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THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

Engineering Training Section, Headquarters, Postmaster-General's Department, Melbourne C.2.

INTRODUCTION TO TELECOM ENGINEERING

PART 1
BASIC THEORY

Page

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1. STRUCTURE OF MATTER.

1.1 Matter is anything that has mass and occupies space. All matter exists in the form of a solid, a liquid or a gas. Liquids and gases are known as fluids.

Matter cannot be created or destroyed, but it can be changed from one form to another, depending on its temperature and the pressure applied to it. For example, water, at normal atmospheric pressure, is a solid (ice) at temperatures below its freezing point, a liquid in its normal state, and a gas (steam) at temperatures above its boiling point. (Fig. 1).

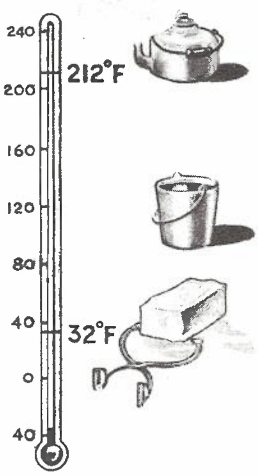


FIG. 1.

WATER EXISTS IN THREE FORMS.

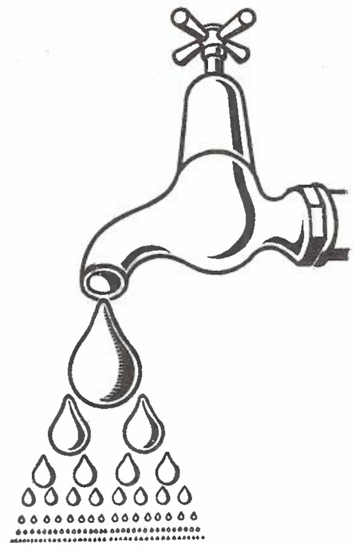


FIG. 2.

SUB-DIVIDING A DROP OF WATER.

1.2 Molecules. The smallest particle into which any substance can be subdivided and still retain all its chemical and physical properties is a molecule of the substance.

For example, if we could subdivide a small drop of water (Fig. 2), into smaller and smaller parts, many thousands of times, the droplet would finally become so small that any further subdivision would cause it to lose the characteristics of water. This last droplet, or particle, is a molecule of water.

All matter is made up of very small particles called molecules. There are as many kinds of molecules in the universe as there are different kinds of substances.

In all forms of matter, the molecules are in a state of rapid and continuous motion.

In a solid, the molecules are crowded very closely together, and the force of attraction between them makes it difficult to alter the shape of solids.

In a liquid, the force of attraction between the molecules still exists, but they are less closely packed, and can move about more easily.

In a gas, the molecules are spaced further apart and can move over longer distances. Hence, a gas tends to expand.

When a solid is heated, the speed of the molecules increases and they move about more easily. As a result, the solid often first softens and then melts to a liquid. When a liquid is heated, the molecules move about more freely and at greater speed, and some escape in the form of gas.

1.3 Atoms. When scientists examine a piece of solid matter beneath a very powerful microscope, it looks like small grains (or crystals) held together in some mysterious way. Each crystal appears to be composed of rows upon rows of smaller submicroscopic particles which are thought to be the molecules of the substance. But molecules can be subdivided into smaller particles, called atoms, which are only about one hundred-millionth of an inch in diameter. Atoms have different properties from the molecules of which they form a part.

An atom is the smallest particle of matter that can enter into a chemical combination.

All molecules are made up of various combinations of different types of atoms.

In an Element, or elementary substance, the molecules are composed of atoms of the same type, for example, hydrogen, oxygen, carbon or copper. There are as many different elements as there are atoms, that is, about 92.

Compound substances are formed when atoms of different types combine. Water is a compound substance made up of two kinds of atoms, hydrogen and oxygen. Two atoms of hydrogen combine with one of oxygen to form a molecule of water. The molecules of many other compound substances are more complex. For example, the molecules of the human body consist of fifteen different kinds of atoms (or elements), the main ones being oxygen, carbon, hydrogen, nitrogen, calcium and phosphorous.

But atoms are constructed of even smaller particles, one hundred thousand times smaller again. Fig. 3 shows a piece of solid matter (not to scale) as we normally see it, and as viewed by various scientific methods.

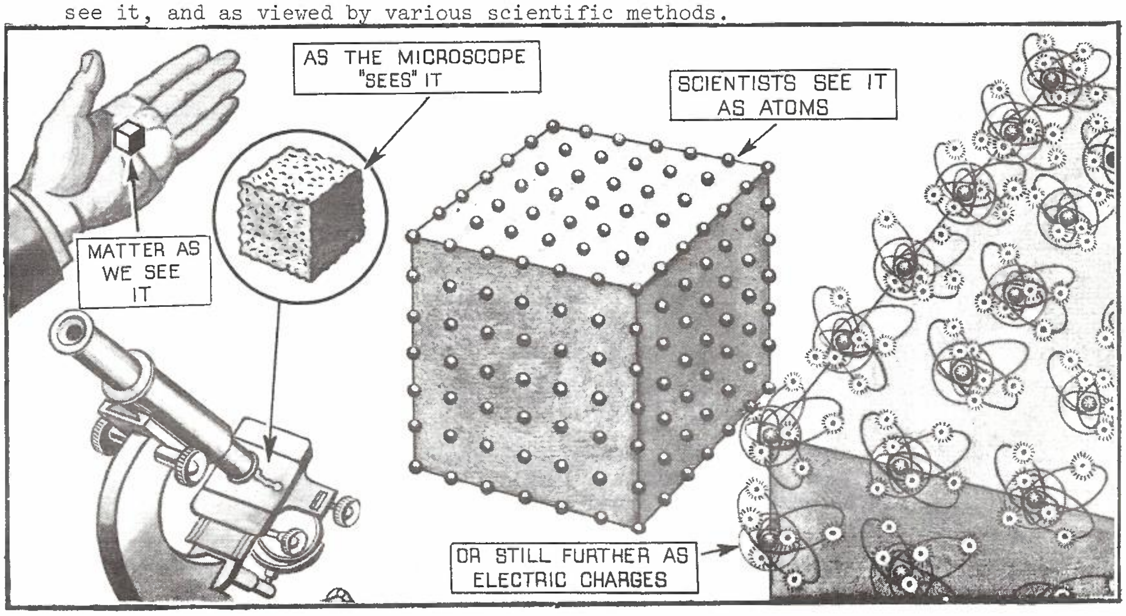


FIG. 3. ALL MATTER IS MADE UP OF ATOMS.

1.4 Within the atom. All atoms consist of a very small central nucleus which contains most of the mass of the atom. It is now generally accepted that this nucleus contains small particles called protons and neutrons, of which the proton is the only one of interest to us at this stage. Other small particles called electrons whirl around the nucleus in various orbits. The arrangement is similar to a miniature solar system in which the planets (electrons) speed around the sun (nucleus). (Fig. 4)

A strong force of attraction exists between the electrons and the nucleus. The centrifugal force of the electrons prevents them from rushing towards the nucleus. This same force counteracts the gravitational pull between the planets and sun in the solar system and prevents the planets from rushing towards the sun.

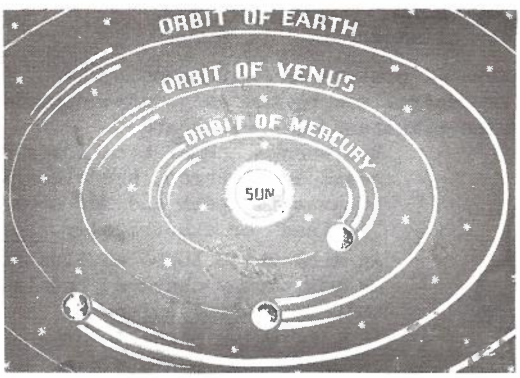
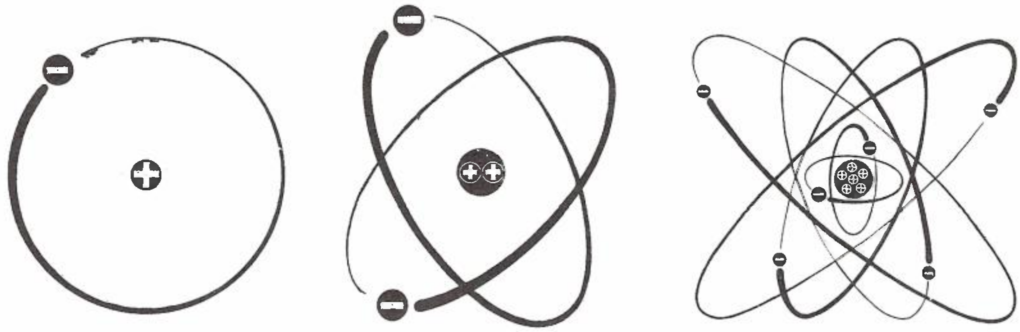


FIG. 4. PLANETS IN THE SOLAR SYSTEM.

Simple picture models (not to scale) of two of the simplest (and lightest) atoms, hydrogen and helium, are shown in Fig. 5.

The protons are shown as ⊕. The electrons are shown as ⊖.
The lines suggest the orbits in which the electrons move.



(a) Hydrogen Atom. (b) Helium Atom. (c) Carbon Atom.

FIG. 5. PICTURE MODELS OF ATOMS.

In the hydrogen atom, one electron moves around a single proton. In the helium atom, two planetary electrons move around a nucleus containing two protons. All other atoms are more complex but the principle of atomic construction still applies.

The number of electrons and protons in an atom determines its properties, and varies for each of the 92 types of atoms. All electrons are similar and all protons are similar, no matter what type of atom with which they are associated. All matter, therefore, contains different combinations of protons and electrons.

The electrons and the nucleus occupy only a small portion of the total volume of the atom as measured by its orbital diameter.

Electrons in the outer orbits of an atom are attracted to the nucleus by less force than electrons in the inner orbits. These outer electrons are called free electrons since they may be more easily forced from their orbits than the inner electrons which are called bound electrons.

1.5 Electric Charges in the Atom. In some forms of matter, the basic particles of the atom can be separated and experiments indicate that:-

(i) A Proton is a small particle of matter, purely electrical in nature. It has a unit (or charge) of electricity which we call a positive charge.

(ii) An Electron is a small particle of matter, also purely electrical in nature. It has a charge of electricity of the same strength but opposite to that of a proton. We call this a negative charge.

(iii) A Neutron is a small uncharged particle of matter.

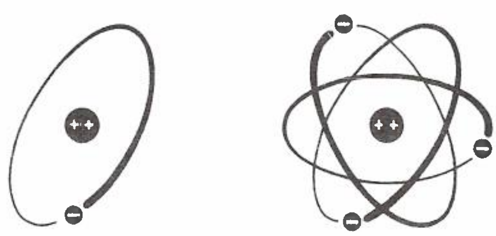
Ionisation. The normal atom has equal numbers of protons and electrons. The electrical effect of the positive protons is neutralised by the associated negative electrons; and the atom as a whole exhibits no resultant electric charge.

But when a normal atom loses or gains an electron, the electrical balance is upset and the atom is "ionised" or electrically charged.

An atom which loses an electron is positively charged, and is called a positive ion.

An atom which gains an electron is negatively charged, and is called a negative ion.

These are shown in the sketches of ionised heliums in Fig. 6.



(a) Positive Ion. (b) Negative Ion.

FIG. 6. IONISATION OF HELIUM ATOMS.

1.6 The Electron Theory is based on the assumption that all matter is composed of minute negative and positive particles of electricity and assumes that all electrical effects are due to the ordered movement of free electrons from atom to atom, or that there are too many or too few electrons in a particular atom.

Other theories have been proposed at various times, but, at the moment the electron theory gives the simplest picture of the nature of electricity.

1.7 Potential. The electrical condition (that is, either a deficiency or surplus of electrons) of a charged substance is called electric potential, or, simply, potential.

A substance with an electron deficiency has a positive potential and is positively charged.

A substance with an excess of electrons has a negative potential and is negatively charged.

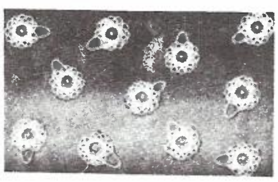
A substance which possesses a charge of electricity (either positive or negative) is electrified, or simply, charged.

A difference of potential or potential difference, abbreviated to P.D., exists between two substances which have different degrees of electric charge. It is not necessary to have unlike charges to have a P.D. For example, a P.D. exists when both charges are positive, providing one charge is stronger than the other.

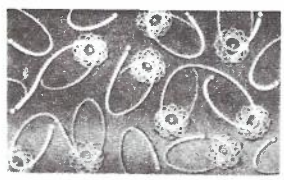
1.8 Conductors and Insulators. Because of differences in atomic structure there is a general division of all substances into two kinds when we consider their electrical properties. We call them insulators and conductors of electricity.

In insulators, the electrons are bound tightly to the nucleus and do not move readily from atom to atom, in the substance. (Fig. 7a). When portion of an insulator is charged, the charges are localised and cannot spread throughout the substance.

In conductors, the free electrons are loosely held by the nucleus, and move continually in random motion between the atoms. (Fig. 7b). When portion of a conductor is charged, for example, negatively, any excess electrons that it acquires can also move easily from atom to atom and the negative charge spreads throughout the conductor.



(a) Insulator



(b) Conductor

FIG. 7. ATOMIC STRUCTURES.

2. ELECTRIC CURRENT.

2.1 E.M.F. Causes Current Flow. When electrons are forced from their orbits under the influence of some external force, and ordered electron movement takes place from atom to atom, the movement is termed an electric current. That is, when bodies at a different potential are joined by a conductor the result is an ordered flow of electrons along the wire from atom to atom, from the negative to the positive substance. (Fig. 8)

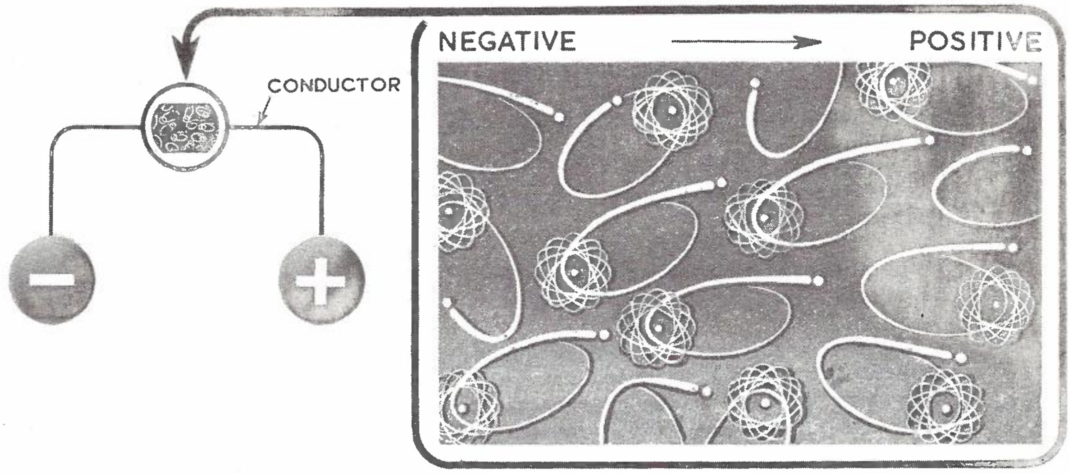


FIG. 8. ELECTRIC CURRENT IN A CONDUCTOR.

The force or potential necessary to produce the electron movement (the electron moving force) is termed electromotive force, abbreviated to e.m.f.

This type of electricity is called current electricity (or dynamic electricity) which means electricity in motion.

2.2 Sources of e.m.f. To produce the e.m.f. necessary to cause ordered electron movement (current flow), one of the following forms of energy can be used:-

Friction, Chemical Action, Magnetism, Heat, Light, Pressure.

Friction. A charge produced on a substance by friction is termed static, or electricity at rest (as distinct from current electricity) but is still an electromotive force. When a conductor is connected between substances possessing static charges of different potentials, an electron flow results. However, this current is only momentary, and cannot do continuous work as it ceases when the static charges have been neutralised.

For example, lightning (Fig. 9) is the result of static charges. The clouds become electrified by friction as they move through the air. When a high P.D. exists between clouds, the air insulation between them cannot resist the electric stress and breaks down. The air between the clouds then becomes a conductor and a long spark discharge, which we call lighning, occurs between the clouds to neutralise the static charges. A lighning discharge can also occur between clouds and the earth.

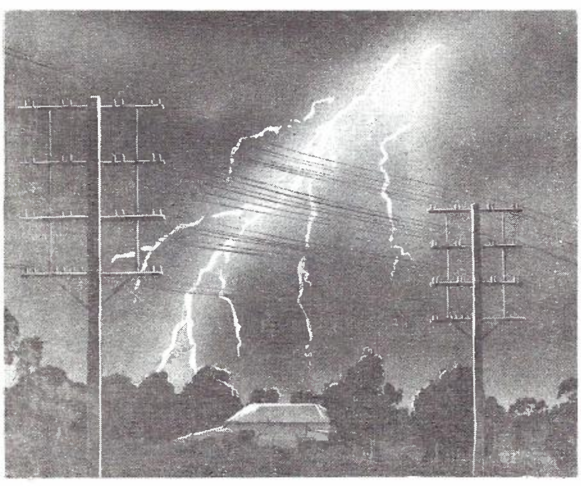
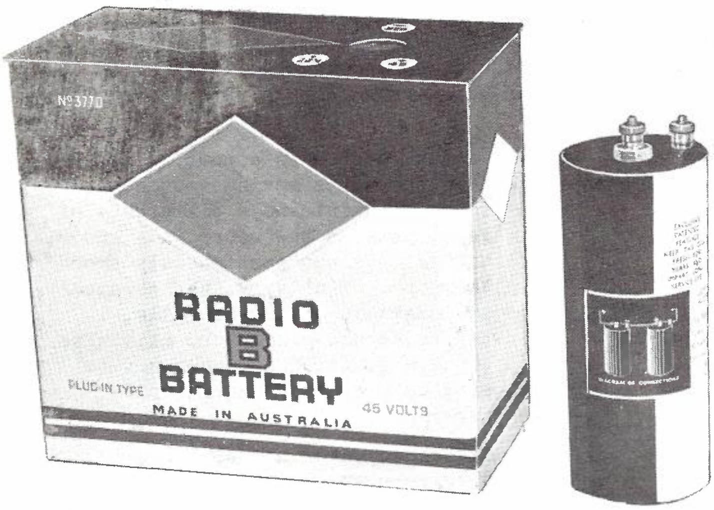
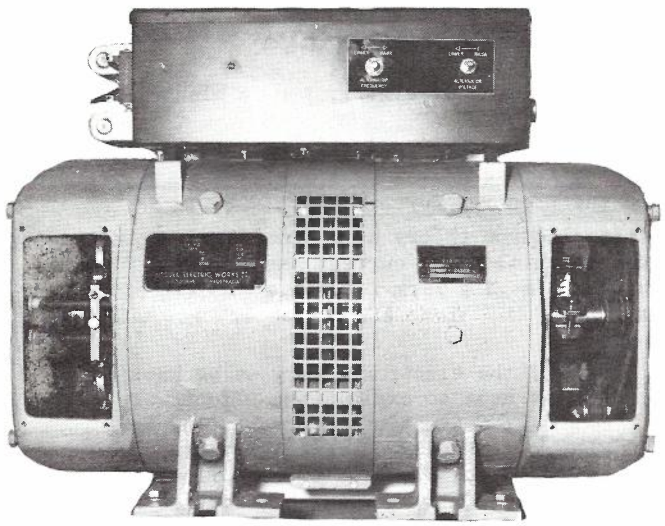


FIG. 9. LIGHTNING - THE RESULT OF STATIC CHARGES.

Chemical Action. Electric cells and batteries (Fig. 10a) are used as sources of e.m.f. When more than one cell is used to supply an e.m.f., the arrangement is called a battery. The chemical action which takes place within the cell provides at the negative terminal, a large number of negative ions, (a surplus of electrons), and at the positive terminal a correspondingly large number of positive ions, (a deficiency of electrons). When some "electrical load", for example, a suitable lamp, is connected to the battery terminals, as in the operation of a torch, the surplus electrons from the negative terminal are conducted through the torch globe filament to the positive terminal and the lamp glows. As long as the chemical action continues, the terminals of the cell remain charged and the electric current flow is maintained.



(a) Battery and Cell.



(b) Electric Generator.

FIG. 10. TWO SOURCES OF E.M.F.

Magnetism. When conductors move past magnets, or magnets move past conductors, an e.m.f. is set up between the ends of the conductor. This principle is used in electric generators (Fig. 10b), and is the most common method of producing electricity.

Heat. When the junction of two dissimilar metals is heated, electric charges are produced. Such a device is called a thermocouple.

Light. When light falls on certain materials, one of which is a selenium alloy, electron movement can result. This principle is used in the light meters used for photography.

Pressure. When a pressure is exerted on crystals of certain materials, one of which is Quartz, electrical charges are developed. This effect is used in crystal pickups in radiograms.

Of the above sources of electricity, chemical action and magnetism are most commonly used to produce a continuous current. Friction, heat, light and pressure are used only in special applications, since they cannot maintain a large enough charge to be used as a source of electric power.

2.3 Electric Current. The term "electric current" suggests a comparison with the flow of water in a pipe and an analogy helps in describing many electric phenomena.

When two vessels containing water are connected by a pipe, water flows from the vessel with the water at the higher level to that at the lower level. A difference of level or pressure must exist between the water in A and B for this current to flow. This flow is not continuous and stops when the water levels are the same. Similarly, an electric current flows in the conductor connecting two differently charged substances. This current stops when the two substances are at the same potential (or electrical pressure).

To produce a continuous current of water, we need a device such as a pump. In Fig.11, the pump supplies the force necessary to keep the water moving continuously. The pump maintains a difference of level between the water in A and B, and water flows continuously around the pipe. Similarly, the chemical and magnetic action of cells, batteries and generators maintains the e.m.f. which is necessary to produce a continuous electric current.

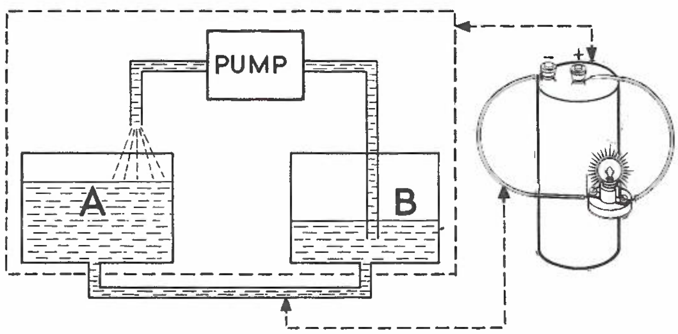


FIG. 11. COMPARING FLOW OF WATER AND ELECTRIC CURRENT.

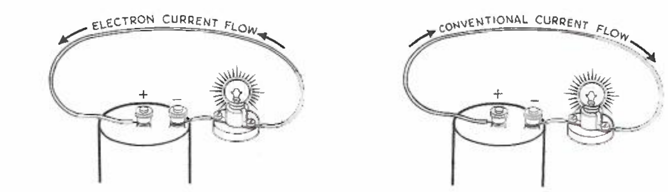
With both water and electricity, we therefore must have a motive-force to produce a continuous current; and yet we can have a motive-force and no current. For example, in Fig.11, when the pipe is blocked, the motive-force supplied by the pump still exists but no water flows; when an insulator is used instead of a conductor, the e.m.f. still exists but no electric current flows.

The complete electrical path, including the source of e.m.f., for an electric current is an electric circuit.

Direction of Current. An electric current in a solid conductor is a flow of electrons from the negative to the positive terminal of the source of e.m.f., that is, from NEGATIVE to POSITIVE. This is called the Electron Current flow.

However, long before the adoption of the electron theory as the means of explaining electrical effects, it was considered that an electric current was always a flow of positively charged particles in a conductor, moving from a positively charged to a negatively charged substance, that is, from POSITIVE to NEGATIVE. This is called the Conventional Current flow.

As this is not in accordance with the facts of the electron theory as we know them, it follows that the many useful rules and laws made to explain the effects of Conventional Current flow are exactly opposite to those based on the Electron Current flow. It does not matter which direction we assume, because, in general, we are more interested in the effects of the current rather than its direction of flow. For example, the globes in Fig. 12 will light irrespective of what direction we consider the current to be moving.



(a) Negative to Positive. (b) Positive to Negative.
FIG. 12. RESULTS ARE INDEPENDENT OF ASSUMED CURRENT DIRECTION.

However, later in the course, some effects produced by current flow in apparatus have to be related to its direction of flow.

Therefore, definitions and laws used in this course will be those which apply to Electron Current flow, but it should be remembered that many text books still use the laws and definitions based on Conventional Current flow.

2.4 Effects of Electric Current. Up to date, we have tried to imagine what happens inside a conductor or insulator when an e.m.f. is applied. We now add to these mental pictures, a knowledge of some of the effects of electricity which we can observe with our senses.

(i) Heating effect. An electric current heats the conductor through which it passes. We can see this effect in such items as electric radiators, stoves, soldering irons, etc., and in electric lamps, where the temperature is raised to white heat to give light.

(ii) Chemical effect. When an electric current flows through a conducting liquid, such as acids and solutions of metallic salts, the liquid undergoes a chemical change. This effect is called electrolysis and has application in the charging of some types of electric cells and batteries.

(iii) Magnetic effect. An electric current sets up a magnetic field around the conductor through which it passes. We use this effect in the electric bell, the telephone receiver, the loud-speaker in a radio receiver, and many other items.

(iv) Effect on human body. An electric current causes the muscles to twitch when it passes through the human body. In certain cases, this effect can cause death. Provided we use the normal safety precautions, however, there is little danger when working with electricity.

These effects are considered in more detail later.

2.5 The different types of electric current can be grouped under four main headings.

(i) Direct Current (D.C.), a "unidirectional" current which flows through the conductor in one direction only. (Fig. 13a)

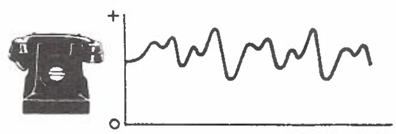
(ii) Varying Current, a form of D.C. which varies in value from instant to instant. (Fig. 13b)

(iii) Pulsating Current which is also unidirectional, but flows in pulses, having complete breaks when no current flows. (Fig. 13c)

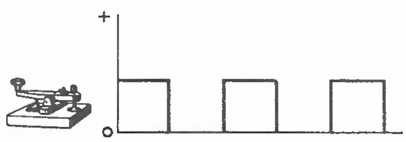
(iv) Alternating Current (A.C.) which regularly alters its direction of flow in a conductor, first flowing in one direction, then reversing and flowing in the opposite direction. (Fig. 13d)

Electric cells and batteries are used as sources of e.m.f. to produce a D.C. flow; generators are either D.C. or A.C.

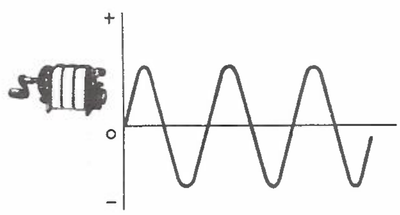
(a) A dry cell produces D.C.



(b) Varying D.C. flows in a telephone circuit.



(c) Pulsating D.C. flows in a telegraph circuit.



(d) A generator produces A.C.

FIG. 13. TYPES OF ELECTRIC CURRENT.

2.6 Resistance. Electric Resistance or, simply, Resistance, is the property of a substance to oppose the flow of an electric current.

In order that current can flow in a substance, internal opposing atomic forces which resist the electron flow must be overcome and work must be done to push the electrons along from atom to atom. The fact that a conductor gets hot when electrons flow in it, indicates the existence of internal forces or resistance opposing the flow. Every substance offers some opposition or resistance to current flow, whether small or large, and this resistance is not the same for all substances.

In a good conductor, the atomic structure contains large numbers of free electrons, and only a small electrical force is required to cause these electrons to be dislodged from their orbits and take up an ordered movement. But in an insulator, the atomic structure possesses few free electrons and a large electrical force is required to cause any substantial current flow.

Metals are the best conductors, and in telecom, copper, brass, iron and lead are commonly used; carbon and liquid solutions are non-metallic materials sometimes used as conductors. Many different non-metallic materials are used as insulators, such as glass, paper, rubber, ebonite, cotton, silk, enamel, porcelain and certain plastics.

Chemically pure water or distilled water is a very poor conductor; but when some salt or a little acid is added, it becomes a much better conductor. Water does not often exist in its pure state, and in general therefore, water (other than distilled water) is a fairly good conductor.

Likewise, the earth is a conductor. The earth has such a large volume and contains so many conducting substances (metals, water, etc.) that electric charges can readily spread throughout it. Moist or wet earth is a better conductor than dry earth.

Also, the human body is a conductor, mainly because of the liquids in it; about 70% of the human body is water. When the skin is moist or wet, the body is a better conductor than when the skin is dry.

Table 1 lists some good conductors, mostly metals, in order of their conducting power, and some good insulators, in order of their ability to resist electron flow.

Conductors	Insulators
Silver	Dry Air
Copper	Glass
Gold	Paraffin Wax
Aluminium	Mica
Zinc	Vulcanite
Platinum	Shellac
Iron	India-rubber
Nickel	Gurra-percha
Tin	Sealing-wax
Lead	Silk
Mercury	Wool
Carbon	Porcelain
Acids	
Metallic Salts	

TABLE 1.

2.7 Electrical Units. In the study of electricity we often have to measure and compare different e.m.f's of batteries and generators, currents of different values, different amounts of resistances to the current flow; and many other electrical quantities. So that we can answer the question "How much?" in any specific case, we must know the more common units of measurement.

The unit of rate of current flow is the Ampere. The rate of flow of a current of water is measured by the quantity of water in cubic feet or gallons passing a given point per second. Similarly, the rate of flow of an electric current is measured by the quantity of electricity in coulombs (that is, the number of electrons) which pass any point in a conductor in one second.

The abbreviation for ampere is A. In telecom, currents exceed 1000A, and the ampere is, therefore, satisfactory as a unit for currents greater than 1A. But currents are often as low as one thousandth of an ampere, or even one millionth of an ampere; and, to measure these values, two submultiple units are commonly used:-

the milliampere (abbreviated mA) equal to one thousandth of an ampere;

the microampere (abbreviated µA) equal to one millionth of an ampere.

The unit of e.m.f. and P.D. is the Volt. To cause a flow of water in a pipe, a pressure is necessary. Water pressure depends on the "head" (or depth) of water and is expressed usually as "feet of water". Similarly, an electrical pressure is required to cause a flow of electricity (or electric current) through a conductor and the unit is the volt.

Electromotive force and potential difference both refer to electrical pressure. They are both measured by the same basic unit, the volt, and are often both referred to as voltage.

The abbreviation for volt is V.

Other units in common use are:-

the kilovolt (kV) equal to one thousand volts;

the millivolt (mV) equal to one thousandth of a volt;

the microvolt (µV) equal to one millionth of a volt.

The unit of resistance is the Ohm. A conductor has a resistance of one ohm when an e.m.f. of one volt applied to the ends of the conductor causes a current of one ampere to flow through it.

(As a matter of interest, the scientific definition of the ohm is - the resistance of a column of pure mercury 106.3 cm. long, of uniform cross-sectional area, and weighing 14.4521 grammes, the temperature being 0°C).

The abbreviation for ohm is the Greek letter, omega (Ω).

Other units in common use are:-

the megohm (MΩ) equal to one million ohms;

the kilohm (kΩ) equal to one thousand ohms;

the microhm (µΩ) equal to one millionth of an ohm.

Many instruments have been developed for the accurate measurement of electrical quantities. Types most commonly used are the ammeter, the voltmeter and the ohmmeter.

3. ELECTRIC CURCUITS.

3.1 Circuit Components. In current electricity, the term circuit signifies the complete electrical path through which an electric current passes, and is comprised usually of a number of components which for example may include:-

- A source of e.m.f., such as a cell, battery or generator.
- The apparatus or "load" to be operated by the current, such as an electric bell or lamp.
- The conductors which connect the various parts of the circuit. The conducting path need not be completely metallic; for example, each of the following could be a conductor in a circuit -

    metallic conductors, the earth, the human body, conducting liquids (car battery), conducting gases (fluorescent lamp).

- Controlling and regulating devices, such as switches, fuses and keys.
- Measuring instruments, such as ammeters and voltmeters.

When the earth is used as part of an electric circuit, this is called an earth return circuit.

3.2 Circuit Symbols. Instead of using pictures to represent an electric circuit, (pictorial method), it is common to use standard symbols in diagrams, to show how electrical apparatus in a circuit is connected together. Such diagrams are called schematic circuit diagrams, or more commonly schematic circuits.

In these diagrams each item of apparatus has a standard symbol, and these are joined together with lines to show the wiring.

For example, typical symbols are:-

When some of these are formed together in a typical circuit they are as shown in Fig. 14.

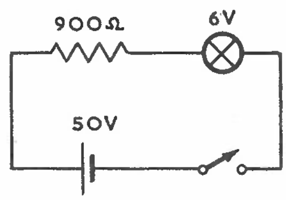


FIG. 14.

Other symbols will be introduced from time to time, but a fuller range of apparatus symbols is given on page 53 at the end of Part 1.

3.3 Symbols used in Telecom Mathematics. Most of the units of electricity have mathematical relationships and can be expressed in mathematical terms. In this course, laws of electricity are discussed, and simple mathematical examples are used to help us understand these laws.

To simplify the working out of these examples, symbols and abbreviations are used; for example, we use the symbol -

I *for electric current.* **E** *for electromotive force.* **R** *for electrical resistance.*

When there is more than one of the same device or quantity on a circuit, a system of subscripts is often used in which the symbol is followed by an identification number. For example, where there are two or more resistance values in a circuit, the first resistor is denoted as R_1, the second as R_2, the third resistor as R_3, and so on.

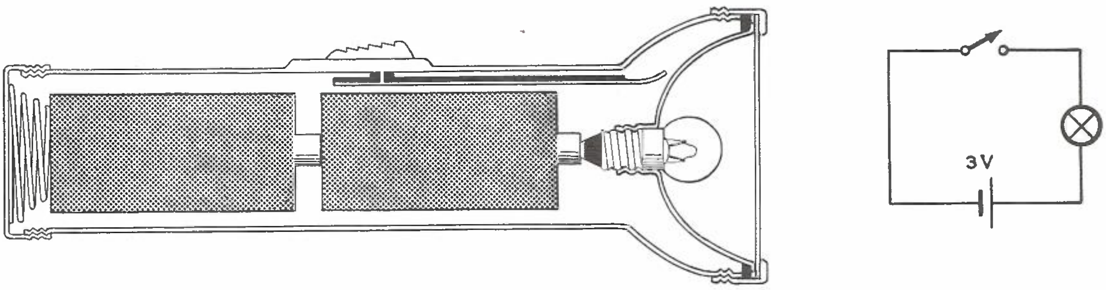
3.4 Types of Electric Circuits. There are two types of electric circuits -

Series circuits.

Parallel (or shunt) circuits.

In telecom equipment we often find a combination of series and parallel arrangements sometimes called a series-parallel circuit, but no matter how complex the equipment, it can always be resolved into series and/or parallel circuit paths.

In a series circuit, the current flows in a single continuous path through each piece of apparatus in turn. The electric torch is an example. (Fig. 15).



(a) Torch. (b) Schematic circuit.

FIG. 15. A SERIES CIRCUIT.

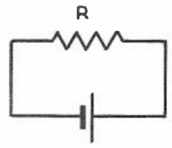
In a parallel circuit, the current divides through two or more paths in the circuit. The lighting arrangement on a bicycle is an example. (Fig. 16).

The dynamo (or generator) is the source of e.m.f. The current from the generator divides at point A (the headlight terminal) and flows through two separate paths, the headlight and the tail-light. The current in each path returns to the generator via the frame of the bicycle. The parallel type of circuit is also used for electric wiring in buildings.

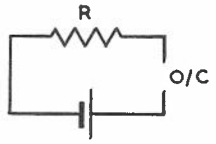
(a) Bicycle. (b) Schematic Circuit.

FIG. 16. A PARALLEL CIRCUIT.

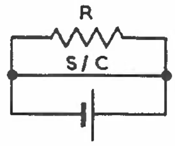
3.5 Electrical Terms.



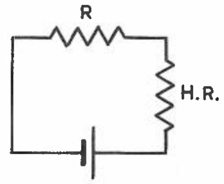
Closed Circuit. When any electrical apparatus is connected to a source of e.m.f. so that a current flows through it, the arrangement is called a closed circuit.



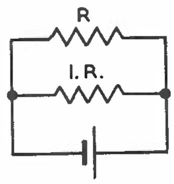
Open Circuit (O/C). This is the condition of a circuit when the continuity has been broken at one or more places, and current ceases to flow through it.



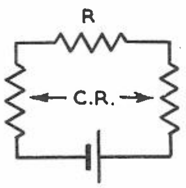
Short Circuit (S/C). A short circuit occurs when a part or the whole of a circuit is shunted by a low resistance path, and current does not flow through the correct circuit.



High Resistance (H.R). When a circuit contains a faulty connection, perhaps a poorly soldered joint caused by a badly cleaned wire, or a wire loose under a screw terminal, an open circuit does not always occur.
The result is usually a high resistance in series with the normal circuit. This is commonly called a dry joint.



Insulation Resistance (I.R). To prevent short circuits, the connecting wires of a circuit are generally surrounded by some type of insulation such as a coating of enamel, or wrappings of silk and cotton, or paper, etc. Similarly, any connecting terminals are mounted on an insulating material.
Although the resistance between the wires or terminals can never be infinite, it must be high to prevent a leakage current through the insulation.
This resistance value is termed the Insulation Resistance of the circuit.
When the insulation of a circuit deteriorates, and an appreciable leakage current flows between the conductors, the circuit is said to possess Low Insulation Resistance (L.I.R.).
For a given circuit, for example, a telephone line, the I.R. decreases as the length of line increases.



Conductor Resistance (C.R). This refers to the electrical resistance of the wiring in a circuit as distinct from the components. For a given size wire, the resistance increases with the length.

Voltage Rating. Electical equipment is designed to operate with a certain current flow. If this rate is exceeded damage may result, but if the current value is low the apparatus may not work properly.

Therefore, for a particular item of equipment, a certain voltage must be applied to produce the correct current.

This voltage is called the voltage rating and is usually marked on the apparatus. It should not be exceeded.

3.6 Factors which Affect Conductor Resistance. The flow of water through a pipe depends on the friction resistance of the pipe. When the pipe is long or its diameter small, or when the inside of the pipe is rough, it usually offers a large resistance to the flow of water. When the difference of level or pressure is kept constant, to increase the rate at which the water flows, we reduce the resistance of the pipe by reducing its length, increasing its cross-sectional area, or making the inside of the pipe smoother. Similarly, the electrical resistance of any material, for example, a conductor or wire, depends on -

(i) its length,
(ii) its cross-sectional area,
(iii) the material from which it is made, and, in addition
(iv) its temperature.

The length affects resistance. When the resistance of two wires is measured, with both of the same type and size, but one twice the length of the other, the longer wire will be twice the resistance of the shorter wire. A wire three times as long as another of similar type and size will be three times the resistance, and so on (Fig. 17).

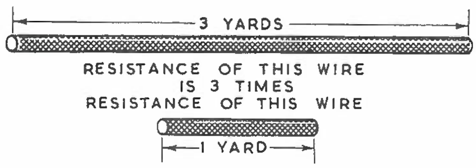


FIG. 17. RESISTANCE DEPENDS ON LENGTH.

This indicates that the resistance of a wire is proportional to its length.

The cross-sectional area affects resistance. When the resistance of two wires is measured, with both of the same type and length, but one twice the cross-sectional area of the other, the resistance of the larger wire will be half that of the smaller. A wire four times the cross-sectional area of another of the same type and length will be one quarter the resistance of the smaller wire, and so on. (Fig. 18). From this it follows that -

The resistance of a wire is inversely proportional to its cross-sectional area.

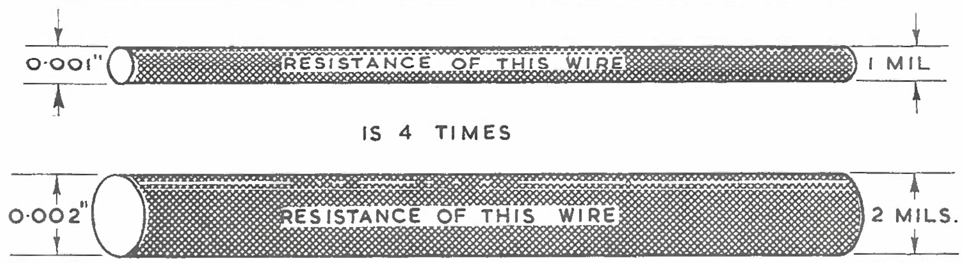


FIG. 18. RESISTANCE DEPENDS ON CROSS-SECTIONAL AREA.

Note: The cross-sectional area of the 0.002" wire is four times the cross-sectional area of the 0.001" wire, as the cross-sectional area (A) increases in direct proportion to the square of the diameter (D), that is, $A \propto D^2$.

The material affects resistance. When a comparison is made between two wires of similar size and length, with one of platinum and the other of copper, the platinum wire will be approximately seven times the resistance of the copper wire. Similarly, an iron wire has about six times the resistance of a copper wire of similar size and length.

The temperature affects resistance. The resistance of all pure metals and most alloys increases as their temperature increases. For most metallic conductors there is a fairly regular law governing the change of resistance caused by change in temperature. Experiments have shown that this variation in resistance is proportional to the variation in temperature.

Resistance Wires. Impurities in a substance can greatly affect the resistance of the substance even though the impurities themselves may be good conductors. Practical advantage is taken of this fact in the manufacture of high resistance alloy wires, which are termed resistance wires.

3.7 Resistors, Fixed and Variable. Resistance if often used in a circuit to:-

Vary or control the current flowing in the circuit.

Vary or control the P.D. across a piece of apparatus.

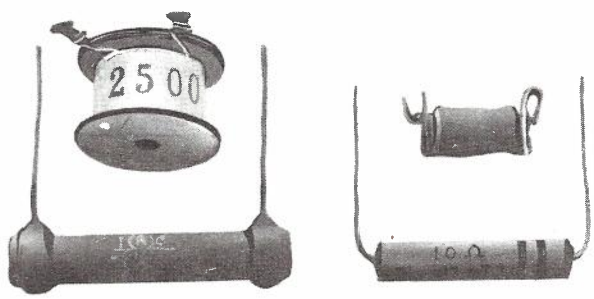
All telecom equipment has a certain amount of resistance. However, sometimes this resistance is not enough to control the current or voltage to the extent required. When additional control is required, resistance is purposely added in an electric circuit. For example, in Fig. 14 (paragraph 3.2) the 900 ohm resistance is added to prevent an excessive current from the 50 volt battery, "blowing" the 6 volt lamp.

Components specially designed to introduce additional resistance are called resistors;they are in many different forms, and in telecom equipment many types are used, either of fixed or variable resistance value.

Resistors are made either of resistance wire, or graphite (carbon) composition, or of a metal film.

Wire-wound resistors are used for large currents; carbon resistors for relatively small currents. (Fig. 19 and 20)

(a) Wire Wound.



(b) Carbon.

FIG. 19. FIXED RESISTORS.

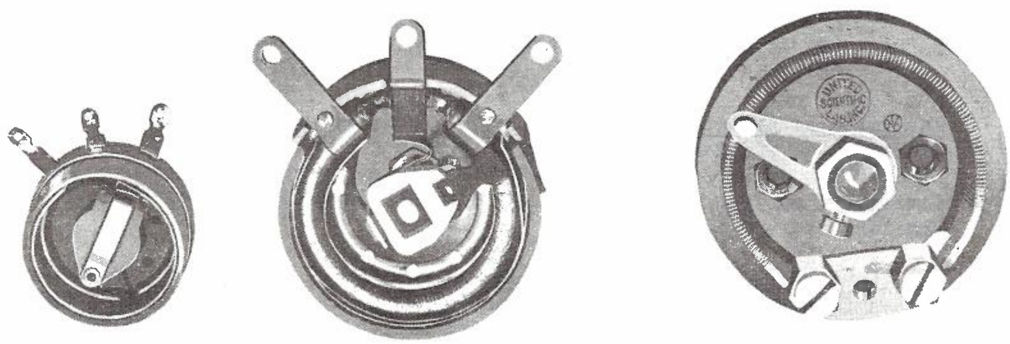
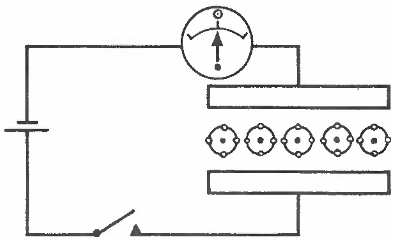


FIG. 20. VARIABLE RESISTORS.

3.8 Capacitors. Another component found in many electric circuits is the capacitor. Formerly termed condensers, they are many and varied in size, type, and shape, and are necessities in all types of telecom circuits from telephone equipment to radio and television.

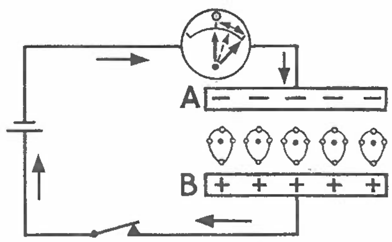
In its simplest form the capacitor consists of two conducting plates separated by a thin layer of air, or other insulator which in capacitors is called the dielectric. If such a combination is connected in series with a switch, a battery, and a suitable ammeter - with the switch open, there is no current flow in the circuit. The plates of the capacitor are of equal potential and the atoms of the dielectric are normal. (Fig. 21a).



(a) Capacitor Normal.

When the switch is closed, the e.m.f. of the battery results in electrons being passed to plate A and being withdrawn from plate B until the plates are at the same P.D. as the battery.

The electric field between the plates causes a distortion in the orbits of the electrons of the dielectric atoms and since most of the electrons in the dielectric are tightly bound to their atoms they cannot leave the dielectric or flow through it, but are strained out of their paths and normal positions as shown in Fig. 21b.

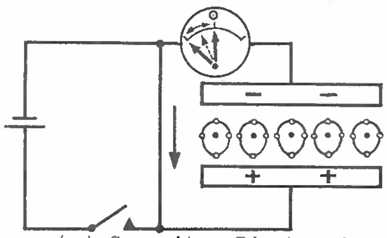


(b) Capacitor Charging.

The limited electron movement in the dielectric is not an actual flow of electrons as in the case of a conductor, but is a small displacement due to the surrounding electrical forces.

There is an instantaneous deflection of the ammeter to a maximum value, which restores to normal as the current flow into the capacitor raises an opposing P.D. across the plates. The current ceases to flow when the plate P.D. equals oppositely the applied voltage.

When the switch is opened the charge remains, but if the plates are connected by a conductor, a neutralising or discharge current will flow in the circuit, and the dielectric atoms restore to normal. (Fig. 21c).



(c) Capacitor Discharging.

FIG. 21.

The ammeter shows by its reverse deflection that the discharge current flows out of the capacitor in the opposite direction to the charging current. The current ceases when the P.D. between the plates falls to zero.

From this it can be said that:-

- A capacitor can be charged.
- The charge causes a displacement of electrons within the insulating dielectric material, resulting in the dielectric surfaces being 'polarised'.
- The charge will remain when the energising source is disconnected.
- The stored charge will flow out of the capacitor when a circuit is provided and the dielectric will restore to normal.

The quantity of electricity stored in a capacitor depends on -

Its capacitance (or capacity).
The e.m.f. applied.

The unit of capacitance is the Farad. A capacitor possessing a capacitance of one farad is too large physically and electrically to be of practical use in electric circuits.

Because of this, the following submultiple units are normally used -

Microfarad (symbol µF).
picofarad (symbol pF) formerly called
Micromicrofarad (symbol µµF)

The microfarad is equal to $\frac{1}{10^6}$ (10^{-6}) or one millionth of one farad.

Practical capacitors are constructed of a variety of materials depending on their use. Brass or aluminium is commonly used for the plates and dielectrics may be air, mica, waxed paper, oxide coating and other insulating materials. The value of capacitance is determined by the area of the plates, the thickness of the dielectric and the material used for the dielectric. For the same dielectric, a large value capacitor would have a greater plate area and/or a thinner dielectric than one of lower capacitance.

Capacitors can be grouped into two classes - (i) Fixed Capacitors, (ii) Variable Capacitors.

Their symbols are:-

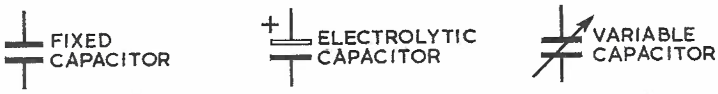
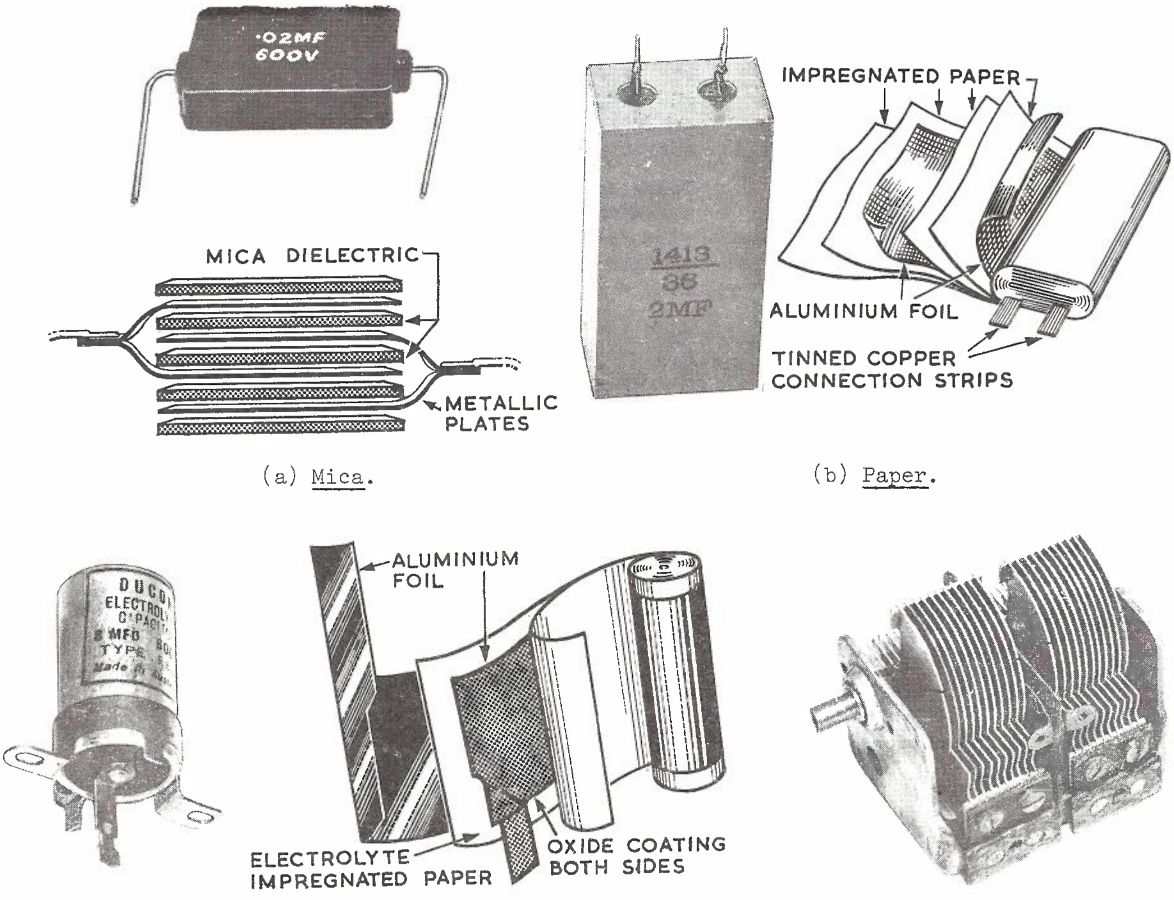


Fig. 22 shows the construction of several common capacitors. The capacitance of the variable type shown is adjusted by turning the spindle which rotates the moving vanes into or out of mesh with the fixed plates. The dielectric is air.



(a) Mica. (b) Paper.

(c) Electrolytic. (d) Variable.

FIG. 22. COMMON CAPACITORS.

3.9 Ohms Law. Basic laws of electricity are merely the application to electric circuits of basic laws of nature. One law states that -

> "The result produced is directly proportional to the magnitude of the effort and inversely proportional to the magnitude of the opposing force."

This relation is written in the form of an equation -

$$\text{Result} = \frac{\text{Effort}}{\text{Opposition}}$$

Applying this basic law to an electric circuit, when a current of electricity is forced along a conducting path -

(i) The current is directly proportional to the applied e.m.f. When there is an increase in the applied e.m.f., there is an increase in the current; reducing the e.m.f. reduces the current.

(ii) The current is inversely proportional to the resistance. When there is an increase in resistance, there is a decrease in current; decreasing the resistance increases the current.

This relationship between the three electical terms is stated in the form of a law called Ohm's Law.

Ohm's Law states that the current in an electric circuit is directly proportional to the applied e.m.f. and inversely proportional to the resistance of the circuit.

Ohm's Law is expressed as an equation -

$$\text{Current (amperes)} = \frac{\text{e.m.f.} \quad \text{(volts)}}{\text{resistance} \quad \text{(ohms)}}$$

or mathematically by the formula -

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

where *I is the current in amperes,*
E is the e.m.f. in volts, and
R is the resistance in ohms.

When any two quantities are known, transpose the formula to find the third, thus -

$$E = I \times R \qquad \& \qquad R = \frac{E}{I}$$

By using one of these equations it is possible to calculate the third quantity if any two are known.

Note:- When substituting in these formulas, each term must be expressed in basic units.

I must always be expressed in amperes.

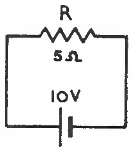
E must always be expressed in volts.

R must always be expressed in ohms.

Remember:- VOLTS drive AMPERES through OHMS.

Example - An e.m.f. of 10 volts is connected to a resistance of 5 ohms. What value of current would flow?

To find the current flowing in the circuit we apply Ohm's Law -



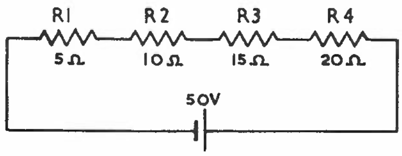
$$I = \frac{E}{R}$$

$$= \frac{10}{5}$$

$$= \underline{2 \text{ amperes}}.$$

Ohms Law in Series and Parallel Circuits.
The current will have the same value at every point in a series circuit.

When resistances are connected in series it has the effect of increasing the length of the conductor. The resistance of a conductor is directly proportional to its length, therefore, the sum of the resistances must be taken to find the total resistance of a series circuit. Consider the following example -



$$\text{Total resistance } R = R_1 + R_2 + R_3 + R_4$$

$$= 5 + 10 + 15 + 20$$

$$= \underline{50 \text{ ohms}}.$$

The current flowing through the circuit may be determined by Ohm's Law -

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

$$= \frac{50}{50}$$

$$= \underline{1 \text{ ampere}}.$$

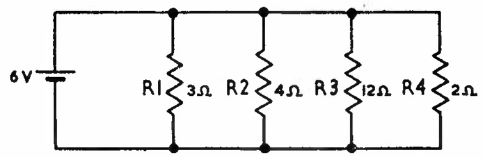
And this will be the value of current at any point in the circuit.

In a parallel circuit, the current will divide in proportion to the resistance of each path. The lower the resistance the greater will be the amount of current that will flow via that path.

To place one conductor in parallel with another conductor has the same effect as increasing the cross-sectional area of the first conductor. The resistance of a conductor is inversely proportional to the cross-sectional area, therefore, every resistance added in parallel must further reduce the joint resistance. The joint resistance of a parallel group of resistances is the single resistance which would replace the group and carry the same current in a particular circuit as the whole group. The result must be lower than the value of the lowest resistor in the group.

In order to find the joint resistance of a group of resistances in parallel, add the reciprocals of all the separate values and the sum is the reciprocal of the joint resistance.

Consider the following example:- $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ etc.



Parallel Circuit.

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

$$= \frac{1}{3} + \frac{1}{4} + \frac{1}{12} + \frac{1}{2}$$

$$= \frac{4 + 3 + 1 + 6}{12}$$

$$= \frac{14}{12}$$

$$= \frac{7}{6}$$

therefore the joint resistance $= \frac{6}{7}$ ohm

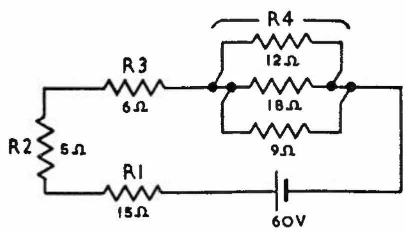
Total current in circuit, $I = \frac{E}{R}$

$$= 6 \div \frac{6}{7}$$

$$= \frac{6}{1} \times \frac{7}{6}$$

$$= 7 \text{ amperes.}$$

A series-parallel circuit is a combination of both series and parallel circuits, as shown below -



Series-Parallel Circuit.

To find the total resistance of a series-parallel circuit, the joint resistance of the parallel groups must be found first, and then we are able to proceed as in a series circuit.

4. POWER AND ENERGY.

4.1 To produce electrical energy we must use one of the following forms of energy.

Friction (mechanical energy);	Heat (heat energy);
Chemical action (chemical energy);	Light (light energy);
Magnetism (magnetic energy);	Pressure (mechanical energy).

These sources provide the energy required to do the work of moving electrons to form an electric charge.

Just as these forms of energy can be converted into electric energy, so can electric energy be converted back into these (and other) forms. As the conversion of some form of energy to electric energy, and vice versa, is the basic on which all items of telecom apparatus operate, we see how the terms Force, Work, Energy and Power, apply in the electric circuit.

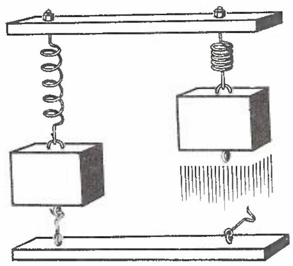
The terms "Force, "Work", "Energy", and "Power", are not always used correctly. For example, we often talk about sources of power when we really mean sources of energy; in daily speech the two words have become almost interchangeable. But what do these terms mean when applied to electricity? A knowledge of the correct use of the terms will give us a clearer understanding of electricity.

4.2 Force. In physics, we think of a force as a push or a pull on a body, tending to move it, or to change its rate or direction of motion when it is already moving. Force may be mechanical, electrical, magnetic or thermal. Force does not always produce movement, a relatively small force may fail to move a large body, but it tends to do so. The word "body" refers to anything that has mass and may be a stone, a dust particle or an electron.

We have learnt that the electric force which tends to move electrons (that is, to produce a current), is called the electromotive force (e.m.f.)

4.3 Work is done whenever a force causes movement (Fig. 23). For example, work is done when a mechanical force lifts or moves a weight. Force exerted without causing movement, such as the force of a spring under tension between two objects which do not move, does not do work.

Similarly in electricity, when an e.m.f. causes current (as in a closed circuit), work is done in moving electrons from one point to another. But an e.m.f. in a circuit without causing current (as in an open circuit) is similar to the spring under tension without moving, and is not doing work.



(a) No work being done. (b) Work being done.

FIG. 23. WHEN A FORCE CAUSES MOVEMENT, WORK IS DONE.

4.4 The Energy of anything is its ability to do work. Electricity is a form of energy and can do work just like heat, light or sound. Some of the many forms of energy are -

- the potential energy possessed by a body due to its height,
- the kinetic energy of a body which is moving,
- the electric energy of bodies which have electric potential,
- the heat energy produced by electric radiators and soldering irons,
- the light energy produced by electric lamps,
- the chemical energy produced when an electric current flows between conductors in a conducting liquid, as in some types of electric cells and batteries,
- the magnetic energy around a metallic conductor carrying a current, as in an electromagnet,
- the mechanical energy of an electric motor,
- the sound energy produced by electric bells, telephone receivers and loudspeakers in a radio set.

Energy can be converted from one form to another. For example, the potential energy of a waterfall drives the rotating water wheels of a turbine, converting potential into kinetic energy. The turbine in turn drives an electric dynamo, converting kinetic into electric energy.

It may be stored as chemical energy in batteries and used (as an example) for the transmission of speech, signals or music from a telephone receiver, telegraph machine or a loud-speaker.

When converting energy from one form to another, losses occur, because some of the energy is converted into forms that have no value. The total amount of energy involved however, remains the same, since energy cannot be created or destroyed.

Whenever energy is changed from one form to another, work is done.

4.5 Power associates energy with time. It is the average rate at which work is done or the rate at which energy is converted; and so electric power is the rate of using (or producing) electric energy.

The same total amount of work may be done in different amounts of time. For example, a given number of electrons may be moved from one point to another in one second, or in one hour, depending on the rate at which they are moved; and the total work done will be the same in each case. When all the work is done in one second, more electric energy is changed to heat or light per second and the power is greater than when the total amount of work is done in one hour.

4.6 Power and Energy in the D.C. Circuit. To measure water power, the head of water and quantity flowing per minute must be known; the water power then equals the product of the head of water by the quantity flowing per minute.

To measure electrical power, the head of electricity (the voltage), and the quantity flowing per second (the current) must be known; the electrical power then equals the product of the voltage and the current.

The unit of Electrical Power is the Watt (W) which represents the RATE at which work is done, or the RATE at which electrical energy is transformed into other forms of energy.

In a circuit where voltage and current are known -

$$P = E \times I$$

Electrical Power = Voltage × Current

Watts = Volts × Amperes

Where large powers are measured, the unit is the kilowatt. In some telecom circuits where small powers are measured, the sub units milliwatt and microwatt are used.

The alternative units are -

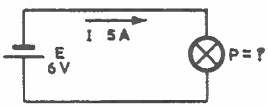
kilowatt (kW) which equals one thousand watts,
milliwatt (mW) which equals one thousandth of a watt,
microwatt (μW) which equals one millionth of a watt.

4.7 Power Rating of Electrical Apparatus. Most items of electrical apparatus are marked in terms of the rate at which they are designed to change electrical energy into some other form of energy. This is called the power rating or wattage rating.

For example, a 240 volt electric lamp may be rated at 100 watts. This indicates the rate at which electrical energy is changed into heat and light energy when the lamp is connected to 240 volts.

Since power is the rate of conversion of energy, a 100 watt lamp will give more light than a 60 watt lamp.

Example. A globe is connected to a 6 volt battery. If the current is 5 amperes what is the power consumption?



$P = E \times I$

$= 6 \times 5 = 30\ W.$

Answer. = *30 Watts.*

5. MAGNETISM AND ELECTROMAGNETISM.

5.1 Magnetism plays an important part in telecommunications. Electric motors and generators, automatic switches and teleprinters, telephone and telegraph relays, microphones and gramophone pickups, loudspeakers and telephone receivers, measuring instruments and many other items of apparatus have their foundations in magnetism.

All matter is affected by magnetic fields to some degree. Those materials intensely magnetic are termed "ferromagnetic materials," and include iron, nickel, cobalt, and certain alloys, such as permalloy and perminvar. The term "magnetic substance" in normal use refers to ferromagnetic materials.

Magnets may be classed as permanent magnets or electromagnets. A hard steel bar when magnetised becomes a permanent magnet, because it retains the magnetism under normal conditions for a long period unless subjected to heat or jarring. Soft iron is easily magnetised when subjected to a magnetising influence, but does not retain an appreciable part of the magnetism.

5.2 Magnetic Fields. Fig. 24 represents a rectangular steel bar magnet, which will attract pieces of iron and will exert a force of either repulsion or attraction upon other magnets. This attraction and repulsion is caused by the magnetic field, which is represented by the curved lines.

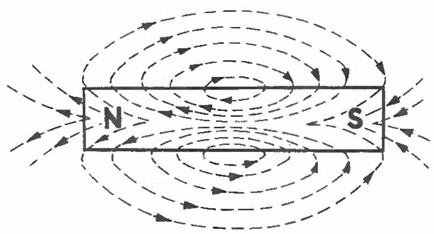


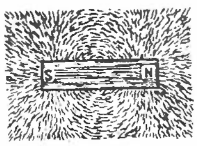
FIG. 24. MAGNETIC FIELD AROUND BAR MAGNET.

The curved lines are commonly known as lines of magnetic induction or lines of force.

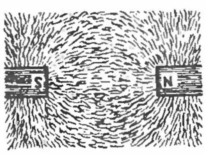
The lines of magnetic induction act through a magnet from the south to the north pole, leaving the magnet at the north pole and re-entering the magnet at the south pole as indicated by the arrows.

Lines of magnetic induction are always closed loops. Each line or loop may be thought of as acting within itself somewhat like a stretched rubber band, in that it tends to become as short as possible. Yet each of these lines or loops has a repelling effect upon neighbouring lines, tending to keep them separated from each other. A practical illustration, not only of the presence of the magnetic field but also of the arrangement of the lines of magnetic induction, is seen when iron filings are sprinkled upon a glass plate placed above a magnet. Fig. 25a shows how the filings arrange themselves under such a condition.

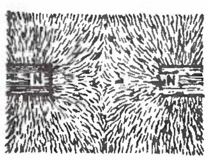
If a second magnet is placed at the end of the bar magnet shown in (a), the magnetic field will become either like that shown in (b) or that shown at (c). In (b), the two magnets will attract each other. If the two magnets should contact and establish a combined magnetic field such as shown in (a), merely changing ends of one magnet will give the effect in (c).



(a) Iron filings indicate the magnetic field.



(b) Magnetic fields aiding.



(c) Magnetic fields opposing.

FIG. 25.

From the action of one magnet toward another, it may be deduced that the two ends of any magnet are unlike. These two ends are called the Poles, and the pole having one influence is called the North Pole and that having the opposite influence is called the South Pole. The distinction comes from the earth, which is itself a magnet. If a bar magnet is suspended to swing freely, that pole which tends to point toward the north is called the north-seeking or north pole; the other is called the south pole. A fundamental law of magnetism is "Like poles repel one another, and unlike poles attract."

Note: Lines of Force do not move from the N to S poles of magnets, but are regarded merely as acting in that direction as a basis of reference. In other words, magnets have a field of influence wherein other bodies having magnetic properties are affected. The imaginary lines of force are merely a convenient way of representing the intensity and extent of this field by a number of lines and their pattern. For example in magnetic calculations a field may be said to have an intensity of 5,000 lines per square centimetre.

5.3 The Domain Theory of Magnetism. Experiments have proved that electric charges in motion induce magnetic fields. The electron is understood to have two states of motion, namely, a spin about its axis and an orbit about the atomic nucleus. This gives rise to two magnetic effects, one parallel to the axis of spin and the other perpendicular to the plane of the orbit.

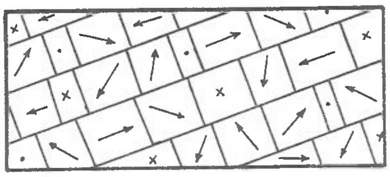
An atom containing many electrons may possess a resultant magnetic field. In a magnetic material great numbers of atoms align with their resultant magnetic fields parallel to one another, forming a micro-crystal or "domain".

A specimen of magnetic material may appear unmagnetised due to the domains not being aligned, thus causing the fields to cancel. If such a specimen is then placed in a magnetic field, some of the domains nearly parallel to the field will be rotated parallel to the field by a small magnetising force, causing an increase in the flux density of the specimen.

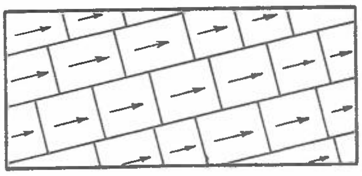
As the magnetising force of the external field is continuously increased, more and more domains are aligned with the field, until ultimately all the domains are rotated parallel to the external field. The specimen will then be magnetically saturated, and behave as a magnet.

When the magnetising field is removed, some domains will lose their orientation slightly, leaving the specimen with residual magnetism. The state of magnetisation can be reversed by the application of a magnetising force opposite to the original.

If the domains return to a random state readily, the material is termed a temporary magnet, and may be used as an electromagnet. If the orientation of the domains is difficult to change, the material is termed a permanent magnet.



(a) Domains in random state.



(b) Domains aligned with magnetic field.

FIG. 26.

5.4 Permanent magnets are of steel or of such alloys as alnico (aluminium-nickel-cobalt) or cobalt-steel.

A permanent magnet may exert, upon pieces of iron or other magnetic materials, forces either large or small. These forces depend, first, upon the magnet's strength and, second, upon the location of the pieces attracted with respect to the magnet's field.

The magnetic field has greatest intensity nearest the poles. If it is desired to create a field of greater intensity, it can be accomplished by bending the magnet into the form of a horse-shoe as shown in Fig. 27a. Here, each line emerging from the north pole returns to the south pole of the magnet through a much shorter distance than that represented by any one of the curved loops in Fig. 28. If the strength of the field between the two poles of a horse-shoe magnet is tested, it would be found more intense than that of a straight magnet of equal strength. Not only is each line (represented by a closed loop) shortened, but more lines are created.

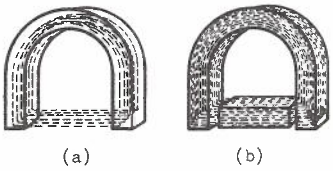


FIG. 27. INCREASING THE LINES OF FORCE.

Again, if a piece of soft iron or other magnetic material is inserted between the poles of the horse-shoe magnet, as shown in Fig. 27b, the number of lines of magnetic induction (in the circuit formed by the magnet itself and the soft iron used for closing this circuit between the north and south poles) is increased.

The function of a permanent magnet is to maintain magnetic flux in a magnetic circuit of which it is a part. In general, the useful part of the flux is in that portion of the magnetic circuit which is external to the magnet.

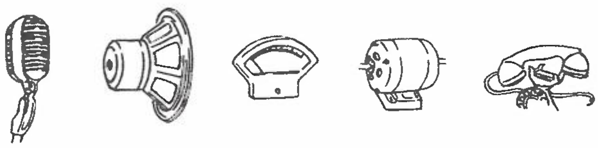


FIG. 28. SOME PRACTICAL APPLICATIONS OF PERMANENT MAGNETS.

5.5 Magnetic Screening. It is often necessary in telecom to shield (or screen) a measuring instrument or other item of apparatus from nearby magnetic fields. A metal partition, cover or shield is often used for this purpose. The principle of this magnetic screening is shown in Fig. 29. If a piece of iron is introduced in this field, the lines of force will be concentrated in the iron as shown.

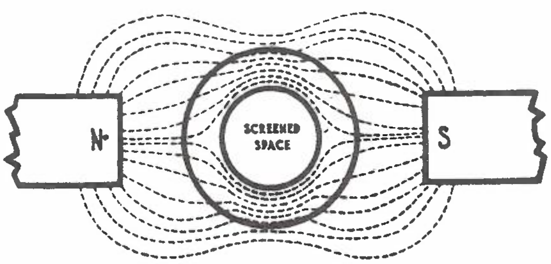


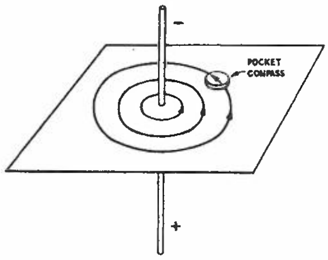
FIG. 29. MAGNETIC SCREENING.

Since the lines of force are concentrated in the iron, there will be no magnetic force in the space marked screened space. If a measuring instrument or other item of apparatus is provided with an iron cover, therefore, the instrument or apparatus would be unaffected by nearby magnetic fields.

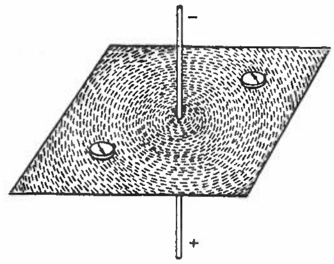
5.6 Electromagnets are used in automatic switches, bells, telephone type relays, receivers and loud speakers, telegraph relays, teleprinters and many other items of telecom apparatus. If a straight vertical conductor carrying an electrical current pierces a cardboard, as shown in Fig. 30, and iron filings are sprinkled on the cardboard, they will form visible concentric circles as shown. Through such observations as these, it is learnt that wherever an electric current is flowing there is an established magnetic field, which acts in a plane perpendicular to the electrical conductor.

If in either (a) or (b) a compass is placed near the conductor, the needle will align itself tangent to the axis formed by the wire.

If the compass is moved slowly around the wire, the needle will revolve on its pivot and maintain this relation. It will also be found that the direction of the field with respect to the direction of current flow is that represented by the arrows.



(a) Magnetic Field Around Current-Carrying Straight Conductor.



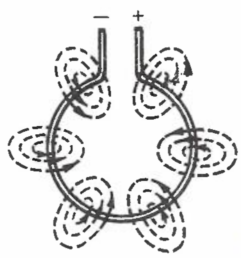
(b) Iron Filings Indicate the Magnetic Field.

FIG. 30.

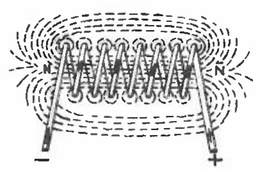
Though this magnetic effect is a positive one, under the conditions shown in the figures and even with a very strong current in the conductor, the magnetic field represented by the concentric circles is relatively weak. But, if the electrical conductor is made to form a loop as in Fig. 31a, the groups of lines of force form concentric circles for every unit of the conductor's length. Accordingly, the intensity of the magnetic field is increased.

If, instead of having an electrical circuit consisting of one loop of wire, the circuit consists of several turns of wire as shown in Fig. 31b, the intensity of the field is multiplied by the number of turns of wire. Thus, the value of the field intensity at any point for two turns would be twice that for a single loop; for three turns, three times that for a single loop; and for 'n' turns, 'n' times that for a single loop, providing the turns are sufficiently close together.

Comparing Fig. 31 with Fig. 24 it may be seen that the current in the coil of wire creates a magnetic field similar to that of the bar magnet.



(a) Lines of Force in a Loop of Wire.



(b) Magnetic Field Around Coils of Wire.

FIG. 31.

In Fig. 27, the number of lines in the magnetic circuit established by the horse-shoe magnet was greatly increased by the insertion of a piece of soft iron between the north and south poles. Likewise, if in Fig. 31b, the spool shown has a soft iron core, the number of lines will be greatly increased. Further, if the core of the winding is bent in the shape of a horse-shoe as shown in Fig. 32, the electromagnet is capable of exerting considerable force.

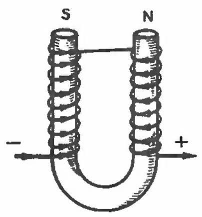


FIG. 32. HORSE-SHOE ELECTROMAGNET.

5.7 Practical Electromagnets. The most common use for electromagnets is as a solenoid. When the current is turned on the electromagnet attracts an iron armature, and this movement made to do mechanical work of some sort. The most common solenoid for telecom use is the telephone relay, where movement of the armature is made to operate electrical contacts for switching in other circuits. (Fig. 33).

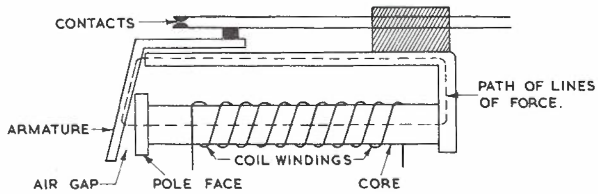


FIG. 33. PRINCIPLE OF RELAY.

5.8 Electromagnetic Induction. One of the most important discoveries concerning electricity and magnetism was made about 140 years ago by Faraday: when a wire moves relative to a magnetic field an e.m.f. is generated in the wire.

It is important to note that there must be a motion of the wire relative to the magnetic field. The wire may be stationary and the magnetic field moving or varying, but as long as there is any motion between the two, an e.m.f. is induced in the wire.

To illustrate this, Fig. 34 shows a coil of wire wound on a tube; the ends of the coil are connected to a sensitive centre zero electrical instrument. When the north pole of a bar magnet is inserted into the middle of the tube, the instrument needle is immediately deflected to one side and then returns to zero. When the magnet is withdrawn, the needle is again deflected, but in the opposite direction and again returns to zero.

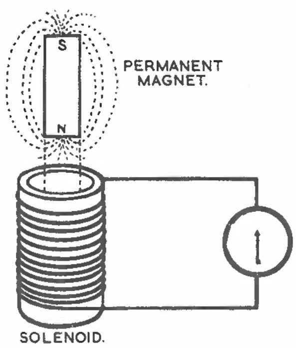


FIG. 34. RELATIVE MOVEMENT INDUCES AN ELECTRIC CURRENT.

When the S pole is inserted a similar "flick" of the needle results, but in the same direction as that produced by the withdrawal of the N pole, and on its withdrawal a flick in the same direction as the insertion of the N pole. Now, the bar magnet has a magnetic field, and when the magnet is inserted into the coil, these lines of force necessarily move with the magnet bodily, and cut the wire of the coil. This cutting sets up an induced current in the coil. The current only occurs when the magnet is in motion; as soon as the magnet comes to rest the current stops. The more powerful the magnet, that is, the greater the number of magnetic lines of force, and the greater the number of turns in the coil, and the quicker the movement of the magnet, the stronger is the momentary current induced in the coil. But it is only transient; it lasts only while the magnet moves.

When an electromagnet is substituted for the permanent magnet, as shown in Fig. 35, similar results are obtained. Further, when the electromagnet is placed in the coil and a means provided of stopping and starting the current through the electromagnet, a current is induced in the coil without movement of the electromagnet. The closing of the circuit of the electromagnet allows current to flow. This current through the electromagnet creates a magnetic field, and as the lines of force are being established they cut the wires of the coil. When the circuit of the electromagnet is opened, the field collapses and the lines of force cut across the wires of the coil in the opposite direction. Such an apparatus is an induction coil or transformer, the coil of the electromagnet acting as the primary circuit and the outer coil as the secondary circuit.

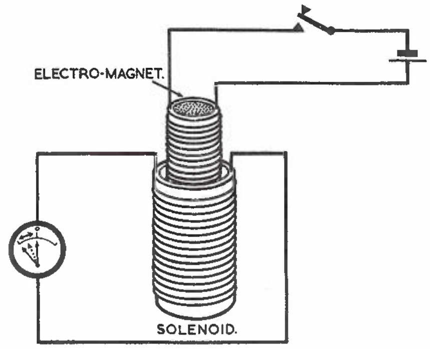


FIG. 35. ANOTHER METHOD OF INDUCING AN ELECTRIC CURRENT.

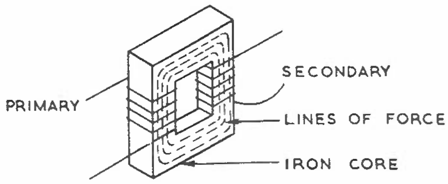
These experiments prove that an e.m.f. is generated in the coil when -

- A magnet is moving in or out of the coil;
- An energised electromagnet is moving in or out of the coil; and
- The current in the electromagnet or inner coil is stopped, started or varied.

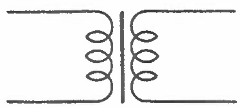
The principle underlying the above experiments is known as Electromagnetic Induction; the magnetic condition of one body produces an electric current in the other. The bodies are near but are not connected to each other in any way.

5.9 Applications of Electromagnetic Induction. Practical use is made of this principle in the generator and in the transformer. The generator (or alternator) as a source of electric energy can use either wires rotated in a steady magnetic field or magnets (permanent or electro) rotated within stationary coils of wire. A generator, then, is actually a means of converting mechanical energy to electric energy. (See Section 6).

Transformers are widely used in telecom and by commercial power supply authorities. They range in size from those in radio equipment weighing less than 1 oz. to massive structures of iron and copper weighing many tons. Basically, all transformers consist of two coils of wire so wound that changes of magnetic field strength produced by a changing current in one coil (the primary) will induce a changing e.m.f. in the other coil. In many cases (but not all) the two coils are wound on a common iron core to give a stronger magnetic field. The primary current must be changing in value for the transformer to operate, so the greatest application for transformers is with alternating currents. (See Section 8).



(a) Basic construction of one type.



(b) Symbol.

FIG. 36. TRANSFORMER.

5.10 Electric Motors and Meters. Faraday's experiments also revealed that a conductor suspended in a magnetic field will move when a current is passed through it; and the direction of movement depends on the direction of current and the direction in which the external field is acting.

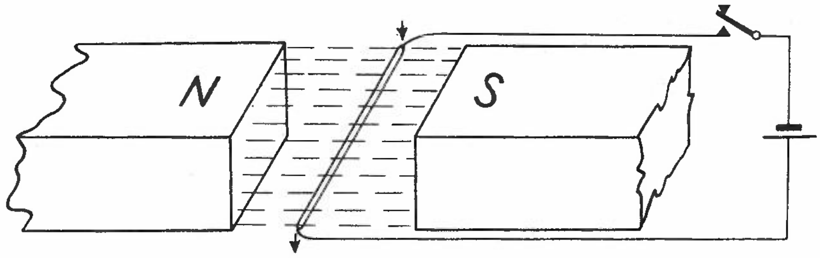
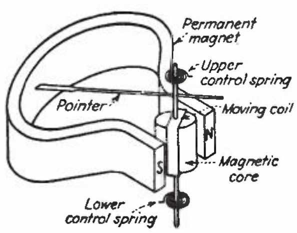


FIG. 37. PRINCIPLE OF ELECTRIC MOTOR.

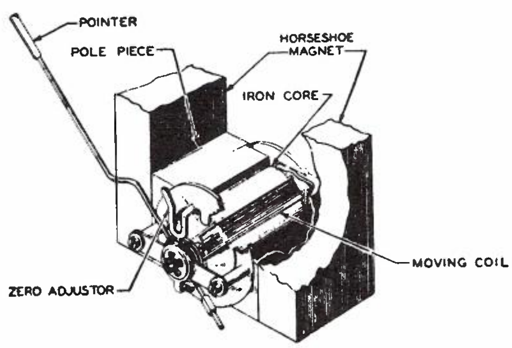
This was to be expected, of course, as a wire carrying current has a magnetic field around it and this must react with any other field to give forces of attraction and repulsion.

In Fig. 37, the wire will move downwards through the field when the switch is closed.

This is the principle on which electric motors work and also many other devices such as meters for measuring current and voltage. (See Fig. 38)



(a) Principle.



(b) Sectional View.

FIG. 38. MOVING COIL METER.

6. SOURCES OF ELECTRIC ENERGY.

6.1 Simple Primary Cell. A steady flow of electricity was first produced in 1799 by chemical action in the Voltaic cell, so called from its originator, Volta, an Italian professor of physics.

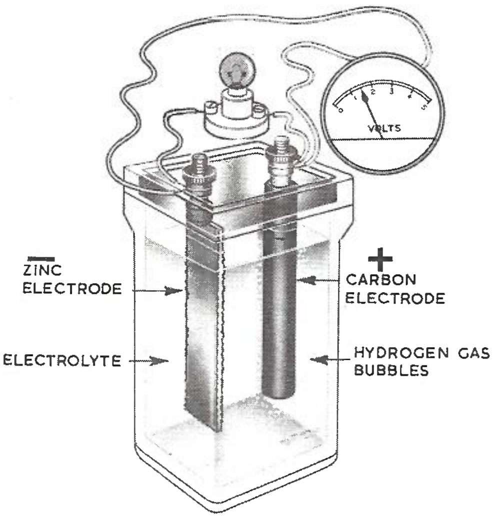


FIG. 39. SIMPLE PRIMARY CELL.

In the simple primary cell of this type, a source of e.m.f. is obtained by placing two dissimilar conductors in a chemical solution. This value of the e.m.f. is dependent on the type of dissimilar conductors and nature of the solution.

In commonly used primary cells, the electrodes are carbon and zinc and the electrolyte is salammoniac, (ammonium chloride). (Fig. 39).

In this cell, the negative terminal is connected to the zinc electrode, and is the terminal from which electrons from the cell pass to the external circuit or load. The positive terminal connects to the carbon electrode.

Operation of Cell. While the electrodes of the simple cell shown in Fig. 39 are disconnected externally no current flows, but when the circuit is closed, for example, by connecting a lamp to the terminals a discharge current will flow from the cell through the lamp.

The chemical changes which result in current flow produce a visible change in the components within the cell: some of the zinc electrode is eaten away and hydrogen bubbles form around the carbon electrode.

The hydrogen tends to set up an electromotive force in a direction opposite to that of the cell, decreasing the effective e.m.f. of the cell. It also reduces the conducting area of the plate and so increases the Internal Resistance of the cell. The formation of hydrogen on the positive electrode is called polarisation.

When a cell which has become polarised is allowed to stand on open circuit, the hydrogen gradually disappears, and the terminal voltage of the cell is eventually restored.

6.2 Leclanche Cell. (Fig. 40). This type of cell uses the same electrodes and electrolyte as shown in Fig. 39, but eliminates polarisation whilst the cell is working, by using a depolariser (manganese dioxide) to chemically absorb the hydrogen gas, and prevent it from affecting the operation of the cell.

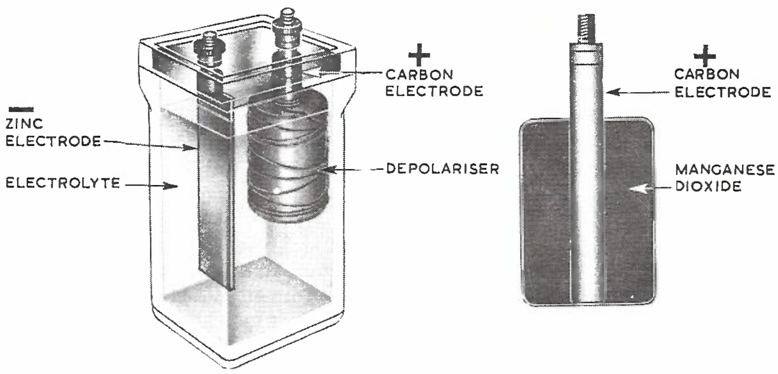


FIG. 40. COMPONENTS OF A LECLANCHE CELL.

6.3 Dry Cell. This cell contains the same components, and has the same chemical action as the Leclanche cell, but the electrolyte is in the form of a thick damp paste, which prevents spilling, and makes the cell more portable.

Actually the cell is not dry, for the electrolyte must be moist or the cell would not work; in practice, a cell often fails because the electrolyte is dry.

Dry cells are made in many different sizes, but the No. 6 dry cell (Fig. 41) is the one most commonly used in the P.M.G's Department, principally in magneto telephones.

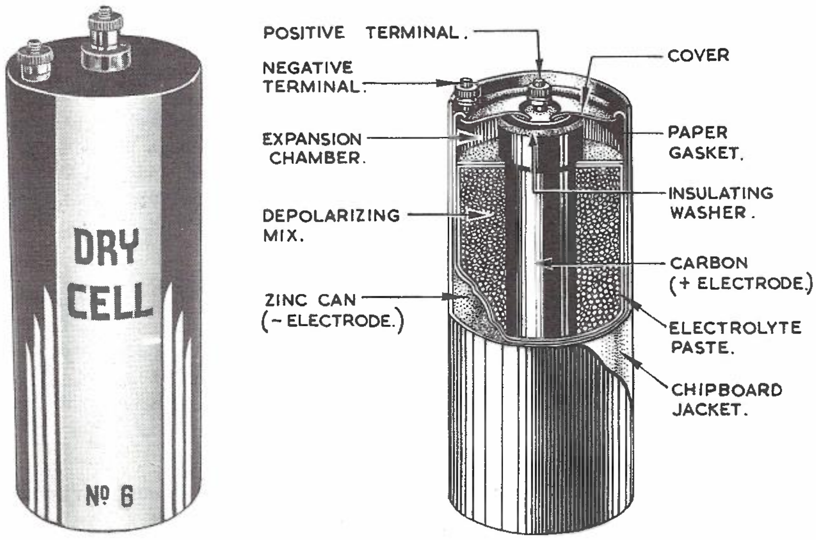


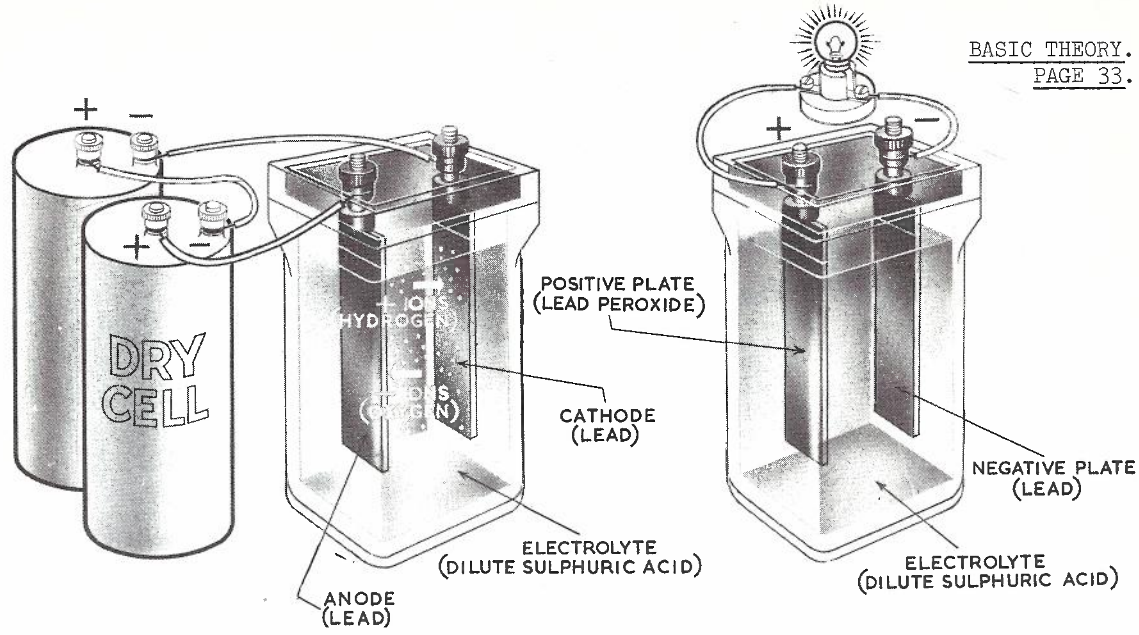
FIG. 41. NO. 6 DRY CELL - SECTIONAL VIEW.

Dry Cell Batteries. A single dry cell has a normal voltage of 1.5 volts. For higher voltages a dry cell battery is used which is constructed of a number of single cells connected in series. The purpose for which the battery is designed determines the size and number of the individual cells, but as dry batteries are not designed to deliver large currents, batteries providing fairly high voltages and low currents can be made in fairly compact sizes.

The purpose of most primary cells and batteries is to provide energy for intermittent discharge purposes only, and when the components are depleted the cell is discarded.

6.4 Secondary cells, such as the lead acid cell or accumulator, have the characteristic of being able to provide a relatively heavy current over long periods. When the chemical components are depleted, current can be passed through the cell in the reverse direction, and the chemical action of the cell will reverse, restoring the components to their original condition.

Simple Accumulator Cell. When two lead plates are immersed in a dilute solution of sulphuric acid, a trace of lead sulphate is formed on the surface of each plate. When a current is passed through the solution (Fig. 42a) the lead sulphate on the cathode is reduced to metallic lead and on the anode the sulphate is chemically changed to lead peroxide (Fig. 42b).



(a) Charging. (b) Discharging.

FIG. 42. SIMPLE ACCUMULATOR CELL.

6.5 Practical accumulators usually have many plates, these being specially constructed to hold a large amount of active material in contact with the electrolyte. The plates are insulated from one another by separators which may be of wood, glass, or plastic. (See Fig. 43).

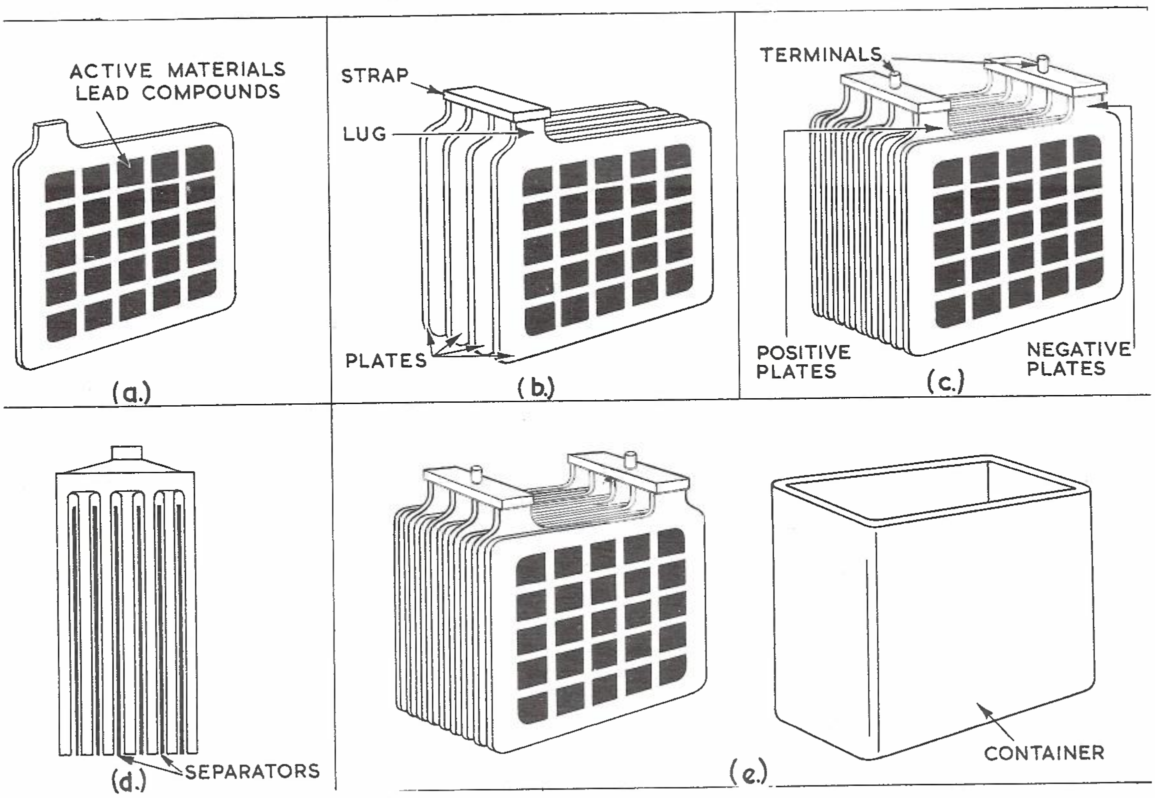
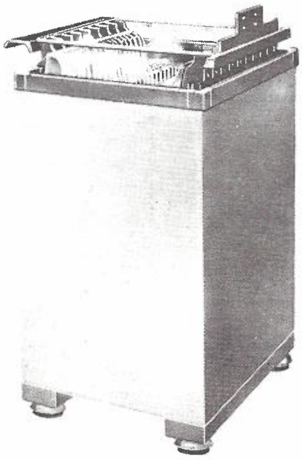
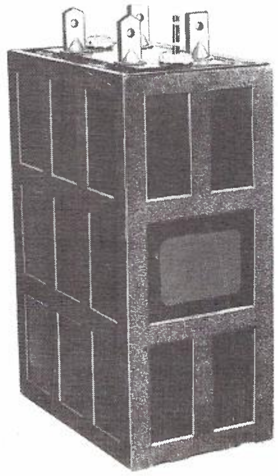


FIG. 43. BASIC CONSTRUCTION OF AN ACCUMULATOR CELL.

The cells may be fully enclosed (except for removable topping - up vent plugs) or open at the top. (See Fig. 44). The modern trend is to use all enclosed cells as they are now available in very large sizes.



(a) 2 Volt Open Type Cell, Lead-Lined Wooden Container.



(b) 2 Volt Cell Enclosed Type Hard Rubber Container.

FIG. 44.

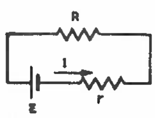
6.6 The capacity of any cell (or battery) is the quantity of electricity it can supply before becoming discharged. It depends on the efficiency of the chemical components and the surface area of the electrodes, and is usually expressed in terms of ampere-hours, which means amperes multiplied by hours.

When a cell is discharged at a constant current, the capacity in ampere-hours is the product of the current and the time that the cell maintains the discharge. For example, when the average discharge rate of a torch cell is 0.3 ampere, and the cell gives this current for 10 hours before becoming discharged, the capacity is 3 ampere-hours. Accumulators have capacities ranging up to 4,500 ampere-hours.

6.7 The Internal Resistance of a Cell is its total resistance to the flow of current. Accumulators have an internal resistance so low that for most purposes it may be neglected, but dry cells have a small internal resistance which increases as the cell is discharged or 'dries out'.

The e.m.f. or open circuit voltage of a cell, is measured in practice by the voltage reading of a high resistance meter connected to the terminals, when the cell is open circuit.

The terminal voltage of a dry cell measured during discharge is always less than the e.m.f. as a proportion of the voltage must be used in forcing current through the internal resistance of the cell. Under load therefore, the voltage applied across the load resistance, (terminal voltage or P.D.), will be equal in value to the e.m.f. minus the voltage drop across the internal resistance. Fig. 45 shows the equivalent circuit of a dry cell under load.



E = *e.m.f. of cell*

R = *Load resistance*

I = *circuit current*

r = *internal resistance of cell*

FIG. 45. EQUIVALENT CIRCUIT SHOWING INTERNAL RESISTANCE.

6.8 Grouping of Cells. In telecom circuits, cells can be connected either in series or in parallel, to increase the e.m.f. or current available from the battery. As a cell is both a source of e.m.f. and a resistance, the method of connection of a number of cells comprising a battery will affect both the e.m.f. and resistance of the battery.

To connect cells in series, join the positive terminal of one cell to the negative terminal of the next cell, and so on. Fig. 46 shows a battery of four cells connected in series.

If the e.m.f. of each cell is 1.5 volts, and the internal resistance of each is 0.3 ohm, then the battery as a whole has an e.m.f. of 6 volts, and an internal resistance of 1.2 ohms.

Cells (and batteries) of different e.m.f's can be connected in series, for example, 2 volt cells can be connected in series with 1.5 volt cells.

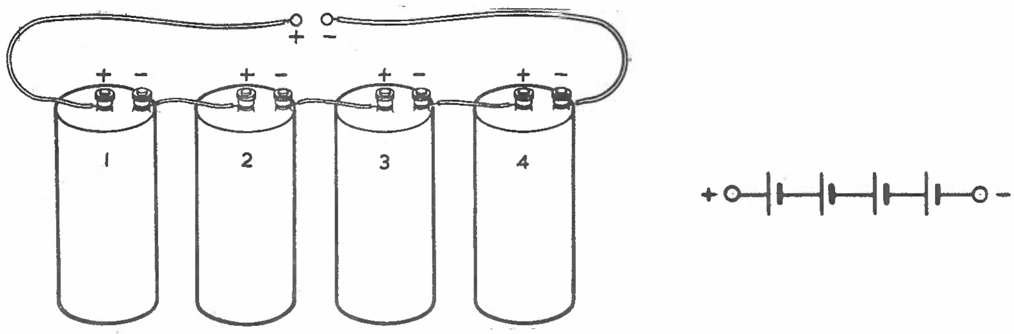


FIG. 46. HOW TO CONNECT CELLS IN SERIES.

To connect cells in parallel, join all the positive terminals together to a single wire, and all the negative terminals to another wire. Fig. 47 shows a battery of four cells (each with the same e.m.f.) connected in parallel. This gives the equivalent of one larger cell. The e.m.f. of the battery is still the same as the e.m.f. of one cell, but the internal resistance is reduced, and is calculated in the same way as for separate resistances in parallel. Under working conditions each cell will supply one quarter of the total current.

Cells (and batteries) should not be connected in parallel unless their e.m.f's are all the same, as those with higher e.m.f's discharge through those with lower e.m.f's.

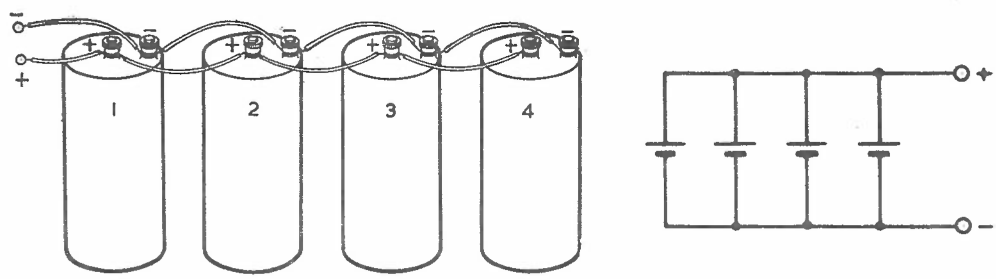


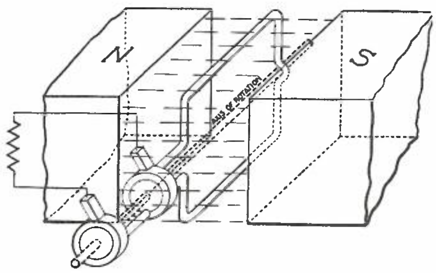
FIG. 47. HOW TO CONNECT CELLS IN PARALLEL.

Present day telecom practice does not require dry cells to be connected as shown in the form of a battery, except as an emergency measure. In this case it should be remembered that cells connected in series will provide the necessary e.m.f., but to supply the circuit current demands and keep the internal resistance within reasonable bounds, banks of cells may have to be connected in parallel.

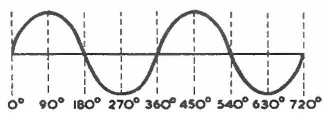
6.9 Generators and Alternators. The generator uses the principle of electromagnetic induction explained in Section 5 to convert mechanical energy into electric energy.

The basic generator consists of one turn of wire rotated by mechanical means in a magnetic field. An e.m.f. is produced as the wires cut the magnetic lines of force and if an external circuit is connected to the loop by means of slip rings and brushes, a current will flow. Since the wires run parallel to the lines of force (no cutting) twice each revolution, and also cut the lines in both directions, the e.m.f. is not a steady one but alternates between two maximum values of opposite polarity, every 360° of rotation as shown by the graph of e.m.f. in Fig. 48b. Each revolution produces one complete cycle or two half cycles of A.C.

A.C. generators are known as alternators.

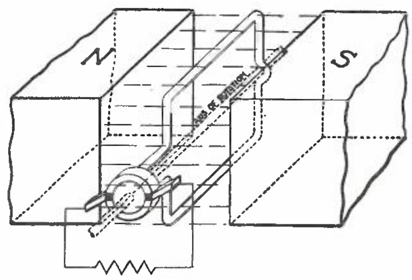


(a) A.C. Generator (Showing Slip Rings).

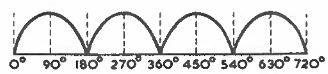


(b) Alternating e.m.f. from A.C. Generator.

FIG. 48. BASIC GENERATOR AND GRAPH OF E.M.F.



(a) D.C. Generator (Showing Simple Commutator).



(b) Unidirectional e.m.f. after Commutation.

FIG. 49. BASIC D.C. GENERATOR.

In a D.C. generator the e.m.f. is produced in exactly the same way but the polarity of one half cycle must be reversed so that unidirectional current is obtained. This is done mechanically by means of a commutator of two segments, each segment having one end of the loop terminated on it. Rotating with the loop (or armature) this reverses the connections to the external circuit via the brushes every half revolution so that the A.C. in the armature is 'rectified' to D.C. pulses in the load. (See Fig. 49).

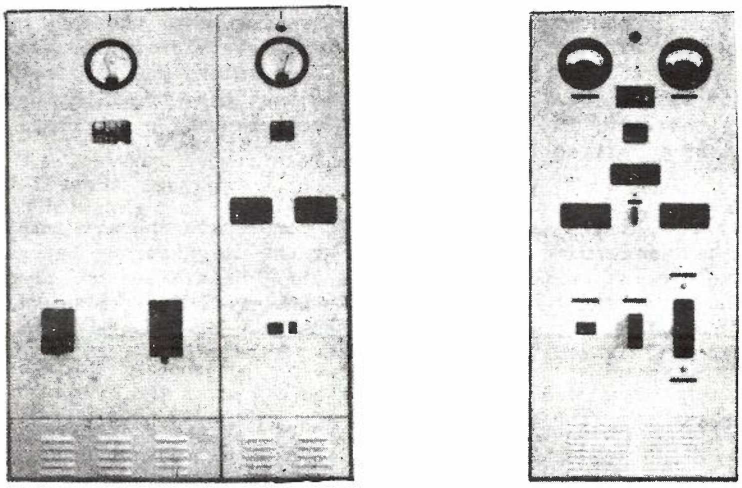
Practical alternators and D.C. generators are of course more complex than this. The armatures have many turns of wire, iron cores and in most cases the fields are 'excited' by an electromagnet. D.C. generators have many segments on the commutator and produce a much steadier output than that shown in Fig. 49b. Large alternators produce 3 separate cycles simultaneously, each output reaching its maximum values at different times (3 phase).

6.10 The Conversion of A.C. to D.C. Most telecom equipment is powered by D.C., while commercial power supply is usually A.C. Conversion equipment therefore plays an important part in telecom. The two common methods of obtaining D.C. from A.C. are by using rectifiers or motor generator sets. (Figs. 50a and 50b).

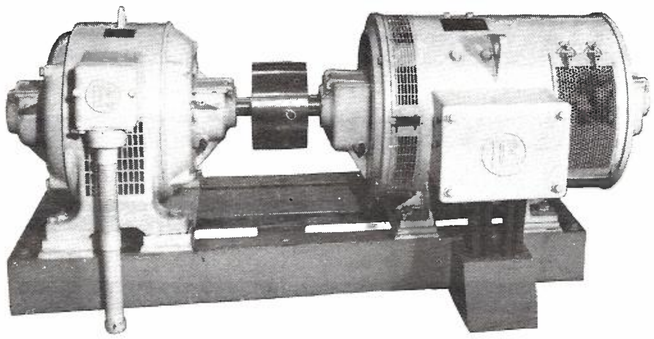
Rectifiers have no moving parts and are sometimes known as static rectifiers for this reason. They are made up of metallic elements or a thermionic valve (or valves) which permit current flow in one direction only.

Motor generator sets are in use having maximum outputs ranging from 30 to 1,000 amperes but are now gradually being superseded by rectifiers which are in use with outputs ranging from a few milliamperes to 800A.

Where they are used in place of batteries, rectifiers are sometimes known as eliminators (from "battery-eliminators").



(a) Rectifiers.



(b) Motor Generator Set.

FIG. 50.

7. SOUND.

7.1 Transmission of Sound. If a sound is traced to its source, the sound will usually be found to emanate from a vibrating body, which sets up corresponding vibrations in the air or whatever the conducting medium may be. A material medium is necessary for the transmission of sound, in which respect sound differs from light which is transmitted quite readily through a vacuum. To demonstrate this, a vibrating electric bell, as shown in Fig. 51 is placed under an inverted glass jar resting on a plate. The plate has an outlet to which a vacuum pump is connected. Before the vacuum pump is operated, the sounds from the bell can be heard quite distinctly. As the air is exhausted from the jar by the operation of the pump, however, the sound heard becomes fainter and fainter until, with a complete vacuum in the jar, no sound is heard although the bell may be seen vibrating. This proves that, in this instance, the air inside the jar is responsible for the transmission of the sound between the bell and the walls of the jar. The walls of the jar are, of course, responsible for conducting the sound between the air inside the jar and that outside of it, so that solids as well as gases will transmit sound. In fact, any material medium will transmit sound, some, of course, to a greater degree than others.

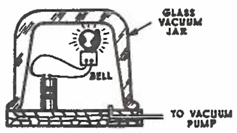


FIG. 51. SOUND NEEDS A TRANSMISSION MEDIUM.

The simplest case which can be found to illustrate how sound is transmitted is that of a tuning fork, the prongs of which are vibrating after the fork has been "struck". As the fork prongs vibrate, the air in the immediate vicinity of the prongs is alternately compressed and rarefied, these compressions and rarefactions being transmitted to succeeding "layers" of air, so that they travel outwards into space. Fig. 52 shows the idea, the denser sections representing a compression, and the lighter sections a rarefaction.

The prong of the vibrating fork advances and compresses the air immediately in front of it (a). The compression is transmitted to the neighbouring layers, and progresses outward at the natural velocity of sound in air. Meanwhile, the prong retreats, leaving behind a partial vacuum (b). Whilst the preceding compression and rarefaction are being transmitted, the prong advances and again compresses the air (c). The prong retreats again and gives rise to another rarefaction (d).

Besides thinking of sound as causing a series of alternate compressions and rarefactions of its conducting medium, it can also be thought of as causing the individual particles of the conducting medium to move backwards and forwards in line with the direction in which the sound is travelling. In Fig. 52, the air particles at the immediate right hand side of the right hand prong move to the right at (a), to the left at (b), to the right at (c), and so on.

FIG. 52. TRANSMISSION OF SOUND.

7.2 Velocity of Sound. Sound travels at a finite velocity which depends on the nature of the transmitting medium. A quite familiar experience is the displacement of air produced by a distant flash of lightning being heard as thunder some time after the flash is seen. Here, there is no vibrating body - the lightning flash disrupts and displaces the air in its immediate vicinity, which disturbance is transmitted to succeeding layers of air just as is the disturbance created by the tuning fork.

Eventually, this disturbance reaches a listener as the sound of thunder. The velocity of sound in air is approximately 1,100 feet per second, whilst in water the velocity is approximately 4,700 feet per second.

7.3 Graphical Representation of Sound. If the vibrations of a tuning fork prong are traced on a moving paper tape by the simple arrangement shown in Fig. 53, the trace will be a sine curve, that is, the graph of the sine function of an angle as it varies from 0° through all angles to 360°.

As the air pressure in the immediate vicinity of the fork prong of Fig. 52 will vary with the position of the prong from instant to instant (that is, the air pressure will be greatest at the instant of time represented by Fig. 52a, return to normal when the prong returns to a vertical position, and will be least at the instant represented by Fig. 52b), then the trace of Fig. 53 will represent the extent to which the air is alternately compressed and rarefied above and below normal with time. Further, the greater the movement of the fork prong of Fig. 52, the greater will be the displacement of the individual air particles. The trace of Fig. 53 can, therefore, also represent the displacement of the air particles as they oscillate backwards and forwards about their normal positions under the influence of the vibrating fork prong.

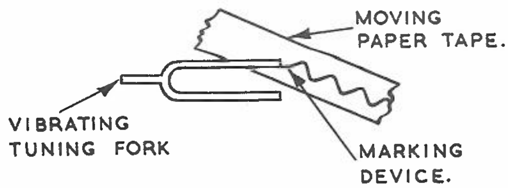


FIG. 53. TRACE OF FORK PRONG VIBRATIONS.

From the shape of this graph, the term "Sound Wave" is correctly applied to the successive compressions and rarefactions existing in the transmitting medium.

The to and fro motion of the air particles from their position of rest occurs in a direction parallel with the direction in which the sound is travelling. Sound waves are, therefore, longitudinal as distinguished from transverse waves, in which the displacement is at right angles to the direction of the waves. As a simple example of a transverse wave, consider the behaviour of a cork placed on perfectly still water. When a disturbance is created in the water some distance from the cork, the waves created by the disturbance will travel to the cork, and in passing it, will cause the cork to rise and fall with the passing waves without travelling with them. The waves are travelling horizontally and the displacement of the cork is vertical, so that these waves are transverse waves.

7.4 Reflection and Echoes. When a sound is produced in air, the waves will continue to travel outwards from the source of sound, provided the air path is uniform. If the air path is short, being terminated some distance from the source of the sound by some object such as a wall, hill, mountain etc., the original sound in the form of an echo will be heard again some time after it is produced. The fact that the sound is heard again some time after it is produced means that some of the energy produced originally by the sound source must return to it.

7.5 Pitch, Volume and Timbre. Sounds differ from each other in three ways -

Pitch; that is, whether the sound is a high or low note.

Volume; that is, the loudness or intensity of the sound.

Timbre or the distinctive quality of a sound.

The pitch of a sound is determined by the number of vibrations per second executed by the vibrating body and, therefore, by the number of complete waves per second transmitted by that body. Referring to Fig. 54, one complete wave is called a cycle, the time taken to execute one cycle is called a period, and the number of cycles produced each second, on which depends the pitch of the sound, is called the frequency of the sound. Increasing the number of vibrations per second with a different tuning fork in Fig. 52 will increase the frequency of the sound or raise the pitch, and reducing the rate of vibrations will lower the pitch.

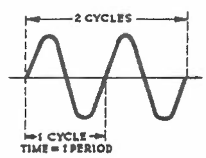


FIG. 54. CYCLES OF A SOUND WAVE.

For concerted music, that is, music involving a number of players such as a band or orchestra, some absolute standard of pitch is necessary. This has been fixed at 435 c/s for the note A above middle C, and is provided to instruments of variable pitch, for example, violins, by instruments of invariable pitch, for example, piano, pipe organ, etc.

The volume, loudness or intensity of a sound is determined by the distance each particle of air is displaced from normal, or the extent to which the air is compressed and rarefied above and below its normal value. The volume is, therefore, determined by the amplitude of vibration of the tuning fork prongs, or other sound source.

Fig. 55 shows how the graphs of sound of differing frequency and amplitude compare with one another.

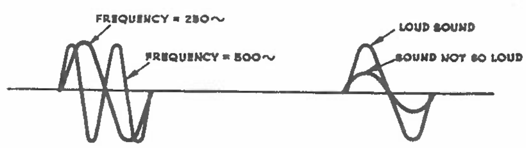


FIG. 55. SOUNDS OF DIFFERING PITCH AND LOUDNESS.

It is an easy matter to distinguish between different musical instruments playing the same note, for example, a trumpet playing a certain note is easily distinguished from a piano playing the same note. That characteristic which distinguishes two notes of the same pitch and volume from two different musical instruments is called "Timbre", a French word for which the nearest English equivalent is "tone colour".

Very few sounds have the pure sine curve formation shown in Fig. 55. Some typical cases are shown in Fig. 56. It will be seen that, although the form of each curve is not sinusoidal, it is regular, that is, each curve is repeated again and again. This is the difference between a musical sound and a noise - the musical sound contains a repetition of a wave form whereas a noise has no recurring wave form.

The wave forms of Fig. 56 can be analysed into a number of pure sine curves, each curve having a frequency which is some simple multiple of a fundamental frequency. This fundamental frequency determines the pitch of the sound and, for any number of different instruments playing the same note, will be the same for all. The multiples when added to the fundamental, vary the characteristic colour of the sound. These multiples are called harmonics. By altering the number of harmonics present and/or their amplitude relations, the characteristic colour of a musical note can be varied almost infinitely and with great subtlety. Fig. 57a shows a fundamental frequency of 500c/s to which is added successively a second and a third harmonic, showing the alteration in the resultant wave form brought about by the addition of the harmonics.

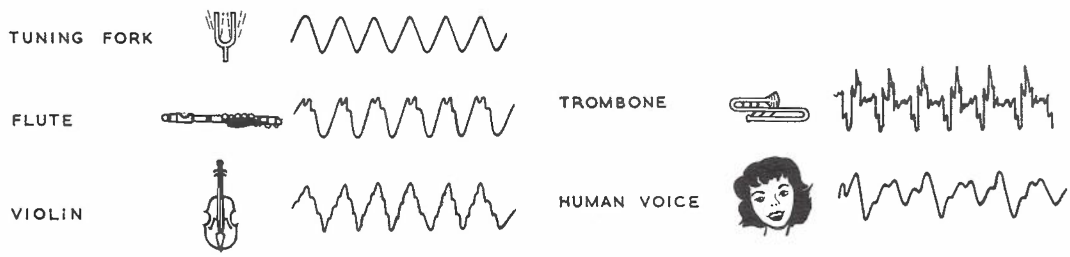
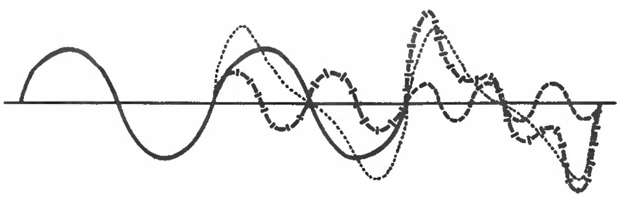
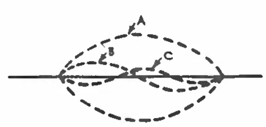


FIG. 56. SOUND WAVES.



Fundamental. Fundamental and 2nd Harmonic. Fundamental and 2nd and 3rd Harmonic.

(a) Analysis of Complex Wave.



(b) Production of Harmonics by Violin String.

FIG. 57. SOUND WAVES.

The means by which the harmonics are produced is usually fairly complicated, but is simply illustrated by a violin string. When the string is bowed, it vibrates not only as a whole, that is, from end to end as in curve A of Fig. 57b, but in two parts as in curve B, three parts as in curve C, and so on. The whole string vibrating produces the fundamental and determines the pitch of the note, whilst the half, third, and so on, lengths of the string vibrating are responsible for the harmonics.

7.6 Natural Frequency - Resonance. Assume that a tuning fork is designed to produce the note of frequency 258c/s. This frequency is termed the 'Natural' or 'Resonant' frequency of the fork. If the fork is at rest and placed in the path of a sound wave of the same frequency, that is 258c/s, the fork prongs will vibrate at this frequency. The fork will not vibrate at other frequencies except when the amplitude of the sound wave applied to it is very large, and then only slightly, unless perhaps the sound is exactly half or twice the resonant frequency of the fork. In just the same way as the natural frequency of this fork (258c/s) is the frequency at which the fork prongs will exhibit the maximum amplitude of vibration, so all objects have a natural or resonant frequency at which they will vibrate most readily when subject to a stimulus. The natural frequency of such objects as transmitter diaphragms, etc., has to be taken into account in the design of speech equipment.

7.7 Attenuation. As the distance from the source of a sound is increased, the loudness of the sound decreases, until it is quite inaudible some distance from the source. The gradual reduction in the sound with increasing distance from the source means that the amplitude of vibration must decrease correspondingly. This is shown in Fig. 58. The gradual reduction in the amplitude of the sound wave, with increasing distance from the source of sound, is called attenuation, or the sound is said to undergo attenuation as it progresses outwards from the source. Note that the frequency is not changed.

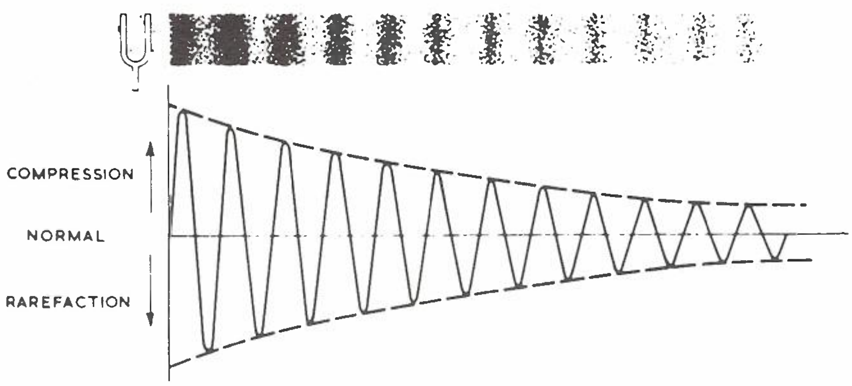


FIG. 58. REPRESENTING ATTENUATION OF A SOUND WAVE.

7.8 Hearing and Speech. The limits of audibility generally accepted for the human ear are 16 to 16,000 complete vibrations per second, but this varies with different persons. The sound from an orchestra may cover most of this range (fundamentals and harmonics)but the range used for speech is very much less.

For telephone communication, the important frequencies are between 200 and 4,000 cycles. The transmission of music, however, requires the transmission of frequencies between 50 and 10,000c/s (or more). It is interesting to note that the sibilant sounds, s and z, for example, include basic frequencies of the order of 4,000c/s; consequently, the correct transmission of these sounds is not always possible in a telephone system, as these higher frequencies are unlikely to be transmitted. The generally accepted frequency range for a telephone channel is 300c/s to 3,400c/s. In this range, speech is intelligible and voices are readily recognised.

8. ALTERNATING CURRENTS.

8.1 The subject of telecom is concerned as much, if not more, with alternating currents and voltages than with direct currents and voltages. It is found that the behaviour of circuits to alternating currents and voltages is, in many cases, quite different from that when direct currents and voltages are used. For even an elementary study of telecom it is important, therefore, to have some understanding of the behaviour of circuits to A.C.

8.2 An alternating voltage (usually abbreviated A.C. voltage) is one which rises from zero to a maximum value acting in one direction in a circuit (that is, sending current through a circuit in one direction), falls to zero and repeats the process acting in the opposite direction. Thus, as the A.C. voltage applied across a circuit reverses in direction, the current will correspondingly reverse, so producing an alternating current in the circuit. Fig. 59 shows the graph of a typical alternating voltage or current.

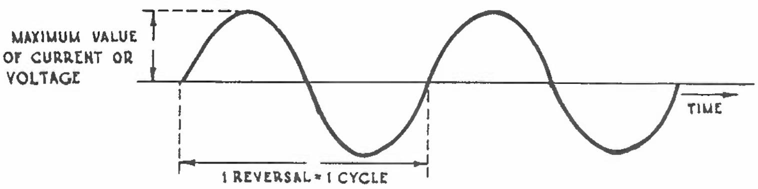


FIG. 59. GRAPH OF ALTERNATING VOLTAGE OR CURRENT.

As for graphs of sound waves, one reversal of current or voltage is called a 'cycle' and the number of reversals per second, that is, the number of cycles per second, is called the 'frequency' of the alternating current or voltage. The value of an alternating current or voltage varies with time, varying from zero to a maximum value and back to zero over each half cycle. The value at any particular instant is called the 'instantaneous' value at the instant concerned, whilst the highest values reached are termed maximum values. The part of the curve of Fig. 59 which is above the zero line represents positive values of current or voltage and indicates the voltage acting across, or the current flowing through, a circuit in one direction. The part of the curve below the zero line represents negative value of current and voltage, and indicates the voltage acting across the circuit or the current flowing through a circuit in a direction opposite to that of the first half-cycle above. A.C. generators of various types and valve oscillators (see Section 9) are the main methods of generating A.C.

The frequencies of alternating currents used in telecom range from a few cycles per second up to as high as 2,000 million cycles per second or even higher. High frequencies are generally expressed in kilocycles (kc/s) and megacycles (Mc/s) - 2,000c/s is 2kc/s and 4,000,000c/s is 4Mc/s.

The voltage or current graph in Fig. 59 is of sine waveform. This is the basic A.C. waveform (as for sound) and will be generated theoretically by a conductor rotating at a uniform speed in a uniform magnetic field.

When sound waves are converted to electricity by microphones and telephones the resulting A.C. assumes the waveform (graphically) of the sound producing it. (See Fig. 56).

8.3 A.C. Circuits with Resistance. If an A.C. voltage is applied to a circuit containing pure resistance (Fig. 60), the current at any instant will depend on the instantaneous e.m.f. and the value of the resistance, and may be found by applying Ohm's law as for a D.C. circuit.

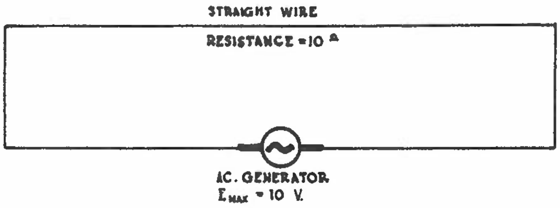


FIG. 60. ALTERNATING VOLTAGE APPLIED TO PURELY RESISTIVE CIRCUIT.

Consequently the graph of the current will be like that of the e.m.f., with maximum and minimum values of the current occuring at the same time as those of the voltage. (Fig. 61).

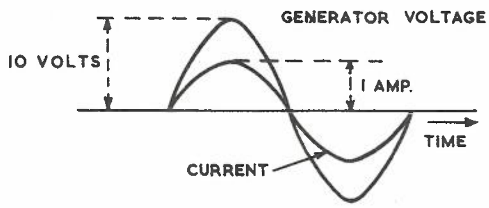


FIG. 61. VOLTAGE AND CURRENT IN FIG. 60.

The current and voltage in this case are said to be 'in phase'.

If the maximum voltage is 10V and the resistance 10Ω the maximum current will be 1A ($I = \frac{E}{R}$).

8.4 Effective value of A.C. As with D.C., the effect of the A.C. will be to heat the wire but it will be apparent that the heating in this case would not be as much as for 1A of D.C. Actually to produce the same heating effect as 1A of D.C. the A.C. would have to be increased to 1.414A max, and the A.C. voltage for the circuit above to 14.14 volts max. In other words an A.C. which reaches 1.414A max. has an effective value of 1A only, when compared with D.C.; or the effective value is $\frac{1}{1.414}$ or 0.707 of the maximum value. (This figure is for sine waves only).

Unless otherwise stated, A.C. voltages and currents are always given as the effective value, for example, 240V A.C. means 240V effective. The maximum value is 240 x 1.414 or nearly 340V. (Effective values are also called R.M.S. values).

8.5 Reactance. Resistance however, is not the only form of opposition encountered in A.C. circuits. Both coils of wire and capacitors introduce types of opposition to the flow of A.C. which is quite distinct from pure "Ohmic" resistance, and this opposition is called reactance.

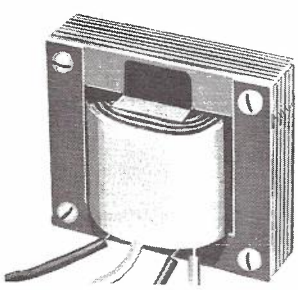


FIG. 62. INDUCTOR OR "CHOKE".

Inductive Reactance. When A.C. flows in a coil the magnetic field rises and falls with the current. In so doing however the lines of force cut the turns of the coil and an A.C. voltage is induced in it by electromagnetic induction (discussed in Section 5). This voltage opposes the applied voltage and the current which can flow in such a circuit is less than would flow if the same wire were not coiled but straight as in Fig. 60. Another effect of a coil is to make the current reach its maximum and minimum values after those of the applied voltage. (Fig. 63).

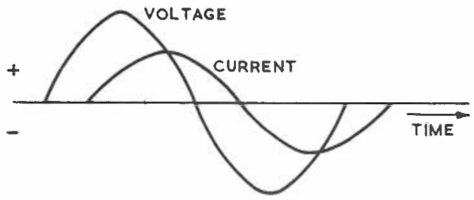


FIG. 63. CURRENT LAGS IN AN INDUCTIVE CIRCUIT.

The current is 'out of phase' with the voltage and 'lagging' it. This opposition is called inductive reactance, and coils in A.C. circuits are called chokes or inductors because they tend to choke back the current and possess the property known as inductance. (Symbol L - unit 1 henry).

The choking effect or the inductive reactance of a certain coil in a circuit depends not only on how strong a field is produced but also on the frequency of the applied A.C. If the rate of current change is doubled (twice the frequency) the choking effect or reactance is doubled. Fig. 62 shows one type of choke.

Capacitive Reactance. We have seen in Section 3 how a capacitor in a D.C. circuit may draw a current to charge it and then release the stored energy as a discharge current.

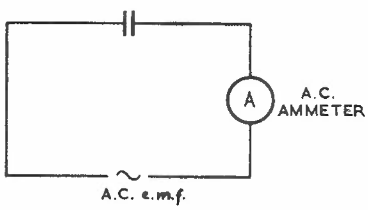


FIG. 64.

In an A.C. circuit the capacitor will charge, discharge, recharge to the opposite polarity and again discharge for each complete cycle (Fig. 64). These charge and discharge currents measured at any point in the circuit make it appear as if the capacitor conducts A.C. While this is strictly not so, it is much the same thing and capacitors are generally regarded as being able to pass a certain amount of A.C. An opposition is introduced to A.C. by a capacitor, which depends on its value (or capacity) and also on the frequency of the A.C.

If the capacity is increased the opposition (capacitive reactance) is reduced, and if the rate of change of current (or frequency) is increased the reactance is reduced. Also, capacitance in an A.C. circuit causes the current to reach its maximum and minimum values before the applied voltage. (Fig. 65).

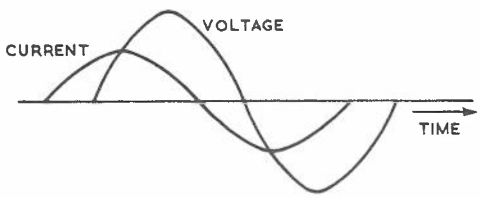


FIG. 65. CURRENT LEADS IN A CAPACITIVE CIRCUIT.

In other words the current is 'out of phase' with, and 'leading' the applied voltage.

The amount by which the current and voltage are out of phase varies with the values of inductance, capacitance, resistance and frequency for the circuit.

It will be noticed that for capacitive circuits, the out of phase effect and the effect caused by a change of frequency, are the opposite of those applying in the case of inductive circuits. Because of this, circuits which contain both inductance and capacitance exhibit special effects, one of which is electrical resonance at a particular frequency (Fig. 66). It is this phenomena which makes long line and radio communication possible.

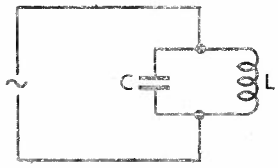


FIG. 66. A 'TUNED' CIRCUIT.
(Possesses the property of electrical resonance at one particular frequency which depends on the respective values of L and C).

Impedance. The total opposition to the flow of A.C. may be made up of a combination of two or all three of the properties of resistance, inductive reactance and capacitive reactance; this combined effect is known as the impedance and is also measured in ohms.

9. ELECTRONICS.

9.1 Under the right conditions, electrons may be made to leave the surface of a conductor and be then controlled by forces outside the conductor. The branch of technology which deals with the behaviour and uses of these 'free' electrons is known as electronics.

9.2 Thermionic emission. If a wire (sealed in an envelope from which all the air has been evacuated) is raised to red heat by means of a current through it, electrons will be emitted from the surface and will form a negatively charged 'cloud' around the conductor which is called a 'space charge'. (Fig. 67).

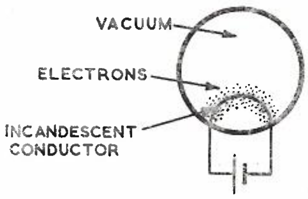


FIG. 67. SPACE CHARGE.

9.3 The Diode. If a second electrode is placed near to the first and a fairly large e.m.f. connected between the two elements so that the second element is positive to the heated element, then electrons from the cloud will flow between the elements resulting in a current in the circuit. This two-element thermionic 'vacuum tube' is called a diode, and the elements or electrodes are the cathode (emitting electrons) and the anode. (See Fig. 68).

If the e.m.f. between anode and cathode is reversed so that the anode is negative with respect to the cathode, there is no current flow since there is no positive potential to attract the negative electrons away from the cathode. Because of this property of thermionic tubes to pass current in one direction only, they are frequently called valves.

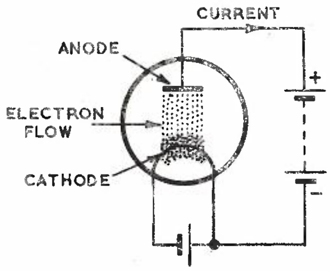


FIG. 68. PRINCIPLE OF DIODE VALVE.

This property is made use of to convert A.C. to D.C., that is, diode valves are used as rectifiers (Fig. 69).

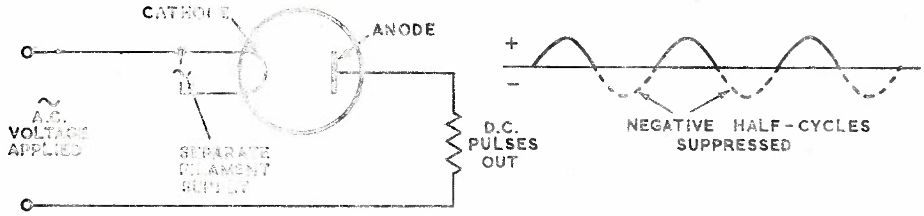


FIG. 69. BASIC VALVE RECTIFIER.

9.4 The Triode. By means of a third electrode in the form of an open mesh, it is possible to control the electron stream between anode and cathode. Very small voltage changes between this control grid and the cathode can be made to cause relatively large changes of current flowing to the anode.

FIG. 70. TRIODE SYMBOL.

The triode valve provided the first means whereby very small A.C. voltages (weak telephone speech signals for example) could be amplified in voltage and power. Triodes are still used today, but since their first development many refinements have resulted in valves with many more elements and capable of far greater degrees of amplification.

Valve envelopes are of glass or metal. The cathode is often raised to working temperature by a separate heating element; this type of cathode is represented in Fig. 70.

Diodes, triodes, tetrodes (4 element) and pentodes (5 element) all have countless applications in telecom equipment.

Besides amplification, a common use of valves is in oscillators, or generators of A.C. voltage at a particular frequency (in conjunction with resonant circuits - Fig. 66, Section 8).

9.5 Transistors. In recent years a form of diode was developed from the crystal and 'cats whisker' arrangement used in simple 'crystal' radio receivers. From this germanium diode two forms of triode were developed which, like triode valves, are capable of amplifying weak signals when connected in a suitable circuit. These devices were named transistors, and the two types are point contact transistors and junction transistors. They have no heater (that is, they are not thermionic) and operate on principles quite different from thermionic valves. Some aspects of transistors are not yet fully understood. The three connections of a transistor are the emitter, the collector and the base. Transistors are very small, (see Fig. 71), require very little power and operate on lower voltages than valves.

FIG. 71. TRANSISTOR (ACTUAL SIZE).

Compared with the versatile thermionic valves they have some limitations but are very useful where space and energy consumption are best kept to a minimum. They will be used more in the future, but it is not likely they will completely replace valves. A present application is for the amplifier in hearing-aid telephones.

10. ELECTRIC SHOCK.

10.1 Electricity can kill. Because many electrical accidents result in death it is of the utmost importance to take every safety precaution before doing work on or near electric circuits. It is equally important to memorise the directions for removing a person from a "live" wire or apparatus, and for artificial resuscitation. This is vital and may save a life. Electricity may kill if it:-

causes unnatural movements of the heart,
paralyses the breathing system,
overheats the body.

The current passing through the body, rather than the voltage contacted, is the important factor in death or shock by electricity. The value of the current depends in part on the body resistance. This may be about 500,000 ohms for a dry calloused palm, but should it become moist due to perspiration or other liquids, its resistance may decrease to a small fraction of this figure, while the passage of current will reduce resistance by causing perspiration. The average resistance value for a dry, healthy body is about 5,000 ohms.

Currents less than 1/5 of an ampere cause pain, loss of muscle control, difficult breathing and unnatural movements of the heart. 10mA directly through the heart will induce a muscular spasm of the heart called "ventricular fibrillation". In this condition the contractions of the heart are irregular, and it becomes ineffective as a pump. This causes circulation and respiration to lapse, depriving the brain and nervous system of oxygen, and will cause the heart to cease.

In some cases of electric shock, the victim becomes unconscious and stops breathing due to the nervous system controlling respiration being affected, but the heart action may continue normally.

Should respiration alone be halted for two to four minutes, the heart will begin to fail, causing the pulse to weaken, and circulation to lapse. If the circulation lapses for more than two to four minutes from any cause, the delicate brain cells are irreparably damaged. Hence, within five to eight minutes of electrical contact, such damage may be caused that the victim, even though later revived, may be permanently affected. If the damage to the nervous system is not severe, the body will resume breathing, if it has been kept alive by the supply of oxygen through artificial resuscitation. It is therefore most urgent that means of resuscitation begin immediately the victim is released from the live electrical contact.

10.2 Begin resuscitation without delay. Medical attention should be sought as soon as possible by some other person, but the rescuer should proceed immediately to attempt to revive the patient.

If more than one person is available to help, while one is performing artificial resuscitation, others can be covering the patient to retain body warmth, securing medical assistance, and controlling bystanders. Nothing must be allowed to interfere with the process of resuscitation, nor must the patient receive any stimulants by mouth until his breathing is fully restored, and he is fully conscious.

Do not be discouraged if a patient takes a long time to revive, as in some cases it has taken several hours to restore breathing. Death must not be assumed, therefore, and artificial respiration should be continued until breathing is restored, or a Doctor declares the patient dead, or if medical attention is not available, until unmistakable signs of death appear (for example, rigor mortis, or blue colour of skin).

When the patient is completely revived, test his ability to swallow with a teaspoonful of warm water, then a weak stimulant such as tea or a teaspoonful of warm brandy and water may be given. Lie him on his side, cover him up well and encourage him to sleep, but watch him carefully for some time to see that breathing does not stop.

10.3 Preliminary. Before starting any method of artificial respiration, loosen any tight clothing and sweep your fingers within the back of the patients throat to remove any obstruction. For example, false teeth may have fallen, in, or foreign matter may be trapped in the back of the throat. A smart slap between the patient's shoulder blades with the flat of the hand while the patient is held face down will help to dislodge obstructions. This should take only a few seconds. Then give six to eight quick breaths by the expired air technique. (see para 10.10).

10.4 Revival in case of heart failure. The heart may cease to be effective in either of two ways; it may cease to beat at all, or it may beat in an irregular manner known as ventricular fibrillation. In both conditions the pulse ceases, and this is accompanied by complete or partial suspension of breathing followed by asphixial gasps, pallor of the skin and loss of all reflexes. Once ventricular fibrillation commences, it is irremediable by manual methods, and must be overcome by medical treatment.

The effects of both conditions of heart failure can be circumvented by "External Cardiac Massage", a process of artificially inducing a pumping action of the heart. By this method, circulation can be maintained even though the heart has lost effectiveness, or if it has ceased to beat at all. "External Cardiac Massage" is potentially dangerous and should be attempted only by persons who have received proper training. Training should never be performed on live patients because of the possibility of injury. Lifelike models fitted with means of gauging the pressure applied are available for training purposes.

10.5 The heart is in the centre of the chest cavity between the breastbone and the spine. When pressure is applied to the lower half of the breastbone, as if to compress the chest cavity, the heart is compressed, and blood is forced into the arteries. When the pressure is released, the breastbone springs back into place, relieving the compression, allowing blood to flow from the veins to the heart. Valves within the heart automatically prevent the passage of blood in the wrong direction. If performed at regular intervals this produces an artificial pulse in the arteries, and circulates blood throughout the body. Unfortunately, this process is potentially dangerous, as too much pressure, or an application of pressure too low down the breastbone towards the abdomen, could fracture ribs, pierce the liver or lungs, or compress the stomach. Anyone intending to use external cardiac massage should strictly observe these points:-

(i) Place the patient on his back on a firm surface.

(ii) Skilfully assess whether there is a normal heart beat or not, by locating a carotid artery pulse on one side or the other of the adam's apple, in the groove ahead of the neck muscle.

(iii) Accurately locate the correct application of the hands on the chest, with the heels of the palms on the breastbone, halfway from the base of the throat to the lower end of the breastbone.

(iv) Carefully regulate the pressure applied so that the breastbone is depressed no more than half an inch in an infant, one inch in a child, and two inches in an adult.

Sufficient pressure will be applied with only the fingers of one hand if the victim is an infant, one hand alone if the victim is a child, and one hand directly above the other (fingers superimposed) in the case of an adult victim, taking care in each case that the point of application of pressure is correctly located.

10.6 The rate of application of pressure should be sixty compressions per minute. If two rescuers are available, the compression of the chest should be timed to correspond with the expiration of air after the chest has been inflated by the expired air technique of rescue breathing, at the rate of ten breaths per minute, with six chest compressions after each breath.

If a rescuer is working alone, one breath must be given followed by six timed chest compressions so that the victim will receive nine breaths and fifty to sixty chest compressions per minute.

10.7 Artificial Respiration. A continuous supply of oxygen is needed to sustain life, and this can only be supplied via the respiratory system. Should the respiratory system fail, even though, at the time, the heart continues its normal function, the lack of oxygen in the system will soon cause the heart action to cease. It is therefore most necessary that oxygen be supplied to a victim of respiratory failure immediately he is released from the electric supply in the case of electric shock, or brought to safety from any other circumstance which could have caused the failure of his breathing.

10.8 Failure of the respiratory system may be caused by electric shock, airway obstruction by foreign material, suffocation, drowning, or the taking of poisons. Respiratory failure not only causes a lack of oxygen to the system, but also causes an accumulation of Carbon Dioxide as this deadly gas is not exhaled. Therefore the system of artificial respiration besides forcing oxygen into the victims lungs must also allow exhalation of the carbon dioxide produced.

10.9 The signs of a lack of oxygen are: a rapid pulse rate, bloated face, blue discoloration of the lips. The victim may be making vigorous efforts to breathe, and may struggle in his fight for oxygen. The victim will ultimately become unconscious, and less than four minutes of unconsciousness will cause the heart to begin to fail. The rescuer must get oxygen into the lungs as quickly as possible by artificial respiration and if carried out before four minutes have elapsed with the victim in an unconscious state, and maintained until normal breathing is recovered, the heart will not fail.

10.10 The expired air techniques are superior to other manual methods of artificial respiration and their simplicity and ease of application make them particularly suitable.

Expired Air resuscitation consists of direct inflation of the lungs by the rescuer blowing into the victim's nose (Mouth-to-Nose method) or his mouth (Mouth-to-Mouth method). The process is rather like inflating a balloon (the lungs of the victim) by a single breath. When the rescuer stops blowing and withdraws his mouth, the air is automatically exhaled from the victim's lungs. The cycle of inflation and deflation of the lungs is repeated until the victim commences to breathe naturally.

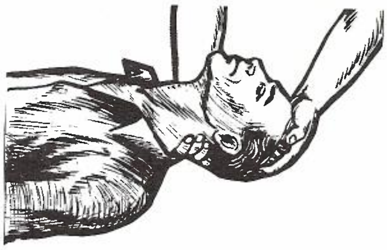
The mouth-to-nose and mouth-to-mouth methods are equally effective. External circumstances such as blockage of the victim's nasal passage, tightly clenched jaw or injury to either his nose or mouth may determine which of the two methods should be used. If one method fails, the other should always be attempted.

10.11 Method of applying artificial respiration.

Place the victim on his back, face up.

Clear any foreign matter from his mouth by turning his head to one side, forcing his mouth open and quickly wiping his mouth and throat clean with your fingers or a piece of cloth.

Where a pad of clothing or similar material is immediately to hand place it under his shoulders (clear of the neck) to raise them a few inches above the ground. With one hand, lift the back of the victim's neck to allow his head to fall as far back as possible, and pull the point of the chin fully upward with the other. This gives a clear air passageway to the lungs.



(i) Mouth-to-Nose method. Lie or kneel to one side of the victim's head so that you are looking downward into his nostrils.

With your hands, continuously maintain maximum extension and backward tilt of the victim's head and hold his mouth closed.

Open your mouth widely and place it around both of his nostrils and well on to the nose, reaching the bony part of the nose. (For infants cover both nose and mouth).

Take care not to press more on one side of the nose than the other (or that side of his nose may become blocked while the other side is possibly blocked already). See that you make a good seal with your mouth.

Press your cheek against his mouth to seal it but make sure you don't 'lose' head-tilt by pressure against his mouth.

Take a deep breath and blow steadily into his nose.

Do not blow with a jerk but steadily as inflating a balloon. Blow forcefully for adults, gently for children and very light puffs only for infants.

Watch the victim's chest as you blow. If you cannot see his chest shift your hand momentarily from his jaw to his chest to feel its expansion.

When his chest rises take your mouth away to let him breathe out naturally. Open the mouth to assist exhalation. Listen to the air being exhaled. When the flow of air stops, blow in the next breath.

Make the first ten breaths deep and at a rapid rate (but without jerking your breath into the patient) to give a good quick supply of life giving oxygen.

Then determine the rate of breathing by the time taken to inflate and deflate the lungs. This varies from 12 breaths per minute for a large adult to 20 breaths for a small child.

The respiratory cycle should last five seconds, two for inflation and three for exhalation. During the first few minutes of resuscitation the cycle should be shorter, one second for inflation and two for exhalation.

(ii) Mouth-to-Mouth method. Use this method if you cannot get air into the victim's lungs by blowing through his nose.

While holding his head back with your hands, separate his lips with your thumb, and lift the jaw upwards. Open your mouth widely and place it tightly over his mouth.

Press your cheek against his nostrils to prevent air leakage.

Blow in steadily to inflate his lungs as described for mouth-to-nose breathing.

If the lungs cannot be inflated draw the tongue further forward to clear the air passageway. Insert your thumb between his teeth and pull his lower jaw forward so that the lower teeth are in front of the upper teeth.

If you have difficulty in sealing his nose with your cheek, pinch his nostrils closed between your fingers and thumb.

In applying either method, blow steadily until you see the victim's chest expand. Don't force more air into the patient than is required to fully inflate his lungs as it serves no useful purpose and can be harmful in the case of children:

If the patient's chest does not rise, increase the backward head tilt, hold the lower jaw upward and blow again. If still unsuccessful, look for and remove any foreign matter present.

The rescuer can induce in himself a feeling of dizziness by excessive deep breathing, and this may interrupt the rescue attempts. This is not normally a serious possibility, but the rescuer should be aware of the problem, and if it does occur he may lie and rest before continuing resuscitation.

Operators may readily be changed in the case of fatigue or dizziness by the relief operator kneeling at the opposite side of the patient, and taking over at the interval of the patient's exhalation.

If the resuscitation attempt is being successful there will be a return of the pulse, colour will improve, and the pupils of the eyes will become smaller.

Always send for a doctor as soon as possible, but do not let this interfere with the commencement or continuation of artificial respiration.

END OF PART 1.

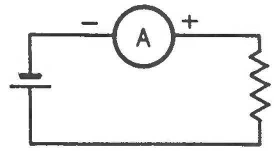
ADDENDUM TO CP 005

INTRODUCTION TO TELECOM. ENGINEERING, PART 1 - BASIC THEORY

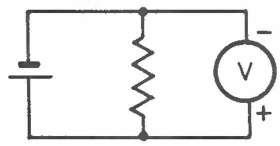
11. MEASUREMENTS IN ELECTRIC CIRCUITS.

11.1 Meters are used to measure current, voltage and resistance in D.C. and A.C. circuits. The moving coil type of movement is commonly used in telecommunications measurements and can be adapted for use as an ammeter, a voltmeter or an ohmmeter. An instrument which combines the functions of the ammeter, voltmeter and ohmmeter, is known as a multimeter.

11.2 An Ammeter measures current and is connected in series with the section of the circuit in which it is desired to measure the current. In a D.C. circuit, it is important to connect the ammeter in the correct polarity, that is, the positive of the meter to the positive side of the circuit and negative to negative, otherwise damage to the moving coil can occur. The ammeter in the D.C. circuit shown is connected in series and with correct polarities. The polarity signs are part of the symbol for the D.C. ammeter. They are omitted for an A.C. ammeter as polarity is not considered in an A.C. circuit.



11.3 A Voltmeter measures voltage and is connected in parallel with the section of the circuit where it is desired to measure the voltage. As with the ammeter, it is important in a D.C. circuit to connect with correct polarity, otherwise damage can occur. The voltmeter in the D.C. circuit shown is connected in parallel and with correct polarities. The polarity signs are part of the symbol for the D.C. voltmeter but are omitted in the A.C. voltmeter.



11.4 An Ohmmeter measures resistance and, to avoid damage or errors, must never be used in an energised circuit. When using an ohmmeter, a preliminary adjustment is necessary for calibration; the connection to the meter must be short circuited and the variable resistor (usually built into the meter case) adjusted until the needle shows full scale deflection (F.S.D.). The ohmmeter is then connected to the component to be measured and resistance can be read directly from the scale.

11.5 A Multimeter combines the functions of the ammeter, voltmeter, and ohmmeter, the required function usually being chosen by means of a switch. The standard multimeter is the A.P.O. No. 3, which, in addition to having special provision for testing dry cells, can be used for measurements over the following ranges.

CURRENT (D.C.)	0-1mA;	0-10mA;	0-100mA;	0-1A;	0-10A.	
VOLTAGE (D.C.)	0-3V;	0-10V;	0-30V;	0-100V;	0-300V;	0-1000V.
CURRENT (A.C.)	0-1mA;	0-10mA;	0-100mA;	0-1A;	0-10A.	
VOLTAGE (A.C.)	0-10V;	0-30V;	0-100V;	0-300V;	0-1000V.	
RESISTANCE	From approximately 1 ohm to 1 megohm in four ranges.					

An A.P.O. No. 3 multimeter is shown in Fig. 72a. A study of the face layout reveals:

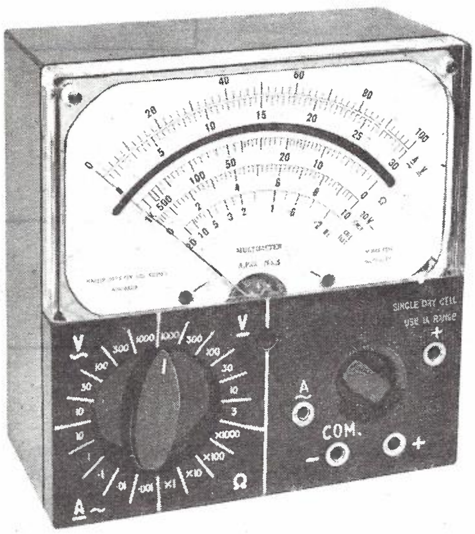
- the scale and pointer.
- the 20 position range or function switch.
- the variable resistor for calibrating the ohmmeter.
- the test jacks for connection of test leads.

11.6 Scales. In Fig. 72b the scales are shown in more detail. The two top scales are used for D.C. and A.C. current and voltage measurements, according to the position of the range switch. For example, with the switch on the 100mA range (A.C. or D.C.), the top scale is used. Each small division equals 2mA and with the pointer (represented by the straight line) in the position shown, the current is 72mA.

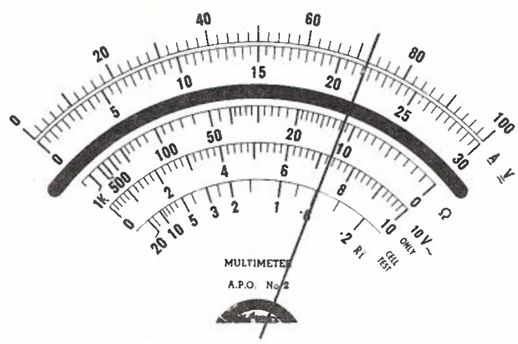
With the switch on the 300V range, the lower scale is the more suitable. Each small division equals 5V and the pointer indicates a voltage of 217V.

Below the heavy black line (which is a mirror included to obtain more accurate readings) is the ohms scale. This scale is different in that the zero mark is on the right. With the range switch on "ohms × 1", the pointer indicates a resistance of 11.6Ω; on "ohms × 10", the pointer indicates a resistance of 116Ω.

Beneath the ohms scale is a special scale for the 10V A.C. position of the switch. The bottom scale is used in conjunction with the testing of dry cells.



(a) Instrument



(b) Scale

FIG. 72. MULTIMETER A.P.O. NO. 3.

11.7 Precautions. The following precautions should be observed when using meters.

1. Connect ammeters in series.

2. Connect voltmeters in parallel.

3. Take first current or voltage reading with meter switched to the highest range and reduce ranges as required.

4. Do not use ohmmeter in energised circuits; calibrate before using.

5. When storing meter after use, switch to the highest voltage range.

12. RESISTOR COLOUR CODE.

12.1 Some types of resistors are marked with coloured bands painted on the body of the resistor as shown in Fig. 73. The colours can be translated into figures which indicate the resistance in ohms and the tolerance, that is, the percentage variation above or below the stated value.

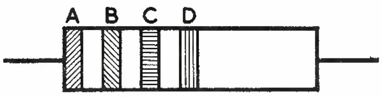


FIG. 73. RESISTOR MARKINGS.

Band A - Indicates first figure of resistance.

Band B - Indicates second figure of resistance.

Band C - Indicates the decimal multiplier.

Band D - Indicates the tolerance limits (if used).

12.2 SIGNIFICANCE OF COLOURS. The range of colours used, and their significance is outlined in Table 1.

Colours	Figure	Decimal Multiplier	Tolerance %	Colours	Figure	Decimal Multiplier	Tolerance %
Black	0	1	-	Violet	7	10^7	-
Brown	1	10	-	Gray	8	10^8	-
Red	2	10^2	-	White	9	10^9	-
Orange	3	10^3	-	Gold	-	10^{-1}	± 5
Yellow	4	10^4	-	Silver	-	10^{-2}	± 10
Green	5	10^5	-	No colour	-	-	± 20
Blue	6	10^6	-				

TABLE 1. RESISTOR COLOUR CODE.

EXAMPLES OF THE RESISTOR COLOUR CODE. Examples of the use of the resistor colour code are shown in Table 2.

BAND A.	BAND B.	BAND C.	BAND D.	RESISTANCE VALUE	
Blue	Grey	Green	Silver	6.8MΩ	$\pm 10\%$
Red	Violet	Yellow	-	270kΩ	$\pm 20\%$
Green	Brown	Orange	Gold	51kΩ	$\pm 5\%$
Orange	Orange	Red	Silver	3.3kΩ	$\pm 10\%$
Brown	Black	Brown	Gold	100Ω	$\pm 5\%$
Red	Red	Gold	-	2.2Ω	$\pm 20\%$
Yellow	Voilet	Silver	Gold	.47Ω	$\pm 5\%$

TABLE 2. EXAMPLES OF RESISTOR COLOUR CODE.

END.