Fuse

Objectives: At the end of this lesson you shall be able to
- **state the need of a fuse in the circuit**
- **state the construction of a fuse**
- **list out the types of fuses**
- **describe the working of fuses**
- **describe the circuit with and without a fuse**
- **describe the circuit breakers.**

Introduction

A fuse is a protective device. It is a weakest portion in the electrical circuit.

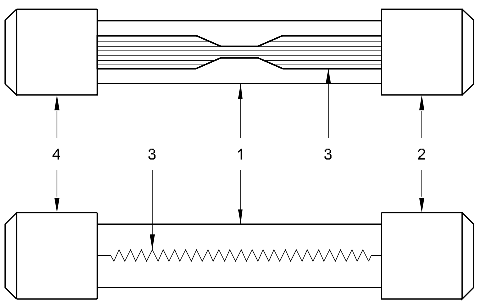
An electric current heats the wire when the current passes through it. The amount of heat depends upon the current and resistance in the wire.

In automobiles, this heating effect is utilized in heaters, bulbs and gauges etc,

The heating effect in the circuit is limited by the fuse. If this limit is not controlled, the circuit of accessories will be overloaded causing severe damage to them.

Purpose of fuse (Fig 1)

Fig 1



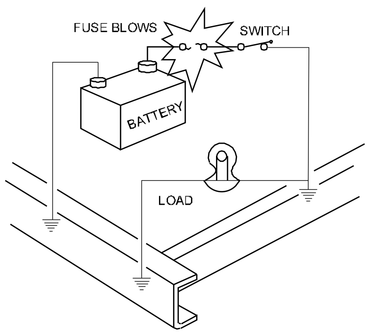
A fuse opens the circuit by blowing out when current (overload) flows in the circuit to prevent severe damage to the accessories.

The flow of excess current in a circuit may be caused by a short circuit.

Construction

Fuse elements are of lead-tin or tin-copper alloy wire in strip of correct amperage for each circuit.

Fig 2



The fuse is assembled in a fuse carrier of glass or ceramic material.

Nowadays fuse elements assembled in glass tubes, called cartridges, are widely used in automobiles.

It consists of a glass tube (1) with metal end caps (2) & (4).

A soft fine wire or strip (3) carries the current from one cap to another (4).

The conductor (3) is designed to carry a specific maximum current.

Working

The current flows through the conductor (3) between two metal caps (2) & (4) and then to the equipment.

If the current value exceeds the limit prescribed on the fuse, the fuse element (3) melts and opens the circuit and prevents the equipment from damage.

Identification of blown fuse

If you look at the burnt fuse and if the element is broken the fuse is burnt due to overloading (Fig 2).

The glass is foggy white or black the fuse is blown out due to short circuit.

Circuits protected with fuse

- Headlight circuit
- Tail - light circuit
- Number -plate circuit
- Panel lamp circuit
- Interior lamp circuit
- Side indicator circuit
- Horn circuit
- Wiper circuit
- Dashboard / panel instruments circuit
- Heater and air conditioner circuit
- Charging circuit
- Radio / Audio / Video circuit

- Cigarette lighter
- Reverse lamp

Circuits without fuse

- Starting circuit
- Ignition circuit
- Fuel pump circuit
- Stop - light circuit
- Oil pressure lamp circuit
- Ignition warning lamp circuit.

Fuse rating and colour

Rating	Colour
3 Amp	Violet
5 Amp	Tan
10 Amp	Red
20 Amp	Yellow
25 Amp	White
30 Amp	Light green

Fusible link and circuit breakers:

Fusible link (Fig 3)

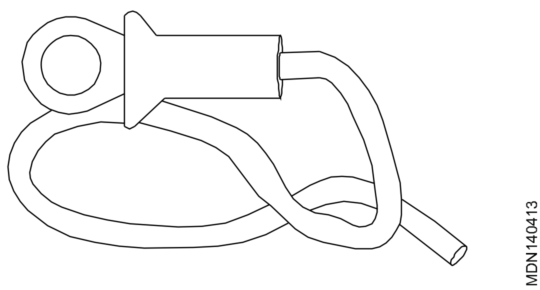
An electrical fusible link is a type of electrical fuse that is constructed simply with a short piece of wire typically four standard wire gauge sizes smaller than the wiring harness that is being protected.

Electrical fusible links are common in high -current automotive applications. The wire in an electrical fusible link is covered with high-temperature fire-resistant insulation to reduce hazards when the wire melts and also encased in special materials that are designed to not catch on fire when exposed to high temperatures.

Fusible links can be found in a variety of places in cars and truck, but they are commonly used in high-amperage applications. Such as starter motors, alternator where load exceeds rated amps.

When this type of fusible link blows, the vehicle will no longer start, but the risks of fire are eliminated.

Fig 3



Circuit Breakers - Automotive

Automotive circuit breakers provide a resettable and reusable alternative over standard fuses for circuit protection, and can altogether replace fuses and fusible links in most applications.

Circuit breakers come in 3 types:

Type 1

This type are auto resettable, and once tripped, will attempt to reset the circuit, as the internal elements of the breaker cool down.

Type 2 (trip and hold)

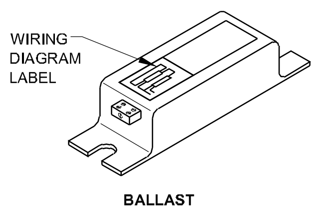
This type are called modified reset, and will remain tripped until the power is removed from the breaker.

Type 3 (circuit breakers)

This type are manual resettable, and require that a button or lever be pushed in order to reset breaker.

Ballast (Choke): The ballast is basically a coil of many turns wound on a laminated iron core (Fig 4). It steps up the supply voltage to start the fluorescent tube conducting. Once the tube is conducting, it regulates the flow of current to the tube cathodes to keep them from burning out.

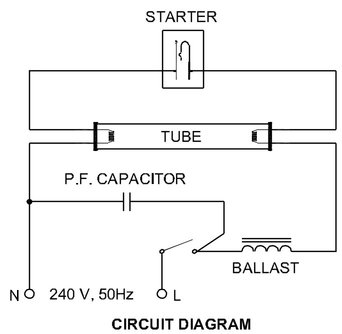
Fig 4



Circuit diagram: The method of connecting the starter, ballast and the tube's electrodes at its either end is shown in Fig 5.

Function of the various parts in a fluorescent light circuit.

Fig 5



Cable colour codes and size

Objectives: At the end of the lesson you shall be able to
- **describe automobile cables**
- **state the needs of colour coding in wiring**
- **state the use of colours in various circuits.**

Description of cables

The cable consists of multi - strand copper conductor covered with good quality PVC insulation.

The current to the various electrical accessories is carried through cables.

The various cables used in wiring are :

- Starting system cable
- General purpose cable
- High tension cable

The specification of the cable refers to the number of stands and diameter of each strand. Eg. 25/012 indicates, the cable consists of 25 strands of 0.012" gauge diameter of each strand.

The size of the cable depends upon the current rating of the accessories connected in that circuit. A thick cable can carry more current and is used in the starting system.

Colour code in cables

In automobiles a number of electric circuits are connnected to the battery which is quite complicated.

The large number of cables are braided into a single har ness assembly.

The automobile manufactures use cables of different colours and usually follow the Lucas colour code system. It consists of basic colours (main colours) and combination of colours to identity individual circuits. (Refer of Fig 1).

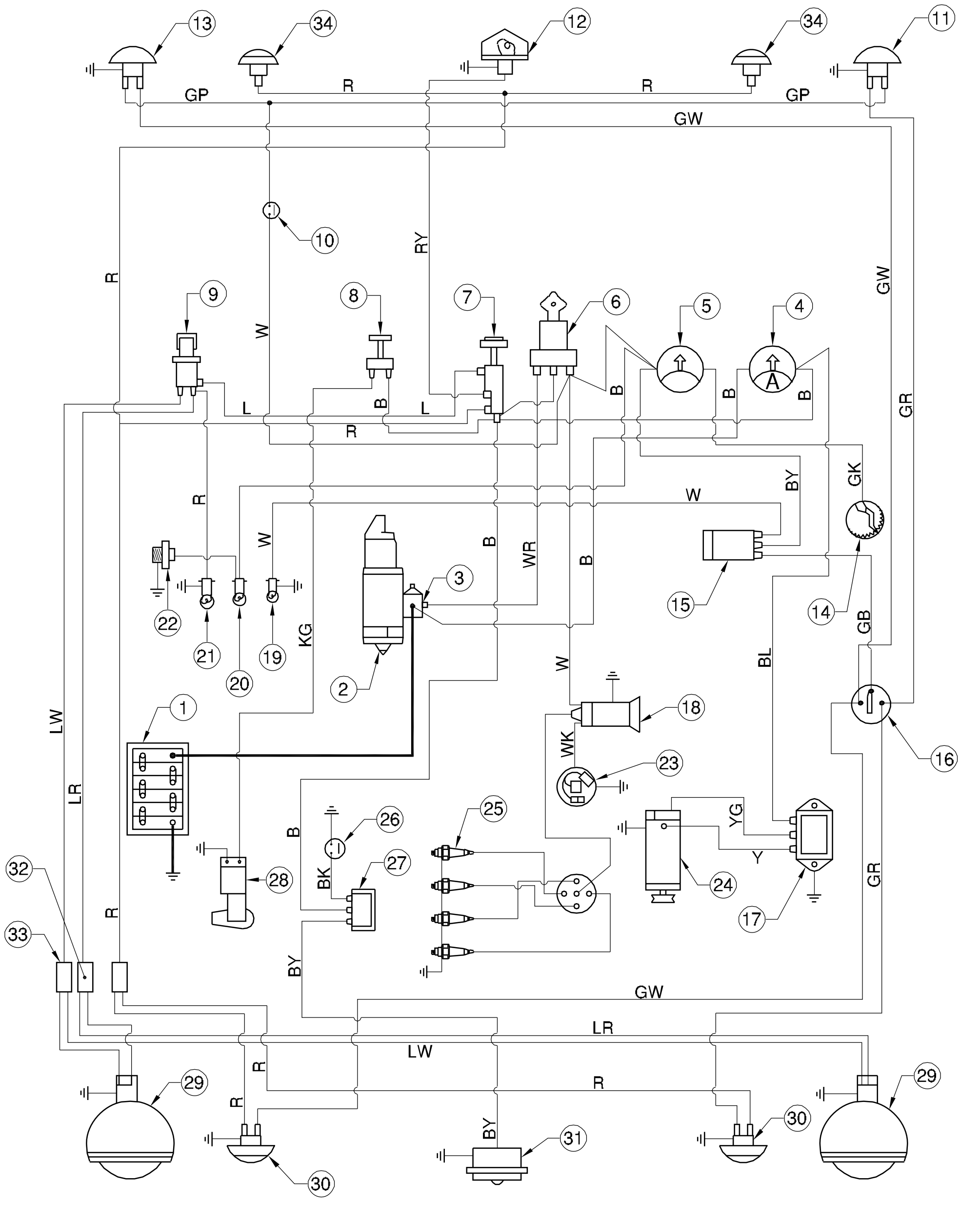
The distinction between wires in a group is done by the use of a coloured bracer on the main colours of the insulator of each wire.

Purpose of colour code

For easy identification of each circuit.

To help to locate the defect easily in a particular circuit and to rectify the same quickly.

Fig 1



NO.	INDEX	NO.	INDEX	COLOUR CODE			
1	BATTERY	18	IGNITION COIL	B	BROWN	GK	GREEN BLACK
2	STARTER MOTOR	19	INDICATOR WARNING LAMP	Y	YELLOW	GP	GREEN PURPLE
3	SOLENOID SWITCH	20	OIL PRESSURE WARNING LAMP	W	WHITE	LR	BLUE RED
4	AMMETER	21	HEAD LIGHT WARNING LAMP	G	GREEN	LW	BLUE WHITE
5	FUEL GUAGE	22	OIL PRESSURE SWITCH	L	BLUE	RG	RED GREEN
6	IGNITION SWITCH	23	DISTRIBUTOR	R	RED	RW	RED WHITE
7	HEADLIGHT SWITCH	24	DYNAMO	K	BLACK	RY	RED YELLOW
8	WIPER SWITCH	25	SPARK PLUG	BL	BROWN BLUE	KG	BLACK GREEN
9	DIM-DIP SWITCH	26	HORN SWITCH	BK	BROWN BLACK		
10	STOP LIGHT SWITCH	27	HORN RELAY	BY	BROWN YELLOW		
11	STOP CUM INDICATOR LAMP	28	WIPER UNIT	BG	BROWN GREEN		
12	NUMBER-PLATE LAMP	29	HEAD LIGHT	YG	YELLOW GREEN		
13	STOP CUM INDICATOR LAMP	30	FRONT PARKING CUM I-LAMP	WR	WHITE RED		
14	FUEL TANK UNIT	31	HORN	WK	WHITE BLACK		
15	FLASHER UNIT	32	DIM SOCKET	GB	GREEN BROWN		
16	INDICATOR SWITCH	33	DIP SOCKET	GW	GREEN WHITE		
17	CONTROL BOX	34	TAIL-LAMP	GR	GREEN RED		

Law of Resistances

Objectives: At the end of this lesson you shall be able to
- **state the Laws of Resistance, compare resistances of different materials**
- **state the formula giving the relationship between the resistance and dimemsions of a conductor**
- **state the effect of temperature on resistance and describe the temperature cofficient of resistance**
- **calculate the resistance of a conductor.**

Laws of resistance (Fig. 1): The resistance R offered by a conductor depends on the following factors.

– The resistance of the conductor varies directly with its length.

– The resistance of the conductor is inversely proportional to its cross-sectional area.

– The resistance of the conductor depends on the material with which it is made of.

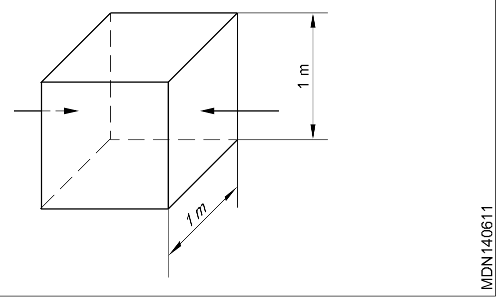
– It also depends on the temperature of the conductor.

Ignoring the last factor for the time being,we can say that

$$R = \frac{PL}{a}$$

where r is a constant depending on the nature of the material of the conductor, and is known as its specific resistance or resistivity.

Fig 1



If the length is one metre and the area, 'a' = 1 m^2, then R = r.

Hence, specific resistance of a material may be defined as `the resistance between the opposite faces of a metre cube of that material'. (sometimes, the unit cube is taken in centimetre cube of that material).

We have $\rho = \frac{aR}{L}$

In the SI system of units

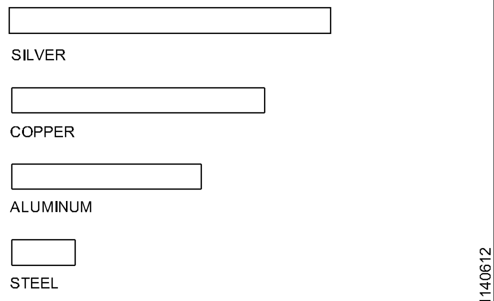
$$\rho = \frac{a\ \text{metre}^2 \times R\ \text{ohm}}{L\ \text{metre}}$$

$$= \frac{aR}{L}\ \text{ohm-metre}$$

Hence the unit of specific resistance is ohm metre (Wm).

Comparison of the resistance of different materials: (Fig 2) gives some relative idea of the more important materials as conductors of electricity. All the conductors have the same cross-sectional area and the same amount of resistance. The silver wire is the longest while that of copper is slightly short and that of aluminium is shorter still. The silver wire is more than 5 times longer than the steel wire.

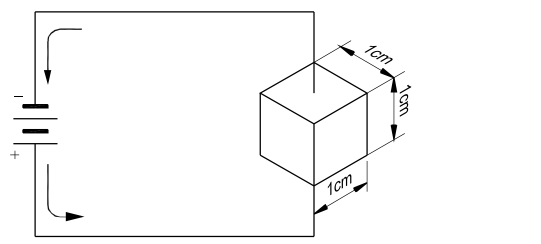
Fig 2



THE CONDUCTANCE OF DIFFERENT MATERIALS

Since different metals have different conductance ratings, they must also have different resistance ratings. The resistance ratings of the different metals can be found by experimenting with a standard piece of each metal in an electric circuit. If you cut a piece of each of the more common metals to a standard size, and then connect the pieces to a battery, one at a time, you would find that different amounts of current would flow. (Fig 3)

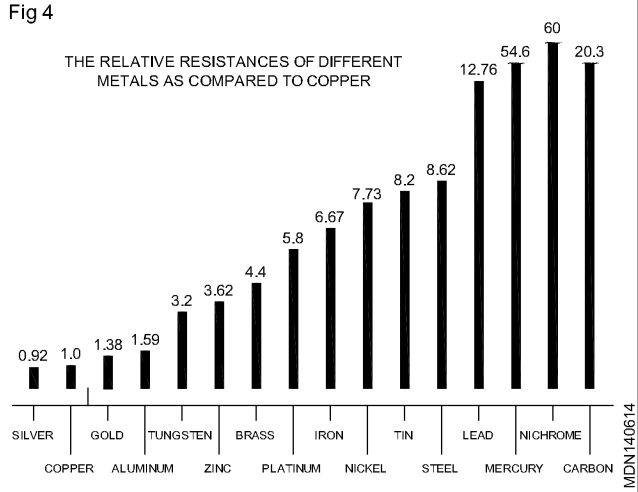
Fig 3



THE MORE RESISTANCE A MATERIAL HAS, THE LESS CURRENT THE MATERIAL WILL CONDUCT. GOOD INSULATORS, SUCH AS GLASS, RUBBER, MICA, POLYSTYRENE, ETC., HAVE CONSIDERABLY MORE THAN A MILLION TIMES THE RESISTANCE OF ANY GOOD CONDUCTOR

The bar graph (Fig 4) shows the resistance of some common metals as compared to copper. Silver is a better conductor than copper because it has less resistance. Nichrome has 60 times more resistance than copper, and copper will conduct 60 times as much current as Nichrome, if they were connected to the same battery, one at a time.

Fig 4



Resistors :

These are the most common passive component used in electronic circuits. A resistor is manufacture with a specific value of ohms resistance. The purpose using a resistor in circuit is either to limit the current to speciifc value or to provide desired voltage drop (IR) The power rating of resistors may be from O.1.W. to hundred of Watts.

Wire - wound resistors

Wire-wound resistors are manufactured by using resistance wire (nickel - chrome alloy called Nichrome) wrapped around an insulating core, such as cerami porcelain bakelite pressed paper etc (Fig 4). The bare wire used in the unit is generally enclosed in insulating material. Wire wound resistors are used for high current application. They are avilable in wattage ratings from one watt to 100 watts or more. The resistance can be less than 1 ohm and go up to several thousand ohms. They are also used where accurate resistance values are required.

One type of Wire-wound resistor is called as fusible resistor enclosed in a porcelain case. The resistance is designed to open the circuit when the current through it exceeds certain limit.

This type of ballast resistor is used in the automobile vechile flasher unit. Due to which the the indicator lamp flash at the regulation of 70-100 times / min.

Resistors and Capacitors

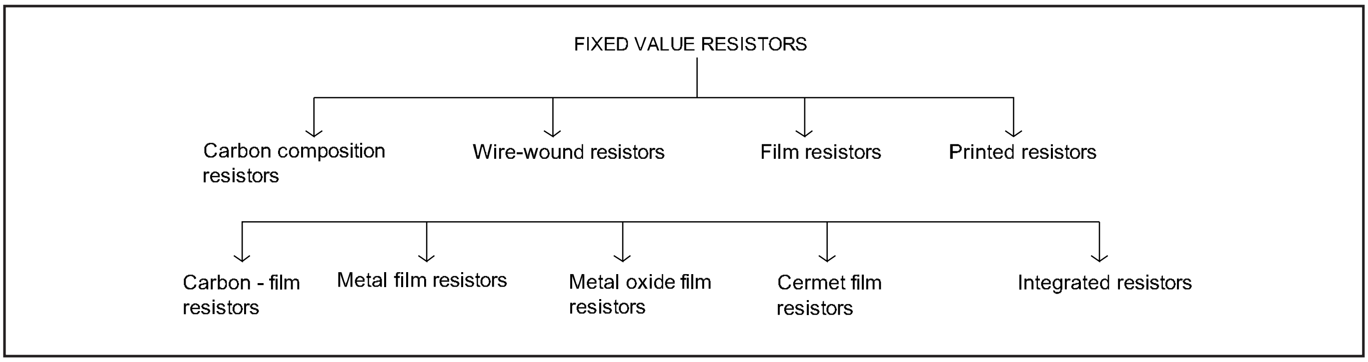
Objectives: At the end of this lesson you shall be able to
- **name the types of resistors**
- **state the meaning of tolerance in resistor**
- **give examples to find the value of a resistor**

Fixed value resistors

Its ohmic value is fixed. This value cannot be changed by the user. Resistors of standard fixed values are manufactured for use in majority of applications.

Fixed resistors are manufactured using different materials and by different methods. Based on the material used and their manufacturing method/process, resistors carry different names.

Fixed value resistors can be classified based on the type of material used and the process of making as follows.

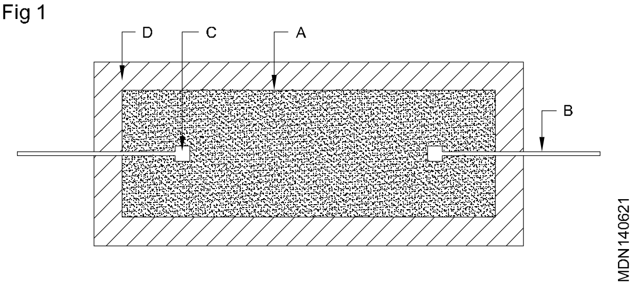


Carbon composition resistors

Construction

These are the simplest and most economical of all other types. Brief constructional detail of the simplest type of carbon composition resistors commonly called carbon resistor is shown in (Fig 1).

Fig 1

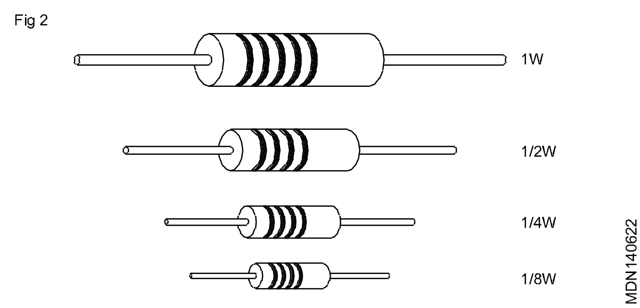


A mixture of finely powdered carbon or graphite(A), filler and binder is made into rods or extruded into desired shapes. Leads(B) made of tinned copper are then attached to the body either by soldering or embedding(C) in the body. A protective layer/tube(D) of phenolic or Bakelite is moulded around the assembly. Finally its resistance value is marked on the body.

Power rating

As already discussed, when current flows through a resistor, heat is generated. The heat generated in a resistor will be proportional to the product of applied voltage (V) across the resistor and the resultant current (I) through the resistor. This product VI is known as *power*. The unit of measurement of power is watts.

Fig 2



The physical size of a resistor should be sufficiently large to dissipate the heat generated. The higher the physical size, the higher is the heat that a resistor can dissipate. This is referred to as the power rating or wattage of resistors. Resistors are manufactured to withstand different power ratings.

(Fig 2) illustrates comparative physical sizes of different wattage resistors. If the product of V and I exceeds the maximum wattage a resistor can dissipate, the resistor gets charred and loses all its property. For instance, if the applied voltage across a 1 watt resistor is 10 volts resulting in 0.5 Amps of current through the resistor, the power dissipated (VI) by the resistor will be 5 watts. But, the maximum power that can be dissipated by the IW resistor is much less. Therefore, the resistor will get overheated and gets charred due to overheat.

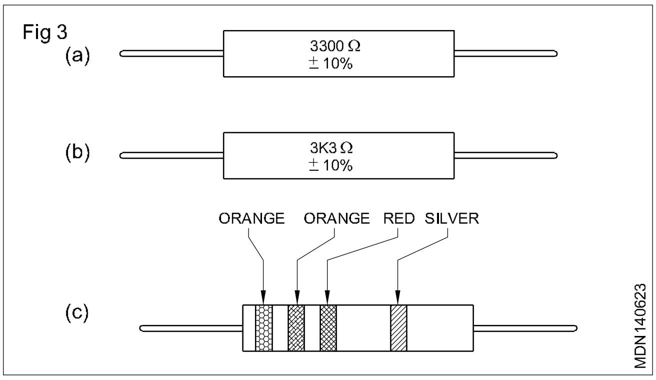
Hence, before using a resistor, in addition to its ohmic value, it is important to choose the correct wattage rating. If in doubt, choose a higher wattage resistor but never on the lower side. The power rating of resistors are generally printed on the body of the resistor.

Resistor values - coding schemes

For using resistors in circuits, depending upon the type of circuit in which it is to be used, a particular type, value and wattage of resistor is to be chosen. Hence before using a resistor in any circuit, it is absolutely necessary to identify the resistor's type, value and power rating.

Selection of a particular type of resistor is possible based on its physical appearance. The resistance value of a resistor will generally be printed on the body of the resistor either directly in ohms as shown in (Fig 3a) or using a typographic code as shown in (Fig 3b) or using a colour code as shown in (Fig 3c).

Fig 3



Colour band coding of resistors

Colour band coding as shown in (Fig 3c) is most commonly used for carbon composition resistors. This is because the physical size of carbon composition resistor is generally small, and hence, printing resistance values directly on the resistor body is difficult. Refer Table 1.

Tolerance

In bulk production/ manufacturing of resistors, it is difficult and expensive to manufacture resistors of particular exact values. Hence the manufacturer indicates a possible variation from the standard value for which it is manufactured. This variation will be specified in percentage tolerance. Tolerance is the range(max -to- min) within which the resistance value of the resistor will exist.

Typographical coding of resistors

In the typographical coding scheme of indicating resistance values, the ohmic value of the resistor is printed on the body of the resistor using an alpha-numeric coding scheme.

> **Some resistance manufacturers use a coding scheme of their own. In such cases it will be necessary to refer to the manufacturer's guide.**

Applications

Carbon composition, fixed value resistors are the most widely used resistors in general purpose electronic circuits such as radio, tape recorder, television etc. More than 50% of the resistors used in electronic industry are carbon resistors.

TABLE 1

Resistor Colour Code

Colour	Significant figures	Multiplier	Tolerance
Silver	-	10^{-2}	± 10%
Gold	-	10^{-1}	± 5%
Black	0	1	-
Brown	1	10	± 1%
Red	2	10^{2}	± 2%
Orange	3	10^{3}	± 3%
Yellow	4	10^{4}	± 4%
Green	5	10^{5}	± 0.5%
Blue	6	10^{6}	-
Violet	7	-	-
Grey	8	-	-
White	9	-	-
(None)	-	-	± 20%

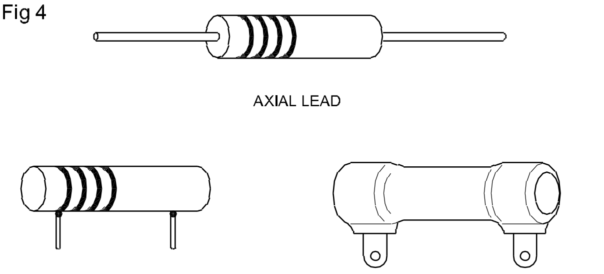
1, 2 and 3: 1st, 2nd and 3rd significant figures ;

M : Multiplier ; T : Tolerance ; T_c : Temperature co-efficient

Types of resistor leads

Resistors are available with different types of lead attachment as shown in Fig 4. This make it easy for the user to mount the resistors in different ways on lug boards, PCBs and other types of circuit boards.

Fig 4



Capacitors

Objectives: At the end of this lesson you shall be able to
- **state and describe a capacitor**
- **state and explain charging of a capacitor**
- **state and explain capacitance and unit of capacitance**
- **state and describe the factors determining the capitance**
- **state and describe the different types of capacitors**
- **explain the defects in capacitors**
- **state and describe the testing of capacitors.**

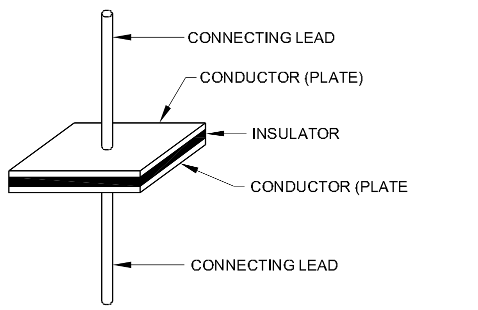
Capacitors

A device designed to posses capacitance is called a capacitor.

Construction

A capacitor is an electrical device consisting of two parallel conductive plates, separated by an insulating material called the dielectric. Connecting leads are attached to the parallel plates. (Fig 1)

Fig 1



SIMPLE CAPACITOR. THE PLATES OF A CAPACITOR ARE ALWAYS INSULATED FROM EACH OTHER

Function

In a capacitor the electric charge is stored in the form of an electrostatic field between the two conductors or plates, due to the ability of dielectric material to distort and store energy while it is charged and keep that charge for a long period or till it is discharged through a resistor or wire. The unit of charge is coulomb and it is denoted by the letter `C'.

How a capacitor stores charge?

In the neutral state, both plates of a capacitor have an equal number of free electrons, as indicated in (Fig 2a). When the capacitor is connected to a voltage source through a resistor, the electrons (negative charge) are removed from plate A, and an equal number are deposited on plate `B'. Plate A becomes positive with respect to plate B as shown in (Fig 2b).

The current enters and leaves the capacitor, but the insulation between the capacitor plates prevents the current from flowing through the capacitor.

As electrons flowing into the negative plate of a capacitor have a polarity opposite to that of the battery supplying the current, the voltage across the capacitor opposes the battery voltage. The total circuit voltage, therefore, consists of two series-opposing voltages.

As the voltage across the capacitor increases, the effective circuit voltage, which is the difference between the battery voltage and the capacitor voltage, decreases. This, in turn, causes a decrease in the circuit current. When the voltage across the capacitor equals the battery voltage, the effective voltage in the circuit is zero, and so the current flow stops. At this point, the capacitor is fully charged, and no further current can flow in the circuit.

Capacitance (Fig 2c)

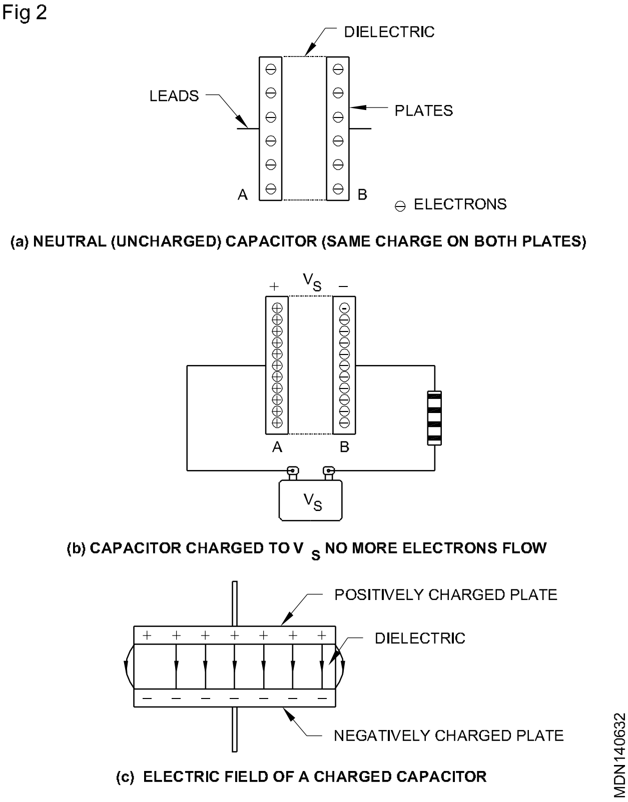
The ability to store energy in the form of electric charge is called capacitance. The symbol used to represent capacitance is C.

Unit of capacitance

The base unit of capacitance is farad. The abbreviation for farad is F. One farad is that amount of capacitance which stores 1 coulomb of charge when the capacitor is charged to 1 V. In other words, a farad is a coulomb per volt (C/V).

A farad is the unit of capacitance (C), and a coulomb is the unit of charge(Q), and a volt is the unit of voltage(V).

Fig 2



Grouping of capacitors

Objectives : At the end of this lesson you shall be able to
- **state the necessity of grouping of capacitors**
- **list the conditions for connecting capacitors in parallel**
- **determine the values of capacitance and voltage in parallel combination**
- **list the conditions for connecting capacitors in series**
- **determine the values of capacitance and voltage in series combination.**

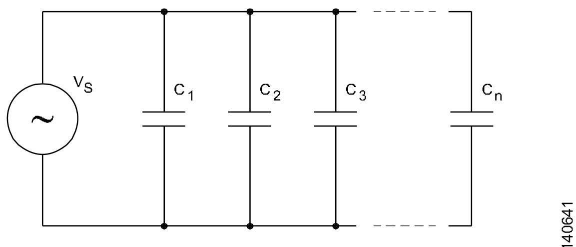
Necessity of grouping of capacitors

In certain instances, we may not be able to get a required value of capacitance and a required voltage rating. In such instances, to get the required capacitances from the available capacitors and to give only the safe voltage across capacitor, the capacitors have to be grouped in different fashions. Such grouping of capacitors is very essential.

Necessity of parallel grouping

Capacitors are connected in parallel to achieve a higher capacitance than what is available in one unit.

Fig 1



CAPACITORS IN PARALLEL

Connection of parallel grouping

Parallel grouping of capacitors is shown in (Fig 1) and is analogous to the connection of resistance in parallel or cells in parallel.

Total capacitance

When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances, because the effective plate area increases. The calculation of total parallel capacitance is analogous to the calculation of total resistance of a series circuit.

By comparing (Fig 2a and 2b), you can understand that connecting capacitors in parallel effectively increases the plate area.

General formula for parallel capacitance

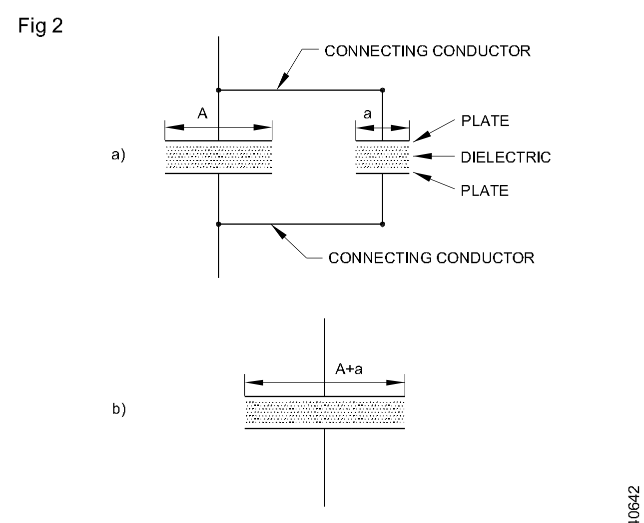
The total capacitance of parallel capacitors is found by adding the individual capacitances.

$$C_T = C_1 + C_2 + C_3 + ... + C_n$$

where C_T is the total capacitance,

C_1, C_2, C_3 etc. are the parallel capacitors.

The voltage applied to a parallel group must not exceed the lowest breakdown voltage for all the capacitors in the parallel group.



CAPACITORS IN PARALLEL. THE EQUIVALENT CAPACITANCE IN (b) IS EQUAL TO THE SUM OF THE CAPACITANCES IN (a).

Example: Suppose three capacitors are connected in parallel, where two have a breakdown voltage of 250 V and one has a breakdown voltage of 200 V, then the maximum voltage that can be applied to the parallel group without damaging any capacitor is 200 volts.

The voltage across each capacitor will be equal to the applied voltage.

Charge stored in parallel grouping

Since the voltage across parallel-grouped capacitors is the same, the larger capacitor stores more charge. If the capacitors are equal in value, they store an equal amount of charge. The charge stored by the capacitors together equals the total charge that was delivered from the source.

$Q_T = Q_1 + Q_2 + Q_3 + ... + Q_n$

where Q_T is the total charge

Q_1, Q_2, Q_3.....etc. are the individual

charges of the capacitors in parallel.

Using the equation Q = CV,

the total charge $Q_T = C_T V_S$

where V_S is the supply voltage.

Again $C_T V_S = C_1 V_S + C_2 V_S + C_3 V_S$

Because all the V_S terms are equal, they can be cancelled.

Therefore, $C_T = C_1 + C_2 + C_3$

Series grouping

Necessity of grouping of capacitors in series

The necessity of grouping capacitors in series is to reduce the total capacitance in the circuit. Another reason is that two or more capacitors in series can withstand a higher potential difference than an individual capacitor. But, the voltage drop across each capacitor depends upon the individual capacitance. If the capacitances are unequal, you must be careful not to exceed the breakdown voltage of any capacitor.

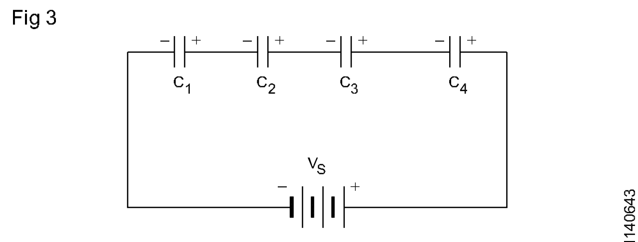
Conditions for series grouping

– If different voltage rating capacitors have to be connected in series, take care to see that the voltage drop across each capacitor is less than its voltage rating.

– Polarity should be maintained in the case of polarised capacitors.

Connection in series grouping

Series grouping of capacitors, as shown in (Fig 3) is analogous to the connection of resistances in series or cells in series.



SERIES CONNECTION OF CAPACITORS

Total capacitance

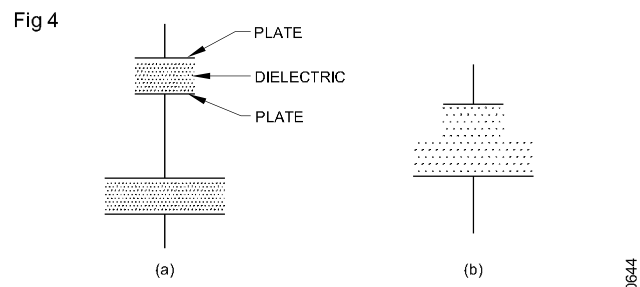
When capacitors are connected in series, the total capacitance is less than the smallest capacitance value, because

– the effective plate separation thickness increases

– and the effective plate area is limited by the smaller plate.

The calcualtion of total series capacitance is analogous to the calculation of total resistance of parallel resistors.

By comparing (Fig 4a and 4b) you can understand that connecting capacitors in series increases the plate separation thickness, and also limits the effective area so as to equal that of the smaller plate capacitor.



THE EQUIVALENT CAPACITANCE IN (b) IS LESS THAN THE LOWER OF THE TWO CAPACITANCES IN (a).

General formula for series capacitance

The total capacitance of the series capacitors can be calculated by using the formula

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}}$$

or

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$$

If there are two capacitors in series

$$C_T = \frac{C_1 C_2}{C_1 + C_2}$$

If there are three capacitors in series

$$C_T = \frac{C_1 C_2 C_3}{(C_1C_2) + (C_2C_3) + (C_3C_1)}$$

If there are `n' equal capacitors in series

$$C_T = \frac{C}{n}$$

Maximum voltage across each capacitor

In series grouping, the division of the applied voltage among the capacitors depends on the individual capacitance value according to the formula

$$V = \frac{Q}{C}$$

The largest value capacitor will have the smallest voltage because of the reciprocal relationship.

Likewise, the smallest capacitance value will have the largest voltage.

The voltage across any individual capacitor in a series connection can be determined using the following formula.

$$V_x = \frac{C_T}{C_x} \times V_s$$

where

V_x - individual voltage of each capacitor

C_x - individual capacitance of each capacitor

V_s - supply voltage.

The potential difference does not divide equally if the capacitances are unequal. If the capacitances are unequal you must be careful not to exceed the breakdown voltage of any capacitor.

Example: Find the voltage across each capacitor in Fig 6.

DC series - parallel - series and parallel combination circuits

Objectives: At the end of this lesson you shall be able to
- **identify the series connection and determine the current in the series circuit**
- **determine the voltage across elements in a series circuit**
- **determine the total voltage in a circuit when the voltage sources are in series**
- **state the uses of a series connection.**

The 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

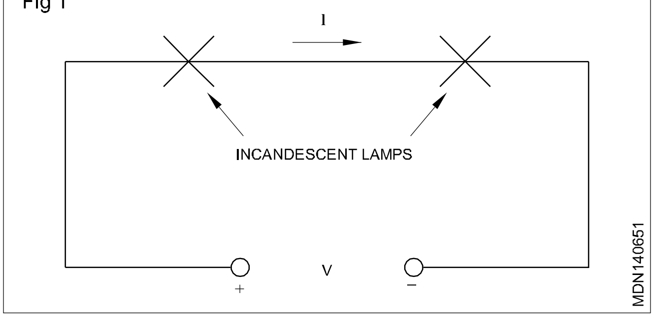
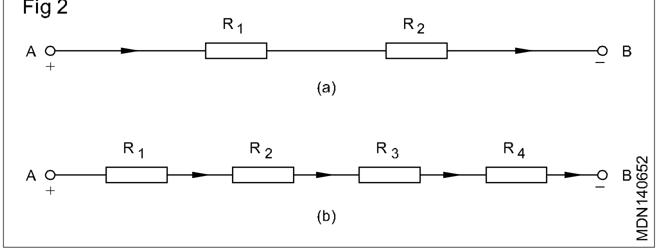


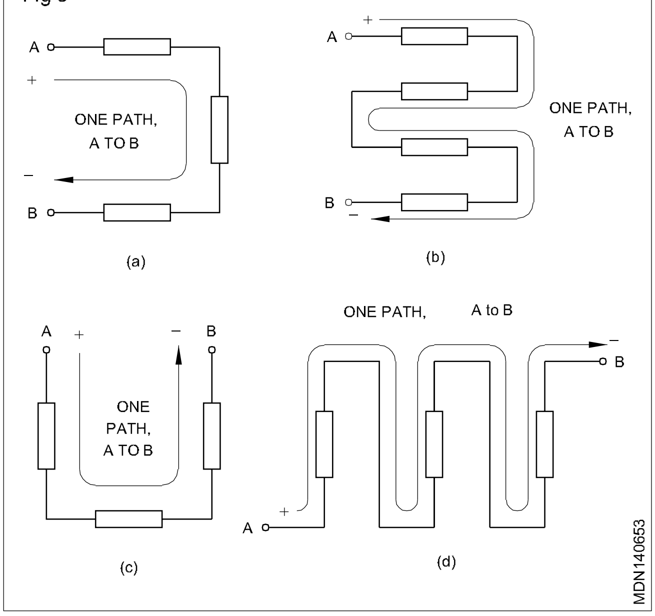
Fig 2



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.

Identifying series connections

Fig 3



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 (Fig 4 (a) and 4(b)). The ammeters will show the same reading.

The current relationship in a series circuit is

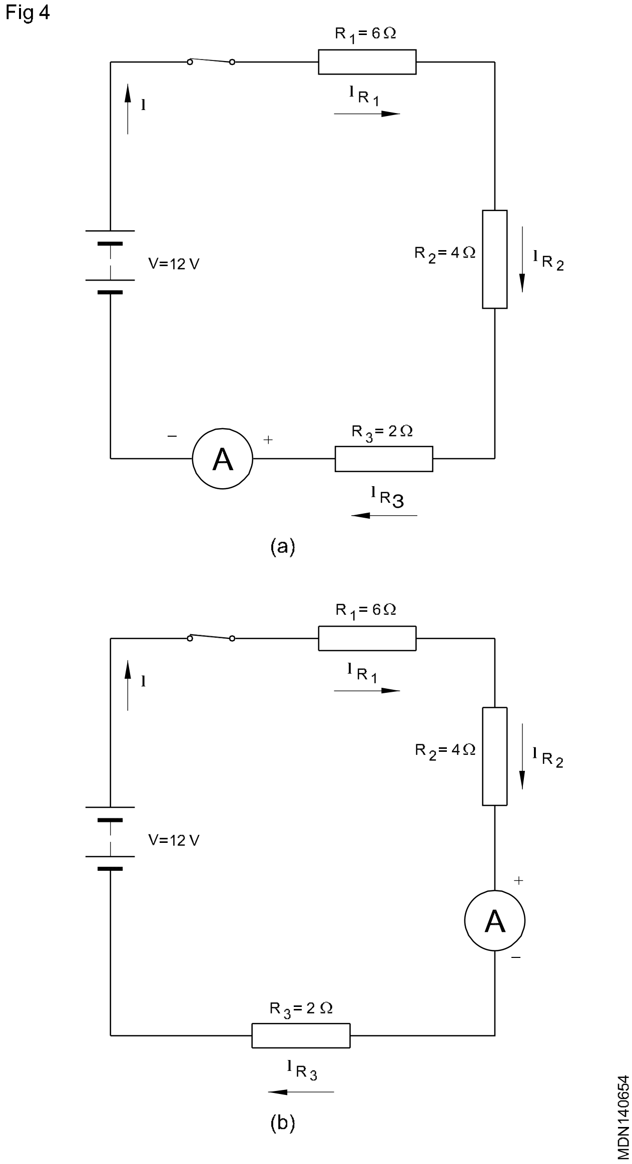
$I = I_{R1} = I_{R2} = I_{R3}$. (Refer Fig 4)

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.

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.

Fig 4



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

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

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 resistances connected in series.

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

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.

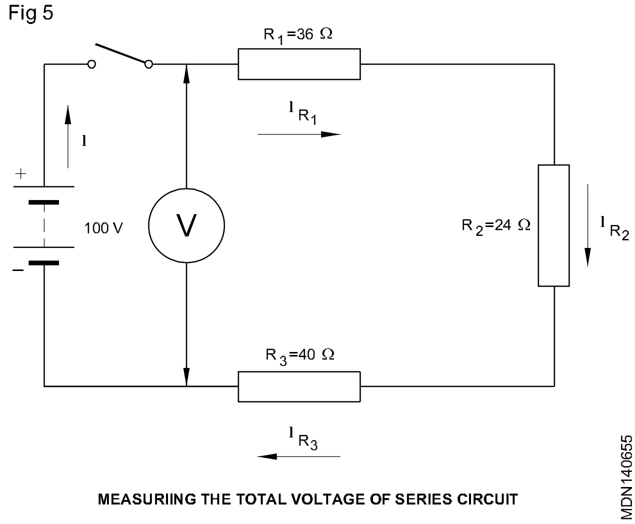
The 3rd characteristic of a DC circuit can be written as follows.

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

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

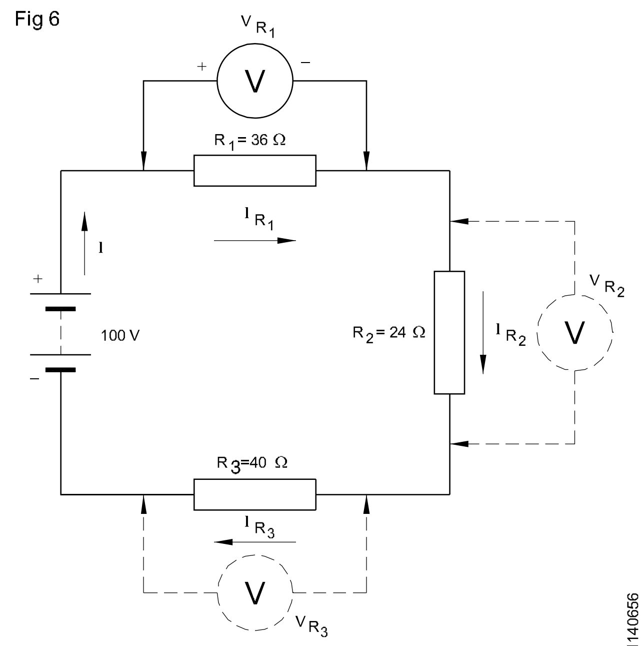
the total voltage of a series circuit must be measured across the voltage source, as shown in (Fig 5).

Fig 5



MEASURIING THE TOTAL VOLTAGE OF SERIES CIRCUIT

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

I = 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

Potential difference and polarity of I R voltage drops

Objectives: At the end of this lesson you shall be able to

- **state the relation between the emf, potential difference and terminal voltage**
- **define I.R. drop (voltage drop) in a DC series circuit**
- **identify polarity of voltage drops**
- **identify positive and negative grounds**
- **mark the polarity of the voltage drop with respect to ground to determine the terminals of the voltmeter.**

Definitions

Electromotive force (emf)

We have seen in Related Theory of Exercise 1.07, 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 = emf – IR

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

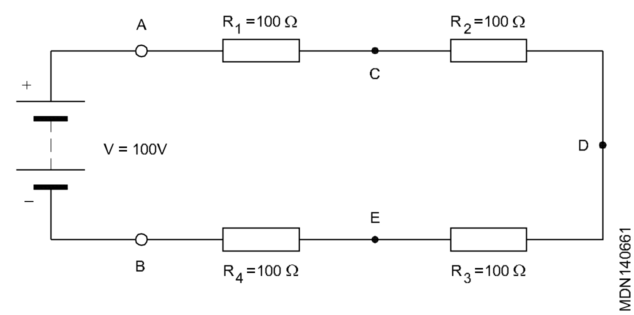
Voltage drop (IR drop)

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)

What are 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 x 100 = 25 V

V_{R2} = 0.25 x 100 = 25 V

V_{R3} = 0.25 x 100 = 25 V

V_{R4} = 0.25 x 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.

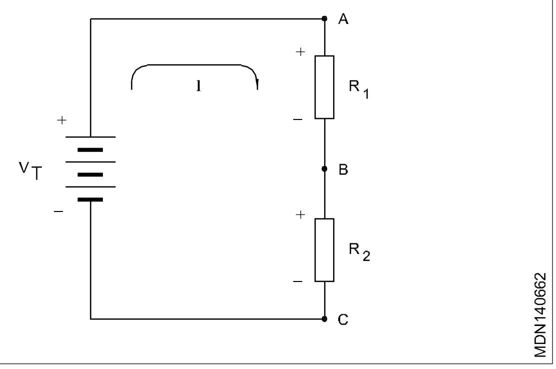
The sum of the voltage drops in a circuit must be equal to the applied voltage.

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

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 (Fig 2), the current direction is through R_1 from point A to B.

Fig 2



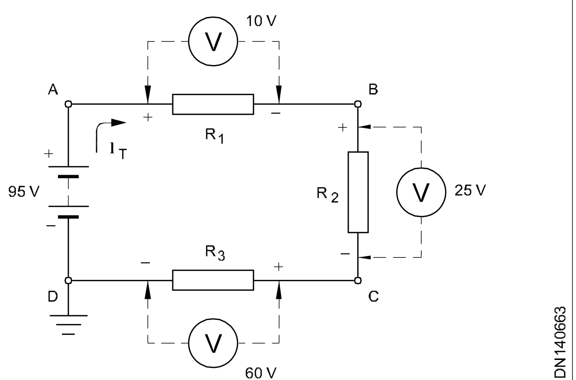
Therefore, the terminal of R_1 connected to point A has a more positive potential than point B. We say that the voltage across R_1 is such that point A is more positive than point B. Similarly the voltage of point B is more positive than point C. Another way to look at polarity between any two points 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)

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.

Fig 3



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.

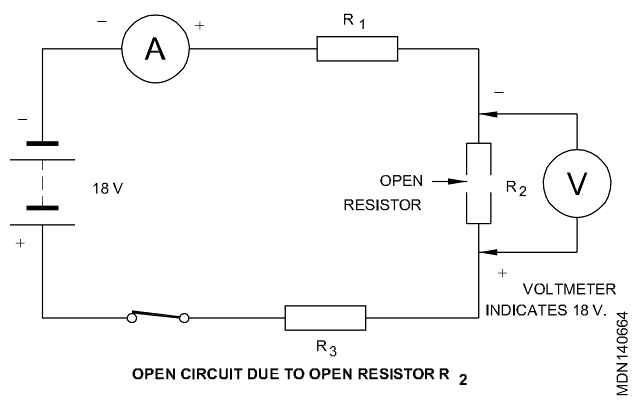
There is a voltage drop of 10 V across R_1; so voltage at B is

$V_B = +85$ V.

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



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.

How can we determine where a 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 wire 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. That is

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.

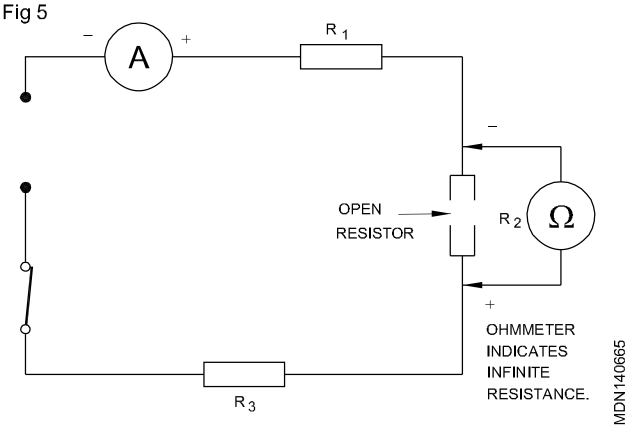
Alternatively, the open circuit may be found using an ohmmeter. With the voltage removed, the ohmmeter will show no continuity (infinite resistance), when connected across the broken wire or open resistor. (Fig 5)

Practical application

With the knowledge gained from this lesson:

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

Fig 5



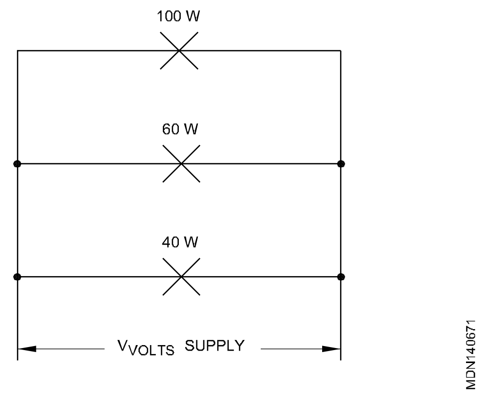
DC parallel circuit

Objectives: At the end of this lesson you shall be able to
- **explain a parallel connection**
- **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.**

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



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) could also be drawn as shown in (Fig 3).

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

Fig 2

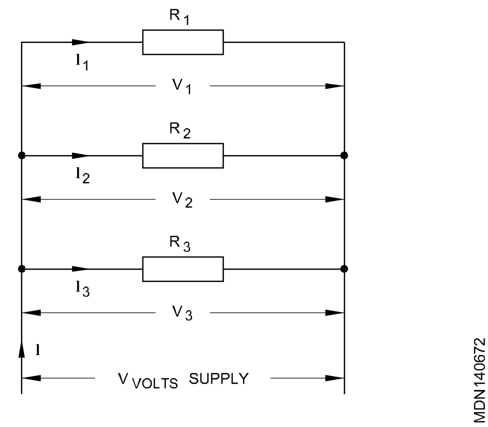
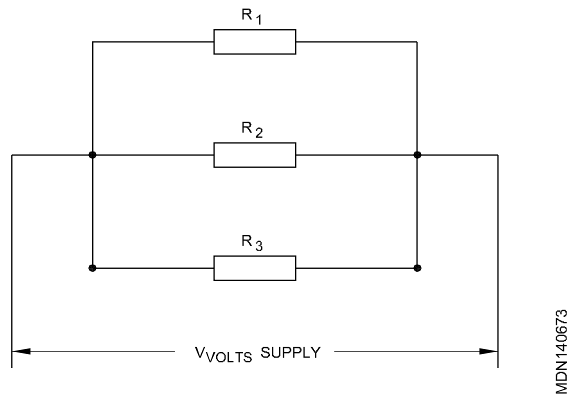


Fig 3



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 $R_1 = I_1 =$ $=$.

Current in resistor $R_2 = I_2 =$ $=$.

Current in resistor $R_3 = I_3 =$ $=$

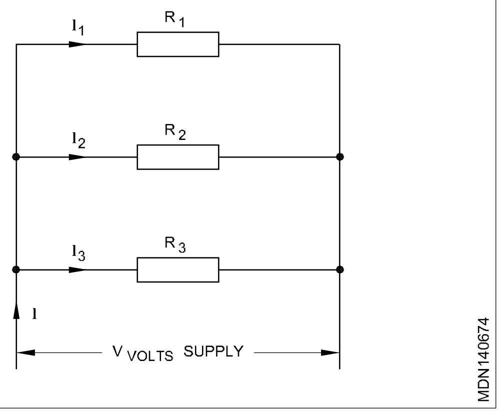
as $V_1 = V_2 = V_3$.

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.

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 (Fig 4)

Fig 4



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

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

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

$$I = I_1 + I_2 + I_3$$

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

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

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

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.

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

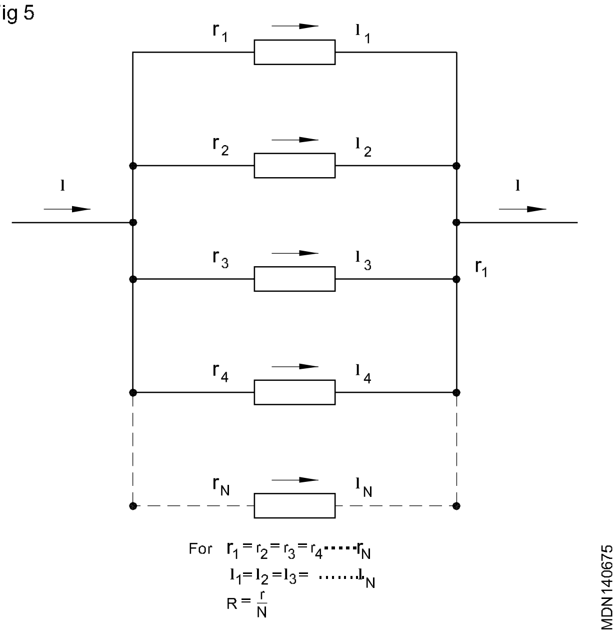
Applications of parallel circuits

An electric system in which section can fail and other sections continue to operate in 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 independently.

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.

Fig 5



Series parallel combination

Objectives: At the end of this lesson you shall be able to
- **compare the characteristics of series and parallel circuits**
- **solve the series-parallel circuit problems**
- **calculate the current in series-parallel circuits.**

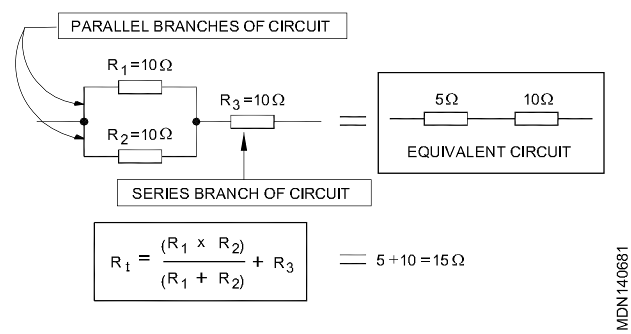
Comparison of characteristics of DC series and parallel ciruits

Series circuit	Parallel circuit
1 The sum of voltage drops across the individual resistances equals the applied voltage.	The applied voltage is the same across each branch.
2 The total resistance is equal to the sum of the individual resistances that make up the circuit. $R_t = R_1+R_2+R_3+...$ etc	The reciprocal of the total resistance equals the sum of the reciprocal of the resistances. The resultant resistance is less than the smallest resistance of the parallel combination.
3 Current is the same in all parts of the circuit.	The current divides in each branch according to the resistance of each branch.
4 Total power is equal to the sum of the power dissipated by the individual resistances.	(Same as series circuit) Total power is equal to the sum of the power dissipated by the individual resistances.

Formation of series parallel circuit

Apart from the series circuit and parallel circuits, the third type of circuit arrangement is the series-parallel circuit. In this circuit, there is at least one resistance connected in series and two connected in parallel. The two basic arrangements of the series-parallel circuit are shown here. In one, resistor R_1 and R_2 are connected in parallel and this parallel connection, in turn, is connected in series with resistance R_3.(Fig 1)

Fig 1

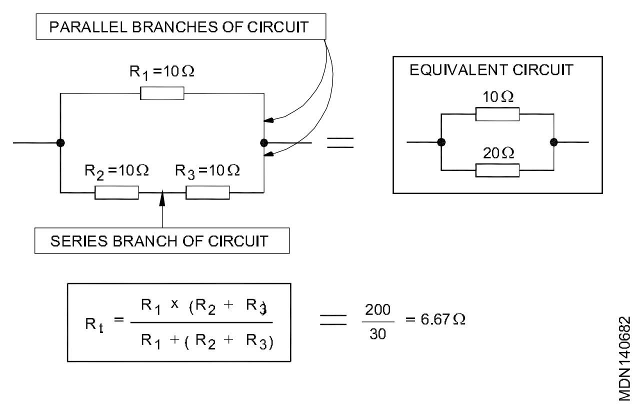


Thus, R_1 and R_2 form the parallel component, and R_3 the series component of a series-parallel circuit. The total resistance of any series-parallel circuit can be found by merely reducing it into a simple series circuit. For example, the parallel portion of R_1 and R_2 can be reduced to an equivalent 5-ohm resistor(two 10-ohm resistors in parallel).

Then it has an equivalent circuit of a 5-ohm resistor in series with the 10-ohm resistor(R_3), giving a total resistance of 15 ohms for the series-parallel combination.

A second basic series-parallel arrangement is shown in (Fig 2) where basically it has two branches of a parallel circuit. However, in one of the branches it has two resistances in series R_2 and R_3. To find the total resistance of this series -parallel circuit, first combine R_2 and R_3 into an equivalent 20-ohm resistance. The total resistance is then 20 ohms in parallel with 10 ohms, or 6.67 ohms.

Fig 2



Combination circuits

A series-parallel combination appears to be very complex.

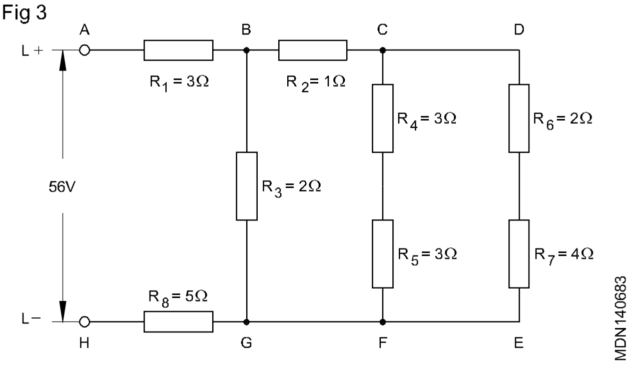
However, a simple solution is to break down the circuit into series/or parallel groups, and while solving problems, each may be dealt with individually. Each group may be replaced by one resistance, having the value equal to the sum of all resistances.

Each parallel group may be replaced by one resistance value equivalent to the combined resistance of that group. Equivalent circuits are to be prepared for determining the current, voltage and resistance for each component.

Example

Determine the combined resistance of the circuit shown in (Fig 3).

Fig 3



PROCEDURE

1) Combine R_6 and R_7.

$R_a = R_6 + R_7$

$R_a = 2 + 4$

$R_a = 6$ ohms.

2) Draw an equivalent circuit with resistance Ra. (Fig 4)

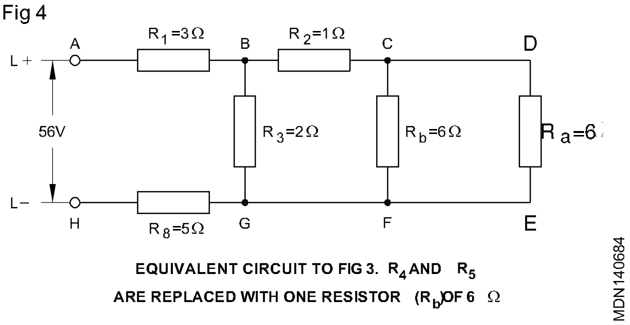
3) Combine R_4 and R_5 of Fig 4.

$R_b = R_4 + R_5$

$R_b = 3 + 3$

$R_b = 6$ ohms.

Fig 4

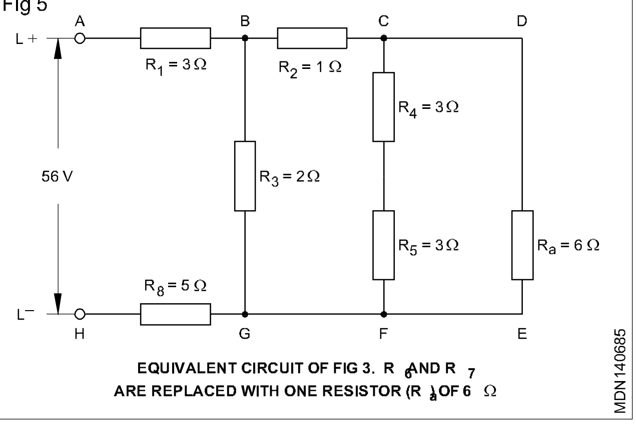


EQUIVALENT CIRCUIT TO FIG 3. R_4 AND R_5 ARE REPLACED WITH ONE RESISTOR (R_b) OF 6 Ω

4) Draw an equivalent circuit as per Figure 5.

5) Combine R_a and R_b and call the equivalent resistance value as R_C. (Fig 5)

Fig 5



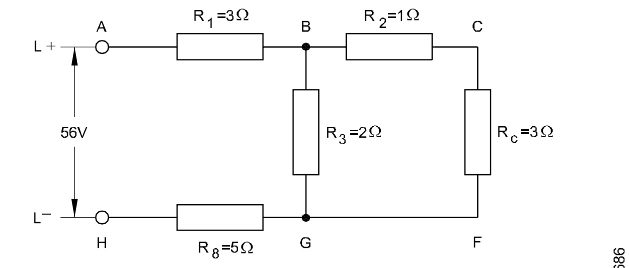
EQUIVALENT CIRCUIT OF FIG 3. R_6 AND R_7 ARE REPLACED WITH ONE RESISTOR (R_a) OF 6 Ω

$$\frac{36}{12} R_c = \frac{R_a \times R_b}{R_a + R_b} = \frac{6 \times 6}{6 + 6}$$

$$= \frac{36}{12} \; 3 \text{ ohms.}$$

6) Draw the equivalent circuit. (Fig 6)

Fig 6



EQUIVALENT CIRCUIT TO FIG 3, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_c) OF 3 Ω .

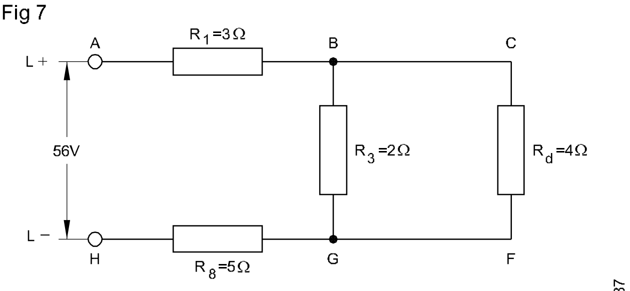
7) Combine R_2 and R_c and call the equivalent resistance R_d.

$R_d = R_2 + R_c$

$R_d = 1 + 3$ $R_d = 4$ ohms.

8) Draw an equivalent circuit. (Fig 7)

Fig 7



EQUIVALENT CIRCUIT TO FIG 3, R_2, R_4, R_5, R_6, R_7 ARE REPLACED WITH ONE RESISTANCE (R_d) OF 4Ω.

9) Now combine R_3 and R_d and call it R_e

$$R_e = \frac{R_3 \times R_d}{R_3 + R_d} = \frac{2 \times 4}{2 + 4}$$

$$= \frac{8}{6} = \frac{4}{3} = 11/3 \text{ ohms.}$$

10) Draw an equivalent circuit. (Fig 8)

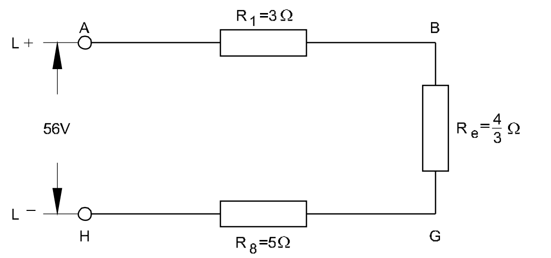
11) Combine R_1, R_e, and R_8.

$R_t = R_1 + R_e + R_8$

$$R_t = 1\frac{1}{3} + 5 + 5$$

$$R_t = 9 = \frac{1}{3} \text{ ohms.}$$

Fig 8



EQUIVALENT CIRCUIT IN FIG 3, R_2, R_3, R_4, R_5, R_6, AND R_7 ARE REPLACED WITH ONE RESISTANCE (R_e) EQUAL TO $\frac{4}{3}\Omega$.

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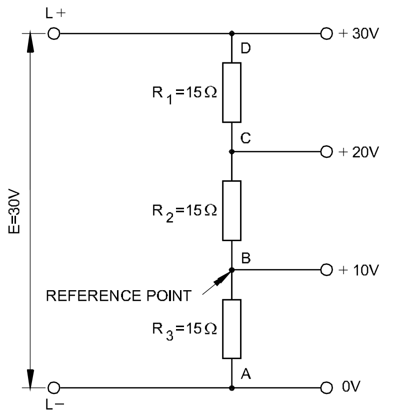
The total combined resistance of the circuit is $9\frac{1}{3}$ ohms.

Application

Series-parallel circuits can be used to form a specific resistance value which is not available in the market and can be used in the voltage divider circuits (Fig 9).

Fig 9



VOLTAGE VALUES ARE GIVEN FOR VOLTAGE DROP TESTS TAKEN ACROSS RESISTORS FROM A TO B (+10V), B TO C (+10V) AND B TO D (+20V). NOTE THAT THE CIRCUIT IS GROUNDED AT REFERENCE POINT B.

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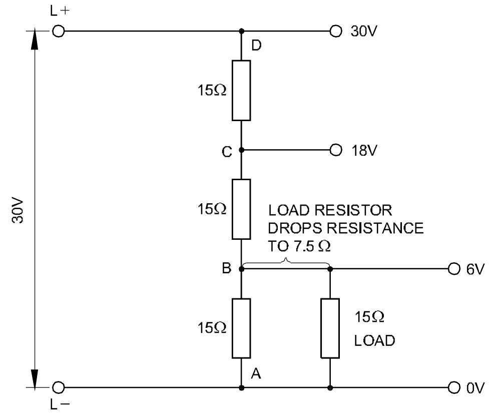
Voltage divider

To have different voltages for different parts of a circuit, construct a voltage divider. In effect, a voltage divider is nothing more than a series-parallel circuit.

A good voltage divider cannot be designed without first looking at the load resistance. Note in (Fig 9) that a voltage divider is made with three 15 ohm resistors to get 10 volts drop across each one.

Fig 10



THREE 15 OHMS RESISTORS AND ONE 15 OHM LOAD RESISTOR SERVE AS A VOLTAGE DIVIDER THAT ROUTES DIFFERENT VOLTAGES TO DIFFERENT PARTS OF THE CIRCUIT.

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However, as soon as another resistor (load) is added as in (Fig 10), there is a further change. The load resistor serves to drop the total resistance of the lower part of the voltage divider. Use this formula for finding the equivalent resistance (R_{eq}) of resistors of equal value in a parallel circuit:

$$R_{eq} = \frac{r}{N}$$

$$R_{eq} = \frac{15}{2} = 7.5\text{ohms,}$$

The equivalent resistance of these two 15 ohm resistors in the lower part of the voltage divider is 7.5 ohms. What will happen to the current and voltage in the circuit as a result of this resistance change?

Remember that, as resistance goes down, current goes up. Therefore, with the addition of the load resistor, the circuit will now carry higher amperage but the voltage between points A and B as well as A and C changes. It is important, then, when constructing a voltage divider circuit, to watch the resistance values which change both voltage and current values. Study Figure 10 carefully to make sure you understand how a voltage divider works.