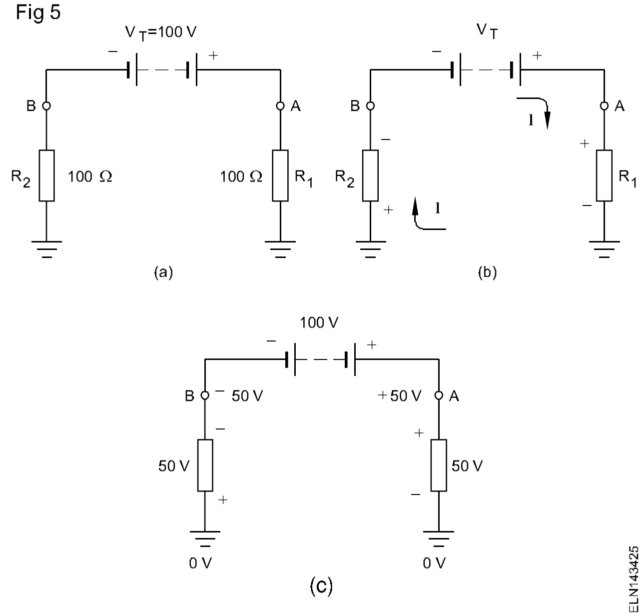
Figure 4c shows symbols for different types of ground systems.

Strictly speaking, the word ground being used for the metal chasis is not correct. A better symbol to use for chassis ground is shown in Fig 4c. This is because ground usually implies a connection to earth ground. (In a car the chassis is insulated from the ground by its rubber tires.) For example, one side of the domestic 240V AC outlet, the neutral is connected to earth by the system earthing method.

Marking the polarity of the voltage drop with respect to ground?

To mark the polarity of the voltage drops across the resistances R_1, R_2, find the voltage drops at points A and B in Fig 5(a), follow the steps as shown in Figures 5(b) and 5(c).

Fig 5



Practical application

The knowledge gained by this lesson will help you to:

- connect resistors in series to limit the current to the required level
- determine the current in the series circuit when PD and resistance value are known
- connect voltage sources like cells in a proper manner to have higher voltage
- determine with polarised meters, the polarity of IR drops, and, thereby, current direction in circuits
- detect faults in series-connected decorative lamp circuits.

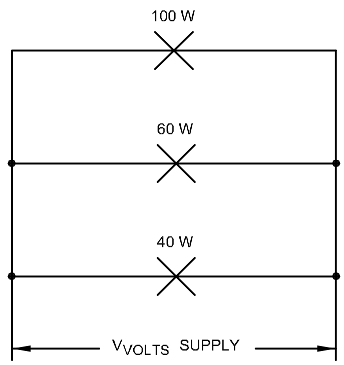
DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **explain a parallel circuit**
- **determine the voltages in a parallel circuit**
- **determine the current in a parallel circuit**
- **determine the total resistances in a parallel circuit**
- **state the application of a parallel circuit.**

In an electrical circuit, if the current has more than one paths and equal voltage in each branch is called parallel circuit.

It is possible to connect three incandescent lamps as shown in Fig 1. This connection is called parallel connection in which, the same source voltage is applied across all the three lamps.

Fig 1



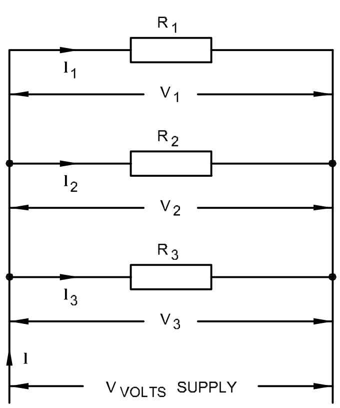
PARALLEL CIRCUIT

Voltage in parallel circuit

The lamps in Fig 1 are replaced by resistors in Fig 2. Again the voltage applied across the resistors is the same and also equal to the supply voltage.

We can conclude that the voltage across the parallel circuit is the same as the supply voltage.

Fig 2

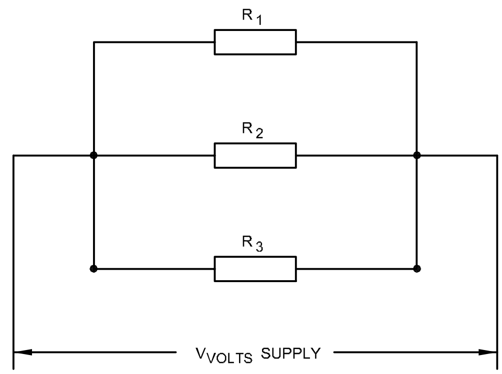


VOLTAGE IN PARALLEL CIRCUIT

Fig 2 could also be drawn as shown in Fig 3.

Mathematically it could be expressed as $V = V_1 = V_2 = V_3$.

Fig 3



PARALLEL CIRCUIT

Current in parallel circuit

Again referring to Fig 2 and applying Ohm's law, the individual branch currents in the parallel circuit could be determined.

Current in resistor $R_1 = I_1 = \dfrac{V_1}{R_1} = \dfrac{V}{R_1}$.

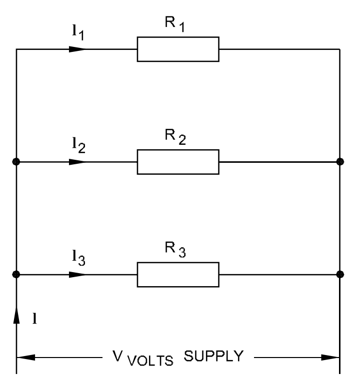
Current in resistor $R_2 = I_2 = \dfrac{V_2}{R_2} = \dfrac{V}{R_2}$.

Current in resistor $R_3 = I_3 = \dfrac{V_3}{R_3} = \dfrac{V}{R_3}$

as $V_1 = V_2 = V_3$.

Refer to Fig 4 in which the branch currents I_1, I_2 and I_3 are shown to flow into resistance branches R_1, R_2 and R_3 respectively.

Fig 4



The total current I in the parallel circuit is the sum of the individual branch currents.

Mathematically it could be expressed as $I = I_1 + I_2 + I_3 + ... I_n$.

Resistance in parallel circuit

In a parallel circuit, individual branch resistances offer opposition to the current flow though the voltage across the branches will be same.

Let the total resistance in the parallel circuit be R ohms.

By the application of Ohm's law

we can write

$$R = \frac{V}{I} \text{ ohms or } = \frac{V}{R} \text{ amps.}$$

where

R is the total resistance of the parallel circuit in ohms

V is the applied source voltage in volts, and

I is the total current in the parallel circuit in amperes.

We have also seen

$I = I_1 + I_2 + I_3$

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

As V is the same throughout the equation and dividing the above equation by V, we can write

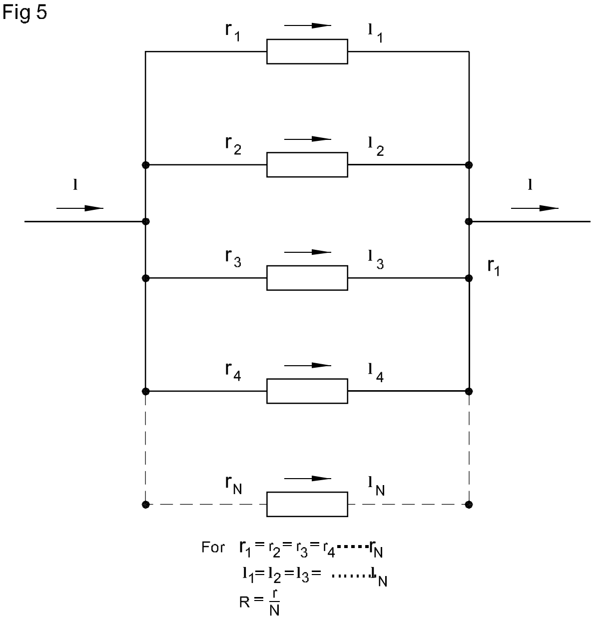
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The above equation reveals that in a parallel circuit, the reciprocal of the total resistance is equal to the sum of the reciprocals of the individual branch resistances.

Special case: Equal resistances in parallel

Total resistance R, of equal resistors in parallel (Fig 5) is equal to the resistance of one resistor, r divided by the number of resistors, N.

Fig 5



$$R = \frac{r}{N}$$

Applications of parallel circuits

An electric system in which one section can fail and other sections continue to operate has parallel circuits. As previously mentioned, the electric system used in homes consists of many parallel circuits.

An automobile electric system uses parallel circuits for lights, horn, motor, radio etc. Each of these devices operates independent of the others.

Individual television circuits are quite complex. However, the complex circuits are connected in parallel to the main power source. That is why the audio section of television receivers can still work when the video (picture) is inoperative.

Open and short circuit in series and parallel network

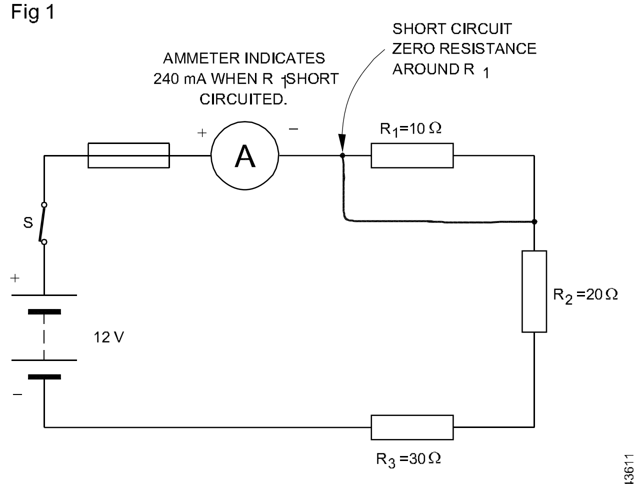
Objectives: At the end of this lesson you shall be able to
- **state about short circuit in series circuit and its effect in series circuit**
- **state the effect of an open circuit in series circuit and its causes**
- **state the effect of shorts and open in parallel circuit.**

Short circuits

A short circuit is a path of zero or very low resistance compared to the normal circuit resistance.

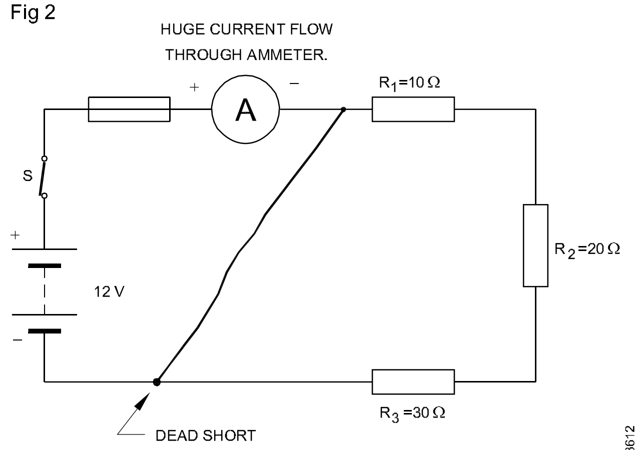
In a series circuit, short circuits may be partial or full (dead short) as shown in Fig 1 and Fig 2 respectively.

Fig 1



PARTIAL SHORT AT R 1

Fig 2



DEAD SHORT ACROSS CIRCUIT

Short circuits cause an increase in current that may or damage the series circuit.

Effects due to short circuit

Excess current due to short circuit can damage the circuit components, power sources, or burn the insulation of connecting wires. Fire is also caused due to intense heat generated in the conductors.

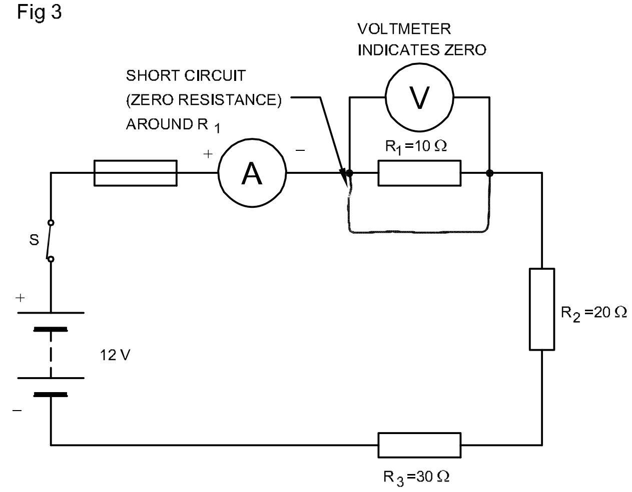
Protection against dangers of short circuit

Dangers of short circuit can be prevented by means of fuses and circuit breakers in series with the circuit.

Detecting short circuit

When the ammeter in the circuit indicates excessive current then it indicates a short circuit in the circuit. The location of short in a circuit can be detected by connecting a voltmeter across each of the elements (resistors) and circuit source. If the voltmeter indicates zero volts or reduced voltage across the element, it is short circuited as shown in Fig 3.

Fig 3



SHORT CIRCUIT IN ONE RESISTANCE

Methods used to protect the circuit in case of a short circuit

As heavy currents flow through the short circuit, the circuit cables should be protected against the large currents. If the short circuit current is allowed to flow through the circuit, the cables which are rated for normal circuit current, will get heated up and become potential fire hazards.

To open the circuit automatically in cases of short circuits, fuses or circuit breakers are used in the circuit. The rating of the fuse wire or setting of the overload relay in circuit breakers will be selected depending upon the lowest rating of any one of the following used in the circuit.

i Load current in the circuit

ii Cable rating of the circuit

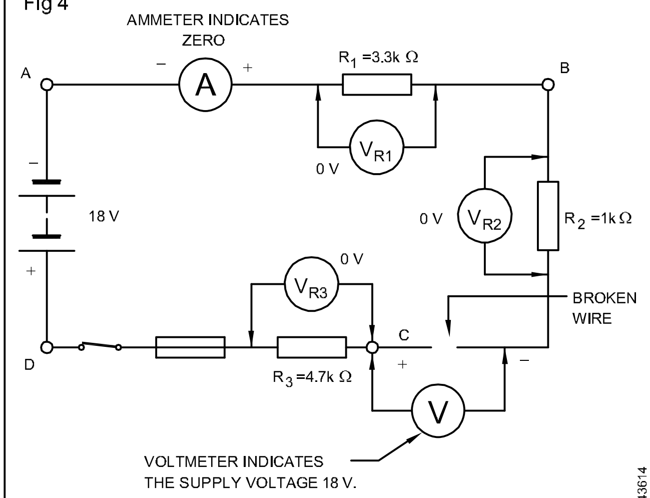
iii Series meter (ammeter etc.) rating of the circuit.

Open circuit in series circuit

An open circuit results whenever a circuit is broken or is incomplete, and there is no continuity in the circuit.

In a series circuit, open circuit means that there is no path for the current, and no current flows through the circuit. Any ammeter in the circuit will indicate no current as shown in Fig 4.

Fig 4



OPEN CIRCUIT IN SERIES CIRCUIT

Causes for open circuit in series circuit

Open circuits, normally, happen due to improper contacts of switches, burnt out fuses, breakage in connection wires and burnt out resistors etc.

Effect of open in series circuit

a No current flows in the circuit.

b No device in the circuit will function.

c Total supply voltage/ source voltage appear across the open.

Determination the location of break in the circuit has occurred

Use a voltmeter on a range that can accommodate the supply voltage; connect it across each connecting wire in turn. If one of the wires is open as shown in Fig 4, the full supply voltage is indicated on the voltmeter. In the absence of a current, there is no voltage drop across any of the resistors. Therefore, the voltmeter must be reading full supply voltage across the open. part of the circuit

Voltmeter reading

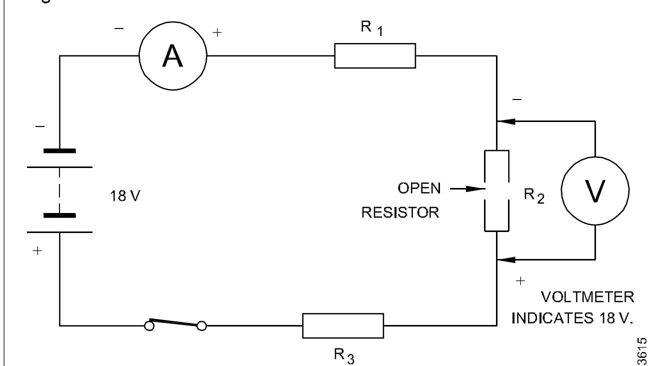
$= 18\ V - V_{R1} - V_{R2} - V_{R3}$

$= 18\ V - O\ V - O\ V - O\ V = 18\ V.$

If the circuit was open due to a defective resistor, as shown in Fig 5 (resistors usually open when they burn out), the voltmeter would indicate 18 V when connected across this resistor, R_2.

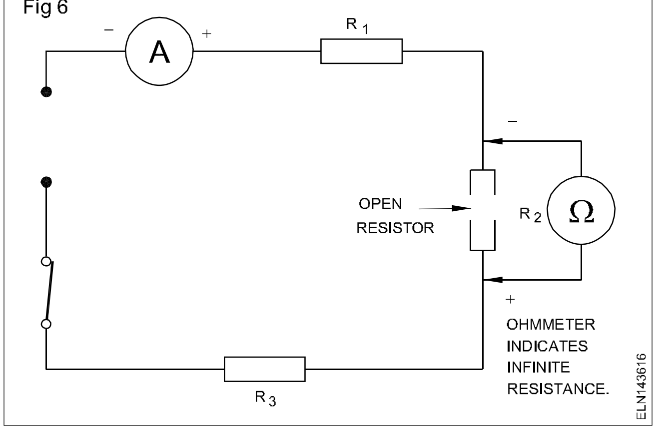
Alternatively, the open circuit may be found using an ohmmeter. With the voltage removed, the ohmmeter will show no continuity (infinite resistance), when connected across the broken wire or open resistor. (Fig 6)

Fig 5



OPEN CIRCUIT DUE TO OPEN RESISTOR R_2

Fig 6



Practical application

With the knowledge gained from this exercise:

- locate open and short circuit faults in a series circuit
- repair series-connected decoration bulb sets.

Shorts and opens in parallel circuits

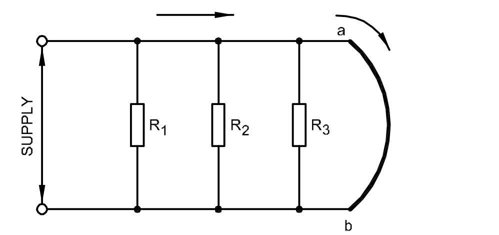
The two possible defects that can occur in an electrical circuit they are:

- short circuit
- open circuit

Shorts in parallel circuit:

Fig 1 shows a parallel circuit with short between points 'a' and 'b'.

Fig 1



SHORT IN PARALLEL

This causes reduction of circuit resistance almost to zero.

Therefore, the voltage drop across 'ab' will be almost zero (by Ohms law).

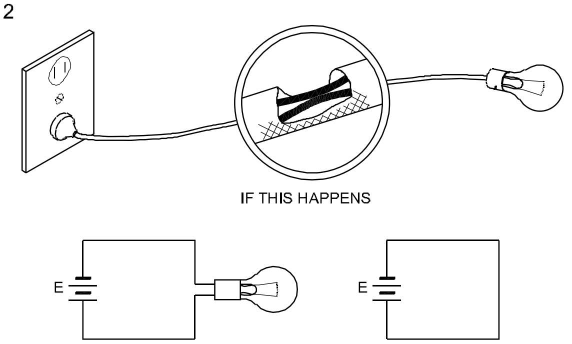
Thus current through the resistors R_1, R_2, R_3 will be negligible and not their normal current.

The result is that a very high current in the order of hundred times of the normal current will flow through the short circuit.

A short circuit exists when current can flow from the positive terminal of the power source through connecting wires and back to the negative terminal of the power source without going through any load. (Fig 2)

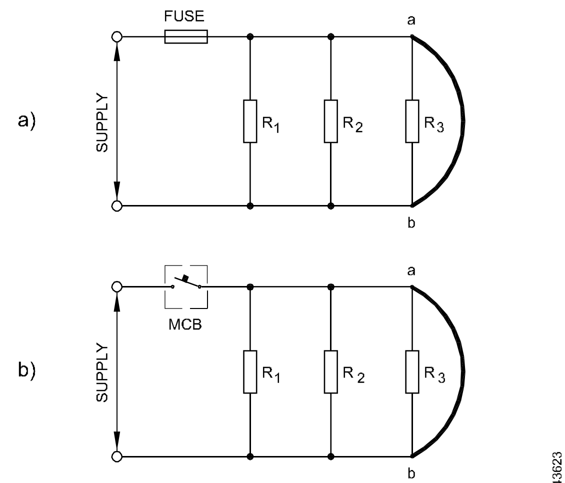
Short circuit may cause burning of the circuit elements like cables, switches etc.

Fig 2



To avoid burning of circuit components safety devices like 'fuse', circuit breakers etc. are used to open the circuit.(Figs 3 a and 3b).

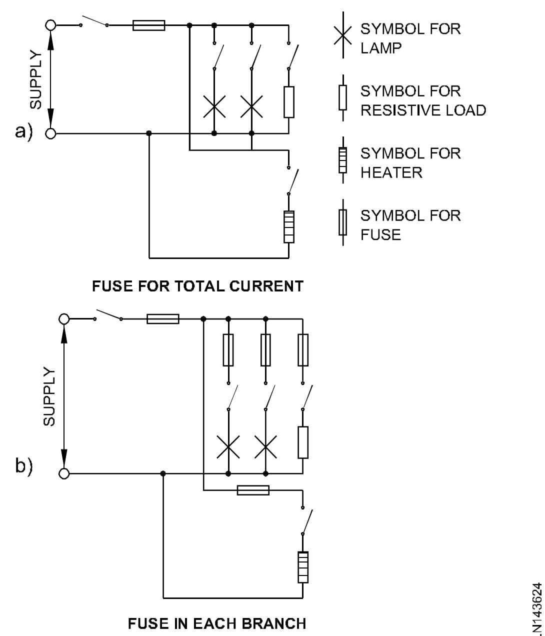
Fig 3



MCB - MINIATURE CIRCUIT BREAKER

For a fuse to protect a parallel circuit, it should be placed in the circuit where the total current flows or else each branch must have a fuse. (Fig 4(a&b))

Fig 4



Opens in parallel circuit

An open in the common line at point A as shown in Fig 5 causes no current flow in that circuit whereas an open in the branch at point B causes no current flow only in that branch. (Fig 6)

However, the current in branches R_1 and R_3 will continue to flow so long as they are connected to the voltage source.

> **Full voltage of the source will be available at open circuit terminals. It is dangerous to meddle with the terminals which are open.**

Practical application

Knowledge gained in this exercise can be applied to identify open circuits or short circuits in wiring installations.

Fig 5

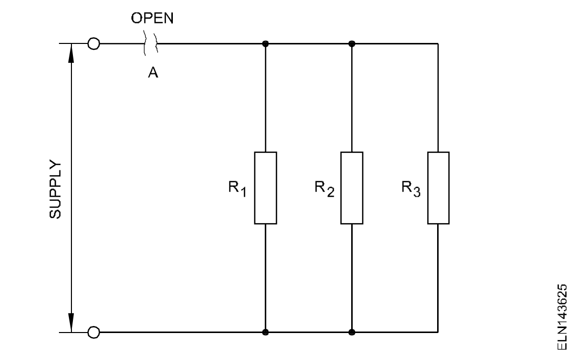


Fig 6