Fundamental of electricity - conductors - insulators - wire size measurement - crimping

Objectives: At the end of this lesson you shall be able to
- **define electricity and atom**
- **explain about the atomic structure**
- **define the fundamental terms and definition of electricity**
- **state the type of supply, polarity and the effects of electric current**
- **state the conductors, insulators, wires - size measurement methods**

Introduction

Electricity is one of the today's most useful sources of energy. Electricity is of utmost necessity in the modern world of sophisticated equipment and machinery.

Electricity in motion is called electric current. Whereas the electricity that does not move is called static electricity.

Examples of static electricity

- Shock received from door knobs of a carpeted room.
- Attraction of tiny paper bits to the comb.

Structure of matter

Electricity is related to some of the most basic building blocks of matter that are atoms (electrons and protons). All matter is made of these electrical building blocks, and, therefore, all matter is said to be 'electrical'.

Atom

Matter is defined as anything that has mass and occupies space. A matter is made of tiny, invisible particles called molecules. A molecule is the smallest particle of a substance that has the properties of the substance. Each molecule can be divided into simpler parts by chemical means. The simplest parts of a molecule are called atoms.

Basically, an atom contains three types of sub-atomic particles that are of relevance to electricity. They are the electrons, protons and neutrons. The protons and neutrons are located in the centre, or nucleus, of the atom, and the electrons travel around the nucleus in orbits.

Atomic structure

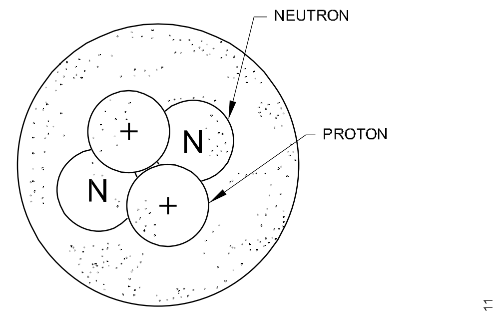
The Nucleus

The nucleus is the central part of the atom. It contains the protons and neutrons in equlal numbrs shown in Fig 1.

Protons

The proton has a positive electrical charge. (Fig 1) It is almost 1840 times heavier than the electron and it is the permanent part of the nucleus; protons do not take an active part in the flow or transfer of electrical energy.

Fig 1

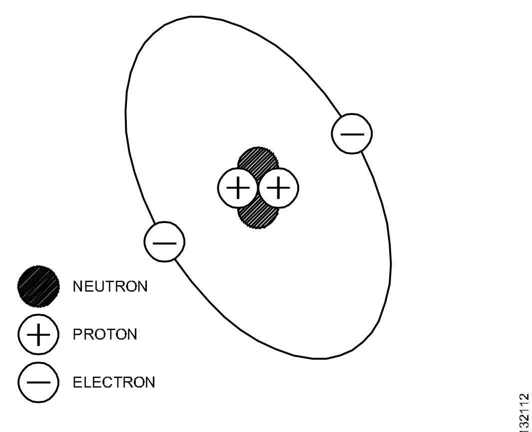


NUCLEUS OF AN ATOM

Electron

It is a small particle revolving round the nucleus of an atom (as shown in Fig 2). It has a negative electric charge. The electron is three times larger in diameter than the proton. In an atom the number of protons is equal to the number of electrons.

Fig 2



REVOLVING OF ELECTRON

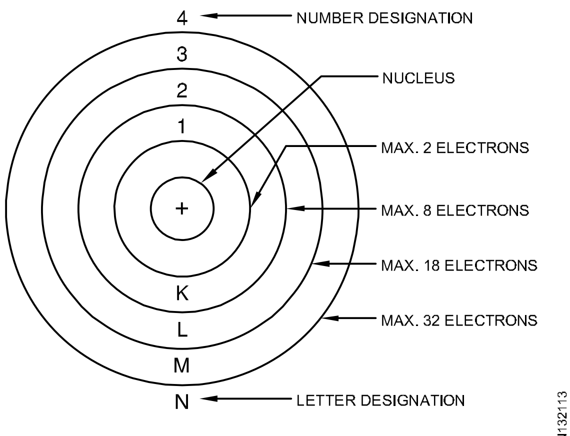
Neutron

A neutron is actually a particle by itself, and is electrically neutral. Since neutrons are electrically neutral, they are not too important to the electrical nature of atoms.

Energy shells

In an atom, electrons are arranged in shells around the nucleus. A shell is an orbiting layer or energy level of one or more electrons. The major shell layers are identified by numbers or by letters starting with 'K' nearest the nucleus and continuing alphabetically outwards. There is a maximum number of electrons that can be contained in each shell. Fig 3 illustrates the relationship between the energy shell level and the maximum number of electrons it can contain.

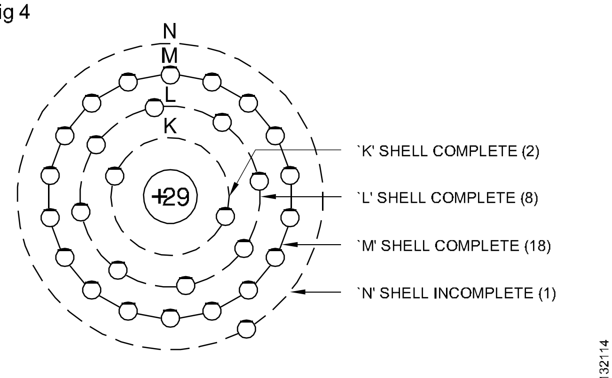
Fig 3



SHELL LEVEL AND ELECTRONS

If the total number of electrons for a given atom is known, the placement of electrons in each shell can be easily determined. Each shell layer, beginning with the first, is filled with the maximum number of electrons in sequence. For example, a copper atom which has 29 electrons would have four shells with a number of electrons in each shell as shown in Fig 4.

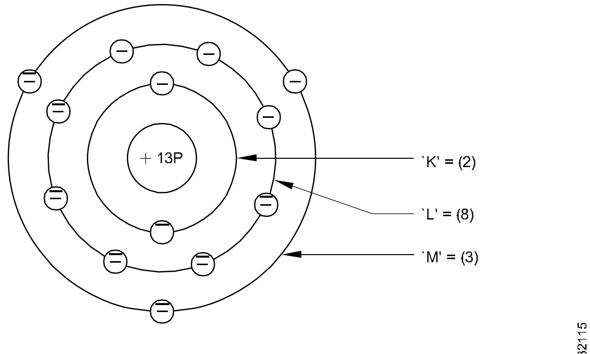
Fig 4



COPPER ATOM

Similarly an aluminium atom which has 13 electrons has 3 shells as shown in Fig 5.

Fig 5



ALUMINIUM ATOM

Electron distribution

The chemical and electrical behaviour of atoms depends on how completely the various shells and sub-shells are filled.

Atoms that are chemically active have one electron more or one less than a completely filled shell. Atoms that have the outer shell exactly filled are chemically inactive. They are called inert elements. All inert elements are gases and do not combine chemically with other elements.

Metals possess the following characteristics.

- They are good electric conductors.
- Electrons in the outer shell and sub-shells can move more easily from one atom to another.
- They carry charge through the material.

The outer shell of the atom is called the valence shell and its electrons are called valence electrons. Because of their greater distance from the nucleus, and because of the partial blocking of the electric field by electrons in the inner shells, the attracting force exerted by nucleus on the valence electrons is less. Therefore, valence electrons can be set free most easily. Whenever a valence electron is removed from its orbit it becomes a free electron. Electricity is commonly defined as the flow of these free electrons through a conductor. Though electrons flow from negative terminal to positive terminal, the conventional current flow is assumed as from positive to negative.

Conductors, insulators and semiconductors

Conductors

A conductor is a material that has many valance electrons permitting electrons to move through it easily. Generally, conductors have many valence shells of one, two or three electrons. Most metals are conductors.

Some common good conductors are Copper, Aluminium, Zinc, Lead, Tin, Eureka, Nichrome, are conductors, where as silver and gold are very good conductors

Insulators

An insulator is a material that has few, if any, free electrons and resists the flow of electrons. Generally, insulators have full valence shells of five, six or seven electrons. Some common insulators are air, glass, rubber, plastic, paper, porcelain, PVC, fibre, mica etc.

Semiconductors

A semiconductor is a material that has some of the characteristics of both the conductor and insulator. Semiconductors have valence shells containing four electrons.

Common examples of pure semiconductor materials are silicon and germanium. Specially treated semiconductors are used to produce modern electronic components such as diodes, transistors and integrated circuit chips.

Simple electrical circuit and its elements

Objectives: At the end of this lesson you shall be able to
- **describe a simple electric circuit**
- **explain the current, its units and method of measurement (ammeter)**
- **explain the emf, potential difference, their units and method of measurement (voltmeter)**
- **explain resistance and its unit, and quantity of electricity.**

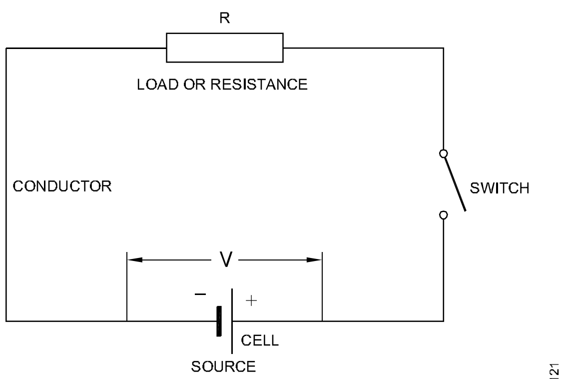
Simple electric circuit

A simple electrical circuit is one in which the current flows from the source to a load and reaches back the source to complete the path.

As shown in Fig 1, the electrical circuit should consist of the following.

- An energy source (cell) to provide the voltage needed to force the current through the circuit.
- Conductors through which the current can flow.
- A load (resistor 'R') to control the amount of current and to convert the electrical energy to other forms.
- A control device (switch 'S') to start or stop the flow of current.

Fig 1



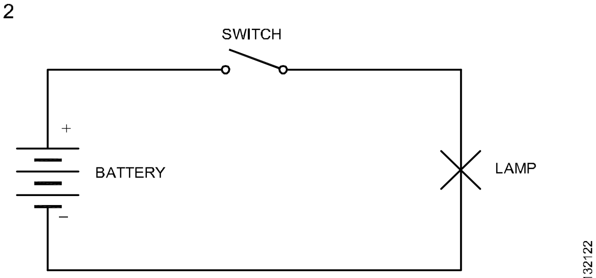
ELECTRICAL CIRCUIT

In addition to the above, the circuit may have insulators (PVC or rubber) to confine the current to the desired path, and a protection device (fuse 'F') to interrupt the circuit in case of malfunction of the circuit (excess current).

Electric current

Fig 2 shows a simple circuit which consists of a battery as the energy source and a lamp as the resistance. In this circuit, when the switch is closed, the lamp glows because of the electric current flows from the +ve terminal of the source (battery) via the lamp and reaches back the –ve terminal of the source.

Fig 2



SIMPLE CLOSED CIRCUIT

Flow of electric current is nothing but the flow of free electrons. Actually the electrons flow is from the negative terminal of the battery to the lamp and reaches back to the positive terminal of the battery.

However direction of current flow is taken conventionally from the +ve terminal of the battery to the lamp and back to the –ve terminal of the battery. Hence, we can conclude that conventional flow of current is opposite to the direction of the flow of electrons. Throughout the Trade Theory book, the current flow is taken from the +ve terminal of source to the load and then back to the –ve terminal of the source.

Ampere

The unit of current (abbreviated as I) is an ampere (symbol A). If 6.24 x 10^{18} electrons pass through a conductor per second having one ohm resistance with a potential difference of one volt causes one ampere current has passed through the conductor.

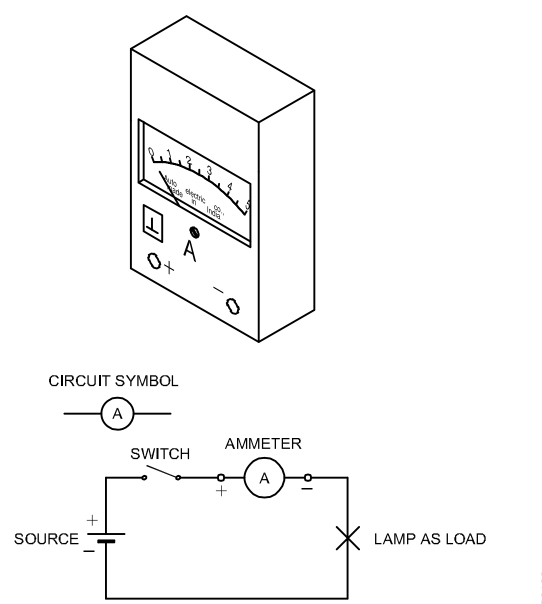
Ammeter

We know the electrons cannot be seen and no human being can count the electrons. As such an instrument called ammeter is used to measure the current in a circuit.

As an ammeter measures the flow of current in amperes it should be connected in series with the resistance (Load).

as shown in Fig 3. For the decimal and decimal sub-

Fig 3



AMMTER WITH LOAD

multiples of the ampere we use the following expressions.

1 kilo-ampere = 1 kA = 1000 A = 1 x 10^3A

1 milli-ampere = 1 mA = 1/1000 A = 1 x 10^{-3}A

1 micro-ampere = 1 μA = 1/1000000 A = 1 x 10^{-6}A

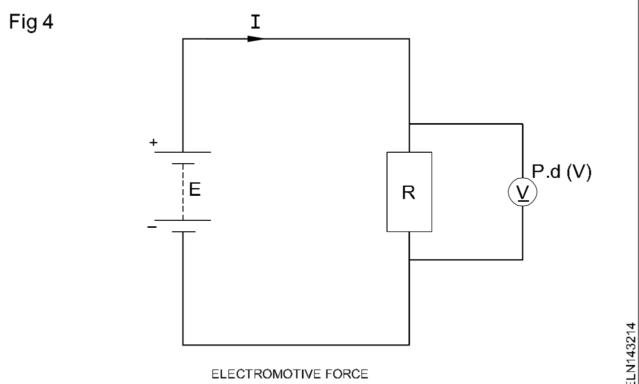
Electro Motive Force (EMF)

In order to move the electrons in a circuit- that is to make the current to flow, a source of electrical energy is required. In a torch light, the battery is the source of electrical energy.

The terminals of the battery are indicated in the circuit symbol by two lines, the longer line for the positive and the shorter for the negative terminal.

Within the battery the negative terminal contains an excess of electrons whereas the positive terminal has a deficit of electrons. The battery is said to have an electromotive force (emf) which is available to drive the free electrons in the closed path of the electrical circuit. The difference in the distribution of electrons between the two terminals of the battery produces this emf.

Fig 4



ELECTROMOTIVE FORCE

In Simple,

Electromotive force (EMF) is the electrical force, which is initially available in elecrical source, cause to move the free electrons in a conductor

Its unit is 'Volt'

It is denoted by letter 'E'

It cannot be measured by any meter. It can be only calculated by using the formula

E = Potential Difference (P.D) + V. drop

= p.d + V.drop

$E = V + IR$

Electromotive force is essential to drive the electrons in circuit

This force is obtained from the source of supply i.e. Torch lights, dynamo

System International (SI) unit of electromotive force is Volts (symbol 'E')

Potential Difference (PD)

The difference of volatge and pressure across two points in a circuit is called a potential difference (p.d) and is measured in volts.

In a circuit, when a current flows, there will be a potential difference across the terminals of the resistor/load. In the circuit shown in Fig 4, when the switch is in open conidition, the voltage across the terminals of the cell is called electromotive force (E) whereas when the switch is in the closed position, the voltage across the cell is called potential difference (p.d) which wil be lesser in value than the electromotive force earlier measured. This is due to the fact that the internal resistance of the cell drops a fer volts when the cell supplies current to the load.

The force which causes current to flow in the circuit is called emf. Its symbol is E and its unit is Volts (V). It can be calculated as

EMF = voltage at the terminal of source of supply + voltage drop in the source of supply

or emf = $V_T + IR$

Terminal voltage (p.d)

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

V_T = EMF - IR

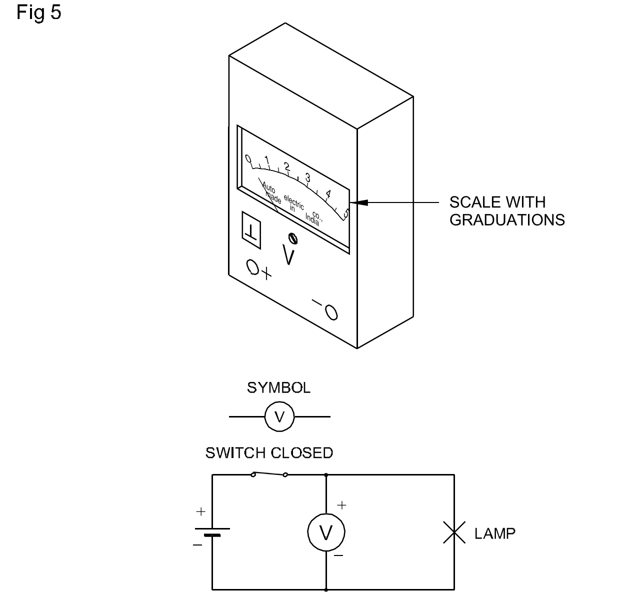
where I is the current and R is the resistance.

Hence EMF is always greater than p.d [E.M.F>p.d]

Voltmeter

Electrical voltage is measured with a voltmeter. In order to measure the voltage of a source, the terminals of the voltmeter must be connected to the terminals of the source. Positive to the positive terminal and negative to the negative terminal, as shown in Fig 5. The voltmeter connection is across or it is a parallel connection.

Fig 5



For the decimal or decimal sub-multiples of the volt, we use the following expressions.

1 kilo-volt = 1 KV = 1000 V

= 1×10^3V

1 milli-volt = 1 mV = 1/1000 V

= 1 x 10^{-3}V

1 micro-volt = 1 μV = 1/1000000 V = 1 x 10^{-6}V

Resistance (R)

In addition to the current and voltage there is a third quantity which plays a role in a circuit, called the electrical resistance. Resistance is the property of a material by which it opposes the flow of electric current.

The resistance is the property of opposition to the flow of the current offered by the circuit elements like resistance of the conductor or load is limit the flow of current

> **In absence of resistance in a circuit, the current will reach an abnormal high value endangering the circuit itself**

Ohm

The unit of electrical resistance (abbreviated as R) is ohm (symbol Ω).

For the decimal multiples or decimal sub-multiples of the ohm we use the following expressions:

1 megohm = 1 MΩ = 1000000Ω = 1 x 10^{6}Ω

1 kilo-ohm = 1 kΩ = 1000Ω = 1 x 10^{3}Ω

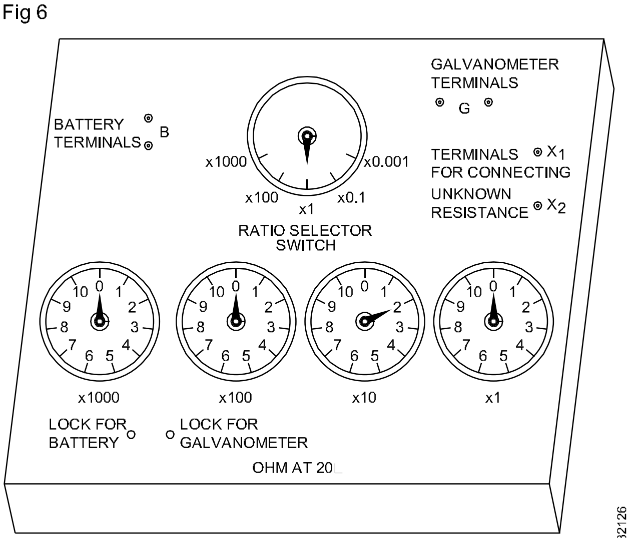
1 milli-ohm = 1 mΩ = 1/1000Ω = 1 x 10^{-3}Ω

1 micro-ohm = 1 μΩ = 1/1000000Ω = 1 x 10^{-6}Ω

Meter to measure resistance

Ohmic value of a medium resistance is measured by an ohmmeter or a Wheatstone bridge. (Fig 6) There is a provision to measure the ohmic value of a resistance in a multimeter. There are various methods to determine the ohmic value of resistance. Some of these methods will be explained later in this book.

Fig 6



WHEATSTONE BRIDGE

International Ohm

It is defined as that resistance offered to an unvarying current (DC) by a column of mercury at the temperature of melting ice (i.e. 0°C), 14.4521 g in mass, of constant cross-sectional area (1 sq. mm) and 106.3 cm in length.

International ampere

One international ampere may be defined as that unvarying current (DC) which when passed through a solution of silver nitrate in water, deposits silver at the rate of 1.118 mg per second at the cathode.

Internation volt

It is defined as that potential difference which when applied to a conductor whose resistance is one international ohm produces a current of one international ampere. Its value is equal to 1.00049V.

Conductance

The property of a conductor which conducts the flow of current through it is called conductance. In other words, conductance is the reciprocal of resistance. Its symbol is G (G = 1/R) and its unit is mho represented by . Good conductors have large conductances and insulators have small conductances. Thus if a wire has a resistance of R Ω, its conductance will be 1/R

Quantity of electricity

As the current is measured in terms of the rate of flow of electricity, another unit is necessary to denote the quantity of electricity (Q) passing through any part of the circuit in a certain time. This unit is called the coulomb (C). It is denoted by the letter Q. Thus

Quantity of electricity = current in amperes (I) x time in seconds (t)

or $Q = I \times t$

Coulomb

It is the quantity of electricity transferred by a current of one ampere in one second. Another name for the above unit is the ampere-second. A larger unit of the quantity of electricity is the ampere-hour (A.h) and is obtained when the time unit is in hours

1 A.h = 3600 Asec or 3600 C

Types of electrical supply

Objectives: At the end of this lesson you shall be able to
- **explain the difference types of electrical supply**
- **differentiate between alternating current and direct current**
- **explain the method of identification of polarity in DC source**
- **state the effect of electric current**

There are various types of instruments working on different principles. Each instrument is designed to measure a particular electrical quantity or more than one quantity with suitable modification and necessary instruction. Further they may be designed to measure AC or DC supply quantities or can be used in either supply.

To enable proper use of the instruments, the technician should be able to identify the type of supply with the help of the details given below.

Type of electrical supply (Voltage)

There are two types of electrical supply in use for various technical requirements. The alternating current supply (AC) and the direct current supply (DC).

___ DC is represented by this symbol.

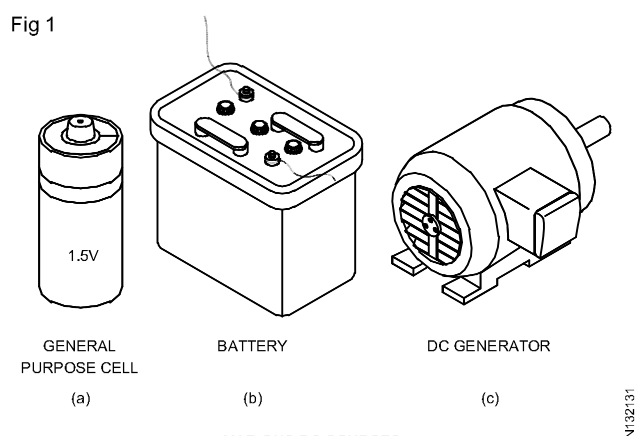
~ AC is represented by this symbol.

DC Supply

The most common sources of DC supply are the cells/ batteries (Figs 1a and 1b) and DC generators (dynamos). (Fig 1C)

Direct voltage is of constant magnitude (amplitude). It remains at the same amplitude from the moment of switching on to the moment of switching off. The polarity of the voltage source does not change. (Fig 2)

Fig 1



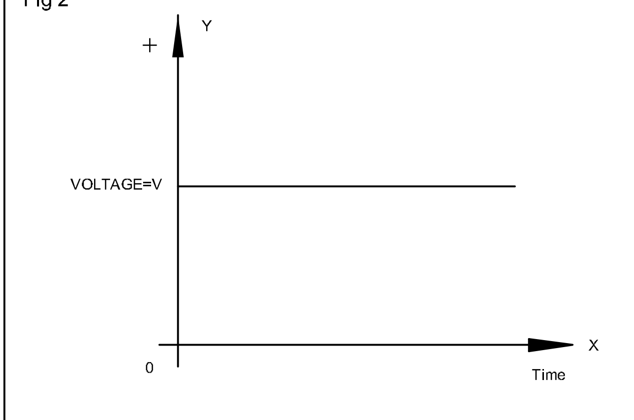
VARIOUS DC SOURCES

The polarity of direct voltage (commonly known as DC voltage) is positive (+ve) and negative (–ve). The direction of conventional flow of current is taken as from the positive to the negative terminal outside the source. (Fig 3)

Direct Current (D.C) (Fig 4)

Voltage is the cause of electrical current. If a direct current flows through a circuit, the movement of electrons in the circuit is unidirectional.

Fig 2



LINEAR VOLTAGE CHARCTERISTIC

Fig 3

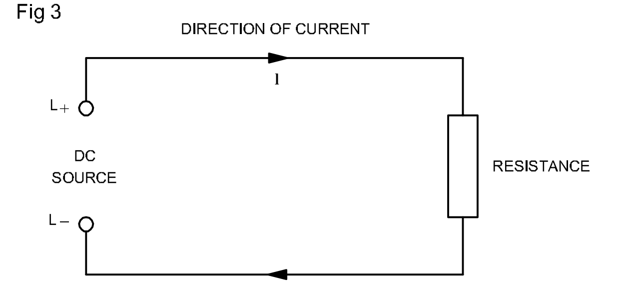
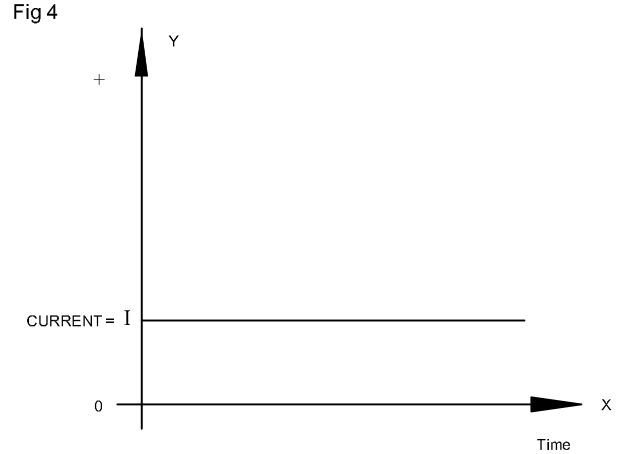


Fig 4



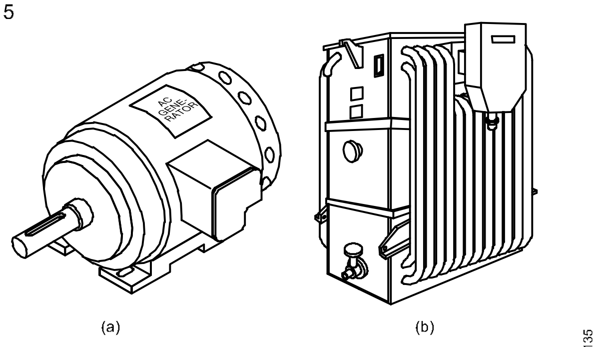
LINEAR CURRENT CHARECTERISTIC

Thus direct current remains at the same value from the moment of switching on to the moment of switching off. (Direct current in common usage is known as DC current.)

AC Supply

The source of AC supply is AC generators (alternators). (Fig 5a) The supply from a transformer (Fig 5b) is also AC.

Fig 5

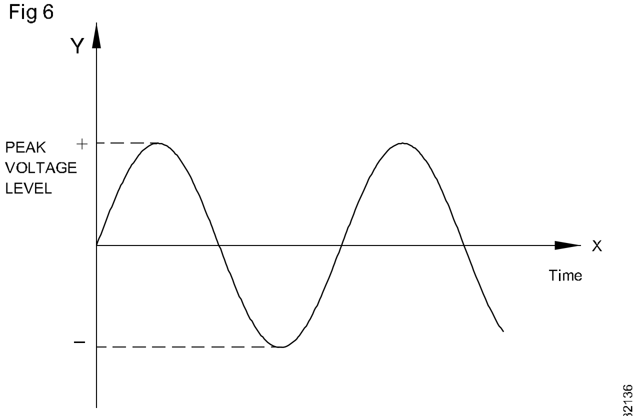


VARIOUS AC SOURCES

Alternating voltage

AC supply sources change their polarity constantly, and consequently the direction of voltage also magnitude. The voltage supplied to our homes by power plants is alternating. Fig 6 shows a sinusoidal alternating voltage over time (wave-form).

Fig 6



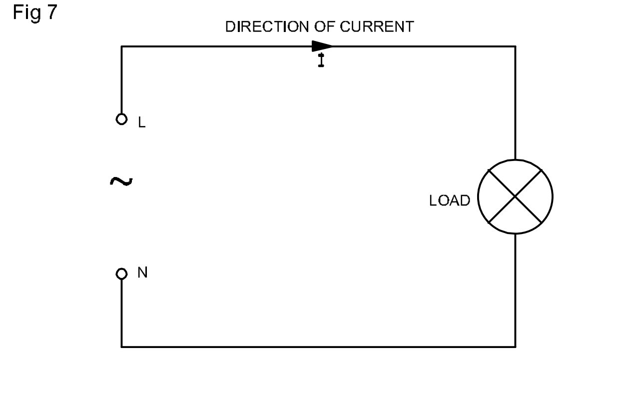
AC VOLTAGE

AC supply is expressed by the effective value of the voltage, and the number of times it changes in one second is known as frequency. Frequency is represented by 'F' and its unit is in Hertz(Hz).

For example, the AC supply used for lighting is 240V 50 Hz. (Alternating voltage in common use is known as AC voltage.) AC supply terminals are marked as phase/line(L) and neutral(N).

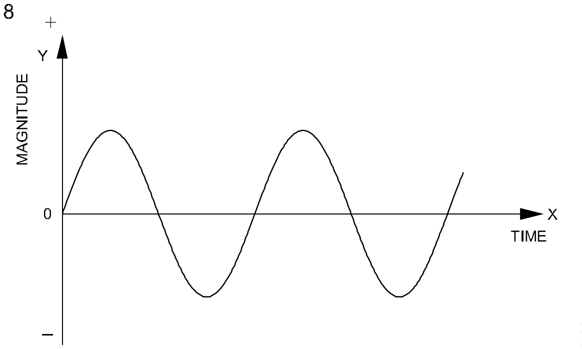
Current is caused in an electric circuit due to the application of voltage. If an alternating voltage is applied to an electrical circuit, an alternating current (commonly known as AC current) will flow. (Figs 7 and 8)

Fig 7



ALTERNATING CURRENT FLOW (AC)

Fig 8



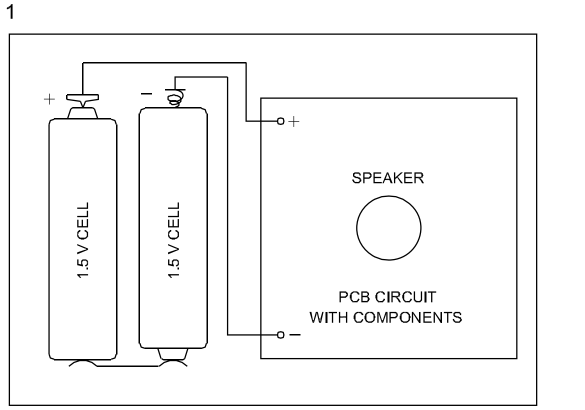
ALTERNATING CURRENT

Polarity test in DC

Polarity

The polarity of a DC supply source should be identified as positive or negative. We can also use the term to indicate how an electric device is to be connected to the supply. For example, when putting new cells in a transistor radio we must put the cells correctly such that the positive terminal of one cell connects to the positive terminal of the radio and the negative terminal of the other cell connects to the negative terminal of the radio as shown in Fig 1.

Fig 1



TRANSISTOR RADIO

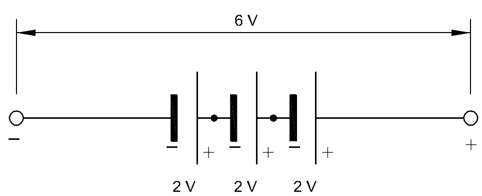
Importance of the polarity

Direct current supply has fixed polarity, positive and negative marked as + and –. Electric devices which have positive and negative identifications on their terminals are said to be polarised. When connecting such devices to a source of voltage (such as a battery or DC supply)

We must observe the correct polarity markings. That is the positive terminal of the device must be connected to the positive terminal of the source, and the negative to the negative. If the polarity is not observed correctly (that is, if +ve is connected to –ve) the device will not function and may be damaged.

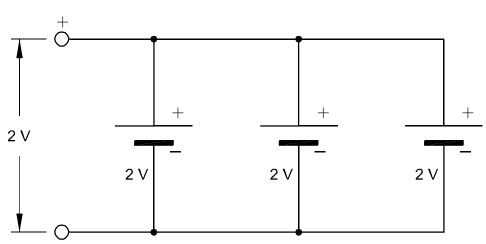
To get more voltage, current and power, the voltage sources like cells, batteries and generator are often connected in series, or in parallel or in series/parallel combination circuit. To connect them in such a manner we must know the correct polarity of the source. Fig 2 shows the method of connecting 3 cells in series to get more voltage. Fig 3 shows connection of 3 cells in parallel for getting more current.

Fig 2



CELL IN SERIES FOR GETTING MORE VOLTAGE

Fig 3



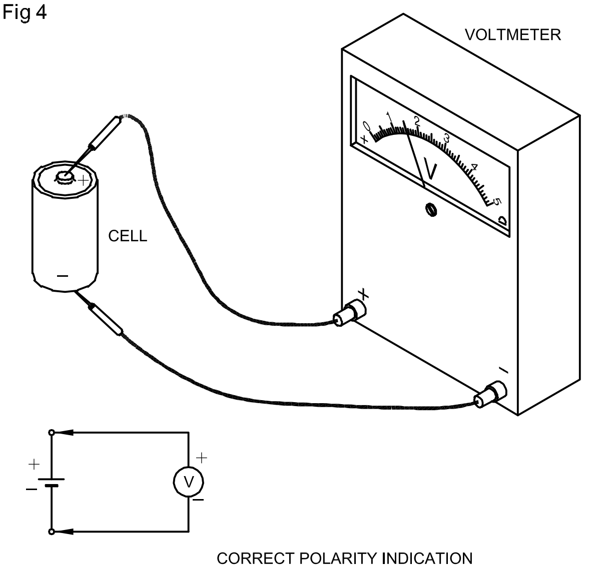
CELLS IN PARALLEL FOR GETTING MORE CURRENT.

Testing polarity by MC meter

The polarity of a cell is determined by the use of a moving coil volt-meter. The terminals of the MC meter are marked as +ve and –ve. MC meters are called as polarised as they have to be connected as per the polarity marking. By using a low range (0-10V) MC voltmeter we can find out the voltage of a cell.

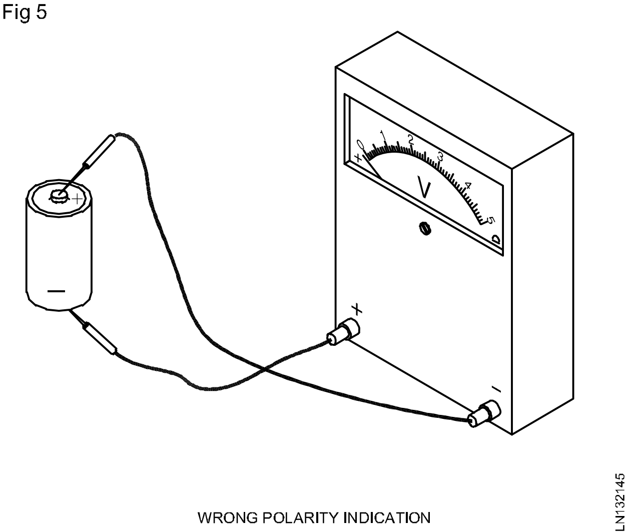
The connections are made as per Fig 4 the voltmeter reads 1.5 volts. The polarity of the cell is correct as per the marked polarity on the meter terminals. If the pointer of the voltmeter deflects as in Fig 5, below zero, the polarity is not correct. From this we conclude that the meter reads in forward direction only if the instrument is connected with correct polarity as per the markings on the instrument terminals.

Fig 4



CORRECT POLARITY INDICATION

Fig 5



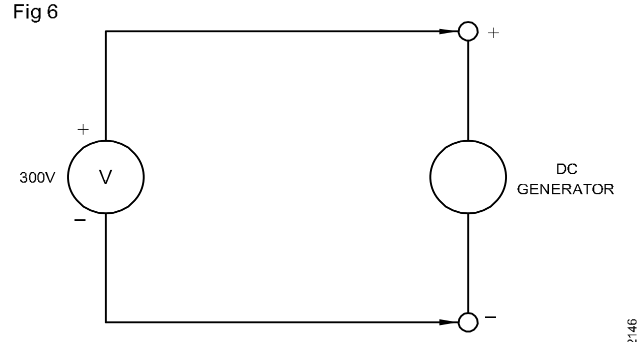
WRONG POLARITY INDICATION

Polarity of the battery

To determine the polarity of the terminals of an unmarked battery, that is +ve and –ve we can use a low range MC voltmeter. If the voltmeter reads positive reading, say 10 or 12 volts then the polarity of the terminals are correct as per the markings on the meter terminals. If the meter reading is negative, that is below zero, the battery polarity is not correct with respect to the meter.

Polarity of DC supply

Fig 6



POLARITY TEST BY D.C GENERATOR

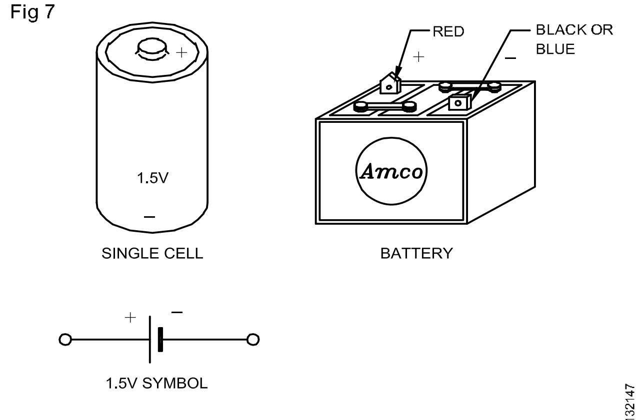
In the same way to find out the polarity of DC generator or a DC source it is advisable to use a moving coil type voltmeter with a suitable range, of say 0-300 volts (Fig 6). To protect the meters, always use higher range meters above the rated voltage of the generator or DC source supply.

Marking made in practice

Generally in DC source the +ve terminal of the supply lead is Red in colour and –ve terminal of the supply lead is Blue or Black in colour. Battery terminals are marked as +ve and –ve on the body or on the terminal post.

- For cells on top of the cell is marked as +ve and the bottom is marked as –ve
- The battery terminal is marked as + and is Red in colour, and the other terminal is marked as – and Black or Blue in colour. (Fig 7)

Fig 7



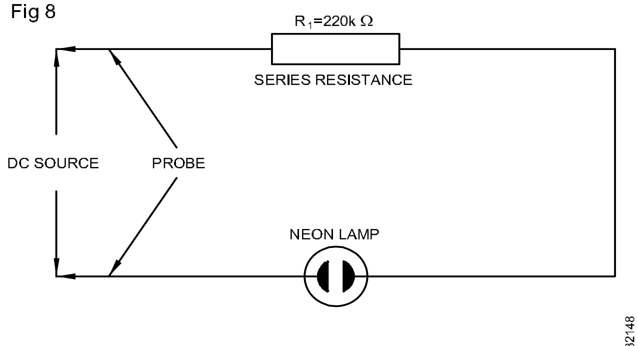
CELL & BATTERY WITH COLOUR POLARITY

Neon polarity indicator

To check the polarity, a neon lamp in series with a 220k ohms resistor could be used (as shown in Fig 8). Touch the probes of the neon lamp circuit across the circuit to be tested. The lamp will light when voltage is present. If both electrodes in the lamp glow, you have an AC power source. If only one electrode glows, the voltage is DC and the lighted electrode will be on the side of the negative polarity of the source.

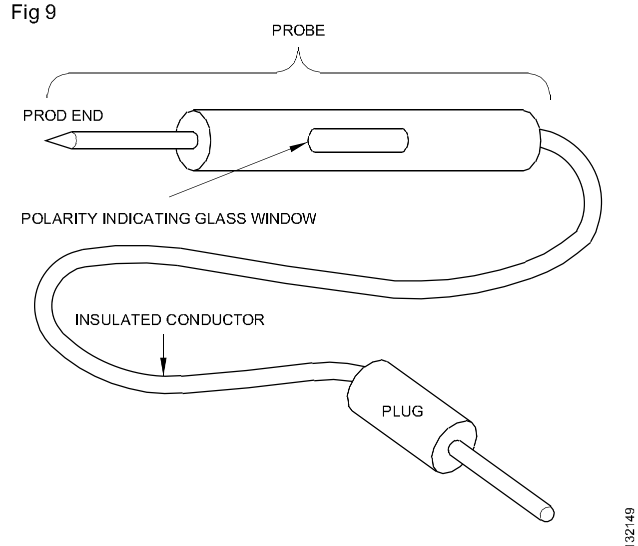
Therefore, you also have a polarity check on DC circuits. (Fig 8) A commercial neon polarity indicator is shown in Fig 9. It has an indicating glass window in which the polarity touched by the pointed end of the indicator will be displayed as +ve or –ve through neon signs.

Fig 8



POLARITY TEST BY NEON INDICATOR

Fig 9



NEON POLARITY INDICATOR

Effects of electric current

When an electric current flows through a circuit, is judged by its effects, which are given below.

1 Chemical effect

When an electric current is passed through a conducting liquid (i.e. acidulated water) called an electrolyte, it is decomposed into its constituents due to chemical action. The practical application of this effect is utilized in electroplating, block making, battery charging, metal refinery, etc.

2 Heating effect

When an electric potential is applied to a conductor, the flow of electrons is opposed by the resistance of the conductor and thus some heat is produced. The heat produced may be greater or lesser according to the circumstances, but some heat is always produced. The application of this effect is in the use of electric presses, heaters, electric lamps, etc.

3 Magnetic effect

When a magnetic compass is placed under a current carrying wire, it is deflected. It shows that there is some relation between the current and magnetism. The wire carrying current does not become magnet but produces a magnetic field in the space. If this wire is wound on an iron core (i.e. bar), it becomes an electro-magnet. This effect of electric current is applied in electric bills, motors, fans, electric instruments, etc.

4 Gas ionization effect

When electrons pass through a certain gase sealed in a glass tube, it becomes ionised and starts emitting light rays, such as in fluorescent tubes, mercury vapour lamps, sodium vapour lamps, neon lamps, etc.

5 Special rays effect

Special rays like X-rays and laser rays can also be developed by means of an electric current.

6 Shock effect

The flow of current through the human body may cause a severe shock or even death in many cases. If this current is controlled to a specific value, this effect of current can be used to give light shocks to the brain for the treatment of mental patients.

Conductors - insulators - wires - types

Objectives: At the end of this lesson you shall be able to
- **differentiate between conducting and insulating materials**
- **state the electrical properties of conducting materials**
- **state the terms used in electrical cables**
- **state the characteristics of copper and aluminium conductors**
- **state the types and propertites of insulating materials.**
- **describe the method of measurement of wire size using SWG**
- **explain the method of measure wire size by outside micrometer**

Conductors and insulators

Material with high electron mobility (many free electrons) are called conductor.

Materials that contain many free electrons and are capable of carrying an electric current are known as conductors.

Examples - silver, copper, aluminium and most other metals.

Materials with low electron mobility (few (or) no free electron) are called insulators

Materials that have only a few electrons and are incapable of allowing the current to pass through them are known as insulators.

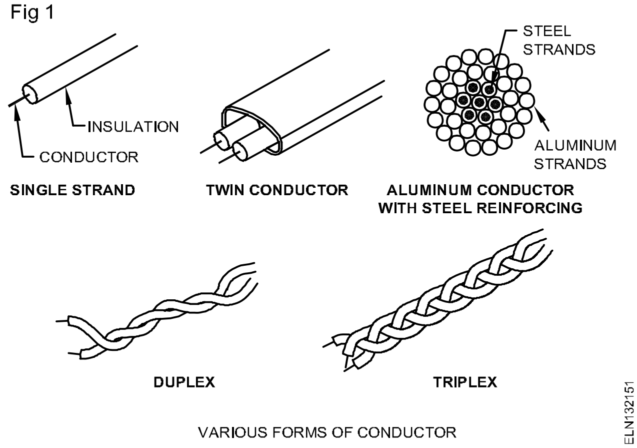
Examples - wood, rubber, PVC, porcelain, mica, dry paper and fibreglass.

Conductors

The use of conductors and their insulation is regulated by I E regulations and BIS (ISI) code of practice.

The I E regulations and I S cover all electrical conductors listing the minimum safety precautions needed to safeguard people, buildings and materials from the hazards of using electricity.

Fig 1



VARIOUS FORMS OF CONDUCTOR

Wires and cables are the most common forms of conductors. They are made in a wide variety of forms to suit many different applications. (Fig 1)

Conductors form an unbroken line carrying electricity from the generating plant to the point where it is used. Conductors are usually made of copper or aluminium.

Current passing through a conductor generates heat. The amount of heat generated depends on the square of the current that passes through the conductor and the resistance of the conductor.

As the heat developed in the conductor depends upon the resistance of the conductor the cross-sectional area of the conductor must have a large enough area to give it a low resistance. But the cross- sectional area must also be small enough to keep the cost and weight as low as possible.

The best cross-sectional area depends upon how much current the conductor can carry without much voltage drop in the line and heat generation in the conductor.

There is a limit to the temperature each kind of insulation can safely withstand and also the type of insulation which can withstand the physical chemical and temperature zones of the surroundings.

BIS (ISI) code specifies the maximum current considered safe for conductors of different sizes, having different insulation and installed in different surroundings.

Size of conductors

The size is specified by the diameter in mm or the cross-sectional area. Typical sizes are 1.5 sq.mm, 2.5 sq.mm, 6 sq.mm etc.

Still in India the old method of specifying the diameter by the standard wire gauge number is in use.

Classfication of conductors

Wires and cables can be classified by the type of covering they have.

Bare conductors

They have no covering. The most common use of bare conductors is in overhead electrical transmission and distribution lines. For earthing also bare conductors are used.

Insulated conductors

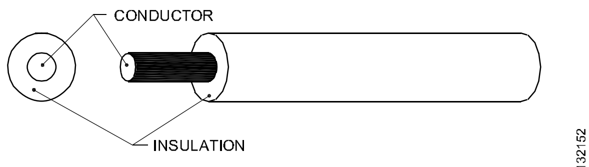
They have a coating of insulation. The insulation separates the conductor electrically from other conductors and from the surroundings. It allows conductors to be grouped without danger. Additional covering over the insulation adds mechanical strength and protection against weather, moisture and abrasion.

Solid and stranded conductors

A solid conductor is one in which there will be only one conductor in the core as shown in Fig 2. A stranded conductor is one in which there will be a number of smaller sized conductors twisted to form the core as shown in Fig 3.

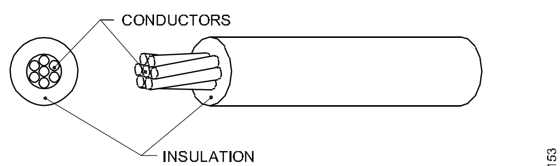
The number of conductors ranges from 3 to 162 and the conductor size varies from 0.193 mm to 3.75 mm diameter depending upon the current carrying capacity and also upon whether these conductors are used in cables or overhead lines.

Fig 2



INSULATED SOLID CONDUCTOR

Fig 3



INSULATED CONDUCTOR

Normally stranded conductors are designated as 10 sq. mm cable of size 7/1.40 where 10 sq.mm gives the area of the cross-section, in the size, numerator (7) gives the number of conductors and the denominator 1.40 gives the diameter of the conductor in mm. Alternatively 7/1.40 cable is the same as 7/17 whereas in the latter case the denominator is expressed in Standard Wire Gauge (SWG) number.

Stranded conductors are more flexible and have better mechanical strength. According to recent stipulation, the cable size should be expressed in sq. millimetres or they can be expressed in terms of the number of conductors in the cable and the diameter of the conductor in mm.

Cable

A cable is a length of single, insulated conductor (single or stranded), or two or more such conductors - each provided with its own insulation, and are laid up together. The insulated conductor or conductors may or may not be provided with an overall mechanical protective covering.

Cable (armoured)

An armoured cable is provided with a wrapping of metal (usually in the form of tape or wire), serving as a mechanical protection.

Cable (flexible)

A flexible cable contains one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.

Core

All cables have one central core or a number of cores of stranded conductors farming high conductivity; generally there are one, two, three, three and half and four cores. Each core is insulated separately and there is overall insulation around the cores.

Wire

A solid substance (conductor) or an insulated conductor (solid or stranded) subjected to tensile stress with or without screen is called a wire.

Copper and aluminium

In electrical work, mostly copper and aluminium are used for conductors. Though silver is a better conductor than copper, it is not used for general work due to higher cost.

Copper used in electrical work is made with a very high degree of purity, say 99.9 percent.

Characteristics of copper

1 It has the best conductivity next to silver.

2 It has the largest current density per unit area compared to other metals. Hence the volume required to carry a given current is less for a given length.

3 It can be drawn into thin wires and sheets.

4 It has a high resistance to atmospheric corrosion: hence, it can serve for a long time.

5 It can be joined without any special provision to prevent electrolytic action.

6 It is durable and has a high scrap value.

Next to copper, aluminium is the metal used for electrical conductors.

Characteristics of aluminium

1 It has good conductivity, next to copper. When compared to copper, it has 60.6 percent conductivity. Hence, for the same current capacity, the cross-section for the aluminium wire should be larger than that for the copper wire.

2 It is lighter in weight.

3 It can be drawn into thin wires and sheets. But loses its tensile strength on reduction of the cross-sectional area.

4 A lot of precautions needs to be followed while joining aluminium conductors.

5 The melting point of aluminium is low, hence it may get damaged at points of loose connection due to heat developed.

6 It is cheaper than copper.

Table 1 shows the properties of copper compared with those of aluminium.

Table 1

Chararacteristics of conductor materials

Sl. No.	Properties	Copper (Cu)	Aluminium (Al)
1	Colour	Reddish	White brown
2	Electrical conductivity in MHO/metre	56	35
3	Resistivity at 20°C in ohm/metre (Cross-sectional area in 1 mm^2)	0.01786	0.0287
4	Melting point	1083°C	660°C
5	Density in kg/cm^3	8.93	2.7
6	Temperature coefficient of resistance at 20°C per °C	0.00393	0.00403
7	Coefficient of linear expansion at 20°C per °C	17×10^{-6}	23×10^{-6}
8	Tensile strength in Nw/mm^2	220	70

Properties of insulating materials

Two fundamental properties of insulation materials are insulation resistance and dielectric strength. They are entirely different from each other and measured in different ways.

Insulation resistance

It is the electrical resistance of the insulation against the flow of current. Megohmmeter (Megger) is the instrument used to measure insulation resistance. It measures high resistance values in megohms without causing damage to the insulation. The measurement serves as a guide to evaluate the condition of the insulation.

Dielectric strength

It is the measure of how much potential difference the insulation layer can withstand without breaking down. The potential difference that causes a breakdown is called the breakdown voltage of the insulation.

Every electrical device is protected by some kind of insulation. The desirable characteristics of insulation materials are:

- high dielectric strength
- resistance to temperature
- flexibility
- mechanical strength.

No single material has all the characteristics required for every application. Therefore, many kinds of insulating materials have been developed.

Insulating tapes

Various tapes are used for insulating electrical equipments, conductors and components. Some of these are adhesive. The tapes commonly used include friction, rubber, plastic and varnished cambric tapes.

Rubber tape

Rubber tapes are used for insulating joints. The tape is applied under slight tension. Pressure causes the layers to bend together. Application of this restores insulation but will not be mechanically strong.

Friction tape

This is used over rubber tape insulation. This is made up of cotton cloth impregnated with an adhesive. It does not stretch like the rubber tape. The friction tape does not have insulating qualities of the rubber tape, hence should not be used by itself for insulation.

Plastic tape (PVC tape)

This is used more than the other tapes. PVC tapes have the following advantages.

- High dielectric strength
- Very thin
- Stretches to conform to contours of joints

Varnished cambric tapes

These tapes are made of cloth impregnated with varnish. It usually has no adhesive coating. Available in sheets and rolls and are ideal for insulating motor connecting leads.

Measurement of wire sizes - standard wire gauge - outside micrometer

Necessity of measuring the wire sizes

To execute a wiring job proper planning is necessary. After considering the requirements of the house owner, the electrician prepares a layout plan of the wiring and an estimate of the cost of the wiring materials and labour. A proper estimate involves determination of current in different loads, correct selection of the type of cable, size of the cable and the required quantity. Any error will result in defective wiring, fire accidents and bring unhappiness to both the house owner and the electrician.

While selecting the cable sizes, the electrician has to take into consideration the proposed connected load, future changes in load, the length of the cable run and the permissible voltage drop in the cable.

A sound knowledge about the area of the cross-section of the core, the diameter of the single strand of the conductor and the number of conductors in each core of the stranded conductor is essential for a wireman to be successful in his carreer.

Table 1 - Conversion table SWG to mm/inch

SWG No.	mm	inch
7/0	12.7	0.500
6/0	11.38	0.464
5/0	10.92	0.432
4/0	10.16	0.400
3/0	9.44	0.372
2/0	8.83	0.348
0	8.23	0.324
1	7.62	0.300
2	7.01	0.276
3	6.40	0.252
4	5.89	0.234
5	5.38	0.212
6	4.88	0.192
7	4.47	0.176
8	4.06	0.160
9	3.66	0.144
10	3.25	0.128
11	2.95	0.116
12	2.64	0.104
13	2.34	0.092
14	2.03	0.080
15	1.83	0.072
16	1.63	0.064
17	1.42	0.056
18	1.22	0.048
19	1.02	0.040
20	0.91	0.036
21	0.81	0.032
22	0.71	0.028

SWG No.	mm	inch
23	0.61	0.024
24	0.56	0.022
25	0.51	0.020
26	0.46	0.018
27	0.42	0.0164
28	0.38	0.0148
29	0.34	0.0136
30	0.31	0.0124
31	0.29	0.0116
32	0.27	0.0108
33	0.25	0.0100
34	0.23	0.0092
35	0.21	0.0084
36	0.19	0.0076
37	0.17	0.0068
38	0.15	0.0060
39	0.13	0.0052
40	0.12	0.0048
41	0.11	0.0044
42	0.10	0.0040
43	0.09	0.0036
44	0.08	0.0032
45	0.07	0.0028
46	0.06	0.0024
47	0.05	0.0020
48	0.04	0.0016
49	0.03	0.0012
50	0.02	0.0010

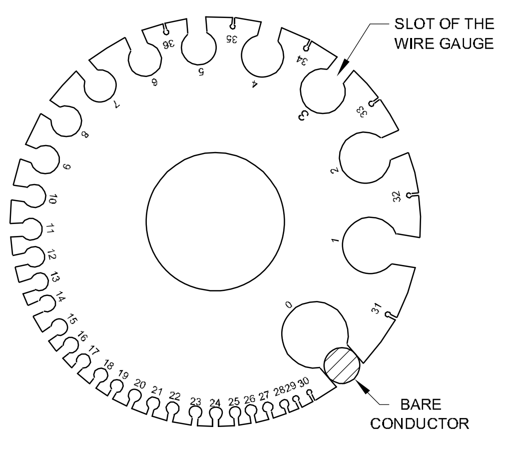
To measure the size of conductors, a electrician can use normally a standard wire gauge or an outside micrometer for more accurate results.

The size of wires are designed more carefully by the manufacturers. Though the Bureau of Indian Standards (BSI) specifies the cables by the area of the cross-section in square millimetres, the manufacturers still produce the cable with the diameter of each wire and number of wires in the stranded cables. Sometimes the indicated size of cable by the manufacturer may not be correct and the electrician has to ascertain the size by measurement.

Standard Wire Gauge (SWG)

The size of the conductor is given by the standard wire gauge number. According to the standards each number has an assigned diameter in inch or mm. This is given in Table 1. The standard wire gauge, shown in Figure 1 could measure the wire size in SWG numbers from 0 to 36. It should be noted that the higher the number of wire gauge the smaller is the diameter of the wire.

Fig 1



STANDARD WIRE GAUGE

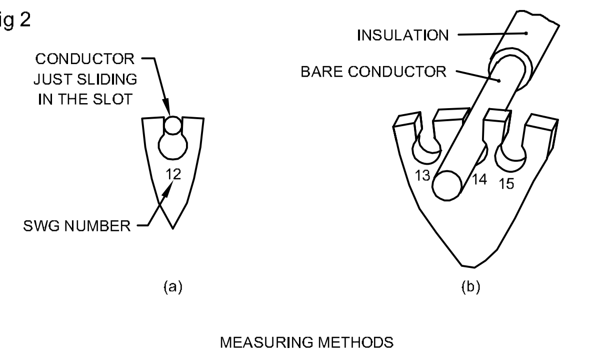
For example, SWG No. 0 (zero) is equal to 0.324 inch or 8.23 mm in diameter whereas SWG No.36 is equal to 0.0076 inch or 0.19 mm in diameter.

While measuring the wire, the wire should be cleaned and then inserted into the slot of the wire gauge to determine the SWG number (Fig 2). The slot in which the wire just slides in is the correct slot and the SWG number could be read in the gauge directly. In most of the wire gauges to save the trouble of referring to the table, the wire diameter is inscribed on the reverse of the gauge.

American Wire Gauge (AWG)

The American wire gauge is different from the British standard wire gauge. In an American wire gauge (AWG) the diameter is represented in mils rather than inch or mm. One mil is one thousandth part of an inch. Please note there is no direct conversion from AWG to SWG.

Fig 2



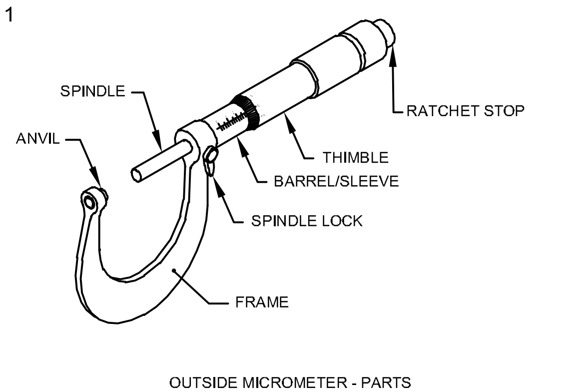
MEASURING METHODS

Measurement of wire size by Outside micrometers

A micrometer is a precision instrument used to measure a job, generally within an accuracy of 0.01 mm.

Micrometers used to take the outside measurements are known as outside micrometers. (Fig 1)

Fig 1



OUTSIDE MICROMETER - PARTS

The parts of a micrometer

Frame

The frame is made of drop-forged steel or malleable cast iron. All other parts of the micrometer are attached to this.

Barrel/sleeve

The barrel or sleeve is fixed to the frame. The datum line and graduations are marked on this.

Thimble

The thimble is attached to the spindle and on the bevelled surface of the thimble, the graduation is marked.

Spindle

One end of the spindle is the measuring face. The other end is threaded and passes through a nut. The threaded mechanism allows for the forward and backward movement of the spindle.

Anvil

The anvil is one of the measuring faces which is fitted on the micrometer frame. It is made of alloy steel and finished to a perfectly flat surface.

Spindle lock-nut

The spindle lock-nut is used to lock the spindle at a desired position.

Ratchet stop

The ratchet stop ensures a uniform pressure between the measuring surfaces.

Principle of the micrometer

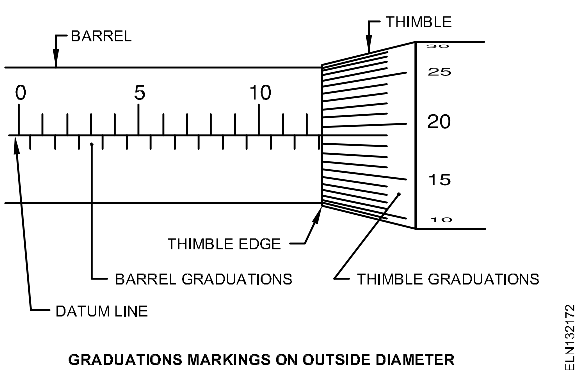
The micrometer works on the principle of screw and nut. The longitudinal movement of the spindle during one rotation is equal to the pitch of the screw. The movement of the spindle to the distance of the pitch or its fractions can be accurately measured on the barrel and thimble.

Graduations

In metric micrometers the pitch of the spindle thread is 0.5 mm.

Thereby, in one rotation of the thimble, the spindle advances by 0.5 mm.

Fig 2



GRADUATIONS MARKINGS ON OUTSIDE DIAMETER

In a 0-25 mm outside micrometer, on the barrel a 25 mm long datum line is marked. (Fig 2) This line is further graduated in millimetres and half millimetres (ie. 1 mm & 0.5 mm). The graduations are numbered as 0, 5, 10, 15, 20 & 25 mm on the barrel.

The circumference of the bevel edge of the thimble is graduated into 50 divisions and marked 0-5-10-15... 45-50 in a clockwise direction.

The distance moved by the spindle during one rotation of the thimble is 0.5 mm.

Movement of one division of the thimble

= 0.5 x 1/50 = 0.01 mm.

This value is called the least count of the micrometer.

> **The accuracy or least count of a metric outside micrometer is 0.01 mm.**

Outside micrometers are available in ranges of 0 to 25 mm, 25 to 50 mm, and so on. For electrician, to read the size of the wire 0 to 25 mm is only suitable.

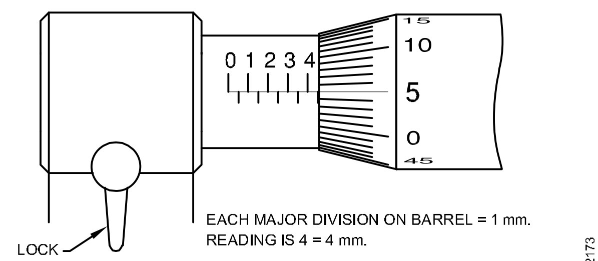
Reading micrometer measurements

How to read a measurement with an outside micrometer?

a) Read on the barrel scale, the number of whole millimetres that are completely visible from the bevel edge of the thimble. It reads 4 mm. (Fig 3)

b) Add to this any half millimetre that is completely visible from the bevel edge of the thimble and away from the whole millimetre reading.

Fig 3

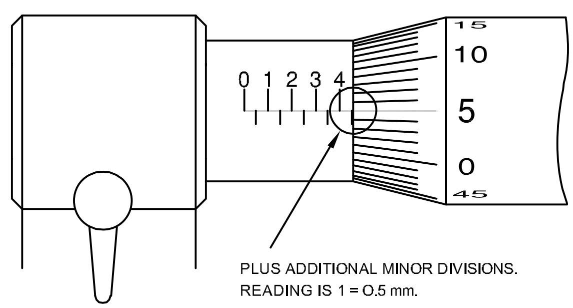


READING MICROMETER MEASUREMENT

The figure reads one division (Fig 4) mm after the 4 mm mark. Hence 0.5 mm to be added to the previous reading.

c) Add the thimble reading to the two earlier readings.

Fig 4



THIMBLE READING ON MICROMETER

The figure shows the 5th division of the thimble is coinciding with the datum line of the barrel. Therefore, the reading of the thimble is 5 x 0.01 mm = 0.05 mm. (Fig 5)

The total reading of the micrometer.

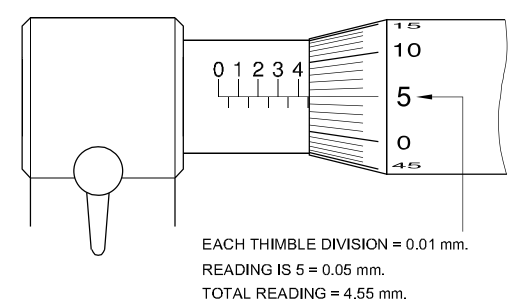
a 4.00 mm

b 0.50 mm

c 0.05 mm.

Total reading = 4.55 mm (Fig 5)

Fig 5



Precautions to be followed while using a micrometer

Before using the micrometer for measurement, it is necessary to ascertain that there is no error in the micrometer. To find the error, close the jaws of the measuring surfaces using the ratchet. Read the micrometer. If the thimble zero is coincident with the datum line of the barrel, error is zero. If it reads higher value, the error is +ve; if it reads lesser value the difference between zero and the read value is -ve error.

If there is minus error it should be added to the total reading and if there is plus error the value should be subtracted from the total reading.

The faces of the anvil and spindle must be free from dust, dirt and grease.

While reading the micrometer, the spindle must be locked with the reading.

Do not drop or handle the micrometer roughly.

Skinning of cables

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

- **state the method of skinning of cable.**

The installation technique for aluminium cables is the same as that for copper cables. Certain additional precautions are necessary as aluminium has low mechanical strength, less current carrying capacity for the same area of cross-section, low melting point, and is quicker in forming oxides on the surface than copper.

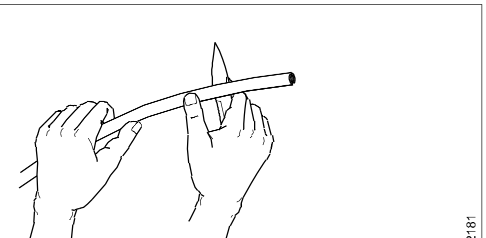
Accordingly, while, using aluminium cables proper care is to be taken regarding the following.

- Handling
- Skinning of the cables
- Connecting the cable ends

Handling: Remember that aluminium conductors when compared to copper conductors have less tensile strength and less resistance to fatigue. As such, bending or twisting of aluminium conductors while laying the cables should be avoided as far as possible.

Skinning of cables: While skinning the insulation from the cables, knicks and scratches should be avoided. As shown in Fig 1, the insulation should not be ringed as there is a danger of nicking the aluminium conductor while ringing the insulation with a knife.

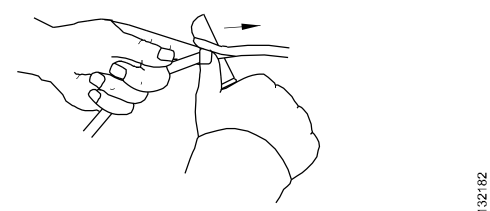
Fig 1



WRONG METHOD

Using the knife as shown in Fig 2 at an angle of 20° to the axis of the core will avoid knicking of the conductor.

Fig 2



RIGHT METHOD

Connecting the cable ends

The following problems are encountered while connecting aluminium cables to the accessories.

The termination holes in the accessories may be undersized.

This normally happens in old accessories as they are designed for copper cable ends. Hence, while selecting accessories, a thorough check is necessary of all accessories to ensure whether the holes in the terminating connectors as shown in Fig 4 are suitable to accommodate the specified aluminium conductors. In any case, the strands should not be cut or the conductor filed as shown in Fig 3 to enable insertion in the undersized hole as this operation results in the heating of the cable end on load condition.

Joints in electrical conductors are necessary to extend the cables, overhead lines, and also to tap the electricity to other branch loads wherever required.

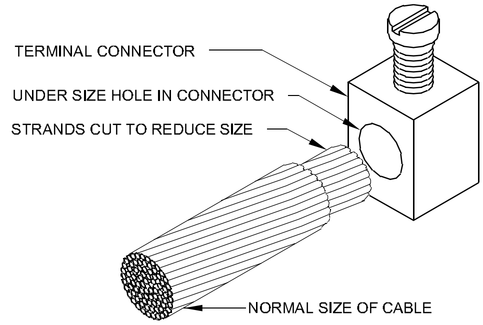


Fig 3

WRONG METHOD

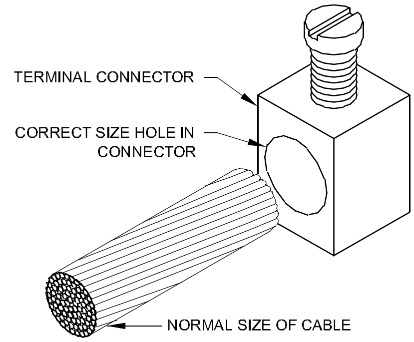


Fig 4

RIGHT METHOD

Cable end termination - crimping tool

Objectives: At the end of this lesson you shall be able to:
- **state the necessity of proper termination**
- **list the different types of terminations**
- **describe the parts and their functions of crimping tool**
- **state the advantages of crimping termination**

Necessity of termination

Cables are terminated at electrical appliances, accessories and equipment etc. for providing electrical connections. All terminations must be made to provide good electrical continuity, and made in such a manner as to prevent contact with other metallic parts and other cables.

Loose terminations will lead to overheating of cables, plugs and other connecting points due to higher resistance at those terminations. Fires may also be started due to the excess heat. Wrong termination like excess or extended conductor touching metallic part of the equipment may lead to giving shock to the person who comes in contact with the equipment.

Touching of strands projecting from one terminal with other terminal leads to short circuit. To conclude, we can state that wrong termination will lead to overheating of terminating points and cables, short circuits and earth leakage.

Types of termination

Crimp connection: In this type of connection the conductor is inserted into a crimp terminal and is then crimped with a crimping tool (Fig 1).

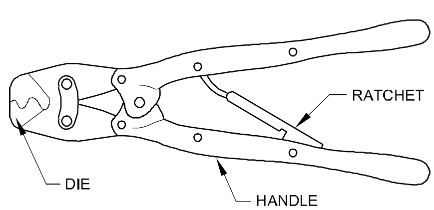


Fig 1

CRIMPING TOOL

It is important to choose a crimp terminal that matches the conductor diameter and the dimensions of the connecting screw terminal. (Figs 2 and 3)

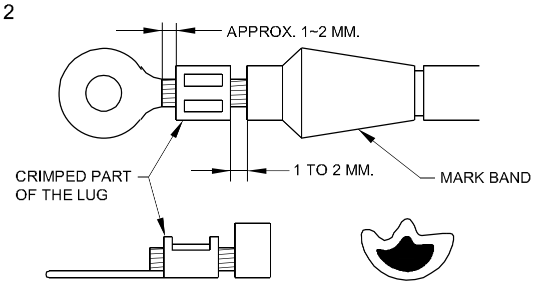


Fig 2

CRIMP TERMINAL CONNECTION

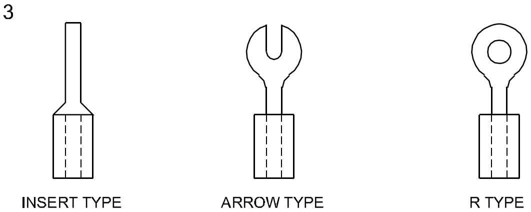


Fig 3

VARIOUS KINDS OF CRIMP TERMINALS

Insert screw setting: The conductor is inserted between the terminal block and the special form of washer (Fig 4), and then the screw is tightened.

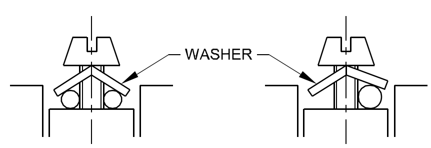
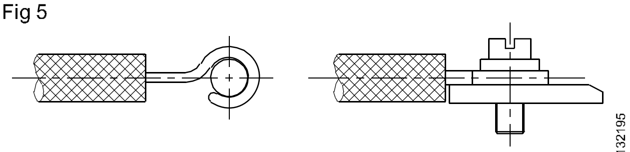


Fig 4

INSERT AND SCREW SETTING

Screw on terminals with loop/ring conductor: A loop is formed clockwise in the bare portion of the conductor to match the size of the screw diameter. Then the loop is inserted to the screw and tightened. (Fig 5) In the case of a stranded conductor, soldering of the loop is essential to prevent strands getting fray.

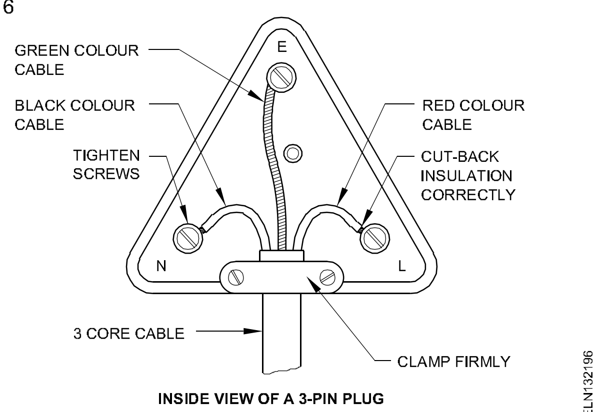
Fig 5



RING MAKE-UP SCREW SETTING

While connecting the plug and socket for extension of the cable, Line (L), the Neutral (N) and Earth (E) terminals must be properly identified by markings on them .(Fig 6)

Fig 6



INSIDE VIEW OF A 3-PIN PLUG

The colour code while connecting 3 core cable must be properly followed. Red wire to L, black/blue to N, green wire or yellow with green line to E terminal. The earth terminal in a 3 pin plug is bigger than the other two.

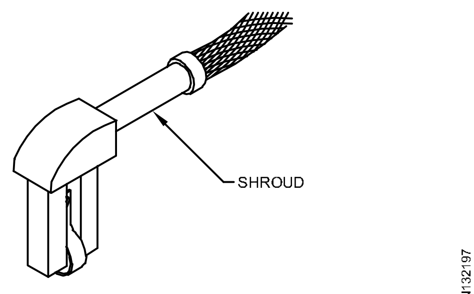
Connections and terminals

There is an electrical fire risk if:

- the current-carrying capacity of the cable is inadequate
- the capacity of the plug is inadequate
- the insulation is cut back too far
- the conductor is damaged while cutting back the insulation
- the connections are not right
- the cable is not adequately supported at the point of entry to the plug or to the appliance.

When a reinforcing rubber shroud is provided, ensure that it is used. (Fig 7)

Fig 7



RUBBER SHROUD FITTING ON CABLE

Crimping and crimping tool

The ends of cables can be prepared for termination with lugs by the soldering process or by mechanical means - compression or crimp fitting.

In crimp compression fitting, a ring-tongued terminal (lug) is to be compressed to the bared end of an insulated multi-strand cable. The process is called crimping and the tool used is called crimping pliers or crimping tool.

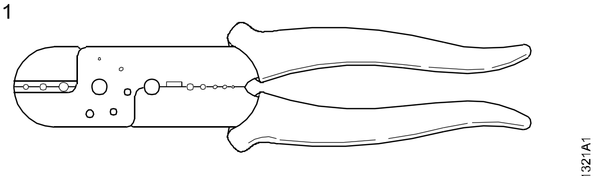
Compression type connectors apply and maintain pressure by compressing the connector around the conductor.

The principal purpose of the pressure is to establish and maintain suitable low contact resistance between the contact surfaces of the conductor. Improper crimping will create increased contact resistance and will cause overheating while carrying electrical load.

Crimping tools

The crimping pliers illustrated in Fig 1 is of a type which crimps from 0.5 to 6 mm cables.

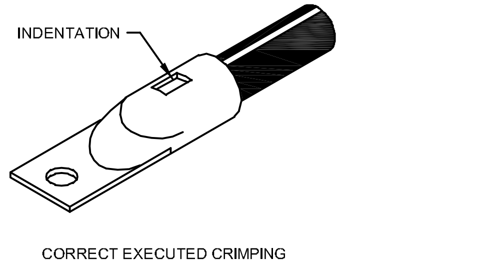
Fig 1



HAND CRIMPING PLIERS

The tool is operated by squeezing the handles. The jaws move together, grip and then crimp the fitting. Using the crimping tool that matches the specific crimp lug will give the correct crimping force for a properly executed crimp. Properly executed crimp will indent the top of the lug and the indentation will hold the conductor securely as shown in Fig 2.

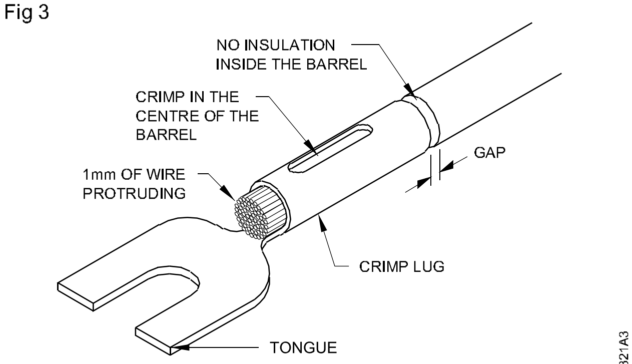
Fig 2



CORRECT EXECUTED CRIMPING

If the terminal has too deep a crimp, the strength of the joint is reduced. With too shallow a crimp, the electrical contact has a high resistance. Selection of the correct crimping tool is essential. A properly crimped terminal is shown in Fig 3.

Fig 3

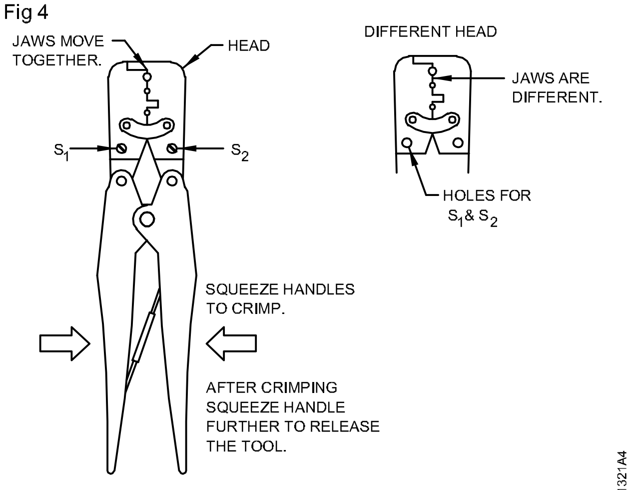


A PROPERLY CRIMPED TERMINAL

Terminal lug crimping pliers are available in lengths ranging from 180 to 300 mm. Crimping tools are available in sets. For higher capacity cables crimping tools are operated by hydraulic force.

Fig 4 shows another type of crimping tool which crimps from 26 to 10 SWG.

Fig 4



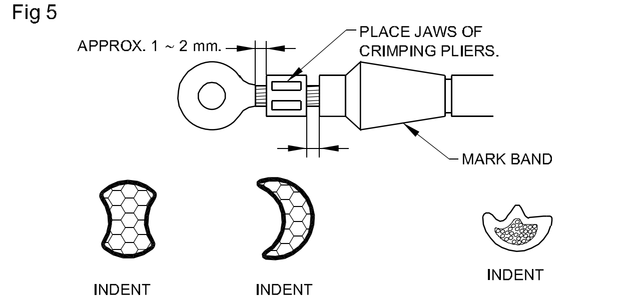
PARTS OF CRIMPING TOOLS

The head and jaws, may be removed, by unscrewing the screws S_1 and S_2. A head with different shaped jaws may then be secured to the tool. The shape of the jaws determines the shape of the crimp (indent). Some crimp sections are shown in Fig 5.

Safety

When using this type of crimping tool care must be taken not to trap the finger, as the operating cycle of the tool is non-reversible i.e. once the handles are squeezed together the jaws can only be released by applying further pressure to the handles as shown in Fig 4.

Fig 5



CRIMPED SECTION

Terminal types

It is important to consider both the mechanical and electrical requirements when selecting a lug connector.

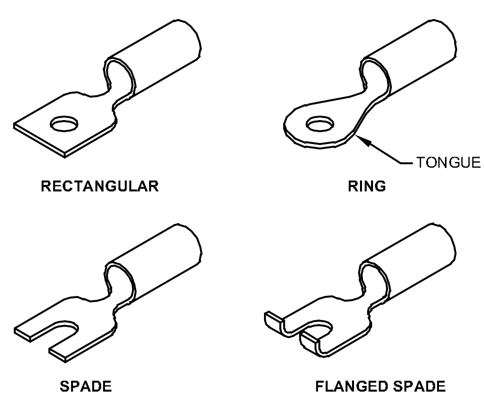
The factors are:

- the type of tongue, i.e. rectangular, ring, spade, etc.
- the mechanical size, i.e. tongue size and thickness, hole size etc. for the cable selected
- the electrical considerations such as the current carrying capacity, that may also determine some of the mechanical dimensions.

The electrical and mechanical requirements for the lug and the base material of the lug are decided by the cable material, and the place of connection will determine the minimum tongue size and the barrel size. The most commonly used base materials are copper and brass. Nickel, aluminium and steel are also used, but less frequently.

Fig 6 shows some lug connectors normally used in practice terminals. They are ring, rectangular, spade, flanged spade etc. Ring and rectangular terminals are not intended for frequent removal to disconnect the terminal whereas in spade and flanged spade lugs (terminals) the screw need not be removed to disconnect.

Fig 6



LUG CONNECTORS

Precautions for crimping tool application

Do not handle the job/tool roughly e.g. drop, hammer, etc. which may harm the tool.

Do not alter the crimping tool, e.g. alter the shape of the die etc.

Do not let metal chips adhere to the working position of the tool, particularly on the lower surface of replaceable die on the crimping part.

If a pin, spring, etc. is found damaged in the crimping tool, repair it immediately.

Apply oxide inhibiting grease to the aluminium conductor end just before crimping.

Advantages of crimping terminations

1 A properly made crimp is better in electrical conductivity and mechanical strength.

2 Less costly.

3 When the same size cables are to be terminated through lug connectors, the crimping process is faster than soldering.

4 The crimping operation surely needs good skill but soldering operation needs advanced skills.

5 Heat generated in the conductor sometimes melts the solder and the connection is open circuited. But crimped connection will not open that easily.

Current carrying capacity of copper & aluminium cables - voltage grading

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

- **list out the factors for selection of cables**
- **state the types of protection based on current carrying capacity**
- **state the size and number of strands available in copper and aluminium cables and their current carrying capacity**
- **state the rating factor and determine the current capacity of cables with respect to temperature**
- **differentiate between solid and stranded conductors.**

Selection of cables

The current carrying capacity of a particular area of cross-section cable depends upon the following factors.

- Type of conductors (metal)
- Type of insulation
- Cable run in conduit or in open surface
- Single or three phase circuit
- Type of protection - coarse or close excess current protection
- Ambient temperature
- Number of cables in bunches
- Length of circuit (permissible voltage drop) - this will be discussed at a later stage.

Depending upon the above factors the current rating of cables may vary to a great extent.

Information in this lesson will enable the wireman to select the correct cable under normal working conditions.

Current rating of cables based on type of protection

Cables insulated with PVC, may sustain serious damage when subjected, even for relatively short periods, to higher temperature than the temperature permissible for continuous operation.

Therefore, current ratings of cables insulated with PVC are determined not only by the maximum conductor temperature admissible for continuous rating but also by the temperature likely to be attained under conditions of excess current.

Hence, the current rating of cables are given under two headings:

- cables provided with coarse excess current protection
- cables provided with close excess current protection.

Coarse excess current protection

In this type of protection, circuit protection will not operate within four hours at 1.5 times the designed load current of the circuit which it protects.

The devices affording coarse excess current protection include:

- fuses which are having a fusing factor exceeding 1.5 times the marked rating.
- carriers and bases used in rewirable type electrical fuses.

Close excess current protection

In this type of protection the circuit protection will operate within four hours at 1.5 times the designed load current of the circuit which it protects.

Devices include:

- fuses fitted with fuse links having fusing factor not exceeding 1.5 times the marked rating (H R C & cartridge etc.)
- miniature and moulded case circuit breakers.
- circuit breakers set to operate at an overload not exceeding 1.5 times the designed load current of the circuit.

Electrical inspectors, who are assigned by the Government to test installation and give permission for effecting supply, now recommend close excess current protection devices like MCB and HRC fuses to be included in the circuit for safety to the user and to reduce fire accidents.

Rating factor with respect to protection

For circuits with coarse excess current protection (rewirable fuse unit) current rating of cables is given in Table 1. Though the cables can carry a higher value of current than the current notified in the Table 1, for circuits having coarse excess current protection, the permissible current in cables is obtained by multiplying the normal current capacity by a rating factor of 0.81, whereas for circuits protected by close current protection the normal current capacity is multiplied by a rating factor of 1.23.

The following example will clarify the above information.

Normal current carrying capacity of 1.5 sq mm copper cable = 16 amps (normal rating)

Current capacity of the same cable when protected by coarse excess current protection (Rating factor 0.81)

= Normal capacity x Rating factor

= 16 x 0.81 = 13 amps.

Close excess current protection (Rating factor 1.23)

= Normal capacity x Rating factor

= 16 x 1.23 = 19.7 = 20 amps.

Current capacity for close excess current protection could be obtained by the following formula also.

$$= \frac{\text{Coarse excess current protection rating}}{\text{Rating factor of coarse protection}} \times \text{Rating factor of close excess current protection}$$

Table 1

Current rating for single core PVC insulated sheathed copper and aluminium conductor cables of size 1 to 50 sq. mm at ambient temperature of 40°c (Refer to IS 694 Part I -1964). (Cables provided with coarse excess current protection.)

Nominal cross-sectional area	Number and diameter of wires	Bunched and enclosed in conduit or trunking			
		2 cables single phase AC or DC		3 or 4 cables 3-phase AC	
mm^2	Number of strands/ dia, in mm	Copper Amps.	Aluminium Amps.	Copper Amps.	Aluminium Amps.
1	1/1.12	11	–	9	–
1.5	1/1.40	13	8	11	7
2.5	1/1.80	18	11	16	10
4	1/2.24	24	15	20	13
6	1/2.80	31	19	25	16
10	1/1.40	42	26	35	22
16	7/1.70	57	36	48	30
25	7/2.24	71	45	60	38
35	7/2.50	91	55	77	47
50	19/1.80	120	69	100	59

Rating factor for ambient temperature

Further the current rating of cables is greatly affected by the ambient temperature. As such if the ambient temperature is other than 40°C the current rating shown in the above table should be multiplied by the rating factor given in Table 2.

Table 2

SL. No.	Ambient Temp. °C Rating factor for cables	25	30	35	40	45	50	55	60	65
1	Having coarse excess current protection	1.09	1.06	1.03	1.00	0.97	0.94	0.82	0.67	0.46
2	Having close excess current protection	1.22	1.15	1.08	1.00	0.91	0.82	0.70	0.57	0.40
3	Flexible cords	--	1.09	1.04	1.00	0.95	0.77	0.54	--	–

Example 1

Find the current rating of 2.5 sq mm, aluminium cable at 50°C. The circuit is single phase AC, protected by rewirable fuses and the cable is run in conduit.

Solution

The protection is coarse excess current protection. Hence referring to Table 1 the current rating of 2.5 sq mm aluminium cable at 40°C is = 11 amps.

Rating factor at 50°C referring to Table 2 = 0.94.

The current rating of 2.5 sq.mm aluminium cable protected by coarse excess current protection run in conduit and at ambient temperature of 50°C = 11 x 0.94 = 10 amps.

Example 2

Find the current rating of 4 sq mm copper cable at 60°C, when used in a 3-phase circuit and the circuit is protected by H R C fuses.

Solution

The protection is close excess current protection.

Referring to Table 1, the current rating of 4 sq. mm copper cable for coarse excess current protection (rewirable fuse) at 40°C, when used in 3 phase circuit is = 20 amps

Current rating for closed excess current protection at 40°C when used in 3-phase circuit =(20 x 1.23)/0.81 = 30.37 amps.

The rating factor at 60°C is (Referring to Table 2) = 0.57.

Hence, the current rating of 4 sq. mm copper cable in a circuit protected by close excess current protection at an ambient temperature of 60°C is = 30.37 x 0.57

= 17.31 amps

= say 17 amps.

Current rating of flexible cables is given in Table 3.

Advantages of stranded conductors over solid conductors

As stranded conductors are more flexible, chances of break of conductors and crack of insulation at the bend is less. They can be easily handled and laid.

Connections and joints of stranded conductors are stronger and have longer life.

Table 3

Current ratings for copper conductor flexible cords, insulated with PVC according to BIS No.694

Nominal cross-sectional area of conductor mm^2	Number and diameter of wires Number/mm	Current rating DC, single phase or 3-phase AC (Amperes)
0.50	16/0.20	4
0.75	24/0.20	7
1.00	32/0.20	11
1.50	48/0.20	14
2.50	80/0.20	19
4.00	128/0.20	26

Comparison between solid and stranded conductors

Solid conductor	Stranded conductor
Rigid.	Flexible.
Less mechanical strength.	More mechanical strength
Available in square,round and flat shapes.	Available in round shape having small diameters.
Used for bus-bars and in the winding of large capacity transformers.	Used for cables and wires.

In stranded conductors the insulation has a better grip on the wire.

Solid conductors between supports of overhead lines may break due to vibration. This breakage is less in stranded conductors.

The space between the strands permits flow of oil in U G cables enabling better insulation properties and cooling.

For a given area of cross- section stranded cables carry more current than solid conductors.

Table 4 shows the various types of cables.

Classification of voltage grading

Voltage is classified as

1 Low voltage (L.V): Normally not exceeding 250V (i.e.) from 0 to 250 volts.

2 Medium voltage (M.V): Exceeding 250V but not exceeding 650V from 250 to 650 volts

3 High voltage (H.V): Exceeding 650V but not exceeding 33000V.(650-33000 volts)

4 Extra high voltage: All voltages above 33000V comes under this category.

TABLE 4

Various types of electrical cables

Type of code	Voltage grade	Range of cross section in (mm^2)	Application	B.I.S. applicable
A.Wiring cable				
1 PVC insulated a)non-sheathed single core	250/440,650/ 1100	1.5 to 50	Domestic/industrial wiring in conduits. Domestic/industrial wiring in batten.	694 part II
b) PVC sheathed				
i) single core	-do-	-do-	-do-	
ii) flat twin-core	-do-	1.5 to 16	Domestic wiring for power plug.	
iii) flat twin-core ECC and 3-core	250/440	1.5 to 50	Domestic/industrial wiring on batten.	
iv) circular 2,3 or 4 core	650/1100V	1.5 to 300	Sub-main/industrial.	
c)non-sheathed single core and twisted twin flexible copper	250/400 650/1100	4 to 5	Temporary wiring interconnections, household applicances.	694 part I 694 part I&II
d)PVC sheathed circular twin, 3 and 4 core flexible copper	-do-	-do-		
e)Single extrusion	-do-	1.5 to 50	Domestic wiring on batten	694 part I,II
2 Polythene insulated and PVC sheathed with aluminium conductor				
a) single core flat & circular twin core	250/440	1.5 to 50	Domestic wiring on batten	1596
b) flat twin with ECC & circular	-do-	1.5 to 10	-do-	1596
3 Lead alloy sheathed i) single core ii) 2,3 and 4-core circular iii) twin & 3 core flat (ECC) 250/440	250/440 650/1100	Aluminium Copper 1.5 to 50 1.5 to 50 70 to 625 64.5 to 645 1.5 to 16 1.5 to 16 corrosive atmosphere.	Industrial wiring in damp	434 part I,II

Type of code	Voltage grade	Range of cross section in (mm^2)	Application	B.I.S. applicable
4 TRS sheathed i) single core ii) 2,3 and 4-core circular iii) Twin & 3 core flat (ECC) e) TRS sheathed flexible f) Fire resisting asbestos sheathed g) Poly Phropene sheathed flexible	 -do- -do- 250/440 650/1100 -do- -do-	 1.5 to 50 0.5 to 50 1.5 to 625 64.5 to 645 1.5 to 16 1.5 to 16	 Wiring residential on batten,industrial wiring Residential batten Welding cables in fire hazards. Training cable for lifts and other mobile equipments	 434 part I,II -do- -do- -do-
5 Weather-proof cables a)VIR insulated cotton, braided and treated with weather resistance compound b)PVC insulated PVC sheathed c)Polythene insulated, taped braided and compounded	250/440 650/1100 -do- -do-	1.50 to 50 -do- -do-	 Service connection and other outdoor application.	 434 part I,II 3035 part I 3035 part II
6 Power cables heavy duty 1.1kV grade PVC insulated PVC sheathed cable a)Unarmoured/armoured i) Single core ii) Twin core iii) Three-core iv) Three and a half core v) Four core	 650/1100 650/1100 -do- -do- -do-	 1.5 to 1000 1.5 to 500 1.5 to 400 16 to 400 1.5 to 50	 Armoured cable in singlecore not available. Unarmoured power cables are used only in protected places. Use of copper is banned for such applications	 1554 Part I/76
7 Paper insulated, lead, covered, single core, unarmoured. a) Twin-core, armoured b) Three and three and half, armoured.	1.1kV -do- -do- -do-	6 to 625 6 to 625 -do- -do- -do- -do- -do- -do-	Dry places, heavy duty, hazardous applications underground. Dry places for cotton braided, otherwise metal sheathed.	692-73 693-1965
8 Varnished cambric insulated	-do-			

N.B. 1 Where material of core is not mentioned, it is aluminium.
2 ECC - Earth continuity conductor.