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

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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 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

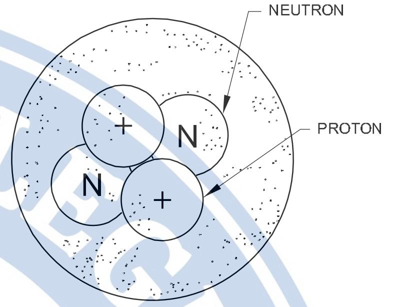
The Nucleus: The nucleus is the central part of the atom. It contains the protons and neutrons in equlal numbrs shown in Fig 1.

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.

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.

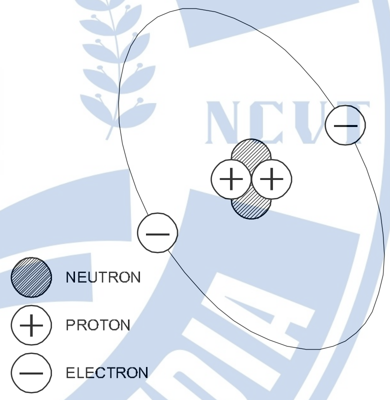
Neutron: A neutron is actually a particle by itself, and is electrically neutral. Since neutrons are electrically neutral, they are not too important to the electrical nature of atoms.

Fig 1



NUCLEUS OF AN ATOM

Fig 2



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.

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 3

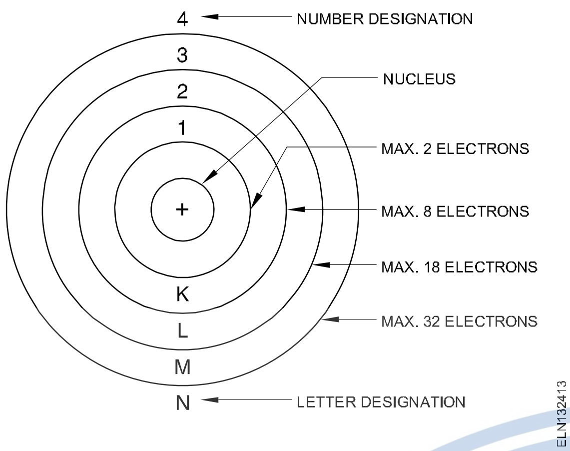
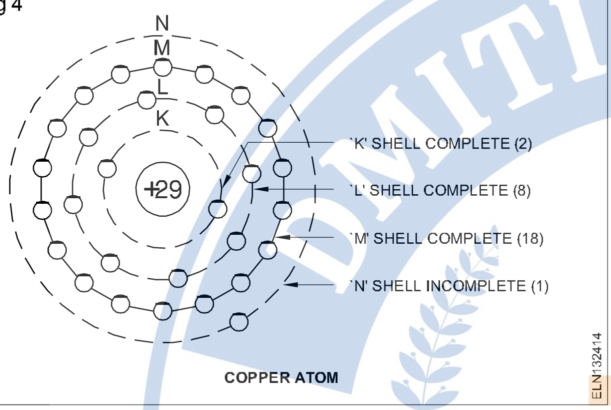


Fig 4



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

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.

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.

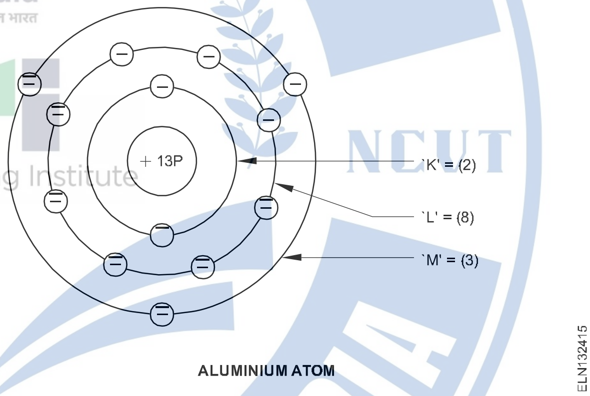
Some common good conductors are Copper, Aluminium, Zinc, Lead, Tin, Eureka, Nichrome, are conductors, where as silver and gold are very good conductors

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.

Fig 5



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.

A simple electrical circuit is shown in Fig 1

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.

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.

Fig 1

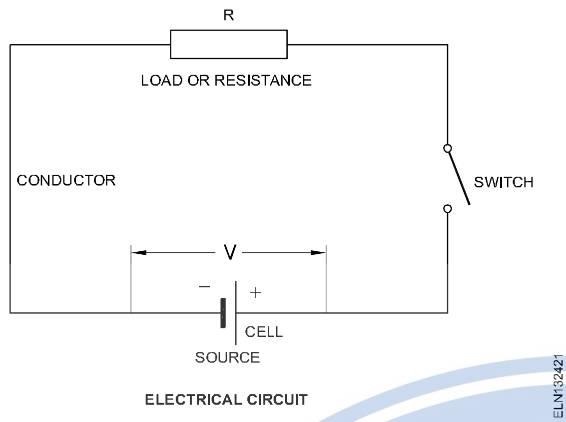
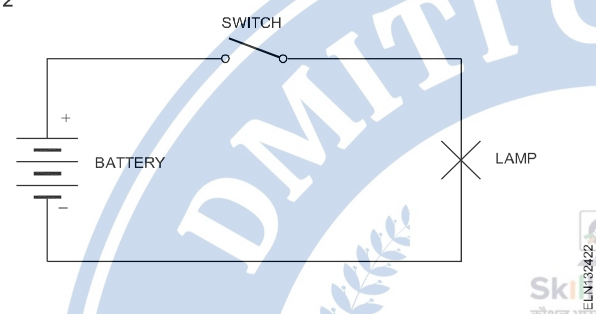


Fig 2



Ampere

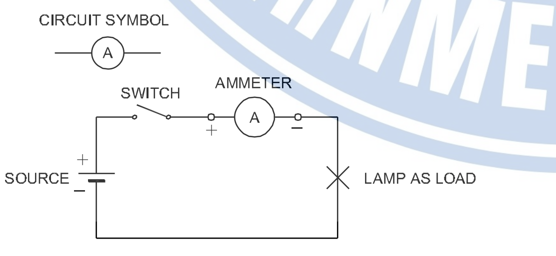
The unit of current (abbreviated as I) is an ampere (symbol A). If 6.24 x 10^{18} electrons pass through a conductor per second having one ohm resistance with a potential difference of one volt causes one ampere current has passed through the conductor.

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.

Fig 3

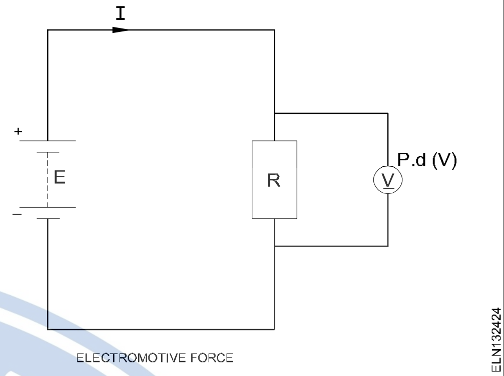


Electro Motive Force (EMF)

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.

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



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

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)

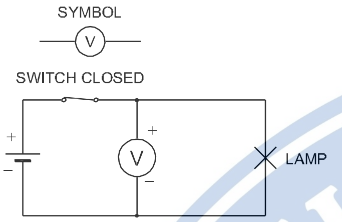
It is the voltage available at the terminal of the source of supply. Its symbol is V_T. Its unit is also the volt and is also measured by a voltmeter. It is given by the emf minus the voltage drop in the source of supply, i.e.

V_T = EMF - IR

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

Voltmeter : Electrical voltage is measured with a voltmeter.The voltmeter connection is across or it is a parallel connection (Fig 5).

Fig 5



Resistance (R) : 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).

Meter to measure resistance

Ohmic value of a medium resistance is measured by an ohmmeter or a 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)

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**

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).

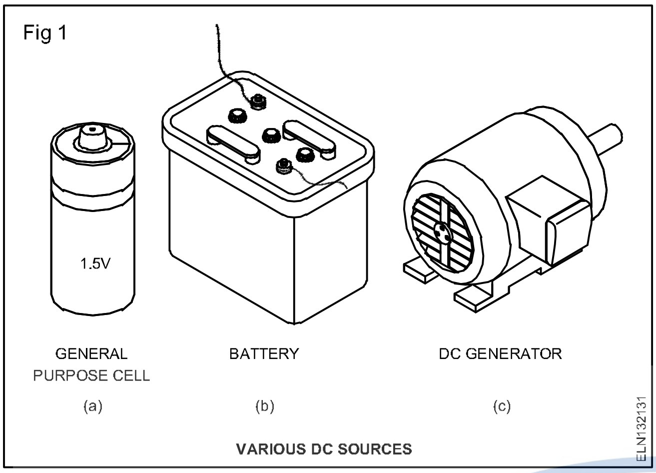
__ DC is represented by this symbol.

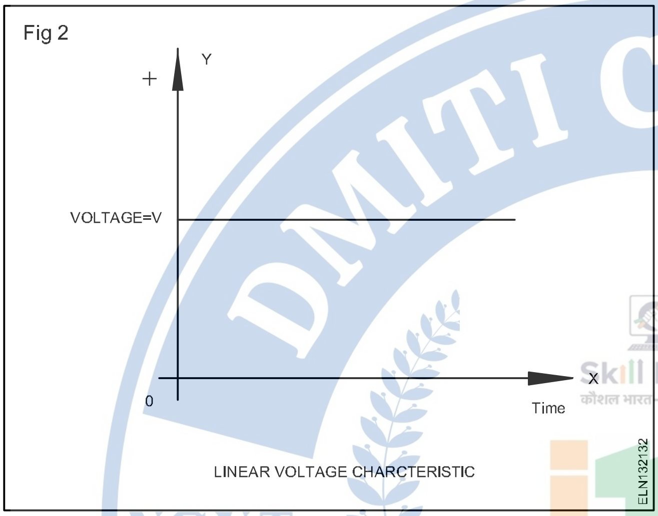
~ AC is represented by this symbol.

DC Supply

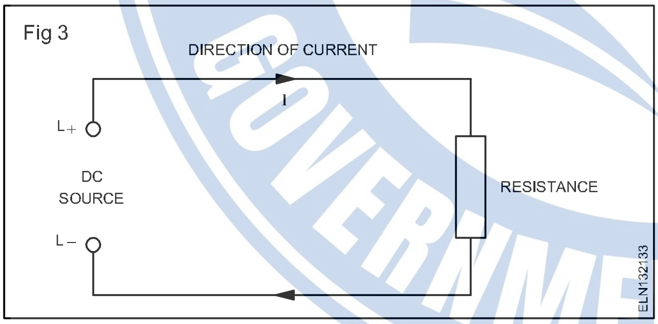
The most common sources of DC supply are the cells/ batteries (Figs 1a and 1b) and DC generators (dynamos). (Fig 1C)

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)





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)



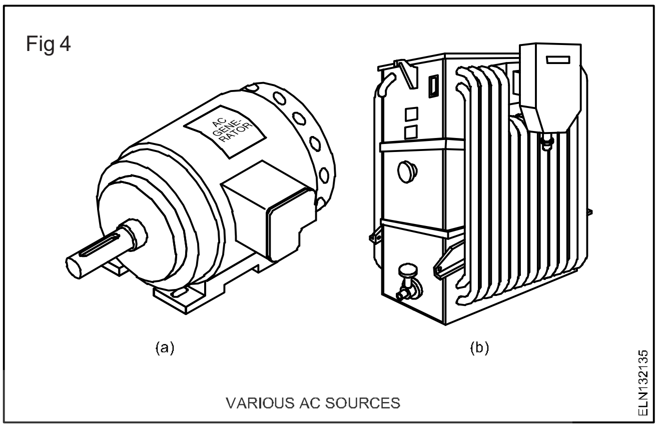
Thus direct current remains at the same value from the moment of switching on to the moment of switching off. (Direct current in common usage is known as DC current.)

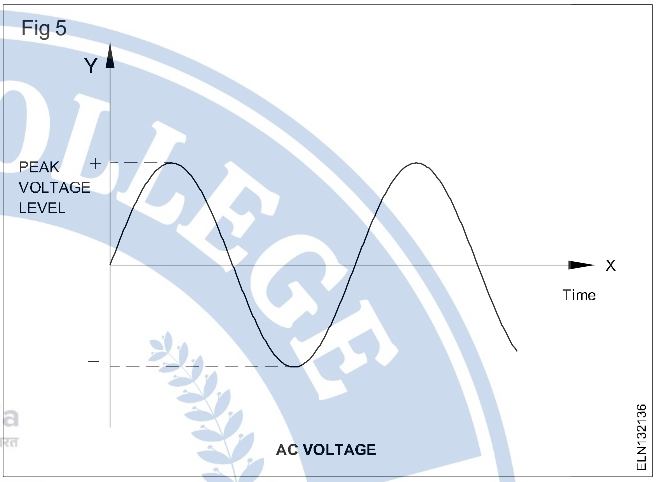
AC Supply

The source of AC supply is AC generators (alternators). (Fig 4a) The supply from a transformer (Fig 4b) is also AC.

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 5 shows a sinusoidal alternating voltage over time (wave-form).

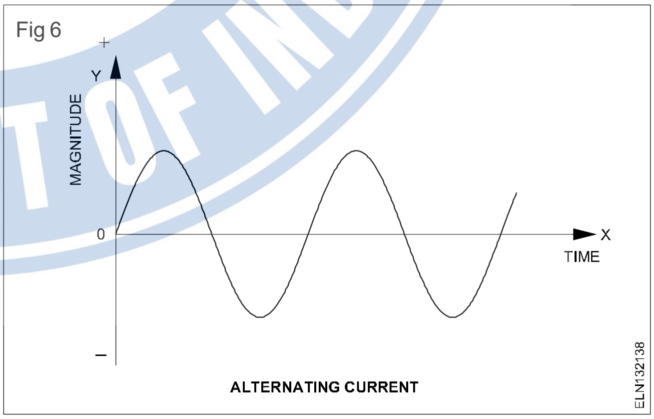




AC supply is expressed by the effective value of the voltage, and the number of times it changes in one second is known as frequency. Frequency is represented by 'F' and its unit is in Hertz(Hz).

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. (Fig 6)

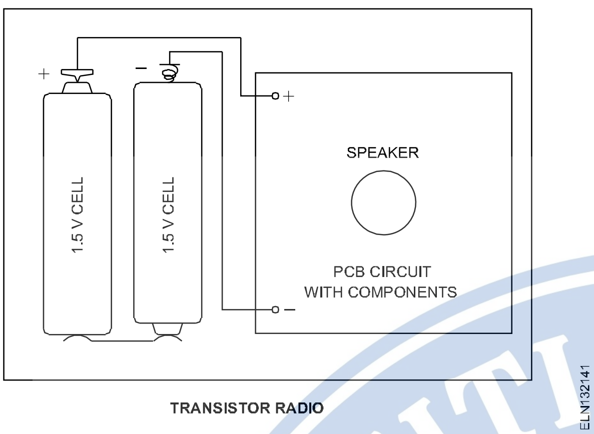


Polarity test in DC

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 7.

Fig 7



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.

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.

Conducting materials and their comparison

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 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.

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

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.

Measurement of wire sizes - standard wire gauge - outside micrometer

Necessity of measuring the wire sizes

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.

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
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
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

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

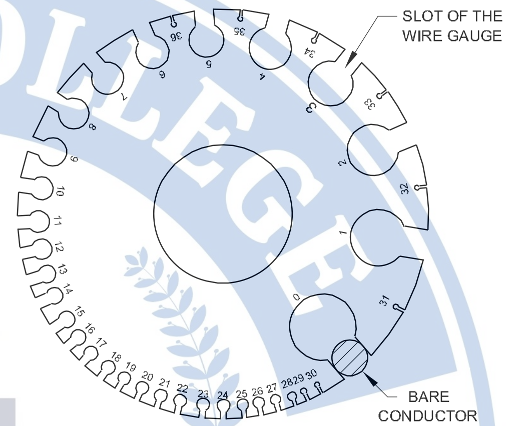
Standard Wire Gauge (SWG)

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.

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 1



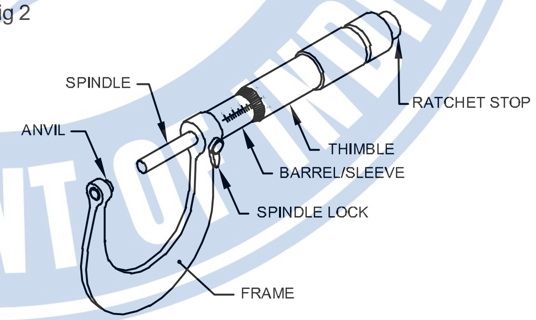
STANDARD WIRE GAUGE

ELN132161

Measurement of wire size by outside mirometers : 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 2)

Fig 2



OUTSIDE MICROMETER - PARTS

ELN132171

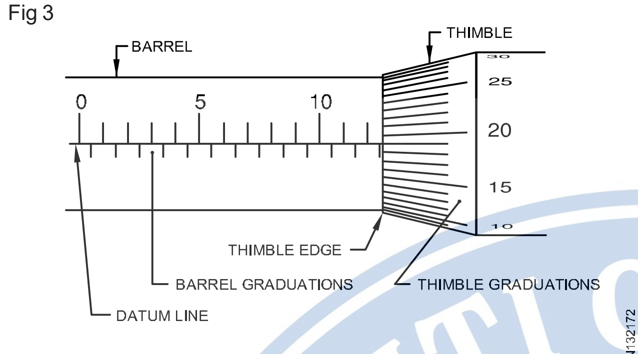
Principle of the micrometer : The micrometer works on the principle of screw and nut. The longitudinal movement of the spindle during one rotation is equal to the pitch of the screw. The movement of the spindle to the distance of the pitch or its fractions can be accurately measured on the barrel and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

In a 0-25 mm outside micrometer, on the barrel a 25 mm long datum line is marked. (Fig 3) 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.

Fig 3



GRADUATIONS MARKINGS ON OUTSIDE DIAMETER

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.

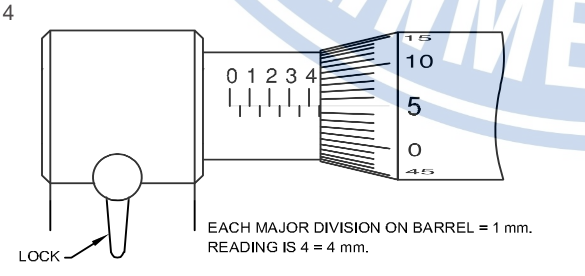
Outside micrometers are available in ranges of 0 to 25 mm, 25 to 50 mm, and so on. For electrician, to read the size of the wire 0 to 25 mm is only suitable.

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 4)

Fig 4

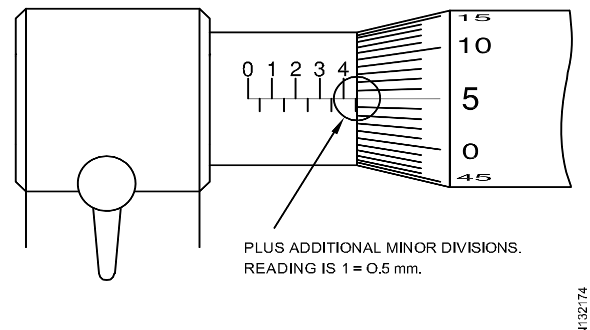


READING MICROMETER MEASUREMENT

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.

The figure reads one division (Fig 5) mm after the 4 mm mark. Hence 0.5 mm to be added to the previous reading.

Fig 5



THIMBLE READING ON MICROMETER

c Add the thimble reading to the two earlier readings.

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.

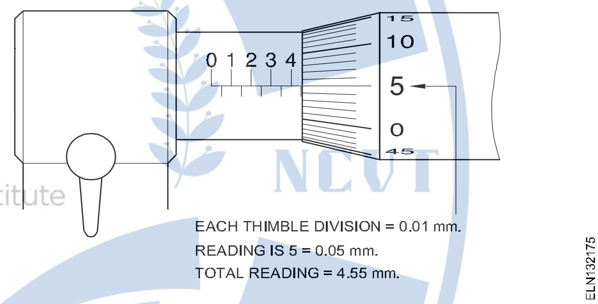
a 4.00 mm

b 0.50 mm

c 0.05 mm.

Total reading = 4.55 mm (Fig 6)

Fig 6



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.**

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

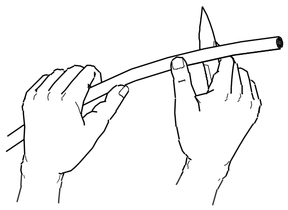
- Handling
- Skinning of the cables
- Connecting the cable ends

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.

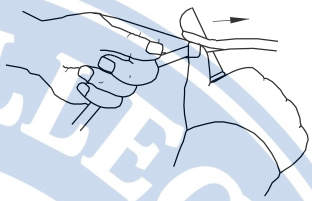
Using the knife as shown in Fig 2 at an angle of 20° to the axis of the core will avoid knicking of the conductor.

Fig 1



WRONG METHOD

Fig 2



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.

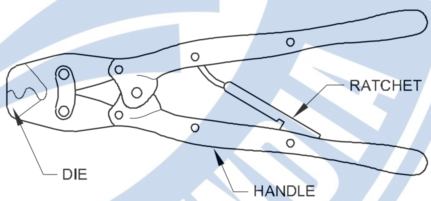
To conclude, we can state that wrong termination will lead to overheating of terminating points and cables, short circuits and earth leakage.

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).

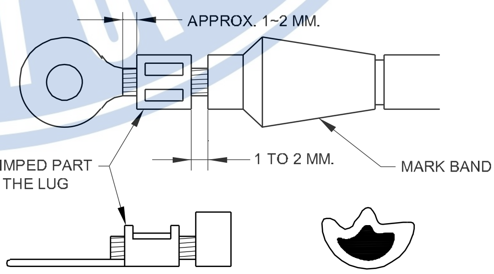
It is important to choose a crimp terminal that matches the conductor diameter and the dimensions of the connecting screw terminal. (Figs 2 & 3)

Fig 1



CRIMPING TOOL

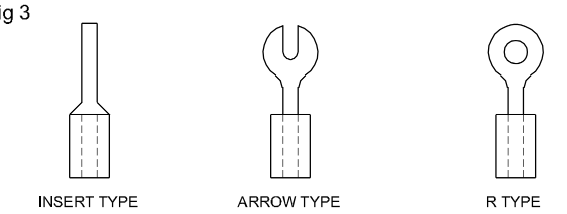
Fig 2



CRIMP TERMINAL CONNECTION

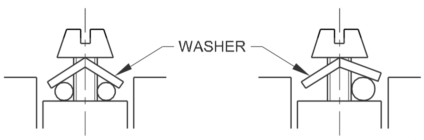
Insert screw setting: The conductor is inserted between the terminal block and the special form of washer (Fig 4), and then the screw is tightened.

Fig 3



VARIOUS KINDS OF CRIMP TERMINALS

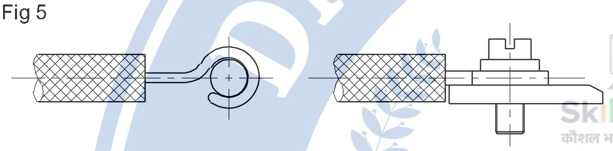
Fig 4



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.

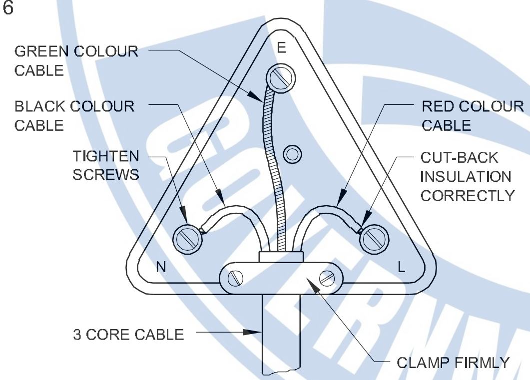
Fig 5



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

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.

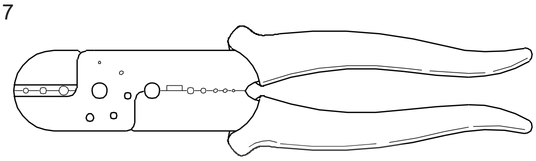
In crimp compression fitting, a ring-tongued terminal (lug) is to be compressed to the bared end of an insulated multi-strand cable. The process is called crimping and the tool used is called crimping pliers or crimping tool.

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 7 is of a type which crimps from 0.5 to 6 mm cables.

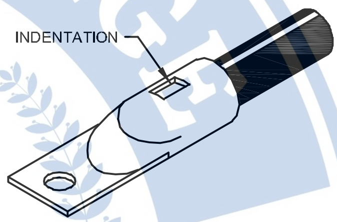
Fig 7



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 8.

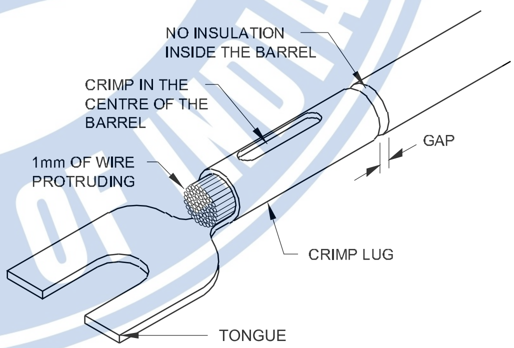
Fig 8



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 9.

Fig 9

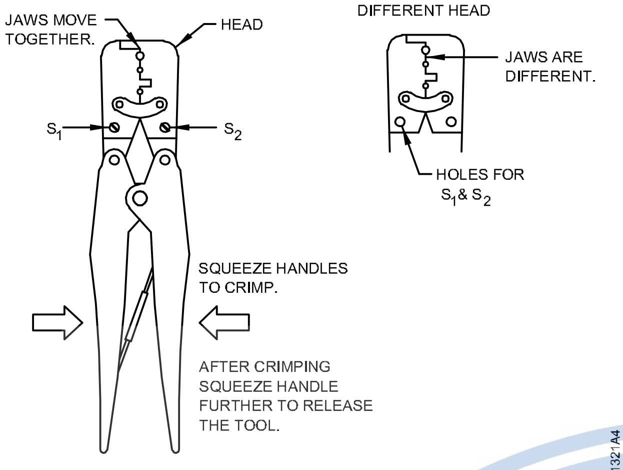


A PROPERLY CRIMPED TERMINAL

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

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 11.

Fig 10

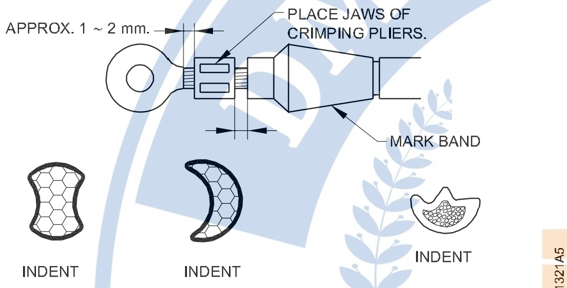


PARTS OF CRIMPING TOOLS

Safety

When using this type of crimping tool care must be taken not to trap the finger.

Fig 11



CRIMPED SECTION

Terminal types

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

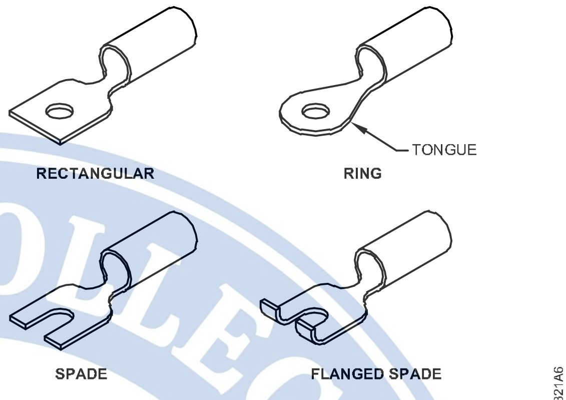
The factors are:

- 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 12 shows some lug connectors normally used in practice terminals. They are ring, rectangular, spade, flanged spade etc.

Fig 12



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.

Cable insulation - voltage grading

Objectives: At the end of this lesson you shall be able to
- **list out the factors for selection of cables**
- **state voltage grading.**

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.

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

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 ii) flat twin-core	 -do- -do-	 -do- 1.5 to 16	 -do- 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 1.5to625,64.5-645 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.

Wire joints - Types - Soldering methods

Scan the QR Code to view the video for this exercise

Objective: At the end of this lesson you shall be able to
- **state the different types of wire joints and their uses**
- **state the necessity of soldering and types of soldering**
- **state the purpose and types of fluxes**
- **explain the different method of soldering and techniques of soldering**
- **explain the type of solder and flux used for soldering aluminium conductor.**

Definition of joint: A joint in an electrical conductor means connecting/tying or interlaying together of two or more conductors such that the union/junction becomes secured both electrically and mechanically.

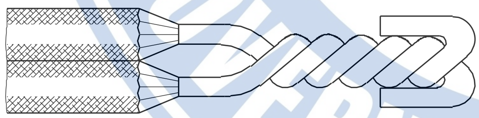
Types of joints: In electrical work, different types of joints are used, based on the requirement. The service to be performed by a joint determines the type to be used.

Some of the commonly used joints are listed below.

- Pig-tail or rat-tail
- twisted joints
- Married joint
- Tee joint
- Britannia straight joint
- Britannia tee joint
- Western union joint
- Scarfed joint
- Tap joint in single stranded conductor

Pig-tail/Rat-tail/Twisted joint: (Fig 1) This joint is suitable for pieces where there is no mechanical stress on the conductors, as found in the junction box or conduit accessories box. However, the joint should maintain good electrical conductivity.

Fig 1



RAT TAIL JOINT

ELN132511

Married joint: (Fig 2) A married joint is used in places where appreciable electrical conductivity is required, along with compactness.

Fig 2

MARRIED JOINT

ELN132512

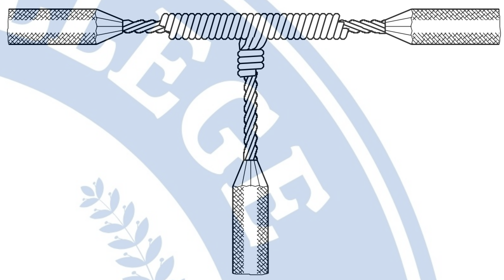
As the mechanical strength is less, this joint could be used at places where the tensile stress is not too great.

Tee joint (Fig 3)**:** This joint could be used in overhead distribution lines where the electrical energy is to be tapped for service connections.

Britannia joint: (Fig 4) This joint is used in overhead lines where considerable tensile strength is required.

It is also used both for inside and outside wiring where single conductors of diameter 4 mm or more are used.

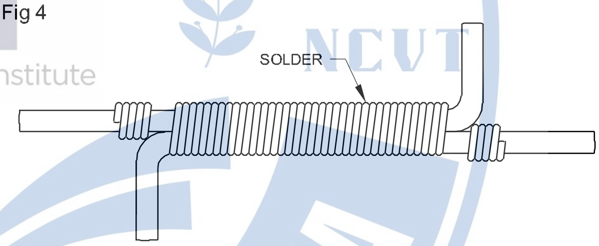
Fig 3



TEE JOINT

ELN132513

Fig 4



BRITANNIA JOINT

ELN132514

Britannia tee joint: This joint (shown in Fig 5) is used for overhead lines for tapping the electrical energy perpendicular to the service lines.

Fig 5

BRITANNIA TEE JOINT

ELN132515

Western union joint (Fig 6)**:** This joint is used in overhead lines for extending the length of wire where the joint is subjected to considerable tensile stress.

Scarfed joint (Fig 7)**:** This joint is used in large single conductors where good appearance and compactness are the main considerations, and where the joint is not subjected to appreciable tensile stress as in earth conductors used in indoor wiring.

Fig 6

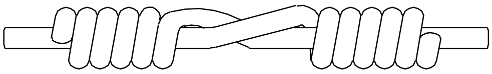
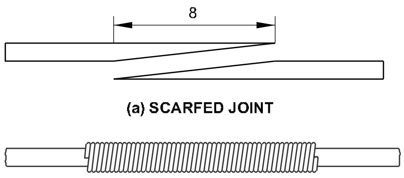


Fig 7



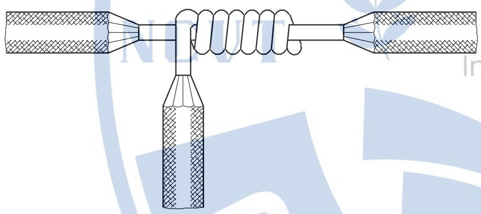
Tap joints in single stranded conductors of diameter 2 mm or less : By definition, a tap is the connection of the end of one wire to some point along the run of another wire.

The following types of taps are commonly used.

- Plain
- Aerial
- Knotted
- Cross - Double - Duplex

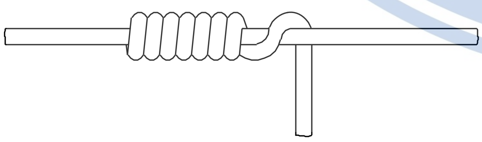
Plain tap joint: (Fig 8) This joint is the most frequently used, and is quickly made. Soldering makes the joint more reliable.

Fig 8



Aerial tap joint : (Fig 9) This joint is intended for wires subjected to considerable movement, and it is left without soldering for this purpose. This joint is suitable for low current circuits only. It is similar to the plain tap joint except that it has a long or easy twist to permit the movement of the tap wire over the main wire.

Fig 9

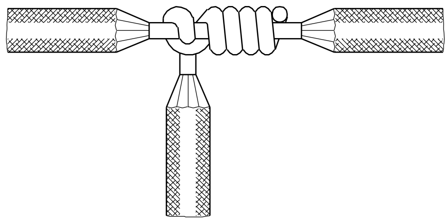


Knotted tap joint : (Fig 10) A knotted tap joint is designed to take considerable tensile stress.

Soldering - types of solders, flux and methods of soldering

Soldering: Soldering is the process of joining two metal plates or conductors without melting them, with an alloy called solder whose melting point is lower than that of the

Fig 10



metals to be soldered. The molten solder is added to the two surfaces to be joined so that they are linked by a thin film of the solder which has penetrated into the surfaces.

Necessity of soldering: Wire and cable joints should have the same electrical conductivity and mechanical strength as that of the parent conductor. This cannot be achieved by a mere mechanical joint. As such cable joints are soldered to have good mechanical strength, electrical conductivity and also to avoid corrosion.

Solders : The following are the general proportions of tin and lead used in the solders.

Designation	Compo-sition	Working temp.	Uses
Electrician's solder	Tin-60% Lead-40%	185°C. or 365°F.	Tinning and soldering electrical joints etc.

Solder used for copper: The metal alloy used as a bonding agent in soldering is called a solder. The solders used for soft soldering consist of an alloy (mixture) of mostly tin and lead.

Factors influencing the choice of a solder

The factors that influence the choice of a solder are:

- melting point
- solidification range
- strength
- hardness
- sealability
- price.

Flux: Flux is a substance used to dissolve oxides on the surface of conductors and to protect against de-oxidisation during the soldering process.

General properties of flux : The purpose of the flux is to

- dissolve oxides, sulphides etc. thereby making the soldering surface free of oxides and dirt
- prevent re-oxidation during the soldering operation thereby making the solder adhere to the surface to be soldered.
- facilitate the flow of the solder through surface tension so as to make the solder flow into the surface to be soldered.

The type of solder often determines the flux to be used for soldering.

The following table lists the fluxes used for soldering.

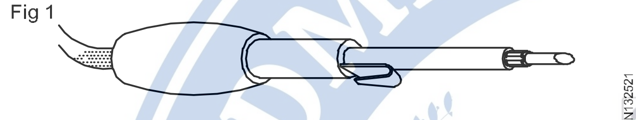
Table

Sl. No.	Suitable flux	Metals/job - used for	Type of solder
1	Sal ammonia rosin (Not fully acid-free)	Copper, brass, tin plate, gun-metal: for clean and finer soldering work.	Coarse solder
2	Rosin	Joining electrical conductors	Electrician's solder
3	Tallow - (turpentine, acid free)	For joining electrical conductors, for soldering.	Electrician's fine solder

Soldering methods

Soldering with a soldering iron: The most common method of soldering is with a soldering iron as shown in Fig 1. This is widely used for most kinds of soft soldering work.

Fig 1



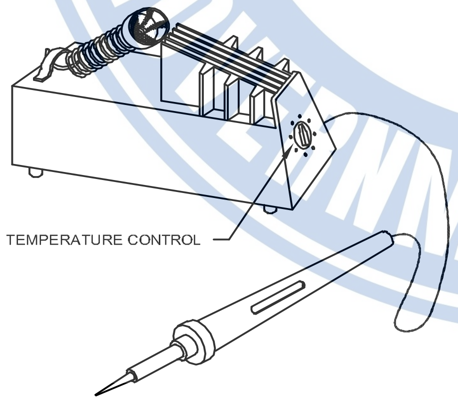
SOLDERING IRON

This tool is simple and inexpensive. Soldering irons are available in a wide range of sizes and models.

Temperature controlled soldering

For soldering miniature components on printed circuit boards, a temperature-controlled soldering iron is used as shown in Fig 2. The electrical supply given to the soldering iron is of low voltage, and is completely isolated from the main supply. Low voltage does not endanger the life of the user and will also not spoil the sensitive electronic components. Controlled temperature makes the job easy for the user.

Fig 2

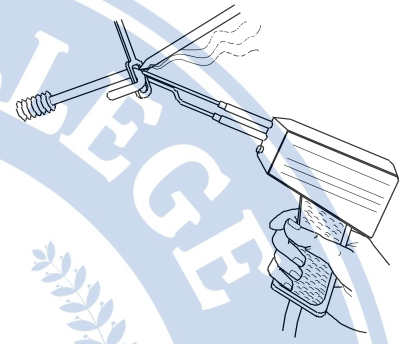


TEMPERATURE CONTROLLED SOLDERING IRON

Soldering with a soldering gun: This method, shown in Fig 3, is used for individual soldering, e.g. for servicing and repair work.

The principle of this method is that an electric current flows through a wire coil heating it. The temperature is difficult to check, and overheating can easily occur. This is the disadvantage.

Fig 3

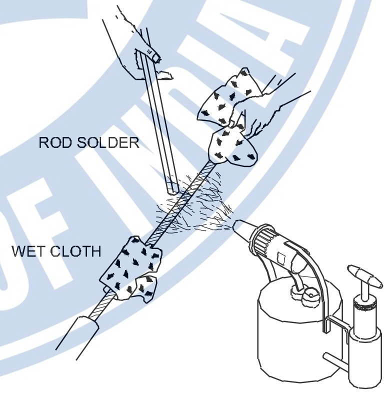


SOLDERING WITH A SOLDERING GUN

Soldering with a flame: Soldering with a flame is used when the heat capacity of a soldering iron is insufficient.

This method, shown in Fig 4, permits rapid heating and is used primarily for larger jobs, such as piping and cable work, vehicle body repairs and some applications in the building trade.

Fig 4



SOLDERING WITH BLOWLAMP

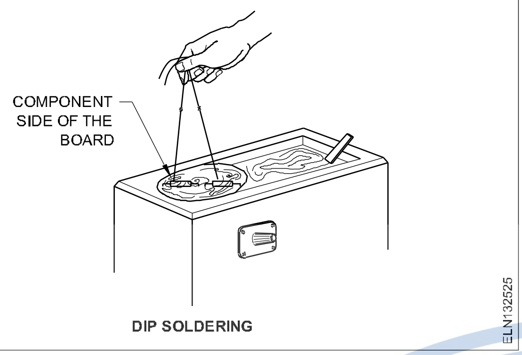
This method requires skilful management of the flame.

Dip soldering: This method, shown in Fig 5, is used for quantity production and for tinning work similar to component soldering on Printed Circuit Boards (P.C.B.). Components to be soldered or tinned are dipped into a bath of molten solder, which is heated electrically.

The temperature can be controlled very accurately.

Machine soldering: This method is used for quantity production, and is based on the principle that molten solder or a mixture of oil and molten solder is set in rapid motion, thus breaking up the oxide film. The solder comes into direct contact with the component ends to be soldered.

Fig 5



DIP SOLDERING

Techniques of soldering : Soldering involves the following main operations.

- Tinning the soldering iron
- Cleaning the parts to be soldered
- Applying the solder

Tinning the soldering iron: To make the solder adhere to the tip of the soldering iron, the surface of the tip must be coated with the solder, and this operation is known as tinning.

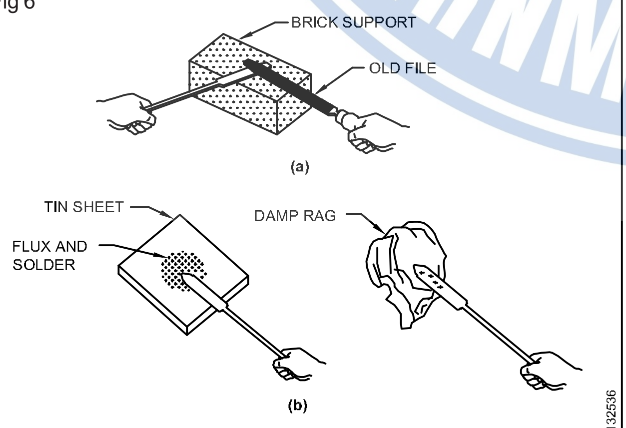
First the tip is cleaned with a cloth and heated either directly or indirectly. The tip is then filed to remove the scales, and is wiped again with a cloth.

The right temperature for tinning could be judged by the change of colour of the tip when heated. If the surface of the copper tip tarnishes immediately, the temperature is high and needs to be cooled slightly by withdrawing the source of heat temporarily. A correctly heated tip tarnishes slowly.

After the soldering iron tip attains the correct temperature, place a small quantity of solder and the flux on a tin plate and rub the bit on the mixture. The solder should stick to the surface of the tip evenly. Wipe out the superfluous solder with a clean damp cloth.

The whole process of tinning is shown in Figures 6a and 6b.

Fig 6



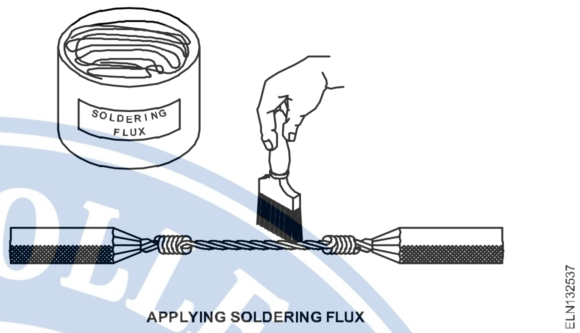
TINNING PROCESS

The surface should present a bright silvery appearance when properly tinned.

Cleaning the surface to be soldered: The parts to be soldered should be well cleaned for perfect soldering. The scales, dirt, oil and grease should be completely removed either by wiping or by rubbing with a sandpaper. Immediately after cleaning, the flux should be applied on the surface to avoid oxidization.

Applying the flux: The rosin which is recommended as a flux may be sprinkled over the surface to be soldered or may be applied with a brush as shown in the Fig 7.

Fig 7



APPLYING SOLDERING FLUX

Applying the solder: The quantity of the solder to be applied depends upon the size of the job. For small jobs like printed circuit boards soldering or soldering joints in wires of diameter 2 mm or lower, an electric soldering iron is used whereas for soldering joints of large sized cables, pot and ladle are used.

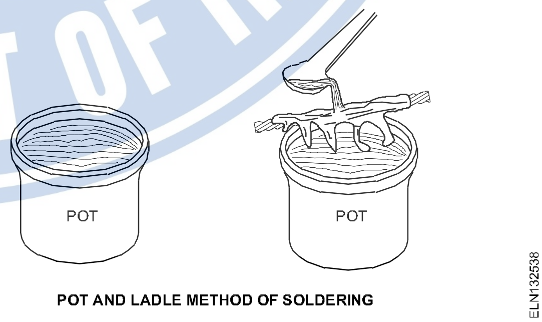
Soldering precautions: Remove the iron as soon as the solder has flowed over the surfaces.

Excessive heating may damage:

- the wire and its insulation
- the component being soldered
- the adjoining components.

Soldering with pot and ladle (Fig 8): For larger sized jobs like underground cable jointing, a melting pot and ladle are used. The solder is kept in the pot and heated either by a blowlamp or by charcoal. Initially the surface to be soldered is cleaned and a coat of flux is given.

Fig 8



POT AND LADLE METHOD OF SOLDERING

Then the surface to be soldered is heated by pouring molten solder over it in quick succession. The dripping solder is collected in a clean tray. After several pourings, the surface attains the same temperature as that of the molten solder. The flux is again applied and the solder is slowly poured on the surface as it forms an even layer. Superfluous solder collected in the tray is re-melted in the pot.

Soldering of aluminium cables: Soldering aluminium conductors is more difficult than soldering copper conductors owing to the highly tenacious, refractory and stable nature of the oxide film which forms immediately on any aluminium exposed to air.

This oxide film does not allow the solder to wet the surface to be soldered, and also prevents the solder from entering the interior surface by capillary action. Hence special solders and fluxes are used for aluminium soldering.

Solder: A special soft solder having a small percentage of zinc is used for joining aluminium conductors. (Soft solders are alloys which have a melting point below 300^{0}C.) IS 5479-1985 gives details of the chemical composition of soft solders and their grades used for soldering aluminium conductors. Details are given in Table 1.

The object of this small zinc content which is a common feature of aluminium solders is to fecilitate the alloying of the solder with an aluminium surface. A typical composition of solder with 51% lead, 31% tin, 9 % zinc and 9% cadmium with the brand name `ALCA P' solder is available in the market for soldering aluminium conductors. In addition a special solder by name Ker-al-lite is also available for soldering aluminium conductors.

Flux: In soldering aluminium conductors, organic fluxes of reaction type, free from chlorides and suitable for soft soldering are used.

The composition of the organic fluxes decomposes at approximately 250°C to effect the removal of the oxide film and also to assist in the spreading of the molten solder to enable tinning the de-oxidised surface immediately.

The major disadvantage of organic flux is that it tends to char at a temp. above 360°C. The charring, thus caused, renders the flux ineffective and gives rise to the danger of creating voids in the joint due to charred flux residues. For this reason, it is essential that the temp. of this solder during the operation is maintained well within 360°C. The commercial name of fluxes used for joining aluminium conductors are Kynal Flux and Eyre No.7.

Procedure of soldering aluminium cables : The procedure of soldering aluminium cables to standard copper lugs employing Kynal's flux and Ker-al-lite special solder is explained below.

Strip the cable in preparation for jointing in the usual manner.

Spread out the strands so as to effect a general loosening and slight displacement of the wires, and clean the surface preferably with a wire brush.

Apply a small quantity of flux by brushing well into the fanned-out ends of the conductor and baste (moisten) the fluxed conductor with a full ladle of molten solder.

Apply more flux and baste again with the molten solder. Continue to make repeated alternate applications of flux and solder until the wires exhibit a brightly tinned surface free from dull spots.

After the final basting, wipe off the surplus metal from the strands with a clean and dry piece of cloth.

Flux the lug inner surface and fill it with the molten solder.

Insert the tinned end of the cable inside the lug and hold both the cable and the lug firmly without shaking.

Allow the lug to cool and baste the surface quickly with the molten solder to remove the excess solder.

Wipe the lug surface with a clean cloth.

Apply a coating of graphite conducting grease on the lug before using.

Precautions to be followed while soldering aluminium

All surfaces must be scrupulously clean.

When a joint is being made between stranded conductors, the strands must be `stepped' to increase the surface area.

The surface must be fluxed before the heat is applied.

Safety

During the jointing operation copious fumes are given off when the flux is heated. These fumes contain small quantities of fluorine, and it is, therefore, advisable not to inhale them.

As smoking during the jointing operation results in the inhaling of toxic fumes, smoking during soldering should be avoided.

Table 1

Grade	% of alloying elements			Melting temp. in °C	Flux type	Applications
	Zinc	Lead	Tin			
SnPb53Zn	1.75–2.25	52–54	45.71–45.21	170–215	Organic	Conductors of electrical cables
SnPb58Zn	1.75–2.25	57–59	40.66–40.6	175–220		-do-

Under ground (UG) cables - construction - materials - types - joints - testing

Objectives: At the end of this lesson you shall be able to
- **define UG cable**
- **explain the construction of UG cables**
- **list and state the insulating materials used in cables**
- **list out and state the types of UG cables used for 3 phase service**
- **state the types of cable joints and laying methods**
- **expalin the faults and testing procedures of cables.**

Under Ground (UG) cables

"A cable so prepared that it can withstand pressure and can be installed below the ground level and normally two or more conductors are placed in an UG cablewith separate insulation on each conductor"

Electric power can be transmitted (or) distributed either by over-head lines system or by underground cable system. The underground cable system have several advantage, such

Advantages

- Less chance to damage through storms or lightning.
- Low maintenance cost.
- Less chances of fault.

Disadvantages

However, their major draw back / disadvantages are

- Initial cost of UG cable system is heavy.
- The cost of joints are more.
- Introduce insulation problems at high voltages compared with O.H lines.

For these reasons UG cables are employed where it is impracticable to use O.H lines like (i) thickly populated areas, where municipal authorities prohibit O.H lines for the reason of safety.

ii Around plants

iii In Substations,

iv Where maintenance conditions do not permit the use of O.H construction.

General construction of UG cables

An underground cable essentially consists of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

Necessity requirements for cables

In general, a cable must fulfill the following necessary requirements.

i The conductor used in cables should be tinned stranded copper or aluminum of high conductivity. (Strands of cable gives flexibility and carry more current).

ii The size of the conductor should be selected, so that the cable carries the desired load current without overheating and limits the voltage drop to a permissible value.

iii The cable must have proper thickness of insulation to ensure the safety and reliability for the designed voltage.

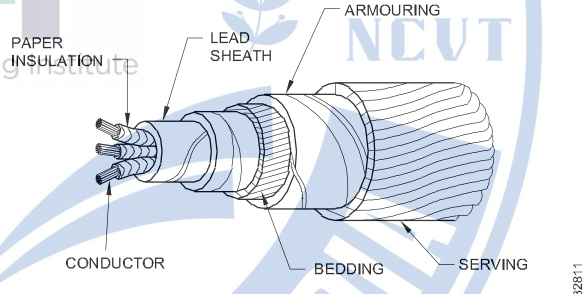
iv The cable must be provided with suitable mechanical protection so that it may withstand the rough use in laying it.

v The materials used in cables should be with complete chemical and physical stability throughout.

Construction of Cables

Fig 1 shows the general construction of a 3-core cable. The various parts are:

Fig 1



CONSTRUCTION OF CORE CABLE

i **Cores or conductors:** A cable may have one or more than one core (conductor) depending upon the type of service for which it is intended. For instance, the 3-conductor cable shown in Fig 1 is used for 3-phase service. The conductors are made of tinned copper or aluminium and are usually stranded in order to provide flexibility to the cable and having high conductivity.

ii **Insulation:** Each core or conductor is provided with a suitable thickness of insulation, the thickness of layer depending upon the voltage to be withstood by the cable. The commonly used materials for insulation are impregnated paper, varnished cambric or rubber mineral compound. Petrolium jelly is applied to the layers of the cambric to prevent damage.

iii **Metallic sheath:** In order to protect the cable from moisture, gases or other damaging liquids (acids or alkalies) in the soil and atmosphere, a metallic sheath of lead or aluminium is provided over the insulation as shown in Fig 1. The metallic sheath is usually a lead or lead alloy.

iv Paper Belt: Layer of imprignated paper tape is wound round the grouped insulated cores. The gap in the cores is filled with fibrous insulating material (jute etc.)

v Bedding: Over the metallic sheath is applied a layer of bedding which consists of a fibrous material like jute or hessian tape. The purpose of bedding is to protect the metallic sheath against corrosion and from mechanical injury due to armouring.

vi Armouring: Over the bedding, armouring is provided which consists of one or two layers of galvanized steel wire or steel tape. Its purpose is to protect the cable from mechanical injury while laying it and during the course of handling. Armouring may not be done in the case of some cables.

vii Serving: In order to protect armouring from atmospheric conditions, a layer of fibrous material (like jute) similar to bedding is provided over the armouring. This is known as serving.

It may not be out of place to mention here that bedding, armouring and serving are only applied to the cables for the protection of conductor insulation and to protect the metallic sheath from mechanical injury.

The principal insulating materials used in cables are

i Rubber

ii Vulcanized India rubber

iii Impregnated paper

iv Varnished cambric and

v Polyvinyl chloride.

Classification of cables

Cables for underground service may be classified in two ways according to (i) the type of insulating material used in their manufacture (ii) the voltage for which they are manufactured. However, the later method of classification is generally preferred as

i Low-tension (L.T) cables – upto 1100 V

ii High-tension (H.T) cables – upto 11,000 V

iii Super-tension (S.T cables – from 22 KV to 33 KV

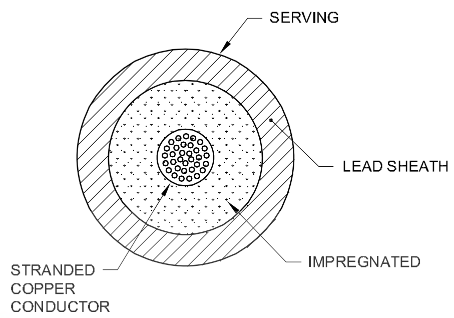
iv Extra high-tension (E.H.T) cables – from 33 to 66 KV

v Extra super voltage cables – beyond 132 KV

A cable may have one or more than one core depending upon the type of service for which it is intended. It may be (i) single-core (ii) two-core (iii) three-core (iv) four-core etc. For a 3-phase service, either 3-single core cables or three-core cable can be used depending upon the operating voltage and load demand.

Single core low tension cable: Fig 2 shows the constructional details of a single-core low tension cable. The cable has ordinary construction because the stresses developed in the cable for low voltages (upto 6600 V) are generally small. It consists of one circular core of tinned stranded copper (or aluminium) insulated by layers of impregnated paper.

Fig 2



SINGLE CORE L.T. CABLE

Cables for 3-Phase Service

In practice, underground cables are generally required to deliver 3-phase power. For the purpose, either three-core cables or three single core cables may be used. For voltages upto 66 KV, 3-core cable (i.e. multi-core construction) is preferred due to economic reasons. The following types of cables are generally used for 3-phase service.

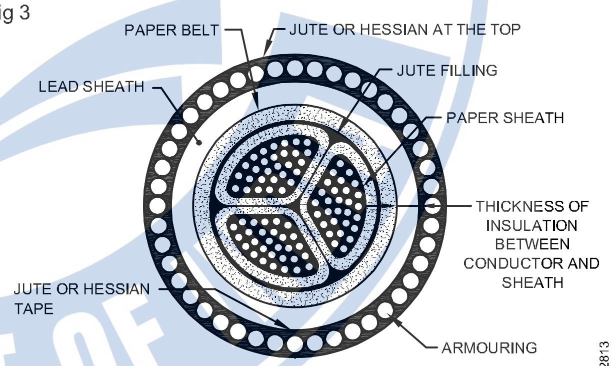
1 Belted cables – upto 11 KV

2 Screened cables – from 22 KV to 66 KV

3 Pressure cables – beyond 66 KV

1 Belted cables : These cables are used for voltages upto 11 KV but in extraordinary cases their use extended upto 22KV. (Fig 3)

Fig 3



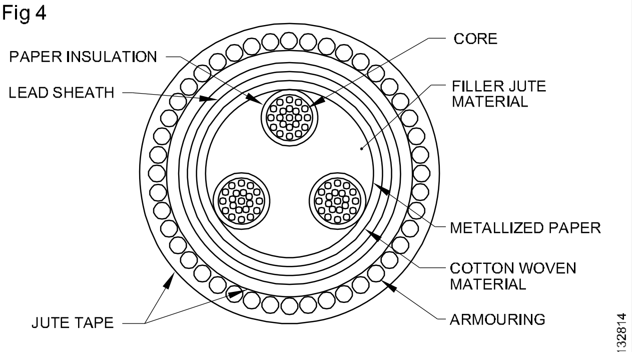
BELTED TYPE CABLE

2 Screened cable

These cables are meant for use upto 33 KV but in particular cases their use may be extended to operating voltages upto 66 KV. Two principal types of screened cables are H-type cable and S.L. type cables.

i **H-type cables** : This type of cable was first designed by H. Horchstadter and hence the name. Fig 4 shows the constructional details of a typical 3-core, H-type cable. Each core is insulated by layers of impregnated paper. The insulation on each core is covered with a metallic screen which usually consists of a perforated aluminium foil.

Fig 4



H TYPE CABLE

Advantages:

- The posibility of air pockets or volds in the dielectric is eleminated
- The metalic screen increase the heat dissipating power of the cable

(ii) **S.L. type cables** Fig 5 shows the constructional details of 3-core S.L **(separate lead)** type cable. It is basically H-type cable but the screen round each core insulation is covered by its own lead sheath. There is no overall lead sheath but only armouring and serving are provided.

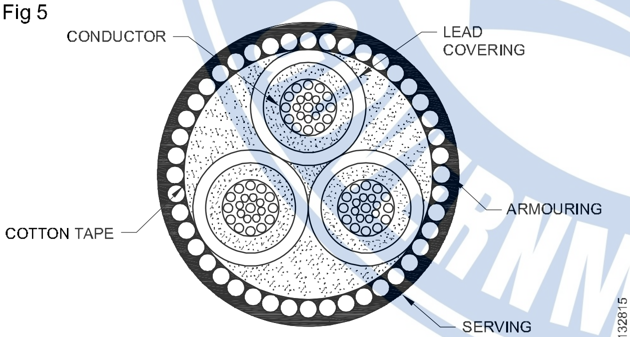
The S.L type cables have two main advantages over H-type cables.

a The separate sheaths minimize the possibility of core-to-core breakdown.

b Bending of cables become easy due to the elimination of overall lead sheath.

The disadvantage is that the three lead sheaths of S.L. cable are much thinner than the single sheath of H-cable

Fig 5



SL TYPE CABLE

3 Pressure cables

For voltages beyond 66 KV, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. When the operating voltages are greater than 66 KV, pressure cables are used. Two types of pressure cables viz oil filled cables and gas pressure cables are commonly used.

i **Oil filled cables.** In such type of cables, channels of ducts are provided in the cable for oil circulation. The oil under pressure (it is the same oil used for impregnation) is kept constantly supplied to the channel by means of external reservoirs placed at suitable distances (say 500 m) along the route of the cable.

Oil under pressure compresses the layers of paper insulation and is forced into any voids that may have formed between the layers. Due to the elimination of voids, oil-filled cables can be used for higher voltages, the range being from 66 KV upto 230 KV.

Oil-filled cables are of three types viz.

i Single-core conductor channel

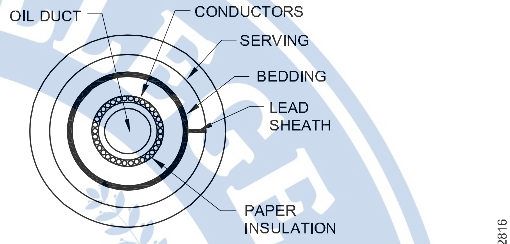
ii Single-core sheath channel and

iii Three-core filler-space channels.

i Single-core Conductor channel

Fig 6 shows the constructional details of a single-core conductor channel, oil-filled cable.

Fig 6

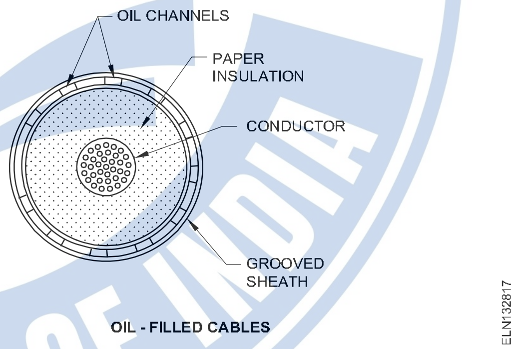


SINGLE - CORE CONDUCTOR CHANNEL OIL - FILLED CABLE

ii Single-core sheath channel (Fig 7)

In this type of cable, the conductor is solid similar to that of solid cable and is paper insulated. However, oil ducts are provided in the metallic sheath.

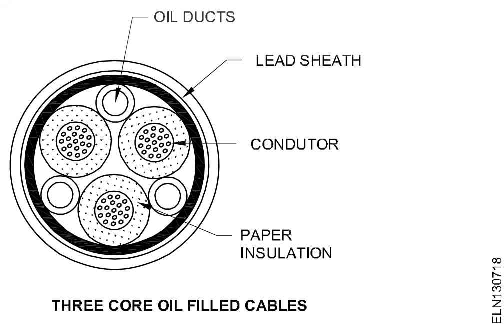
Fig 7



OIL - FILLED CABLES

iii 3-core oil-filled cable (Fig 8): The oil ducts are located in the filler space. These channels are composed of perforated metal-ribbon tubing and are at earth potential.

Fig 8



THREE CORE OIL FILLED CABLES

Advantages

a Formation of voids and ionization are avoided.

b Allowable temperature range and dielectric strength are increased.

c If there is leakage, the defect in the lead sheath is at once indicated and the possibility of earth faults is decreased.

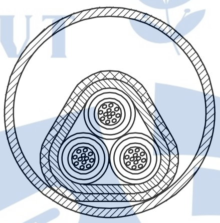
Disadvantages

a High initial cost and complicated system of laying

ii **Gas pressure cables**. The voltage required to set up ionization inside a void increases as the pressure is increased. Therefore, if ordinary cable is subjected to a sufficiently high pressure, the ionization can be altogether eliminated. At the same time, the increased pressure produces radial compression which tends to close any voids. This is the underlying principle of gas pressure cables.

Fig 9 shows the section of external pressure cable designed by Hockstadter, Vogal and Bowden. The construction of the cable is similar to that an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable. The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the lead sheath acts as a pressure membrane. The sheath is protected by a thin metal tape. The cable is laid is a gas-tight steel pipe.

Fig 9



EXTERNAL PRESSURE CABLE

The pipe is filled with dry nitrogen gas at a pressure of 12 to 15 atmospheres. The gas pressure produces radial compression and closes the voids that may have formed between the layers of paper insulation.

Advantages:

a Cables can carry more load current

b Operate at higher voltages than a normal cable.

c Maintenance cost is small and the nitrogen gas helps in quenching any flame.

Disadvantages:

The overall cost is very high.

Further the cables are also classified according to their insulation system as under:

PVC insulated cables	(Poly vinyl chloride)
MI cables	(Mineral insulation)
PILC cables	(Paper insulated lead covered)
XLPE cables	(Cross linked poly ethylene)
PILCDTA cables	(Paper insulated lead covered double tape armoured)

UG cables laying method

The reliability of the underground cable (UG) installation depends upon the proper laying and attachment of fittings (i.e) cable and boxes, joints, branch connectors etc.

Methods of laying of UG cables

The following are the methods of laying underground cables

1 Laying direct in ground

2 Laying in ducts

3 Laying on racks in air.

4 Laying on racks inside a cable tunnel.

5 Laying along buildings or structures.

Precautions while handling cables

1 Prevent the cable from dragging on the floor.

2 Prevent kinking of the cable.

3 After laying the cable in the ducts it should be immediately covered or suspended.

Cable jointing methods: This process consists of the following steps.

a Exact measurement of the cable for insulation removal.

b Removal of insulation.

c Replacing of the original insulation with high grade tapes and sleeves.

d Dressing the cable ends and conductor joints through sleeves/split sleeves.

e Providing separators between cables.

f Fixing a cast iron or any other protective shell around the joint and filling the joint boxes with molten bitumen compound.

g Plumbing metallic sleeves or brass glands to the lead sheath of the cable to prevent moisture from entering the joint in case of cast iron joint boxes or tape insulation in case of cast resin kit joint boxes.

Straight through joints

The emphasis should be laid on quality and selection of proper cable, cable accessories, proper jointing techniques.

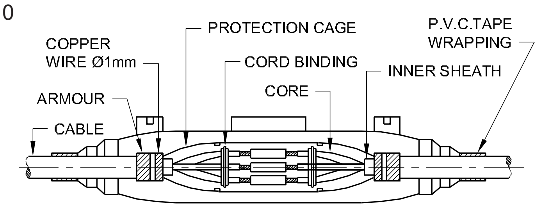
For PILC cable: For paper insulated lead sheathed cables, straight joints are made either by using sleeve joints or crimping joints up to voltage grade 11 KV. Above 11 KV, compound filled copper or brass sleeves, along with cast iron, fibre glass protection boxes are used.

Fig 10 shows such a joint.

Tee joint: These joints are to be restricted up to 11 KV.

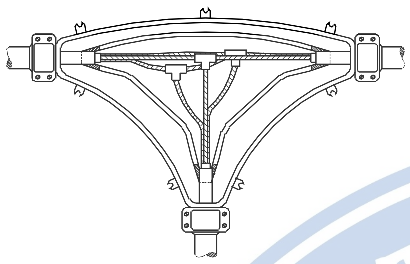
These joints are made either using cast resin kits or C.I. boxes with or without sleeves for PILC cables and cast resin kits for PVC and XLPE cables. (Fig 11)

Fig 10



STRAIGHT THROUGH JOINTS FOR CABLES 3.3 KV GRADE

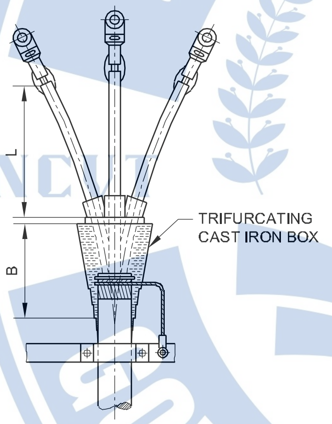
Fig 11



TEE JOINT OF 11 kV PAPER INSULATED CABLE

Tri-furcating end connections: In order to connect UG cables to the air break switches etc. tri-furcating boxes are used. They can be either cast resin type up to 1.1 KV or cast iron type for 11 KV and above. This type of box is shown in Fig 12.

Fig 12



TERMINATION FOR PVC CABLE

Method of preparing and filling compounds

– Hot pouring

– Cold pouring

Hot pouring compounds: A bituminous compound of melting temperature 90°C and pouring temperature 180°C - 190°C is used for hot pouring.

Cold pouring compound: Cold pouring is used by using cast resin system for PVC cable jointing. This has been developed for application up to 11 KV grade cables. The compound consists of a resin base and a polyamino hardener. The two component liquids are mixed at the site in accordance with the recommendation of the manufacturer.

Types of cable faults and testing procedure

The common faults which are likely to occur in cables are:

1 **Ground fault.** The insulation of the cable may breakdown causing a flow of current from the core of the cable to the lead sheath or to the earth. This is called "Ground Fault".

2 **Short circuit fault.** If the insulation between two conductors is faulty, a current flows between them. This is called a "short circuit fault".

Methods for locating ground and short circuit faults.

The methods used localizing the ground and short circuit faults differ from those used for localizing open circuit faults.

In the case of multi core cables it is advisable, first of all, to measure the insulation resistance of each core to earth and also between cores. This enables us to sort out the core that is earthed in-case of ground fault; and to sort out the cores that are shorted in case of a short circuit fault. Loop tests are used for location of ground short circuit faults. These tests can only be used if a sound cable runs along with the faulty cable or cables.

The loop tests work on the principle of a Wheatstone bridge. The advantage of these tests is that their setup is such that the resistance of fault is connected in the battery circuit and therefore does not effect the result. However, if the fault resistance is high, the sensitivity is adversely affected. In this section only two types of tests viz., Murray and Varley loop tests are being described.

Murray Loop Test. The connection for this test are shown in Fig 13a relates to the ground fault and Fig 13b relates to the short circuit fault.

In both cases, the loop circuit formed by the cable conductors is essentially a wheatstone bridge consisting of resistances P, Q, R and X. G is a galvanometer for indication of balance,

The resistors P, Q forming the ratio arms may be decade resistance boxes or slide wires.

Under balance conditions :

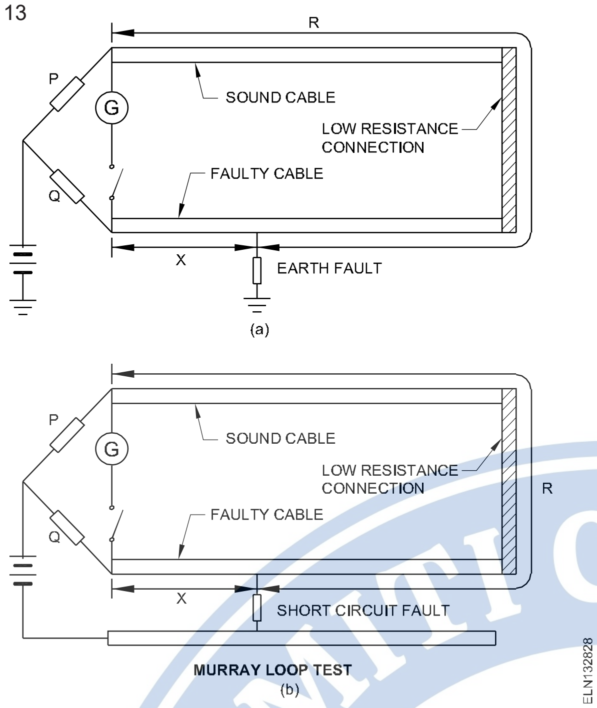
$$\frac{X}{R} = \frac{Q}{P} \text{ or } \frac{X}{R+X} = \frac{Q}{P+Q}$$

$$\therefore X = \frac{Q}{P+Q}(R+X)$$

Where (R+X) is total loop resistance formed by the sound cable and the faulty cable. When the conductors have the same cross-sectional area and the same resistivity, the resistance are proportional to lengths. If l_1 represents the length of the fault from the test end and 'l' is the length of each cable. Then

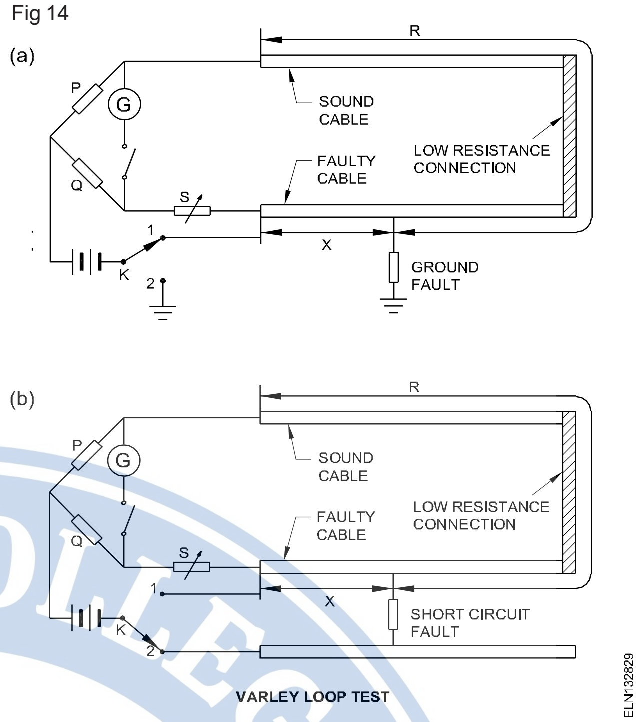
$$l_1 = \frac{Q}{P+Q} \cdot 2l$$

Fig 13



MURRAY LOOP TEST
(b)

Fig 14



VARLEY LOOP TEST

The above relation shows that the position of the fault may be located when the length of the cable is known. Also, the fault resistance does not alter the balance condition because its resistance enter the battery circuit hence effects only the sensitivity of the bridge circuit. However, if the magnitude of the fault resistance is high, difficulty may be experienced in obtaining the balance condition on account of decrease in sensitivity and hence accurate determination of the position of the fault may not be possible.

In such a case, the resistance of the fault may be reduced by applying a high direct or alternating voltage, in consistence with the insulation rating of the cable, on the line so as to carbonize the insulation at the point of the fault.

Varley loop test. In this test we can determine experimentally the total loop resistance instead of calculating it from the known lengths of the cable and its resistance per unit length. The necessary connections for the ground fault are shown in Fig 14a and for the short circuit fault in Fig 14b. The treatment of the problem, in both cases, is identical.

A single pole double throw switch A is used in this circuit. Switch K is first thrown to position 'I' and the resistance 'S' is varied and balance obtained.

Measurement of resistance

Let the value of S for balance be S. The four arms of the Wheatstone bridge are P, Q, R + X, S_1 at balance:

$$\frac{R+X}{S_1} = \frac{P}{Q}$$

This determines R + X i.e. the total loop resistance as P, Q and S_1 are known.

The switch K is then thrown to position '2' and the bridge is rebalanced. Let the new value of S for balance be S_2. The four arms of the bridge now are P, Q, R, X + S_2.

At balance

$$\frac{R}{X+S_2} = \frac{P}{Q}$$

$$\frac{R+X+S_2}{X+S_2} = \frac{P+Q}{Q} \text{ or } X = \frac{(R+X)Q - S_2 P}{P+Q}$$

Hence, X is known from the known value of P, Q, S_2 from this equation and R+X (the total resistance of 2 cables) as determined from Eqn. knowing the value of X, the position of the fault is determined.

Now

$$\frac{X}{R+X} = \frac{l_1}{2l} \text{ or } l_1 = \frac{X}{R+X}2l$$

Where

l_1 = length of fault from the test end and

l = total length of conductor.

Equations for murrary loop test and varley loop test are valid only when the cable sections are uniform throughout the loop. Corrections must be applied in case the cross-sections of faulty and sound cables are different or when the cross-section of the faulty cable is not uniform over its entire length.

Since temperature affects the value of resistance, corrections must be applied on this account if the temperatures of the two cables are different. Corrections may also have to be applied in case the cables have a large number of joints.