COURSE OF TECHNICAL INSTRUCTION

APPLIED ELECTRICITY 1

Engineering Training Section, Headquarters, Postmaster-General's Department, Melbourne C.1

THE AUSTRALIAN POST OFFICE
COURSE OF TECHNICAL INSTRUCTION

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

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ELECTRON THEORY

Page

1. INTRODUCTION.

1.1 How to understand the operation of Telecom Equipment. The study of telecom equipment requires a practical knowledge of electricity and magnetism. There are many applications in our everyday life, for example, -

(i) electricity lights lamps, heats electric radiators, stoves and irons, and operates the radio, vacuum cleaner, refrigerator, washing machine, etc.;

(ii) a magnetic compass shows us the directions of north and south.

But do we know how and why these things happen? As telecom technicians, we must learn and understand how electricity and magnetism make telecom equipment work, so that we can install and maintain the equipment.

The exact nature of electricity and magnetism is still uncertain but their effects can be observed and, from these observations certain rules and laws have been made. These simplify the application of electricity and magnetism to our telecom studies, and are explained in this course.

In some applications of electricity and magnetism, we can see or hear action taking place; in other cases, however, we cannot. Many items of telecom apparatus look exactly the same whether working or not. In these cases, we must learn to form mental pictures of what is happening even though we cannot see it. As we proceed, certain theories are explained. These theories are merely word expressions of mental pictures to help us imagine what is happening in telecom apparatus.

As a further help, a comparison is often made with something with which we are more familiar. This comparison is an analogy. For example, electricity is often compared with a flow of water. This water analogy does not represent exactly the real nature of electricity, but it does help us understand its behaviour.

1.2 This Paper gives a general idea of the modern theory of electricity called the electron theory. To help us understand this theory, we first review the nature of matter. The theory of magnetism is covered later.

2. THE MAKE-UP OF MATTER.

2.1 Matter is anything that has mass and occupies space. All matter exists in the form of a solid, liquid or gas.

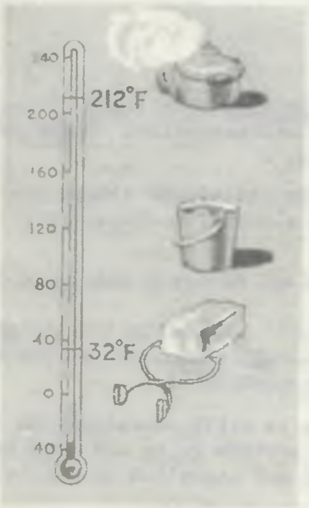
Solids have a definite shape and size (or volume). A solid resists any force that tends to change its shape or size.

Liquids have a definite volume but no definite shape. A liquid takes the shape of any container into which it is poured.

Gases have neither definite shape nor volume. Like a liquid, a gas takes the shape of the containing vessel; and, in addition, it can adapt its volume to completely fill the containing vessel.

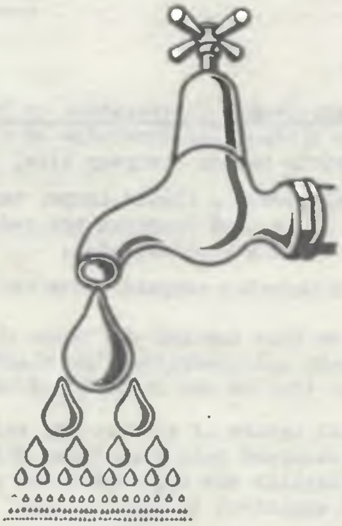
Liquids and gases are known as fluids.

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.)



WATER EXISTS IN THREE FORMS.

FIG. 1.



SUB-DIVIDING A DROP OF WATER.

FIG. 2.

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

For example, if we could sub-divide 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 sub-division would cause it to lose the characteristics of water. This last particle is a molecule of water.

All matter, therefore, 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.

2.3 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.

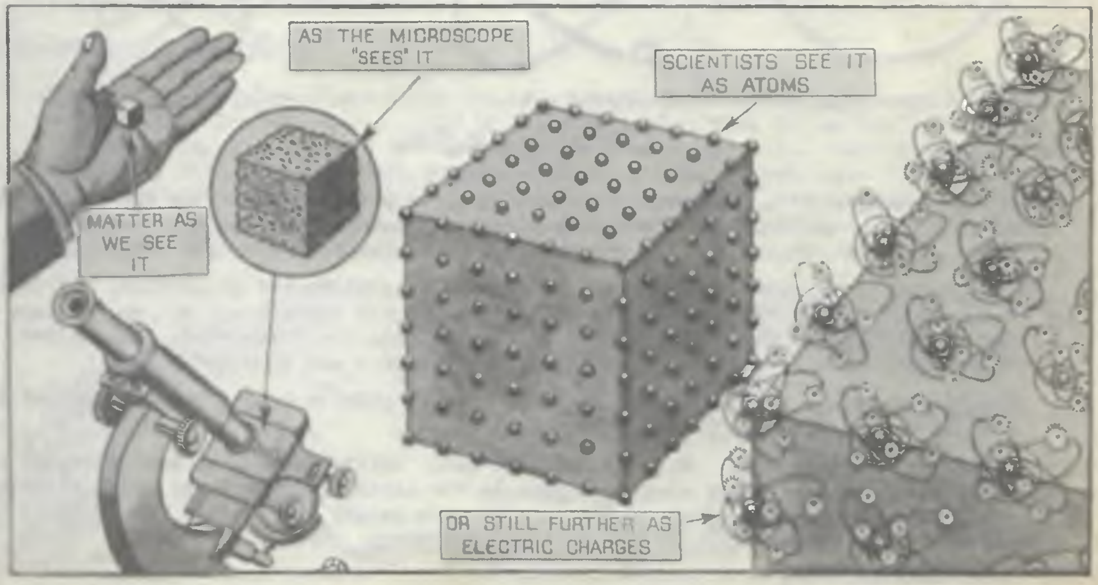


FIG. 3. ALL MATTER IS MADE UP OF ATOMS.

3. WITHIN THE ATOM.

3.1 Protons and electrons. 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.

PLANETS IN THE SOLAR SYSTEM.

FIG. 4.

3.2 Atomic Structure. 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.

PICTURE MODELS OF ATOMS.
FIG. 5.

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.

3.3 Free and Bound Electrons. 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.

4. ELECTRIC CHARGES IN THE ATOM.

4.1 Positive and Negative Charges. In some forms of matter, the fundamental 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.

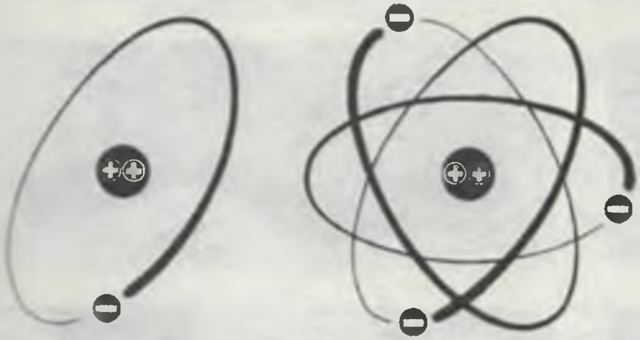
4.2 Ionisation. The normal atom has equal numbers of protons and electrons. The electrical effect of the positive protons is neutralised by the associated negative electrons; and the atom as a whole exhibits no resultant electric charge.

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 Fig. 6 for a helium atom.



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

FIG. 6. IONISATION OF HELIUM ATOM.

4.3 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.

5. STATIC ELECTRIC CHARGES.

5.1 Charging by Friction. Electricity was first produced by friction. About the year 600 B.C. the Ancient Greeks found that amber, rubbed with fur or wool, attracted pieces of dry leaves, hair and thread, etc. About 1600 A.D., other substances such as glass, ebony, sealing-wax, resin and sulphur, when rubbed, were found to attract small particles. This effect was called electrification, and the substances were said to be electrified, from the Greek word "Elektron", meaning amber. From this the word Electricity was subsequently derived.

The electricity of charged substances produced by friction is called static electricity; it is at rest (or static) in the form of a charge on the substance.

5.2 We can produce static electricity and observe the force of electric attraction by a simple experiment -

Rub the end of a vulcanite fountain pen or hair-comb (not a metal one) on your coat sleeve, and bring it down gradually over some small pieces of paper. When it is a short distance away, the paper jumps and clings to it. (Fig. 7.)

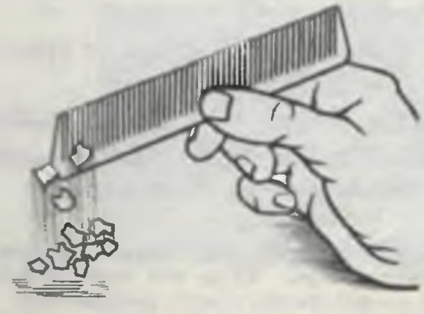
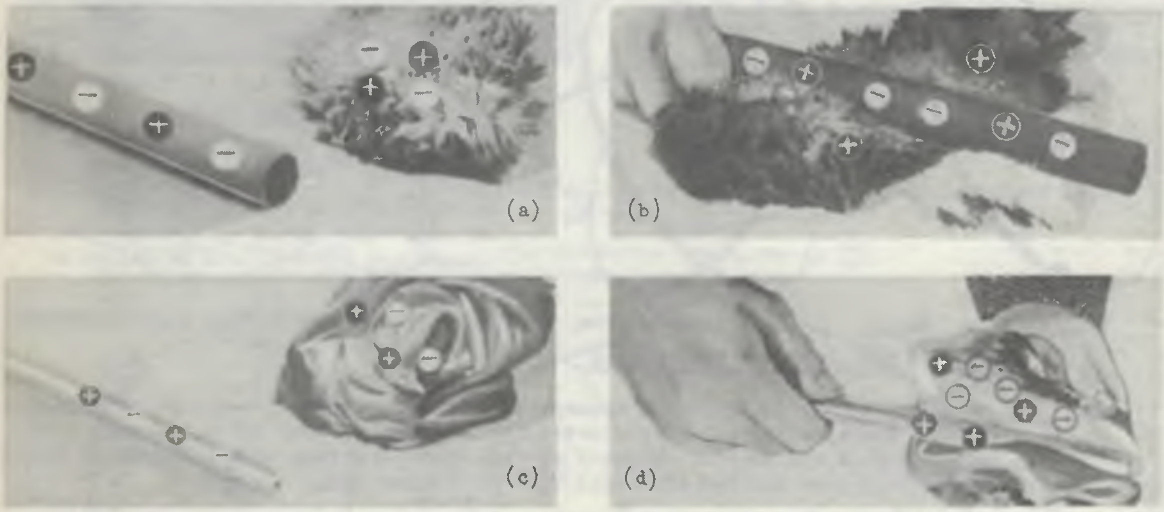


FIG. 7. ELECTRIC FORCE OF ATTRACTION.

This effect is produced in many other substances. For example, when an ebonite rod is rubbed with fur or wool, it attracts small pieces of paper; similar results are seen when a glass rod is rubbed with silk.

5.3 Why does friction produce static electricity? When we rub any two different substances together, electrons may be forced out of their orbits in one substance and captured in the other. The substance which gives up electrons more freely is left with a positive charge; the substance which captures these electrons has a negative charge.

For example, in Fig. 8a, the fur and the ebonite rod are normally uncharged because the protons and the electrons are present in equal quantities. But when rubbed together, the fur loses some electrons to the rod. The fur acquires a positive charge; the ebonite rod, a negative charge (Fig. 8b). Similarly, a glass rod and a silk cloth are normally uncharged (Fig. 8c). But when rubbed together, the glass rod loses some electrons to the silk. The glass rod acquires a positive charge; the silk, a negative charge (Fig. 8d).



STATIC CHARGES ARE PRODUCED BY FRICTION.

FIG. 8.

The degree and type of electrification depends on the substances used; some substances can be charged more readily than others, sometimes they can be charged positively, sometimes negatively.

As a result of experiments, substances can be arranged in a list, so that any one has a positive charge when rubbed by a substance which follows it; and a negative charge when rubbed by any substance which precedes it. Some common items are:-

(+) fur, flannel, ivory, glass, cotton, paper, silk, wood, metals,
rubber, sealing-wax, resin, ebonite, amber, sulphur (-).

5.4 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.

5.5 Law of Electric Charges. It can be proved by experiment that protons and electrons (and their combinations, positive and negative ions) obey the following law:-

Like charges repel; unlike charges attract.

When two similarly charged substances (either both positive or both negative), which are free to move, are brought close together, the force of repulsion between the electric charges causes the substances to repel each other. (Fig. 9a.) But when one substance is positive and the other negative, they tend to attract. (Fig. 9b.)

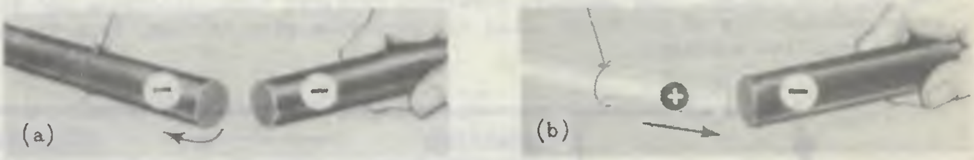


FIG. 9. LIKE CHARGES REPEL. UNLIKE CHARGES ATTRACT.

The force (F) of attraction or repulsion between two charged substances is directly proportional to the product of the individual charges (Q_1 and Q_2), and inversely proportional to the square of the distance (d) between them.

Expressed mathematically: $F \propto \frac{Q_1 \times Q_2}{d^2}$. (Note: $\propto$ signifies "varies as".)

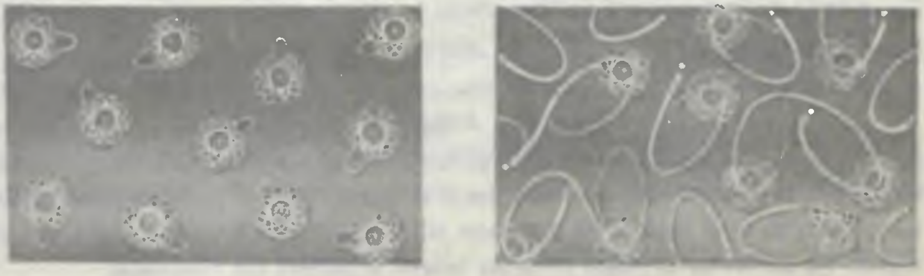
When the charged substances touch, the excess electrons of the negative charge are attracted to and enter the positively charged substance. The charges tend to neutralise and both substances are then at the same potential.

6. FLOW OF ELECTRIC CHARGES.

6.1 Atomic Structure of Insulators and Conductors. When most non-metallic substances are charged by friction, the electric charges are produced only on the portion of the surfaces which are rubbed together. But when metallic substances are charged, the charge spreads throughout the whole of the substance. This gives 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. 10a.) 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. 10b.) 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. 10. ATOMIC STRUCTURES.

6.2 Electron Flow between charged substances. When a P.D. exists between two charged conductors separated by an insulator, for example, dry air, the substances are insulated from one another, and they will retain their charges for a long period of time. But when connected by a conductor, for example, a length of copper wire, the negative charges are conducted along the wire until both substances are at the same potential. (Fig. 11.)

The negative substance repels the free electrons in the adjacent copper atoms; the positive substance attracts free electrons from atoms of the copper wire. The free electrons in the conductor move toward the positive substance, where they neutralise the positive charge. The negative substance replaces these electrons and the result is an ordered flow of electrons along the wire from atom to atom, from the negative to the positive substance.

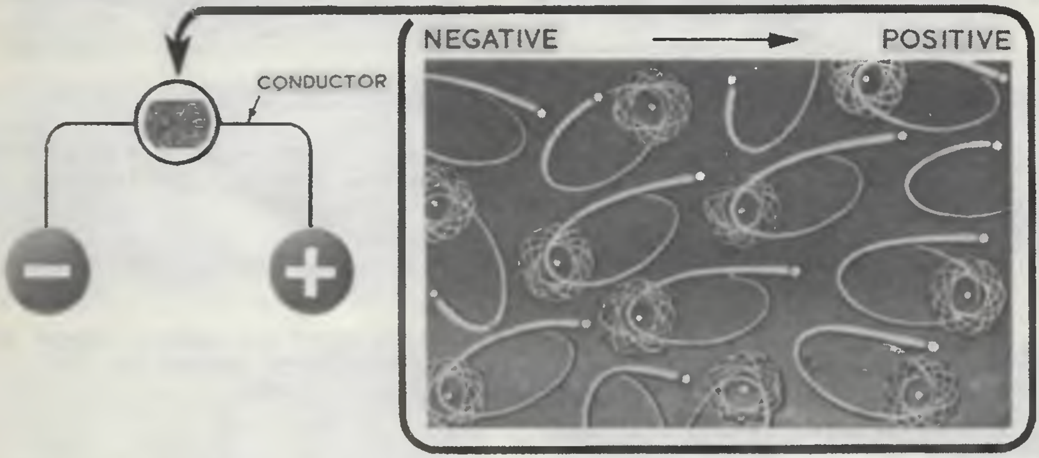


FIG. 11. ELECTRON FLOW IN A CONDUCTOR.

7. TEST QUESTIONS.

1. What is matter? In how many forms does it exist? Give an example of each of these forms.
2. Substances made up of only one type of atom are called ....
3. What is the smallest part of a chemical compound? ....
4. There are about .... different types of atoms.
5. The fundamental particles of an atom are (1) .... (2) .... (3) ....
6. The central part of an atom is called ....
7. The particles which exist at the atoms centre are (1) .... (2) ....
8. Which particle of an atom is considered to move? This particle possesses a .... charge.
9. The particle which possesses a positive charge is called ....
10. A normal atom possesses a ....charge.
11. An ion is an atom with ....of electrons. A positive ion possesses ....of electrons; A negative ion possesses...................of electrons.
12. A.............. charge is formed on ebonite when rubbed with fur. Has the fur gained or lost elect
13. What effect is produced when two substances with like charges are placed near one another?
14. What is said to exist between two substances which have different degrees of electric charge?
15. What is the difference in atomic structure between conductors and insulators?

END OF PAPER.

THE AUSTRALIAN POST OFFICE

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CURRENT ELECTRICITY.

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1. E.M.F. CAUSES CURRENT FLOW.

1.1 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.

1.2 The force necessary to produce the electron movement is termed an electron moving force, or, more correctly, electromotive force, abbreviated to e.m.f.

1.3 This type of electricity is called current electricity (or dynamic electricity) which means electricity in motion. It is used in telecom to operate telephone, telegraph and radio apparatus, and to provide light, heat and power for home and industry.

2. SOURCES OF E.M.F.

2.1 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.

2.2 Friction. Although a charge produced on a substance by friction is termed static, or electricity at rest, it is 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. 1) 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 strain and breaks down. The air between the clouds then becomes a conductor and a long spark discharge, which we call lightning, occurs between the clouds to neutralise the static charges. A lightning discharge can also occur between clouds and the earth.

LIGHTNING - THE RESULT OF STATIC CHARGES.

FIG. 1.

2.3 Chemical Action. In telecom, electric cells and batteries (Fig. 2a) 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.

2.4 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. 2b), and is the most common method of producing electricity.

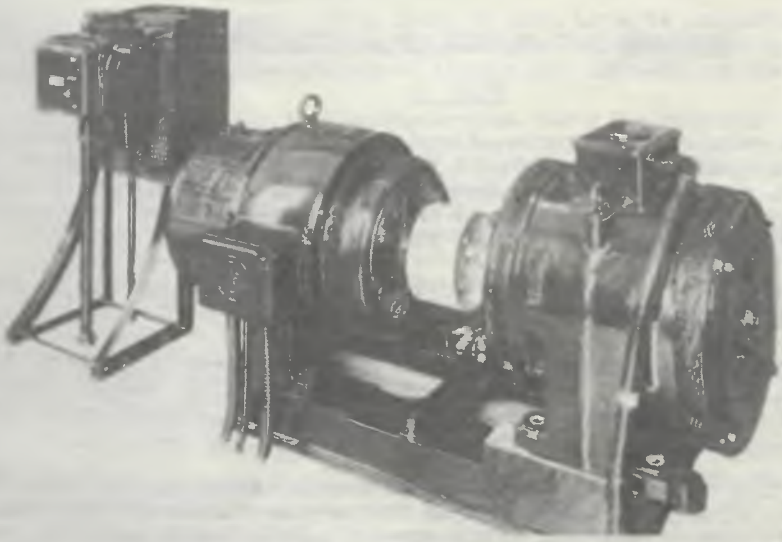
2.5 Heat. When the junction of two dissimilar metals is heated, electric charges are produced Such a device is called a thermocouple.

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

2.7 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 pick-ups in radiograms.

2.8 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.

(a) Battery and Cell.



(b) Electric Generator.

SOURCES OF E.M.F.

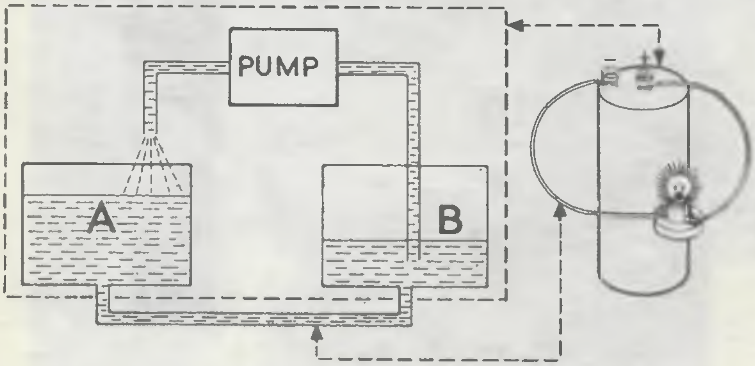
FIG. 2.

3. ELECTRIC CURRENT.

3.1 Water Analogy. The term "electric current" suggests a comparison with the flow of water in a pipe.

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. 3, 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.



COMPARING FLOW OF WATER AND ELECTRIC CURRENT.

FIG. 3.

With both water and electricity, therefore, we 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. 3, 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.

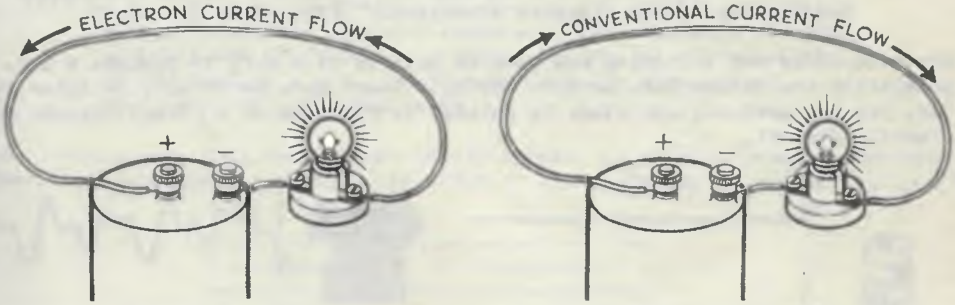
3.2 Direction of Current. The electron theory explains an electric current in a solid conductor as a flow of electrons from the negative to the positive terminal of the source of e.m.f., that is, from NEGATIVE to POSITIVE. This is called the Electron Current flow.

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.

What direction should we consider the electric current for our study?

For this stage of our study 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. 4 will light irrespective of what direction we consider the current to be moving.



(a) Negative to Positive. (b) Positive to Negative.

RESULTS ARE INDEPENDENT OF ASSUMED CURRENT DIRECTION.

FIG. 4.

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.

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 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. (Physiological effect). 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.

We will consider these effects in more detail in later Papers.

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

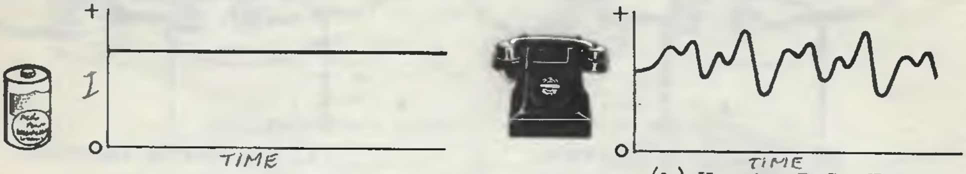
(i) Direct Current (D.C.), a "unidirectional" current which flows through the conductor in one direction only, and maintains a steady rate of flow. (Fig. 5a).

(ii) Varying Current, a form of D.C. which varies in value from instant to instant. (Fig. 5b).

(iii) Pulsating Current which is also unidirectional, but flows in pulses, having complete breaks when no current flows. (Fig. 5c).

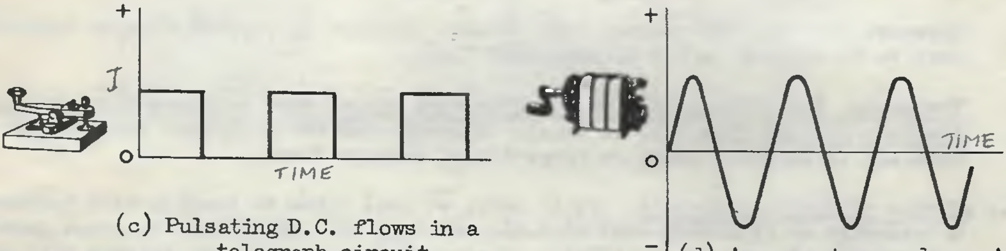
(iv) Alternating Current (A.C.) which regularly alters its direction of flow in a conductor, first flowing in one direction, then reversing and flowing in the opposite direction. (Fig. 5d).

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. We will learn more about A.C. in later Papers; but, for the present, our study is related to the flow of a direct current in the electric circuit.



(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.

TYPES OF ELECTRIC CURRENT.

FIG. 5.

4. RESISTANCE OPPOSES CURRENT FLOW.

4.1 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.

4.2 Conductance is the property of a substance to conduct an electric current; it is the opposite (or reciprocal) of resistance. When the resistance is considered as the difficulty with which an electric current is forced through a material, conductance is the ease with which it flows.

CONDUCTORS AND INSULATORS.

5.1 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. Summarising, -

(i) A conductor is a substance in which electrons can flow readily with the application of a small e.m.f. Good conductors have a low resistance or high conductance.

(ii) An insulator is a substance which does not readily conduct an electric current, unless a large e.m.f. is applied. Whether an insulator insulates or conducts depends on the magnitude of the applied e.m.f. Insulators normally have a high resistance or low conductance.

5.2 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	Gutta-percha
Tin	Sealing-Wax
Lead	Silk
Mercury	Wool
Carbon	Porcelain
Acids	
Metallic Salts	

TABLE 1.

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.

5.3 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.

5.4 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.

5.5 Also, the human body is a conductor, mainly because of the liquids in it; for example, 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.

6. UNITS OF ELECTRICITY.

6.1 Why we need electrical units. In the study of electricity we often have to measure and compare currents of different values, different e.m.f's of batteries and generators, different amounts of opposing 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. Throughout this Course other electrical units are described and a summary is given in the Tables at the end of this book.

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

6.2 The unit of electric charges is the Coulomb. When working with electric charges either at rest (static electricity) or in motion as current flow (current electricity), a unit is needed to measure the amount of electric charge.

The electron is the basic unit, but its charge is very small.

A more practical unit is the coulomb, which is approximately 629×10^{16} electrons; six trillion electrons, in round figures.

The abbreviation for coulomb is C.

The coulomb measures the quantity of electric charge (or number of electrons) regardless of whether the charge is at rest or moving.

6.3 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 basic unit used to measure rate of electric current flow is the ampere. One ampere of current flows when one coulomb of electricity passes in a conductor in one second; two amperes when two coulombs pass per second; five amperes when fifteen coulombs pass in three seconds, etc. Therefore, -

$$I = \frac{Q}{t}$$

where

I = current in amperes;

Q = quantity of electricity in coulombs;

t = time in seconds.

The abbreviation for ampere is A.

In telecom, currents seldom 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 -

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

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

REMEMBER: It is important to remember that the coulomb is a measure of quantity and represents the number of electrons in a charge. The ampere is a measure of the rate at which electrons are moving in a conductor.

For example, if the current in a conductor is said to be 5 amperes, it is a convenient way of expressing that 5 coulombs of electricity pass any and every point in the conductor in each second.

(A current flow of one ampere can also be measured and related to its chemical effect. This will be considered in the paper, Primary and Secondary Cells.)

6.4 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 -

(i) the kilovolt (kV) equal to one thousand volts;
(ii) the millivolt (mV) equal to one thousandth of a volt;
(iii) the microvolt (μV) equal to one millionth of a volt.

6.5 Difference between Electromotive Force and Potential Difference. Although e.m.f. and P.D. are measured in volts, the terms are not always interchangeable, and are often incorrectly used.

The term e.m.f. always refers to the electrical pressure generated within a device or source of energy. In practice it is measured at the terminals of a cell or generator when current is not flowing.

As P.D. is a term used to compare the electrical condition between two points, it is also correct to use the term P.D. with respect to the voltage existing between the terminals in the above example.

However, when an e.m.f. is applied to a conductor a current flows, and as we shall see later, a voltage exists between any two points of the conductor as a result of this current. As this voltage is not generated from a source of energy within the conductor the term e.m.f. cannot be used. The term P.D. must be used.

Briefly, an e.m.f. can always be expressed as a P.D., but a P.D. due to current flow cannot be expressed as an e.m.f.

6.6 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 uniform column of pure mercury 106.3 cm. long, weighing 14.4521 grammes. This corresponds to a cross-sectional area of 1 sq. millimetre.)

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

Other units in common use are -

(i) the megohm (MΩ) equal to one million ohms;
(ii) the kilohm (kΩ) equal to one thousand ohms;
(iii) the microhm (μΩ) equal to one millionth of an ohm.

6.7 The unit of conductance is the Mho, which is simply the term ohm spelt backwards.

Another unit used to measure the conductance of high values of resistance, is -

(i) the micromho (abbreviated μmho) equal to one millionth of a mho, and equivalent to a resistance of 1MΩ.

6.8 Conversion of Units. When working with electrical units, we often use the multiple or submultiple expressions of the unit.

Multiple Units use a prefix -

mega - (M) meaning "one million times", or 10^6;

kilo - (k) meaning "one thousand times", or 10^3.

Submultiple units use a prefix -

milli - (m) meaning "one thousandth of", or $\frac{1}{10^3}$;

micro - (μ) meaning "one millionth of", or $\frac{1}{10^6}$.

Sometimes, these units are shortened, for example, "mega" becomes "meg", as in megohm.

Often, conversions have to be made between these, and for ease of understanding, the following rules will assist -

(i) To change to a smaller unit, multiply by the ratio between the units.

(ii) To change to a larger unit, divide by the ratio between the units.

Therefore -

To change amperes to milliamperes, multiply by 1,000.

To change microhms to ohms, divide by 10^6.

Examples -

(i) Change 45 milliamperes to amperes	45 mA = $\frac{45}{1000}$A = 0.045A
(ii) Change 0.00012 ampere to microamperes	0.00012A = 0.00012 × 10^6 μA = 120 μA
(iii) Change 0.0015 millivolts to microvolts	0.0015 mV = 0.0015 ×1,000μV = 1.5μV
(iv) Change 6,600 volts to kilovolts	6,600V = $\frac{6600}{1000}$ kV = 6.6 kV
(v) Change 0.25 megohm to ohms	0.25 MΩ = 0.25 × 10^6 Ω = 250,000 Ω

The relation between the conductance G (in mhos) and the resistance R (in ohms) is -

$$G = \frac{1}{R}, \quad \text{or} \quad R = \frac{1}{G}.$$

Thus, a circuit with a resistance of 20 ohms has a conductance of $\frac{1}{20}$ mho = 0.05 mho: and a circuit with a conductance of 0.1 mho has a resistance of $\frac{1}{0.1}$ ohms = 10 ohms.

6.9 Summary of Units.

A coulomb is the quantity of electricity passing through a material in one second, when the rate of current flow is one ampere, and is equal to a charge of 629×10^{16} electrons.

An ampere is the current which flows when an e.m.f. of one volt is applied to a circuit having a total resistance of one ohm, and is equal to a rate of 629×10^{16} electrons passing a given point in one second.

A volt is the e.m.f. which produces a current of one ampere, when applied to a circuit having a total resistance of one ohm.

Also, a volt is the P.D. between the ends of a one ohm resistance through which one ampere of current is flowing.

An ohm is the resistance of a material which allows a current of one ampere to flow when an e.m.f. of one volt is applied.

A mho is the conductance of a material which has a resistance of one ohm. Conductance is the reciprocal of resistance.

Electrical Term	Symbol	Unit	Abbreviation	Relation
Quantity	Q	Coulomb	C	–
Current	I	Ampere	A	–
		Milliampere	mA	$1\text{mA} = \frac{1}{1000}\text{ A}$
		Microampere	μA	$1\mu\text{A} = \frac{1}{1,000,000}\text{ A}$
Voltage (e.m.f. or P.D.)	E	Kilovolt	kV	1kV = 1,000V
		Volt	V	–
		Millivolt	mV	$1\text{mV} = \frac{1}{1,000}\text{ V}$
		Microvolt	μV	$1\mu\text{V} = \frac{1}{1,000,000}\text{ V}$
Resistance	R	Megohm	MΩ	1MΩ = 1,000,000Ω
		Kilohm	kΩ	1kΩ = 1,000Ω
		Ohm	Ω	–
		Microhm	μΩ	$1\mu\Omega = \frac{1}{1,000,000}\ \Omega$
Conductance	G	Mho	–	–
		Micromho	μmho	$1\mu\text{mho} = \frac{1}{1,000,000}\text{ mho}$

TABLE 2.

7. TEST QUESTIONS.

1. An ordered movement of electrons is called....DOMAIN CURRENT....
2. The force which produces this movement is called....E.M.F....
3. The most common sources of electricity are (1)....CHEMICAL....(2)....MAGNETISM....
4. Explain the difference between electron current flow and conventional current flow.
5. What are the four effects of an electric current?
6. What is the difference between direct and alternating currents?
7. What is meant by "electrical resistance"?
8. Good conductors have....HIGH....conductance or....LOW....resistance.
9. Insulators normally have a ..HIGH....resistance or ....LOW....conductance.
10. Which of the following are insulators: carbon, glass, brass, the human body, soft iron, mica, lead, porcelain, wet earth, silk?
11. A coulomb represents a ..QUANTITY.. of electricity. It is equivalent to a charge of ..ELECTRONS....
12. An ampere is an expression of ....CURRENT.... and is equivalent to ..6.27×10^{18}.. electrons passing a given point in ....ONE SECOND....
13. A volt is the ....CHARGE.... which produces....ONE AMP....when applied to a circuit containing....ONE OHM....
14. Explain the difference between P.D. and e.m.f.
15. An ohm is the ....RESISTANCE.... which allows a current of ....1 AMP.... to flow when an e.m.f. of ....1 VOLT.... is applied.
16. A mho is an expression of the ..CONDUCTANCE.. of a material, which is the ..OPPOSITE.. of resistance.
17. The relation of a milliampere to an ampere is ...$\frac{1}{1000}$ OF AMP....
18. There are ..1000000.. microamperes in an ampere.
19. There are ....·525....amperes in 525 milliamperes.
20. Change 1250 microamperes to milliamperes ....1·25 mA....
21. The relationship of a volt to a kilovolt is ..$\frac{1}{1000}$ VOLT....
22. Bring 7.627 ohms to microhms ....7627000 $\mu\Omega$....
23. 250,000 ohms represents ....·25 MΩ.... megohms.
24. Change 1.25 megohms to ohms ....1250000 Ω....

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

ELECTRIC CIRCUITS.

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1. THE MAKE-UP OF AN ELECTRIC CIRCUIT.

1.1 In current electricity, the term circuit signifies the complete electrical path through which an electric current passes.

1.2 Component parts of electric circuit.

(i) A source of e.m.f., such as a cell, battery or generator.

(ii) The apparatus or "load" to be operated by the current, such as an electric bell or lamp.

(iii) 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).

(iv) Controlling and regulating devices, such as switches, fuses and keys.

(v) Measuring instruments, such as ammeters and voltmeters.

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

2. ELECTRICAL SYMBOLS.

2.1 Circuit Symbols, the Shorthand of Electrical Apparatus. Instead of using pictures to represent an electrical circuit, (pictorial method), it is common to use standard symbols in diagrams, to show how electrical apparatus in a circuit is connected together by wires. 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 -

FIG. 1.

When some of these are formed together in a typical circuit they are as shown -

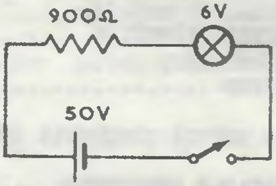


FIG. 2.

Other symbols will be introduced from time to time, but the full range of apparatus symbols, and a general description of schematic circuit diagrams, are given in the Course of Technical Instruction Book "Drawing for Telecommunication".

2.2 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.

G for electrical conductance.

When there is more than one of the same device or quantity in 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 resistor as R_2, the third resistor as R_3, and so on. Similarly, E_1, E_2, E_3, etc., or I_1, I_2, I_3, etc., are used to denote different values of voltage or current in a circuit.

Sometimes, subscript letters are used instead of numbers, for example, R_a, R_b, R_c or E_a, E_b, E_c, etc.

Regardless of the method used, the subscript marking is used only to identify an individual device or quantity; it does not indicate a value.

3. TYPES OF ELECTRIC CIRCUITS.

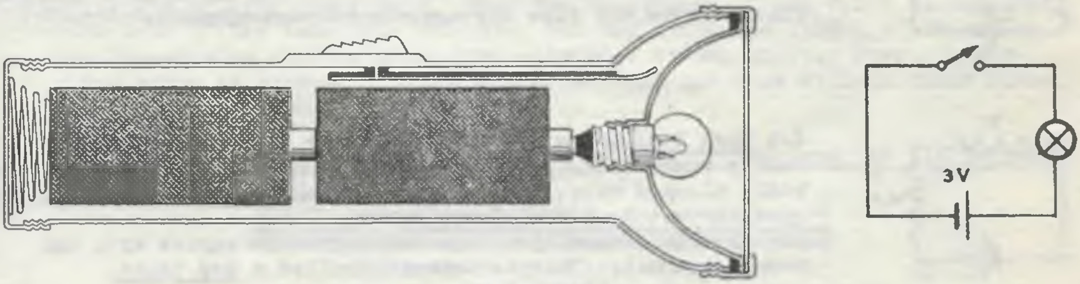
3.1 There are two types of electric circuits-

(i) Series circuits.

(ii) 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 either a series or parallel circuit connection.

3.2 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. 3.)



(a) Torch. (b) Schematic Circuit.

A SERIES CIRCUIT.

FIG. 3.

3.3 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. 4).

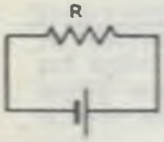
The dynamo (or generator) is the source of e.m.f. The current from the generator divides at point A (the headlight terminal) and flows through two separate paths, the headlight and the tail-light. The current in each path returns to the generator via the frame of the bicycle. The parallel type of circuit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

(a) Bicycle (b) Schematic circuit.

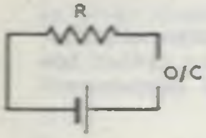
A PARALLEL CIRCUIT.

FIG. 4.

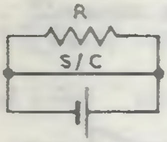
4. ELECTRICAL TERMS.



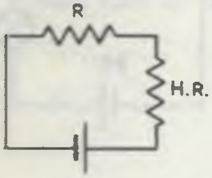
4.1 Closed Circuit. When any electrical apparatus is connected to a source of e.m.f. so that a current flows through it, the arrangement is called a closed circuit.



4.2 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.

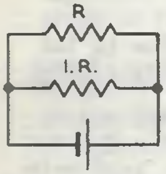


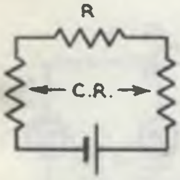
4.3 Short Circuit (S/C). A short circuit occurs when a part or the whole of a circuit is shunted by a low resistance path, and current does not flow through the correct circuit.



4.4 High Resistance Joint (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.

4.5 Insulation Resistance (I.R.) To prevent short circuits, the connecting wires of a circuit are often 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, and is therefore a shunt component.





4.6 Conductor Resistance (C.R.) This refers to the electrical resistance of the conductors in a circuit. For a given size wire, the resistance increases with the length, and conductor resistance is therefore a series component.

4.7 Voltage Rating of Electrical Apparatus. Electrical 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.

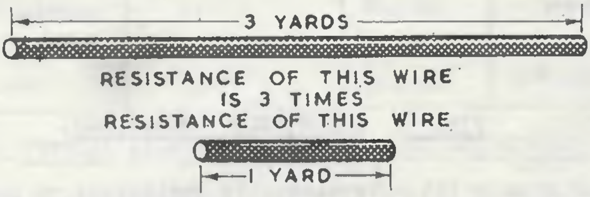
5. FACTORS WHICH AFFECT CONDUCTOR RESISTANCE.

5.1 The flow of water through a pipe depends on the friction or 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.

5.2 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. 5).

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

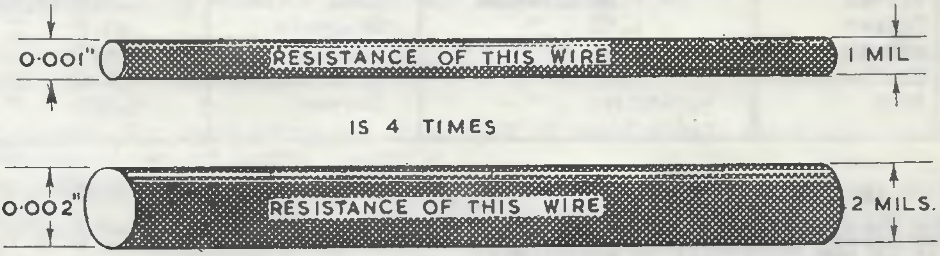


RESISTANCE DEPENDS ON LENGTH.

FIG. 5.

5.3 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. 6). From this it follows that -

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



RESISTANCE DEPENDS ON CROSS-SECTIONAL AREA.

FIG. 6.

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 $A \propto D^2$.

5.4 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.

Fig. 7 shows a comparison of different types of materials. The different lengths of wires shown have approximately the same resistance.

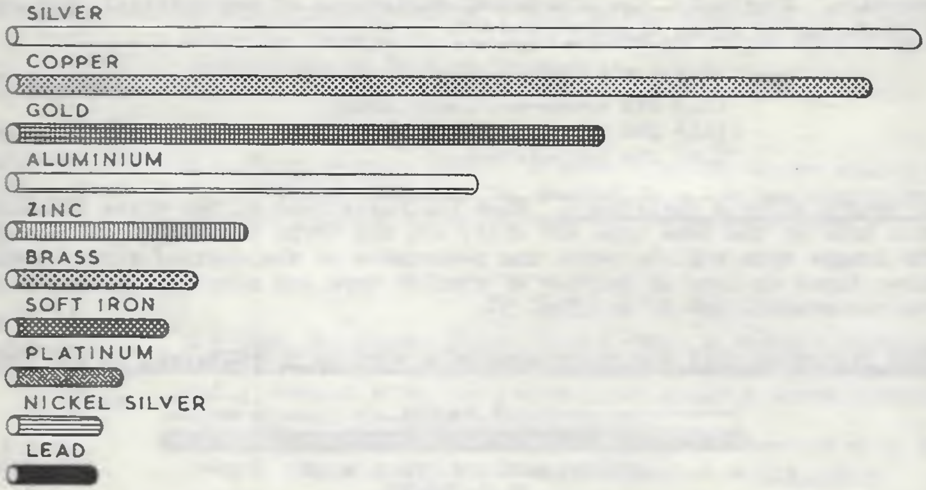


FIG. 7. RESISTANCE COMPARISONS.

5.5 The Resistivity of a material determines its resistance to current flow and is usually expressed as that material's specific resistance.

5.6 The Specific Resistance of a material is the resistance measured between opposite surfaces of a one centimetre cube of the substance, at a given temperature. The symbol is the Greek letter ρ (Rho) and the resistance is generally expressed in microhms.

Some typical values taken at 18° C are shown in Table 1.

Material	Specific Resistance	Material	Specific Resistance
Silver	1.64 microhms	Lead	22.0 microhms
Copper	1.78 "	Manganin	44.8 "
Aluminium	2.83 "	Eureka	49.0 "
Platinum	11.6 "	Nichrome	112.0 "
Iron	9.0-12.0 "	Carbon	5,000 "

TABLE 1. TYPICAL EXAMPLES OF SPECIFIC RESISTANCE.

5.7 The Conductivity of a material is a measure of its ability to conduct a current. It is the reciprocal of Resistivity.

5.8 Summarising - The resistance R of a material increases in direct proportion to its length L and its specific resistance ρ (Rho) and in inverse proportion to its cross-sectional area A.

These factors are combined in the equation -

$$R \propto \rho \frac{L}{A}$$

5.9 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.

For each degree rise above a specified figure in temperature of a wire, each ohm resistance of the wire is increased by a constant amount, which is called the temperature coefficient of resistance.

For example, pure copper wire has a temperature coefficient of resistance of 0.00427; that is, if a copper wire has a resistance of 1 ohm at 0° C, it will have a resistance of 1.00427 ohms at 1° C, and 1.427 ohms at 100°C.

Typical examples are shown in Table 2.

Material.	Temperature Coefficient of Resistance.	Material.	Temperature Coefficient of Resistance.
Silver	0.0037	Lead	0.0042
Copper	0.00427	Manganin	± 0.000025
Aluminium	0.004	Eureka	± 0.0002
Platinum	0.0038	Nichrome	0.00017
Iron	0.006	Carbon	- 0.0005

TABLE 2. TYPICAL EXAMPLES OF TEMPERATURE COEFFICIENT OF RESISTANCE.

Materials whose resistances increase with a rise in temperature have a positive temperature coefficient of resistance.

Materials whose resistances decrease with a rise in temperature, have a negative temperature coefficient of resistance. Examples of these are carbon, glass, porcelain, electrolytes.

5.10 Resistance Wires. Impurities in a substance can greatly affect the specific 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.

These provide a high resistance for a short length, with the resistance remaining substantially constant during any temperature rise.

Nichrome (nickel and chromium), Eureka (nickel and copper) and Manganin (copper, manganese and nickel) are examples of materials used for resistance wires.

5.11 Wire Sizes. For convenience and uniformity of manufacture, wires are produced in graduated diameters termed "gauges".

The two systems most commonly used are the S.W.G. (Standard Wire Gauge) British system, and the B and S (Brown and Sharpe's) American system. In either system the size of wire is expressed in terms of gauges corresponding to given diameters, the lower number gauges for the larger diameter wires.

For example, the diameter of 8 gauge B and S wire is 0.1285", and the diameter of 20 S.W.G. wire is 0.0360".

An alternative method used, particularly in reference to telephone lines, is to express the size of wire in terms of its weight in pounds per mile of single wire.

6. FIXED AND VARIABLE RESISTORS.

6.1 Why we need resistors.

Resistance is often used in a circuit to -

(i) Vary or control the current flowing in the circuit.
(ii) 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. 2 (para 2.1) 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.

6.2 Fixed Resistors.

(i) Wire-wound resistors (Fig. 8) are made up of resistance wires wound on an insulating spool or card, such as a porcelain or bakelite spool, or a mica or fibre card, etc. The wire ends are attached to metal terminals.

FIG. 8. TYPES OF WIRE WOUND RESISTORS.

In some cases, a connection or "tap" is made to one or more intermediate points of the wire winding. These connections are brought out to wires on terminals. This type of resistor is called a "tapped resistor".

Wire-wound resistors are available in resistance values up to about 50,000 ohms, and the value is usually printed on the resistor.

(ii) Carbon resistors (Fig. 9) are made up from carbon rod or graphite, or take the form of a thin layer of carbon sprayed on an insulating base, such as a glass or ceramic rod (or tube). Wires (sometimes called pigtail leads) are attached to each end of the carbon.

FIG. 9. TYPICAL CARBON RESISTORS.

The temperature coefficient of resistance of carbon resistors is much higher than wire-wound resistors; but in cases where this is not a disadvantage, carbon resistors are used because of their cheapness.

Sometimes the carbon layer is coated in spiral form similar to winding a wire around the rod. Metal film resistors are made in the same way as spiral-coated carbon resistors except that the film is metallic instead of carbon.

6.3 Variable Resistors.

(i) Potentiometers. (Fig. 10). There are two main types of potentiometer, the wire wound type used in circuits requiring low resistance and fairly large currents, and the carbon type for high resistance and low currents. The wire wound potentiometer consists of a circular shaped resistance-wire wound former, over which slides a conducting arm. The two ends of the winding and the arm are brought out to terminals for connection in a circuit.

When the shaft attached to the movable arm is turned, the arm provides a variation in resistance between each end and the arm, one increasing in resistance as the other decreases.

Potentiometers are generally used to regulate the voltage in a circuit to some desired value.

In the carbon type potentiometers, the wire wound former is replaced by a former which has a carbon layer deposited on it. The variable arm moves over the carbon to provide the desired resistance.

FIG. 10. TYPICAL POTENTIOMETERS.

FIG. 11. A TYPICAL RHEOSTAT.

(ii) Rheostats are usually wire wound and are similar to potentiometers, but have only two terminals, one connected to one end of the winding and the other to the movable arm (Fig. 11).

As in the case of the potentiometer, the movable arm selects any desired resistance within the range of the rheostat. Rheostats are generally used to regulate the current in a circuit to some desired value.

In practice, suitably ranged potentiometers are often used in place of rheostats. The connections are, of course, only made to the moving arm and one end of the winding.

(iii) Other types of variable resistors are the Resistance Box and the Voltage Divider.

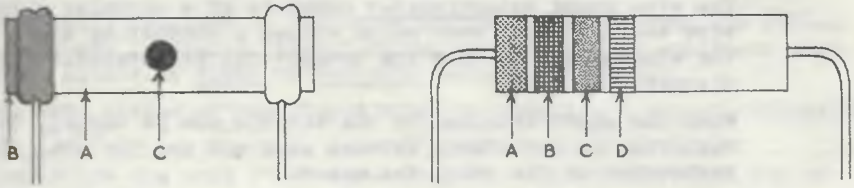
(a) The resistance box consists of a number of wire wound resistors mounted in a box. The resistors are connected to selecting switches, and different values of resistance can be provided by operation of the calibrated switches.

(b) The voltage divider is a form of potentiometer. The resistance wire is wound on a tubular former, and the ends of the winding are connected to terminals. Adjustable metal clips are provided to make connection at any intermediate point, by being moved along the winding, and tightened by means of a screw.

7. RESISTOR COLOUR CODE.

7.1 In general, wire wound resistor values are printed on the resistor. The resistance values of carbon type resistors are generally indicated by colours painted on the body of the resistor (Fig. 12).

7.2 The colours can be translated by the Code into figures which indicate the resistance in ohms, and the tolerance, (the percentage variation above or below the stated value).



(a) Body-end-dot code.

(b) End to centre code.

FIG. 12. RESISTOR COLOUR CODE MARKINGS.

Body-end-dot Code.	End to Centre Code.	Significance.
Body A	Band A	Indicates first figure of resistance
End B	Band B	Indicates second figure of resistance
Dot C	Band C	Indicates the number of zeros after the first two figures
(When the coloured end, or centre dot is missing, these values are the same as the body value).		
	Band D	(if any) indicates the tolerance limits

TABLE 3. INTERPRETATION OF RESISTOR COLOURS.

In some cases a coloured band around the body of resistor is used in place of the coloured dot, but the same code applies.

7.3 The range of colour designations and their significance is outlined in Table 4 -

Colour	Figure	Tolerance %	Colour	Figure	Tolerance %
Black	0		Violet	7	
Brown	1		Grey	8	
Red	2		White	9	
Orange	3		Gold	-	± 5
Yellow	4		Silver	-	± 10
Green	5		No colour	-	± 20
Blue	6				

TABLE 4. RESISTOR COLOUR CODE.

7.4 Preferred values for resistors. Resistors are mass produced, and owing to manufacturing difficulties, are supplied in certain tolerance ranges. In general, these are ± 5%, ± 10%, ± 20% of the stated resistance.

To minimise the number of resistance ranges manufactured, resistors are supplied in preferred values.

This means that with respect to any particular tolerance, each manufactured resistance range overlaps that of the preceding or succeeding range.

The series of preferred values and their associated tolerances are set out in Table 5.

Tolerance			Tolerance		
± 5%	± 10%	± 20%	± 5%	± 10%	± 20%
1.0	1.0	1.0	3.3	3.3	3.3
1.1			3.6		
1.2	1.2		3.9	3.9	
1.3			4.3		
1.5	1.5	1.5	4.7	4.7	4.7
1.6			5.1		
1.8	1.8		5.6	5.6	
2.0			6.2		
2.2	2.2	2.2	6.8	6.8	6.8
2.4			7.5		
2.7	2.7		8.2	8.2	
3.0			9.1		

PREFERRED VALUES FOR RESISTORS.

TABLE 5.

7.5 Examples: (i) Resistor with banded colours

Band A : Red   Band B : Violet
Band C : Yellow   Band D : Silver

This resistor has a resistance of 270,000 ohms with a tolerance of ± 10%.

(ii) Resistor with body-end-dot markings

Body colour : Red   End colour : same as body
Dot (or band) colour : Orange.

This resistor has a resistance of 22,000 ohms with a tolerance of ± 20%.

7.6 Resistor Rating. During use, the current passing through a resistor generates heat, and the resistor must be constructed to dissipate this heat without deterioration of the materials comprising the resistor.

Resistors are rated in terms of wattage (this will be explained in a later paper).

Typical ratings for carbon resistors are ½ watt, 1 watt and 2 watts.

8. TEST QUESTIONS.

1. The complete path for an electric current is called ....

2. In telecom, diagrams using standard symbols joined together by lines representing the wiring are called ....

3. For what purpose is a resistor used?

4. The symbol for resistance is ....

5. The symbol for a lamp is ....

6. The symbol for a battery of 6 volts is ....

7. In problems relating to electrical matters, the abbreviations for electric current, electrical resistance and electromotive force are respectively -

   (i) .... (ii) .... (iii) ....

8. What constitutes a closed circuit?

9. In telecom, a faulty soldered joint often results in a high resistance. This is commonly called - ....

10. Explain what is meant by "Insulation Resistance".

11. Electrical equipment often has a "voltage rating" stamped or written on it. Why is this important?

12. The factors which affect the resistance of a conductor are -

    (i) .... (ii) ....

    (iii) .... (iv) ....

13. The resistance of a wire is directly proportional to its .... and inversely proportional to its ....

14. Two wires, "a" and "b", are of similar length and material. "a" is 3 times the diameter of "b", therefore, "a" is .... the resistance of "b".

15. The specific resistance of a material refers to ....

16. The resistance of all pure metals, falls? rises? remains constant? as the temperature increases? decreases? (Correct this statement).

17. This is called .... and pure metals are said to possess a ....

18. The opposite effect to this is called .... and occurs when a temperature rise, causes an increase? decrease? no change? in the resistance of the material. (Correct this statement).

19. Briefly describe the construction and operation of a potentiometer.

20. State the characteristics of the following resistor, with end to centre colour markings as follows - ORANGE, ORANGE, YELLOW, SILVER.

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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OHMS LAW

1. INTRODUCTION.

1.1 Ohms Law is one of the most important laws in electricity and concerns the association between the current, e.m.f., and resistance in an electric circuit.

It was formulated in about 1827 by Dr. George Simon Ohm (1781 - 1854), a German physicist.

Before the acknowledgment of Ohm's Law, only intensity and quantity were used in electricity, and there were no accurate definitions of these.

Ohm discovered and defined accurate relationships between electromotive force, current strength, and resistance.

2. OHM'S LAW - THE LAW OF CURRENT FLOW.

2.1 Current depends on Voltage and Resistance. Basic laws of electricity are merely the application to electric circuits of fundamental 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 fundamental 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 electrical terms is stated in the form of a law called Ohm's Law.

2.2 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 -

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

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 -

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

Note:- It is important to understand that the three terms must always be expressed in volts, ohms, and amperes. If the quantities are expressed in terms of multiple or submultiple units, they must always be brought to the unit. For example, milliamperes must be converted and expressed as amperes; and etc.

Remember:- VOLTS drive AMPERES through OHMS.

2.3 **How to work out Ohm's Law problems.** The following examples show some simple problems in Ohm's Law.

It is essential when solving problems in electrical circuits to adopt a methodical approach to the method of calculation. Therefore, in the initial stages of understanding how to apply Ohms Law to problems, it is recommended that certain simple steps should be taken which apply basically to all such problems, whether simple or complex, and assist in their solving.

These steps are stated as follows:-

(1) Read and understand the question.

(2) Draw a simple schematic circuit of the problem and indicate the given values. (If the problem is involved, later subdivide into simple sections of the circuit.)

(3) State the formula which applies to the problem.

(4) Bring the stated values to their basic units (mA to A, etc.) and substitute units for the formula.

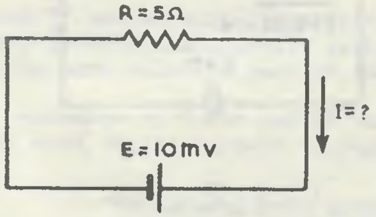
(5) Solve the equation, and express your answer in convenient submultiple or multiple units, where necessary.

For example, $\frac{1}{20}$ ampere could be expressed as 50 mA.

2.4 **Example No. 1.** What is the current when an e.m.f. of 10 millivolts is applied to a resistance of 5 ohms.

Step 1. READ AND UNDERSTAND THE QUESTION.

Step 2. Draw the schematic circuit and state values of components.



Step 3. The formula ... $I = \frac{E}{R}$

Step 4. Basic units ... $E = \frac{10}{1000}$ volts. $R = 5$ ohms.

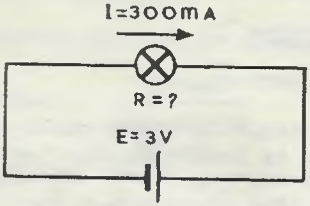
Step 5. Substitute and solve ... $I = \frac{10}{1000} \times \frac{1}{5} = \frac{1}{500}$ ampere.

Express in convenient form (in this case milliamperes) $= \frac{1}{500} \times \frac{1000}{1} = 2$ mA.

Answer:- 2 mA.

2.5 Example No. 2. A torch globe is connected to a 3 volt battery. If 300 mA flows through the globe, what is its resistance?

Step 1. READ AND UNDERSTAND THE QUESTION.



Step 2.

Step 3. $R = \frac{E}{I}$

Step 4.

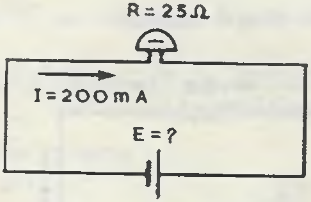
$E = 3$ volts.

$I = \frac{300}{1000}$ ampere.

Step 5. $R = \frac{3}{1} \times \frac{1000}{300} = 10$ ohms.

Answer:- 10 ohms.

2.6 Example No. 3. What voltage is needed to supply a current of 200 mA to operate an electric bell of resistance 25 ohms.



$E = I \times R$

$I = \frac{200}{1000}$ ampere.

$R = 25$ ohms.

$E = \frac{200}{1000} \times \frac{25}{1} = 5$ volts.

Answer:- 5 volts.

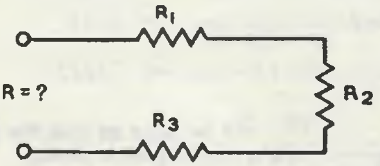
3. SERIES CIRCUITS.

3.1 In a series circuit with a battery and one or more pieces of apparatus, the current has only one path, which is through each part of the circuit, and must, therefore, be the same value through each part.

The voltage required to cause the current flow is applied across the whole of the circuit; but the voltage is distributed over the parts of the circuit in proportion to the "effort" involved in causing current flow through each part.

3.2 A knowledge of these factors allows us to understand the following important points which relate to any series circuit.

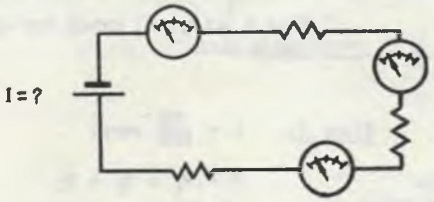
(i) The total resistance of a series circuit is the sum of all the individual resistances in the circuit. (Fig. 1.)



$R = R_1 + R_2 + R_3$

FIG. 1.

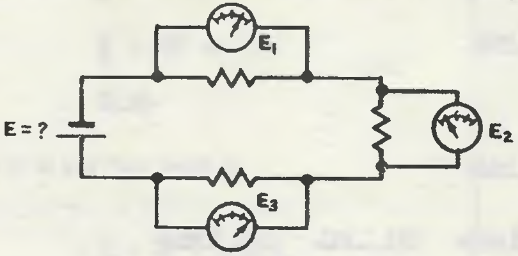
(ii) The current is the same value in all parts of the circuit. (Fig. 2.)



Similar meter readings indicate same value I through all parts of circuit.

FIG. 2.

(iii) The applied e.m.f. equals the sum of the potential differences across each part of the circuit. (Fig. 3.)



$E = E_1 + E_2 + E_3$

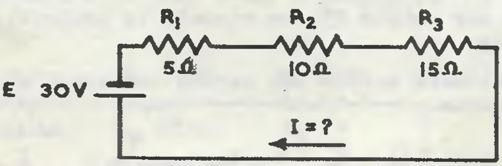
FIG. 3.

(iv) Ohms Law can be used in series circuits either as applied to the complete circuit, or to only part of the circuit, providing the values used are those taken from the same relative part of the circuit.

3.3 Example No. 4. If three resistors of 5, 10 and 15 ohms are connected in series across a 30 volt battery, what is the current through the 10 ohm resistor?

Step 1. READ AND UNDERSTAND. This is a series circuit, therefore the current through the 10 ohm resistor must be the same as the circuit current.

Step 2.



Step 3. $I = \frac{E}{R}$

Step 4.

$E = 30$ volts.

$R = R_1 + R_2 + R_3$

$= 5 + 10 + 15$

$= 30$ ohms.

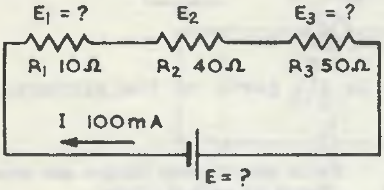
Step 5. $I = \frac{30}{30} = 1$ ampere.

Since resistor current is the same as circuit current.

Answer:- 1 ampere.

3.4 Example No. 5. Three resistors of values 10 ohms, 40 ohms and 50 ohms are connected in series with a battery. If the circuit current is 100mA, find - (i) Total Voltage, (ii) Potential Difference across the 10 ohm resistor, (iii) Potential Difference across the 50 ohm resistor.

Steps 1 and 2.



If two values are given from any part of a circuit the third may be found.

Since total I and R are known, total E can be found.

Since R_1 and R_3 and I through them is known, E_1 and E_3 can be found.

Step 3. $E = I \times R$

Step 4. $I = \frac{100}{1000}$ ampere

$R = R_1 + R_2 + R_3$

$= 100$ ohms.

Step 5. Total $E = \frac{100}{1000} \times \frac{100}{1} = \underline{10 \text{ volts}}$.

To find E_1 $\quad E_1 = I \times R_1$

$= \frac{100}{1000} \times \frac{10}{1} = \underline{1 \text{ volt}}$.

To find E_3 $\quad E_3 = I \times R_3$

$= \frac{100}{1000} \times \frac{50}{1} = \underline{5 \text{ volts}}$.

Answer:- (i) 10 volts. (ii) 1 volt. (iii) 5 volts.

Since the circuit potential differences when added should equal the applied voltage, the proof of the answers in Example No. 5 may be found by finding the potential difference across the resistor R_2, then adding the circuit potential differences. The answer should equal the applied voltage.

3.5 Another way to find Potential Difference across a resistance. It will be noticed from Example No. 5, that the potential difference across each series resistor is in proportion to its resistance.

Also, from Example No. 5, it can be seen that in a series circuit the potential difference between any points of the circuit is proportional to the resistance between those points.

The ratio of the voltages across the series resistors equals the ratio of the respective resistances.

$$\frac{E_1}{E_3} = \frac{R_1}{R_3} \quad \text{or from Example No. 5,} \quad \frac{1}{5} = \frac{10}{50}$$

Also, the voltage across any part of a series circuit bears the same ratio to the applied voltage, as the resistance of that part has to the total resistance.

$$\frac{E_1}{E} = \frac{R_1}{R} \quad \text{or from Example No. 5,} \quad \frac{1}{10} = \frac{10}{100}$$

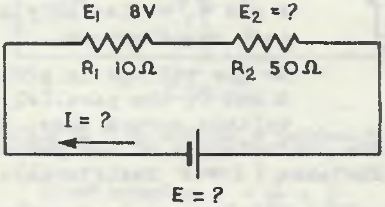
REMEMBER:- If two factors of the circuit are known, the third may be found by using OHMS LAW. THE VALUES USED MUST ALWAYS BE FROM THE SAME PART OF THE CIRCUIT.

3.6 Example No. 6. A 10 ohm and a 50 ohm resistor are connected in series with a battery. The potential difference across the 10 ohm resistor is 8 volts. Find -

(i) the P.D. across the 50 ohm resistor,

(ii) the applied voltage,

(iii) the circuit current.



ALTERNATIVE METHODS.

I through R_1 = $\frac{E_1}{R_1}$

= $\frac{8}{10} \times \frac{1000}{1}$ mA

= 800 mA.

Since 800 mA also flows through R_2

E_2 = I × R_2

= $\frac{8}{10} \times \frac{50}{1}$ = 40 volts.

Since total voltage equals the sum of circuit P.D.'s,

then E = $E_1 + E_2$

= 8 V + 40 V = 48 volts.

Since the circuit P.D.'s are proportional to the resistances in a series circuit,

then $\frac{E_2}{E_1} = \frac{R_2}{R_1}$

$\therefore E_2 = \frac{E_1 \times R_2}{R_1}$

= $\frac{8 \times 50}{10}$ = 40 volts.

Applied voltage E = $E_1 + E_2$

= 8 + 40 = 48 volts.

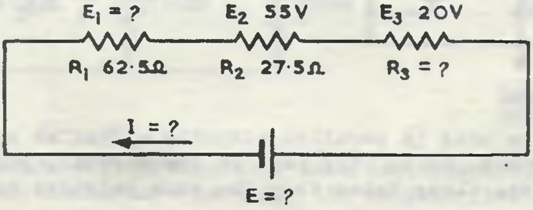
Circuit current I = $\frac{E}{R}$

= $\frac{48}{60} \times \frac{1000}{1}$ mA

= 800 mA.

Answer:- (i) 40 volts. (ii) 48 volts. (iii) 800 mA.

3.7 Example No. 7.



Solve for:- (i) E_1, (ii) I, (iii) R_3, (iv) E.

(Where possible use alternative methods to check your answer).

4. PARALLEL CIRCUITS.

4.1 In a parallel circuit the apparatus is connected so that the current flowing from the source of e.m.f. has two or more paths to flow through the circuit.

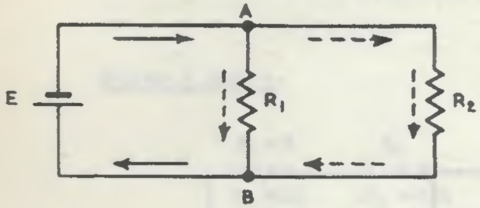


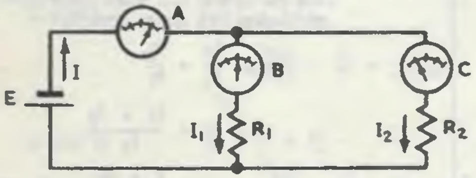
FIG. 4.

For example, in Fig. 4 the total current from the battery divides at junction A, portion flowing through each resistor, and reuniting at junction B. From this it can be seen that the total current flows in the section before the branches A and B, whilst only a proportion flows through each resistor.

As the voltage is effectively applied at points A and B, the parallel resistors have the same voltage across them, but the current divides according to the ratio of the conductances of the paths, the greater current passing through the larger conductance (lower resistance).

4.2 From this the following important points must be remembered in dealing with problems of parallel circuits:-

(i) The total current flowing into and out of a parallel circuit equals the sum of the currents in each part of the circuit and is governed by the total conductance of the circuit. (Fig. 5.).

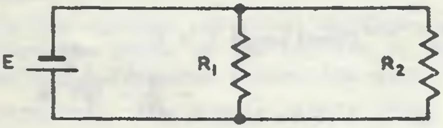


The readings on meters B and C together equal the reading on meter A:

$$I = I_1 + I_2$$

FIG. 5.

(ii) The total conductance of the circuit equals the sum of the conductance of the separate parts. (Conductance is the reciprocal of resistance). (Fig. 6).

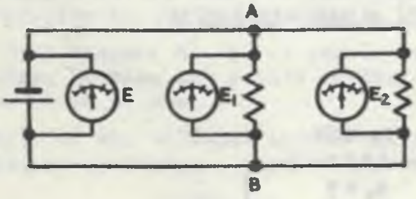


$$G = G_1 + G_2$$

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}} \qquad \left(\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}\right)$$

FIG. 6.

(iii) The P.D. is the same across each item of apparatus in parallel. (Fig. 7).



Since the battery is effectively joined across points A and B, all voltmeters read the same:

$$E = E_1 = E_2$$

FIG. 7.

(iv) Ohms Law can be used in parallel circuits either as applied to the complete circuit, or to only part of the circuit, providing the values used are those taken from the same relative part of the circuit.

4.3 Series and parallel circuits are, in a sense, opposites.

In a series circuit the current is the same in all parts, and the separate P.D.'s are added to find the total applied voltage.

In a parallel circuit, the P.D. is the same across all parts, and the separate currents are added to find the total current.

4.4 To find the total resistance of a parallel circuit.

(i) The total or equivalent resistance of a parallel group of resistances is that value of single resistance which, connected in place of the group, still carries the same current as the whole group. The current in Fig. 8. is determined by the total conductance of the circuit.

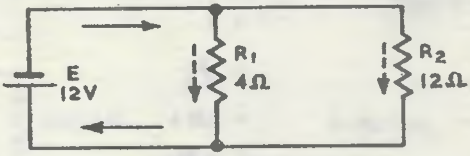


FIG. 8.

As conductance (G) is the reciprocal of resistance it follows that -

$$\text{Circuit conductance } G = \frac{1}{R_1} + \frac{1}{R_2}$$

$$G = \frac{1}{4} + \frac{1}{12} = \frac{1}{3} \text{ mho}$$

Since $G = \frac{1}{3}$ mho, then $\underline{R} = \underline{3 \text{ ohms.}}$

The parallel network can then be represented by a single resistor of 3 ohms (Fig. 9).

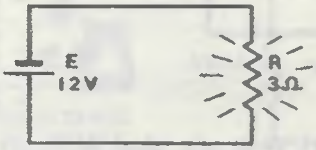


FIG. 9.

(ii) For parallel circuits with any number of parallel paths, the same formula is used.

$$G = G_1 + G_2 + G_3 + G_4 \text{ etc.}$$

or

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

(iii) A simple formula for finding the joint resistance of two parallel paths is -

$$R = \frac{R_1 \times R_2}{R_1 + R_2}$$ (Divide the product of the resistance values by the sum).

(iv) Where two or more equal resistances are connected in parallel (Fig. 10) the following formula should be used.

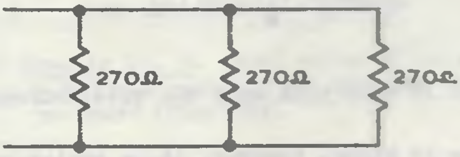


FIG. 10.

$$\text{Total Resistance} = \frac{\text{Resistance of one path}}{\text{Number of paths in parallel}}$$

For example, in Fig. 10 -

$$R = \frac{270}{3}$$

$$\underline{\text{Equivalent resistance}} = \underline{90 \text{ ohms.}}$$

It must be understood from this that each additional resistor connected in parallel provides another conductance path for the current flow and decreases the total resistance.

<u>Therefore, the total resistance of a parallel resistance network must always be less than the smallest value of resistance in the network.</u>

4.5 <u>How Current Divides in a Parallel Circuit</u>. The currents through apparatus connected in parallel are in the inverse ratio of the respective resistances. For example, in Fig. 11, calculation will show that the combined resistance (R) of R_1 and R_2 is 33.3 ohms.

Therefore, to find the total current -

$$I = \frac{E}{R} = \frac{3.0}{33.3} = 0.09 \text{ A} = \underline{90 \text{ mA}}.$$

The total current divides into the current I_1 through the 50 ohms resistor R_1, and the current I_2 through the 100 ohm resistor R_2.

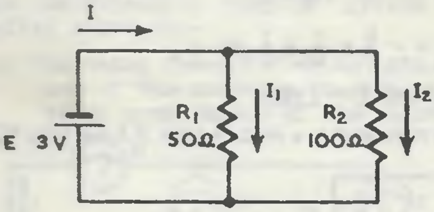


FIG. 11.

$$I_1 : I_2 :: R_2 : R_1$$
$$I_1 : I_2 :: 100 : 50$$
$$I_1 : I_2 :: 2 : 1$$
$$\therefore I_1 = \frac{2}{3} \text{ of the total current.}$$
$$= \frac{2}{3} \times 90 \text{ mA} = \underline{60 \text{ mA}}.$$
$$\text{and } I_2 = \frac{1}{3} \text{ of the total current}$$
$$= \frac{1}{3} \times 90 \text{ mA} = \underline{30 \text{ mA}}.$$

The currents in each parallel path are also directly proportional to the conductances of the paths. For example, in Fig. 12 -

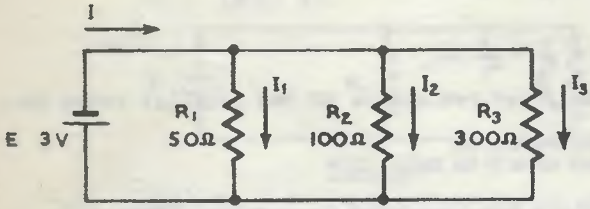


FIG. 12.

$$\text{Total Conductance} = \frac{1}{50} + \frac{1}{100} + \frac{1}{300}$$
$$= \frac{6 + 3 + 1}{300} = \frac{10}{300} \text{ mho.}$$

The total current, therefore, divides into 1 parts, and -

$$I_1 = \frac{6}{10} \text{ of the total current,}$$
$$I_2 = \frac{3}{10} \text{ of the total current,}$$
$$I_3 = \frac{1}{10} \text{ of the total current.}$$

This method is used to find the current in each path when the total current is known.

When the P.D. across the parallel paths is known, however, it is easier and quicker to apply Ohm's Law. In Fig. 12, for example, where the P.D. across the circuit is 3 volts -

$$I_1 = \frac{E}{R_1} = \frac{3}{50} = 0.06 \text{ ampere} = \underline{60 \text{ mA}}.$$
$$I_2 = \frac{E}{R_2} = \frac{3}{100} = 0.03 \text{ ampere} = \underline{30 \text{ mA}}.$$
$$I_3 = \frac{E}{R_3} = \frac{3}{300} = 0.01 \text{ ampere} = \underline{10 \text{ mA}}.$$

Comparing Figs. 11 and 12, when further resistances are added in parallel to an existing parallel circuit, the total resistance of the circuit decreases and the total current increases. The currents in the existing paths, however, do not change

4.6 Problems in parallel circuits.

(i) Example No. 1. Relays used in telecom sometimes have a resistance (called a shunt resistance) connected in parallel. From the simple schematic circuit shown in Fig. 13 find (i) Total Resistance, (ii) the current through the relay, (iii) the current through the resistor.

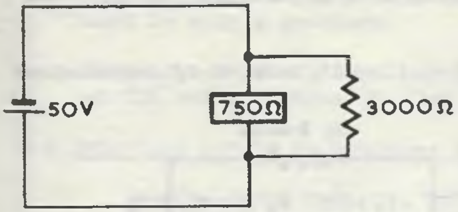


FIG. 13.

$$\text{Total } R = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$= \frac{750 \times 3000}{750 + 3000} = \underline{600 \text{ ohms.}}$$

By Ohm's Law, $I = \frac{E}{R}$ (Since E is the same across each parallel path).

$$\therefore \text{ Current through relay } = \frac{50}{750} \times \frac{1000}{1} = \underline{66.7 \text{ mA.}}$$

$$\text{and current through resistance } = \frac{50}{3000} \times \frac{1000}{1} = \underline{16.7 \text{ mA.}}$$

Answer:- (i) 600 ohms (ii) 66.7 mA (iii) 16.7 mA.

(ii) Example No. 2. At a telephone exchange, 2000 telephone conversations are simultaneously taking place. When the average resistance of each telephone circuit is 625 ohms, find the total current flowing through the telephones from the exchange 50 volt battery. (Fig. 14).

(a) Diagrammatic. (b) Schematic.

FIG. 14. SIMPLIFIED CIRCUIT FOR ONE TELEPHONE CONVERSATION.

When 2,000 telephone conversations are in progress, 4,000 telephones must be connected in parallel. Then, the total resistance -

$$R = \frac{\text{Resistance of one path}}{\text{Number of paths}} = \frac{625}{4000} \text{ ohms}$$

By Ohm's Law, $I = \frac{E}{R}$ (Similar P.D. across all telephones)

$$= \frac{50}{1} \times \frac{4000}{625}$$

Answer:- = 320 Amperes.

(iii) Example No. 3. What value of resistance must be connected in parallel with a 300 ohm resistor so that the total resistance of the combination is 50 ohms? (Fig. 15).

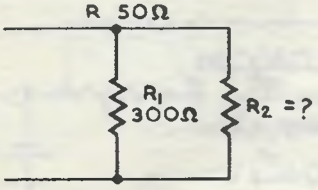


FIG. 15.

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

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

$$\frac{1}{R_2} = \frac{1}{50} - \frac{1}{300}$$

$$= \frac{6 - 1}{300} = \frac{1}{60}$$

$$\therefore R_2 = 60 \text{ ohms.}$$

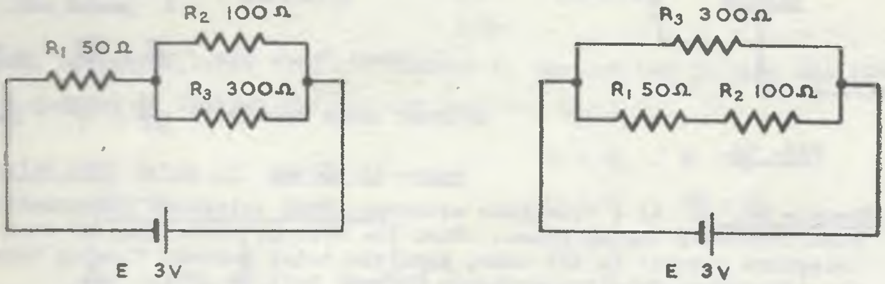
Answer = 60 ohms.

5. COMBINED SERIES AND PARALLEL CIRCUITS.

5.1 Series-Parallel Circuits are formed when three or more resistors are connected in a complex circuit, part series and part parallel. There are two basic arrangements -

(i) when a resistance is connected in series with a parallel combination, (Fig. 16a), and

(ii) when one or more branches of a parallel circuit consist of resistances in series. (Fig. 16b).



(a) (b)

FIG. 16. TWO WAYS TO CONNECT RESISTANCES IN SERIES-PARALLEL.

5.2 How to work out problems in series-parallel circuits. No new formulas are needed to work out problems in series-parallel circuits.

Instead, the complete circuit must be subdivided into parts consisting of simple series and parallel circuits.

Each part is then solved separately, and the parts are combined using the same formulas used previously in series and parallel circuits.

The solution of these circuits is often simplified by reducing the circuit to an equivalent single resistance which replaces the original circuit without change of current or voltage.

5.3 To find the equivalent resistance the following basic steps should be followed.

(i) When any of the parallel combinations have branches consisting of two or more resistances in series, find the total value of these resistances by adding them.

(ii) Using the formula for parallel resistances, find the total resistance of the parallel parts of the circuit.

(iii) Add the combined parallel resistances to any resistances which are in series with them.

5.4 For example -

(i) To find the equivalent resistances of Fig. 16a.

(a) Find the joint resistance of the parallel paths R_2 and R_3.
(b) Add the result to the series component R_1.

(ii) To find the equivalent resistance of Fig. 16b.

(a) Add the series resistances R_1 and R_2 .

(b) Combine the result with R_3 in a parallel network and solve.

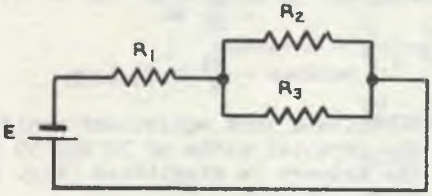
5.5 Problems in Series-Parallel Circuits. In applying Ohms Law to problems in series-parallel circuits, there are usually a number of alternative methods of approach available which vary according to the nature of the problem.

Practice in these calculations will produce a suitable approach but it must always be remembered that the steps necessary to find I, E or R, in any involved series-parallel resistance network can be related to the Ohms Law application used in simple problems.

However, as in all Ohms Law problems, the values used must be those from the part of the circuit where the law is applied.

5.6 Important points to remember in Series-Parallel circuits.

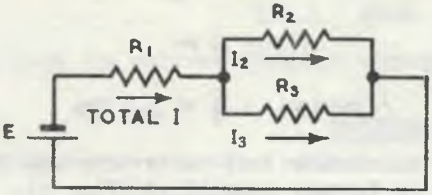
(i) The total current, voltage, or resistance may be found providing the two known values apply to the whole of the circuit (Fig. 17).



Total I = $\frac{\text{Total E}}{\text{Total R}}$ etc.

FIG. 17.

(ii) The division of currents may be found by using the inverse ratio of the resistances, providing the total current and the total resistance values are known or can be found (Fig. 18).



The total current flows through R_1.

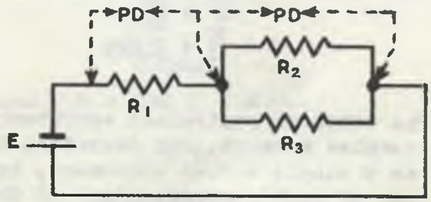
Only a proportion of the circuit current flows through R_2 and R_3.

FIG. 18.

(iii) The potential difference over a number of circuit components can be found by applying Ohms Law to each part of the circuit in turn, using the relative values.

Alternatively, where some potential differences in the circuit are known, or can be found, the unknown potential difference can be found.

Remember - the sum of the potential differences around a circuit must equal the applied voltage. (Fig. 19).

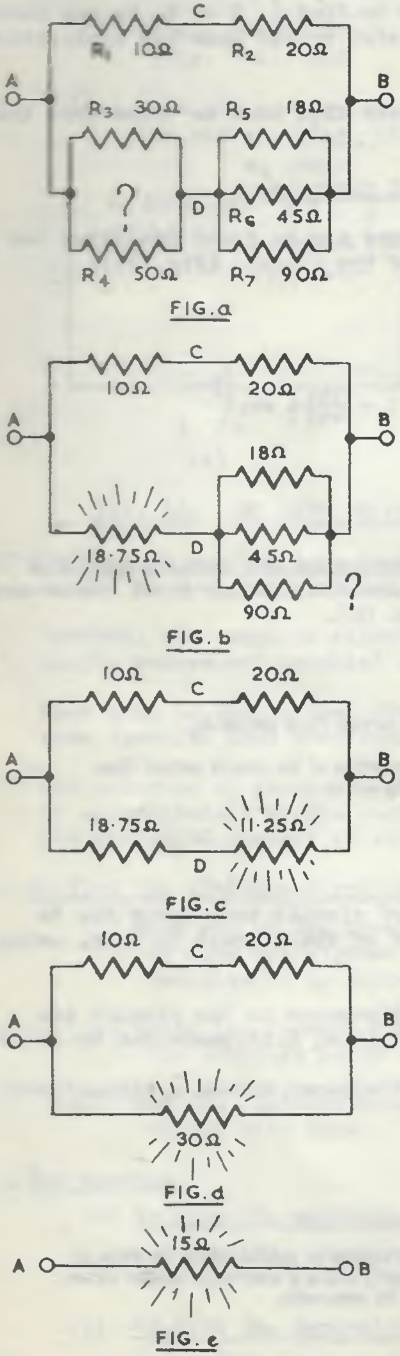


The total voltage is applied across the whole of the circuit, only a proportion is dropped across each of the components.

FIG. 19.

5.7 **Example No. 1.** More complicated circuits only require more steps, not any additional formulas.

For example, find the total resistance of the network in Fig. 20(a).



(i) First solve for the section A to D.

$$G = \frac{1}{R_3} + \frac{1}{R_4}$$

$$= \frac{1}{30} + \frac{1}{50}$$

$$= \frac{8}{150} \text{ mho}$$

$$\therefore \text{ resistance } = \frac{150}{8} \text{ or } \underline{18.75 \text{ ohms}}.$$

(ii) Substitute this equivalent resistance for the parallel paths of 30 and 50 ohms, and the network is simplified (Fig. b).

(iii) Now solve for the section D to B.

$$G = \frac{1}{18} + \frac{1}{45} + \frac{1}{90}$$

$$= \frac{5 + 2 + 1}{90}$$

$$= \frac{8}{90} \text{ mho}$$

$$\therefore \text{ resistance } = \frac{90}{8} \text{ or } \underline{11.25 \text{ ohms}}.$$

(iv) Substitute this resistance and the network is further simplified (Fig. c).

(v) Now add the two series sections AD and DB, then substitute as in (Fig. d).

$$18.75 + 11.25 = \underline{30 \text{ ohms}}.$$

(vi) This branch is in parallel with the branch ACB consisting of 10 + 20 = 30 ohms, and there are, therefore, two 30 ohm branches in parallel.

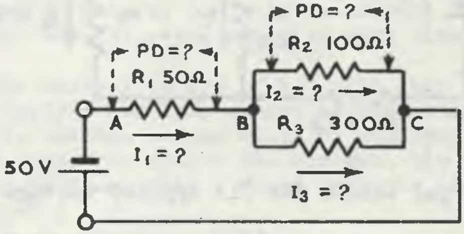
The equivalent resistance is then

$$R = \frac{30}{2} = \underline{15 \text{ ohms}}.$$

(vii) The total or equivalent resistance of the complex network, can therefore be shown as a single series component, by the use of simple applications of Ohms Law (Fig. e).

FIG. 20. THE EQUIVALENT RESISTANCE OF A COMPLEX NETWORK.

5.8 Example No. 2. Two parallel resistors of value 100 ohms and 300 ohms are together connected in series with a 50 ohm resistor. If this combination is connected across a 50 volt battery, find (i) total current, (ii) current through the 100 ohm resistor, (iii) current through the 300 ohm resistor, (iv) the P.D. across the 50 ohm resistor, and (v) the P.D. across the 100 ohm resistor.



To find the resistance of the network it is first necessary to solve BC.

$$\text{R section BC} = \frac{R_2 \times R_3}{R_2 + R_3} \quad \left(\text{or } \frac{1}{R} = \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$= \frac{100 \times 300}{100 + 300}$$

$$= 75 \text{ ohms}$$

$$\underline{\text{Total R}} = 75 + 50 = \underline{125 \text{ ohms.}}$$

$$\text{circuit current} = \frac{\text{circuit voltage}}{\text{circuit resistance}} \quad \left(I = \frac{E}{R}\right)$$

$$= \frac{50}{125} \times \frac{1000}{1} \text{ mA}$$

$$\underline{\text{Total I}} = \underline{400 \text{ mA.}}$$

To find the current division through $R_2 + R_3$, and the circuit P.D's.

ALTERNATIVE METHODS.

The current divides inversely as the ratio of resistances.

$I_2 : I_3 :: R_3 : R_2$

$I_2 : I_3 :: 300 : 100$

$I_2 : I_3 :: 3 : 1$ (4 parts)

$I_2 = \frac{3}{4}$ of $\frac{400}{1} = \underline{300 \text{ mA}}$

$I_3 = \frac{1}{4}$ of $\frac{400}{1} = \underline{100 \text{ mA}}$

$\underline{\text{P.D. across } R_2} = I_2 \times R_2$

$= \frac{300}{1000} \times \frac{100}{1}$

$= \underline{30 \text{ volts.}}$

$\underline{\text{P.D. across } R_1} = \text{Total E} - 30 \text{ volts}$

$= 50 - 30$

$= \underline{20 \text{ volts.}}$

P.D. across AB $=$ Total I $\times R_1$

$= \frac{400}{1000} \times \frac{50}{1}$

$= \underline{20 \text{ volts.}}$

P.D. across BC $=$ Total E $-$ 20 volts

$= \underline{30 \text{ volts.}}$

As 30 volts is the P.D. across both R_2 and R_3

$$I_2 = \frac{\text{P.D. across } R_2}{R_2}$$

$$= \frac{30}{100} \times \frac{1000}{1} \text{ mA}$$

$$= \underline{300 \text{ mA.}}$$

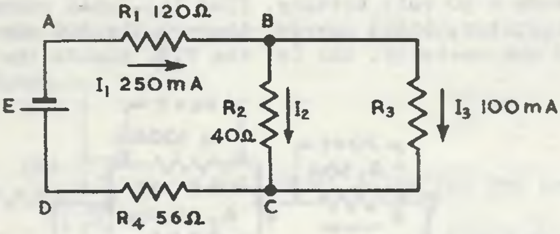
$$I_3 = \frac{\text{P.D. across } R_3}{R_3}$$

$$= \frac{30}{300} \times \frac{1000}{1} \text{ mA}$$

$$= \underline{100 \text{ mA.}}$$

Answer:- (i) 400 mA. (ii) 300 mA. (iii) 100 mA. (iv) 20 volts. (v) 30 volts.

5.9 Example No. 3.



Find values for (i) applied voltage

(ii) resistance of R_3

Since the current through R_1 divides at B and 100mA passes through R_3, the remaining 150mA passes through R_2.

$$\text{P.D. across } R_2 = I_2 \times R_2$$

$$= \frac{150}{1000} \times \frac{40}{1}$$

$$= \underline{6 \text{ volts.}}$$

Since 6 volts is applied at points B and C and is, therefore, across R_3 -

$$\text{Resistance of } R_3 = \frac{\text{P.D. across } R_3}{I_3}$$

$$= \frac{6}{\frac{100}{1000}}$$

$$= \frac{6}{1} \times \frac{1000}{100}$$

$$= \underline{60 \text{ ohms.}}$$

As R_1 and R_4 are both series components with the circuit current of 250mA passing through them both, their combined P.D. will be

$$E = I \times R$$

$$= \frac{250}{1000} \times \frac{120 + 56}{1}$$ (The same result will be achieved by finding individual P.D.'s and adding.)

$$= \frac{250}{1000} \times \frac{176}{1}$$

$$= \underline{44 \text{ volts.}}$$

The applied voltage equals the sum of the circuit P.D's.

$$\underline{\text{Total voltage}} = 44 + 6$$

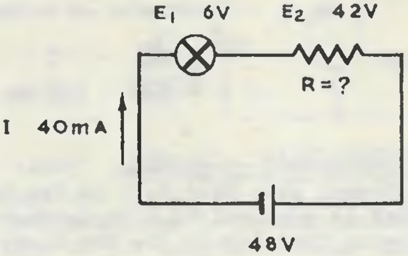
$$= \underline{50 \text{ volts.}}$$

Answer:- (i) 50 volts (ii) 60 ohms.

6. USING RESISTORS TO CONTROL CURRENT AND VOLTAGE.

6.1 To vary or control the current in a circuit, either the applied e.m.f. and/or resistance must be altered. In practice, current control by altering the resistance is generally the simplest, and often the only way. Many items of electric apparatus, however, have fixed resistance, and fixed and variable resistors are used to vary or control the current in them, (or the P.D. between their terminals). The following examples show some practical applications.

6.2 Example No. 1. The current rating of a 6 volt lamp is 40mA. How can it be lit from a 48 volt supply? The lamp cannot be connected directly across the 48 volts, because its voltage rating would be exceeded and the excessive current would "blow" the lamp. To reduce the current, the resistance of the circuit must be increased by connecting a fixed resistor (called a dropping resistor) in series. (Fig. 21.)



Maximum allowable P.D. across lamp with current of 40 mA = 6 volts.

∴ Resistor must have a P.D. of 48 volts − 6 volts = 42 volts with 40 mA flowing through it.

$$\therefore R = \frac{E}{I} = \frac{42}{1} \times \frac{1000}{40} = \underline{1050 \text{ ohms}}.$$

FIG. 21. REDUCING THE CURRENT THROUGH A LAMP WITH A SERIES RESISTOR.

Answer:- 1050 ohms.

6.3 Example No. 2. The moving coil system of the Detector No. 4 has a resistance of 10 ohms and the pointer reads full scale when a current of 10mA passes through the coil.

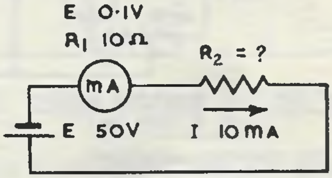
Therefore, the maximum voltage across which the meter may be connected -

$$E = I \times R = \frac{10}{1000} \times \frac{10}{1} = \underline{0.1 \text{ volts}}.$$

To use this milliammeter as a voltmeter which will measure 50 volts with full scale deflection, there must be a resistor connected in series to provide the necessary voltage drop when maximum current flows.

Resistors used for this purpose are termed "multipliers" for they "multiply" the range over which the meter can be used to measure voltages.

To find the resistance of the multiplier needed for a Detector No. 4 to measure 50 volts on full scale deflection. (Fig. 22).



P.D. required across R_2 when 10 mA flows through it,

$$= 50 - 0.1 = 49.9 \text{ volts}$$

$$R_2 = \frac{E}{I} = \frac{49.9}{1} \times \frac{1000}{10} = \underline{4990 \text{ ohms}}.$$

FIG. 22. REDUCING CURRENT THROUGH A METER BY A SERIES RESISTOR.

Answer:- Resistance of multiplier = 4990 ohms.

6.4 Example No. 3. Just as the moving coil system of the Detector No. 4 can be adapted to read different ranges of voltage, so can it be adapted to read different ranges of current flow. To accomplish this a resistor, called a shunt resistor, must be connected in parallel with the moving coil.

For example, when the meter is required to read 5 amperes on full scale deflection, the resistor must be such that when the 5 amperes flows in the circuit, only 10mA flows through the moving coil, and the remainder (5000-10) = 4990mA, then flows through the shunt resistor. (Fig. 23).

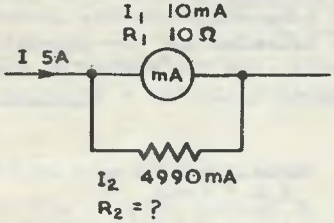


FIG. 23. LIMITING THE CURRENT WITH A PARALLEL RESISTOR.

REMEMBER: The currents flowing in apparatus in parallel are in inverse ratio to their respective resistances.

$I_1 : I_2 :: R_2 : R_1$

I_1 and R_1 = milliammeter current and resistance respectivel

I_2 and R_2 = resistor current and resistance respectively.

∴ 10 : 4990 :: R_2 : 10

$R_2 = \frac{10 \times 10}{4990} =$ 0,020 ohms.

Check your answer by using the alternative method of solving. First find the P.I across the meter when 10mA is flowing through it. This P.D. is the same as that across the unknown resistance when 4990mA is required to flow through it. Then the resistor value can be found by applying Ohms Law to the two known values.

6.5 Example No. 4. Rheostats are used in telecom circuits, -

(i) to vary the current gradually between certain limits, or

(ii) to keep the current constant, even though the battery voltage varies.

For example, in Fig. 24a, a 50 volt battery is used to operate a 2000 ohm relay. The current in the circuit is 25mA. How can the current be varied to find the value at which the relay releases? One way is to vary the battery voltage by connecting a different number of cells; but this does not give a continuous contro of current. A better way is to connect a rheostat in series with the relay (Fig. 24b). When the rheostat is adjusted to its minimum setting of zero ohms, the current is still 25mA. As the rheostat arm is turned to its maximum position, the resistance gradually increases and the current decreases, until the relay finally releases.

Should a steady current be required to flow through the relay, even if the batter voltage varies, the rheostat arm can be varied accordingly to alter the series resistance, and maintain the desired current as recorded on the milliammeter.

(a) (b)

FIG. 24. USING RHEOSTAT TO CONTROL CURRENT.

What is the resistance of the rheostat when the relay releases at a current of 20mA? (Answer: 500Ω).

6.6 Example No. 5. Potentiometers are used in telecom circuits -

(i) to vary the voltage continuously between certain limits, or

(ii) to keep the voltage applied to a circuit (output voltage) constant, even though the voltage applied to the potentiometer (input voltage) varies.

For example, in Fig. 25, the input voltage is connected to the outer terminals of the potentiometer. Current flows in the resistance wire and there is a steady drop of potential along the wire. The potentiometer arm is turned to tap off any desired P.D. between 0-6V by connecting to the movable arm and to one end of the potentiometer. This end is the minimum position; it gives the least P.D. The opposite end is the maximum position; it gives a P.D. equal to the applied input voltage.

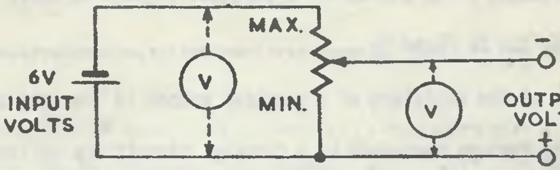


FIG. 25. USING POTENTIOMETER TO VARY VOLTAGE.

To keep the output voltage constant when the input voltage rises, the potentiometer arm is turned towards the minimum setting to reduce the output voltage to its original value. When the input voltage falls, the arm is turned towards the maximum setting.

The connections to the potentiometer are usually made so that the arm is turned in a clockwise direction from minimum to maximum settings.

6.7 Example No. 6. Both potentiometers and voltage dividers are used to tap off smaller P.D's from a larger one. The potentiometer taps off a variable P.D.; the voltage divider taps off one or more fixed P.D. values. Fig. 26 shows a voltage divider connected to 100V. The connections are adjusted to tap off any desired P.D. between 0-100V. For example, the potential at point B, quarter of the distance from A to E is 25V; at the halfway point C, 50V; and at the three-quarter point D, 75V. These points are all negative with respect to A.

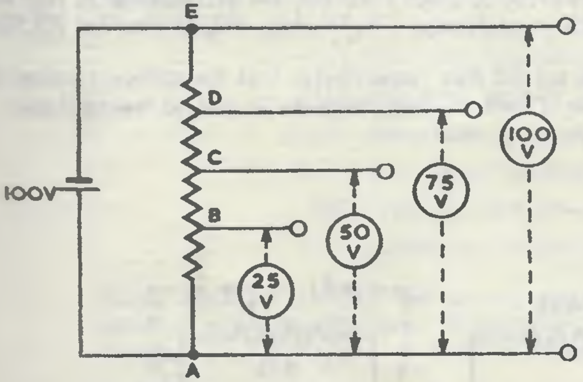


FIG. 26. USING VOLTAGE DIVIDER TO TAP OFF P.D's.

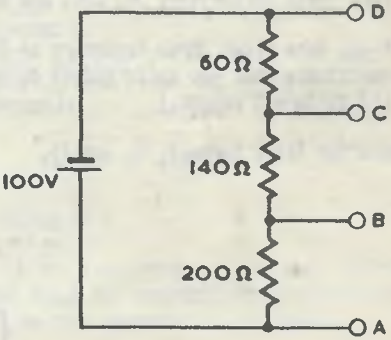


FIG. 27. USING FIXED RESISTORS TO TAP OFF P.D's.

A simple form of voltage divider is obtained by connecting two or more fixed resistors in series. In Fig. 27, what is the P.D. between terminals A and D, A and C, A and B? (Answer: 100V, 85V, 50V.)

7. TEST QUESTIONS.

1. Define Ohms Law, and state three equations which express the law.

2. In Series circuits -

   (a) the current flow is .... in all parts of the circuit.

   (b) the P.D's, when added, equal ....

   (c) the P.D. across each series resistor is proportional to ....

3. In Parallel circuits -

   (a) the total current flowing in to and out of a parallel circuit is equal to ....

   (b) the total resistance can be found by ....

   (c) the P.D. across one of the resistors of a parallel branch is the same as ....

   (d) the currents flowing through resistors in a parallel circuit are in inverse ratio to ....

4. Ohms Law can be used in series or parallel circuits either as applied to the complete circuit or to only part of the circuit, providing that ....

5. Find the total resistance of three resistors of 44, 66 and 88 ohms respectively, connected in parallel. (20.3 ohms).

6. What voltage is necessary to cause an operating current of 20 mA to flow through a telephone relay of 2,500 ohms. (50 volts).

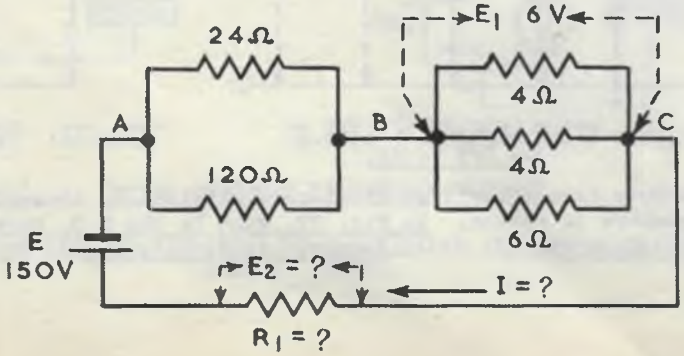
7. What is the resistance of a radiator element which carries 4.2 amperes when connected to a 240 volt supply. (57.1 ohms).

8. A milliammeter has a resistance of 50 ohms. What value of shunt resistance must be connected in parallel with it to give a resistance of 5 ohms. (5.56 ohms).

9. Calculate the resistance of the multipliers required to adapt a 100 ohm, 0-1 milliammeter to read with full scale deflection, 50, 250, and 1000 volts respectively. (49,900 ohms, 249,900 ohms and 999,900 ohms

10. If you were given three resistors of 210, 420 and 840 ohms respectively, list the different values of resistance that you could obtain by using one or more of these resistors in various combinations. (17 different values.)

11. Solve for Total Current, R_1 and E_2.



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THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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ELECTRICAL ENERGY AND POWER

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1. INTRODUCTION.

1.1 We have seen that electrical effects are due to the ordered movement of free electrons, which have been forced from their normal orbits around the nucleus of their atoms. To produce electrical energy we must use one of the following forms of energy -

(i) friction (mechanical energy);
(ii) chemical action (chemical energy);
(iii) magnetism (magnetic energy);
(iv) heat (heat energy);
(v) light (light energy);
(vi) pressure (mechanical energy).

These sources provide the energy required to do the work of moving electrons to form an electric charge. Regardless of the kind of energy used to create a charge, it is changed to electric energy once the charge is created.

1.2 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 basis on which all items of telecom apparatus operate, we see now how the terms Force, Work, Energy and Power, apply in the electric circuit.

2. FORCE, WORK, ENERGY AND POWER.

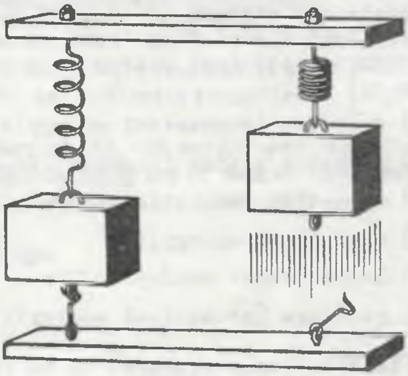
2.1 The terms "Force", "Work", "Energy" and "Power", are not always used correctly. For example, we often talk about sources of power when we really mean sources of energy; in daily speech the two words have become almost interchangeable. But what do these terms mean when applied to electricity? A knowledge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

2.2 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.

In Paper No. 1 we learnt that the electric force which tends to move electrons (that is, to produce a current), is called the electromotive force (e.m.f.).

2.3 Work is done whenever a force causes movement (Fig. 1). 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.

WHEN A FORCE CAUSES MOVEMENT, WORK IS DONE.

FIG. 1.

2.4 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 -

(i) the potential energy possessed by a body due to its height,

(ii) the kinetic energy of a body which is moving,

(iii) the electric energy of bodies which have electric potential,

(iv) the heat energy produced by electric radiators and soldering irons,

(v) the light energy produced by electric lamps,

(vi) the chemical energy produced when an electric current flows between conductors in a conducting liquid, as in some types of electric cells and batteries,

(vii) the magnetic energy around a metallic conductor carrying a current, as in an electromagnet,

(viii) the mechanical energy of an electric motor,

(ix) the sound energy produced by electric bells, telephone receivers and loudspeakers in a radio set.

2.5 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. This electric energy travels over power lines to power stations and hence to such places as telephone exchanges, telegraph offices, and radio stations.

Here, it is stored as chemical energy in batteries and used as required for the transmission of speech, signals or music from a telephone receiver, telegraph sounder or a loud-speaker. Thus, the received electric energy is converted into sound energy, or, as required, into other forms of energy, such as heat, light or mechanical energy.

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 into another, work is done.

2.6 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.

3. POWER AND ENERGY IN THE D.C. CIRCUIT.

3.1 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.

3.2 The unit of Electrical Power (P) is the Watt, 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 -

$$\text{Electrical Power} = \text{Voltage} \times \text{Current}$$

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

$$P = E \times I$$

In a circuit where current and resistance are known -

$$P = E \times I \text{ and } E = I \times R$$

$$\therefore P = I \times R \times I$$

$$P = I^2 R$$

In a circuit where voltage and resistance are known -

$$P = E \times I \text{ and } I = \frac{E}{R}$$

$$\therefore P = E \times \frac{E}{R}$$

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

For these expressions -

P - Power in Watts
I - Current in Amperes
E - Voltage in Volts
R - Resistance in Ohms

The three power formulas stated are intended to apply only in direct current circuits, as their application in alternating current theory involves other factors, and in general the formulas must be modified.

3.3 Where large powers are measured, as in power transmission, power is measured in kilowatts. In telecom circuits where small powers are measured, the sub units milliwatt and microwatt are used.

The subsidiary units are -

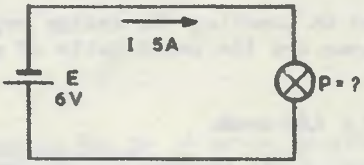
(i) kilowatt (kW) which equals one thousand watts,
(ii) milliwatt (mW) which equals one thousandth of a watt,
(iii) microwatt (μW) which equals one millionth of a watt.

3.4 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 230 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 230 volts.

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

3.5 Example No. 1. A globe is connected to a 6 volt battery. If the current is 5 amperes what is the power consumption?

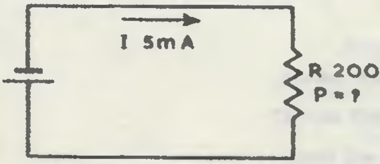


$P = E \times I$

$= 6 \times 5 = 30$ W.

Answer. = 30 Watts.

3.6 Example No. 2. A 200 ohm resistor is connected in a circuit with 5 mA's flowing. What is the power consumption of the resistor?

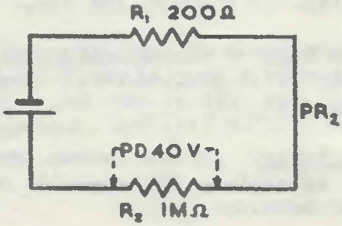


$P = I^2R$

$= \frac{5 \times 5 \times 200}{1000 \times 1000} \times \frac{1000}{1} = 5$ mW

Answer. = 5 Milliwatts.

3.7 Example No. 3. Two resistors of 200 ohms and 1 megohm are connected in series with a battery. If the P.D. across the 1 megohm resistor is 40 volts, what is its power consumption?



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

$= \frac{40 \times 40}{10^6} \times \frac{1000}{1} = 1.6$ mW

Answer. = 1,6 Milliwatts.

3.8 Example No. 4. An electric radiator rated at 1.5 kilowatts is connected to a 250 volts D.C. supply. What current flows through the radiator?

From $P = E \times I$

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

$= \frac{1500}{250} = 6$ amperes

Answer. = 6 amperes.

3.9 Electrical Energy. We have seen that power is the rate of doing work, and in the electrical circuit is the rate at which electrical energy is transformed into other forms of energy, such as heat, light and mechanical energy.

The QUANTITY of electrical energy required to perform any work relates the RATE of doing the work (Power) with the TIME taken to perform it.

3.10 The electrical unit of energy is expressed by the work done by 1 watt in 1 second, and is called the watt-second, or sometimes a Joule.

ENERGY = RATE x TIME.

or Watt-seconds = watts x seconds.

The watt-second is inconveniently small, and in practice the energy represented by 1 watt for 1 hour, or 1 kilowatt for 1 hour are the usual units of electrical energy.

1 watt hour (Wh) = 1 watt x 3,600 seconds.

1 kilowatt hour (kWh) = 1000 watt hours.

For example, when the rating of an item of electrical apparatus is 100 watts, the energy used by this apparatus -

in one second = 100 watt seconds,
in one minute = 6000 watt seconds,
in one hour = 100 watt hours,
in 20 hours = 2000 watt-hours or 2 kilowatt-hours.

The term kilowatt-hour means that power is supplied at the rate of 1000 watts for 1 hour, or 500 watts for 2 hours, or 2 kilowatts for $\frac{1}{2}$ hour, and etc.

The kilowatt is the unit of energy used in the sale of electricity for home and industry, and the electricity supply meters (kilowatt-hour meters) show the consumption of electrical energy in terms of this unit.

3.11 Relationship between Electrical and Mechanical Power. It has become accepted practice to rate the power of some electrical apparatus, for example, motors, in terms of the mechanical horsepower they can develop.

The conversion from electrical to mechanical power is given by the relation -

746 watts = 1 horsepower.

3.12 Efficiency of Electrical Apparatus. In general, the efficiency of any device used for converting one form of energy to another, such as a radiator, or a motor-generator, is represented by the ratio of the energy output from the device and in the form desired, to the energy input to effect the conversion.

Efficiency is usually represented as a percentage, and can be found from the following expression -

$$\text{Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}} \text{ of } 100\%$$

3.13 Example No. 5. An electric motor connected to a 250 volt D.C. supply develops $\frac{1}{2}$ H.P. If its efficiency be 85%, calculate (i) the power input to the motor, and (ii) the current it is taking.

$$\tfrac{1}{2}\text{ H.P.} = 373 \text{ watts}$$

(i) .... $$\text{Input power} = \frac{\text{Output power}}{1} \times \frac{100\%}{\text{Efficiency}}$$

$$= \frac{373}{1} \times \frac{100}{85} = \underline{439 \text{ watts.}}$$

(ii) .... $$\text{From } P = E \times I,$$

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

$$= \frac{439}{250} = \underline{1.756 \text{ amperes.}}$$

Answer:- (i) 439 watts, (ii) 1.756 amperes.

3.14 Example No. 6. A motor generator set charges a battery of 50 volts at an average rate of 200 amperes for 8 hours. If the efficiency of the set is 90% and the charge per kWh is $1\frac{1}{2}$d., what is the cost of the operation?

$$\text{Output Power} = E \times I$$

$$= 50 \times 200 = 10 \text{ kW.}$$

$$\text{Output Energy} = P \times t$$

$$= 10 \times 8 = 80 \text{ kWh}$$

$$\text{Input Energy} = \frac{\text{Output Energy}}{1} \times \frac{100\%}{\text{Efficiency}}$$

$$= \frac{80}{1} \times \frac{100}{90} = 88.9 \text{ kWh}$$

Cost of 88.9 kWh @ $1\frac{1}{2}$d. unit = 11/1d.

Answer:- 11/1d.

3.15 Example No. 7. In a suburban house, there are 8 lamps of 100 watts, 5 of 60 watts, 2 of 20 watts, and a 1500 watt radiator. If the supply is 240 volts, and the cost per kWh is $1\frac{1}{2}$d. for lighting, and $1\frac{1}{4}$d. for heating, calculate (i) the total current, and (ii) total cost if all are in use for 3 hours.

$$\text{Total Power} = 800 + 300 + 40 + 1500$$

$$= 2640 \text{ watts.}$$

(i) .... $$\text{From } P = E \times I, \quad I = \frac{P}{E}$$

$$\text{current} = \frac{2640}{240} = \underline{11 \text{ amperes.}}$$

(ii) .... $$\text{Heating cost} = \frac{1500 \times 3 \times 5}{1000 \times 4} = 5.625\text{d.}$$

$$\text{Lighting cost} = \frac{1140 \times 3 \times 3}{1000 \times 2} = 5.13\text{d.}$$

$$\text{Total cost} = 5.625\text{d.} + 5.13\text{d.} = \underline{10.755\text{d.}}$$

Answer:- (i) 11 amperes. (ii) 10.755d.

4. HEAT AND TEMPERATURE.

4.1 To understand how electrical energy is converted into heat energy, we first review the nature of heat and the distinction between heat and temperature.

4.2 Heat is a form of energy. All matter is made up of small particles called molecules which are said to be in a constant state of agitation. The friction between molecules generates heat, and when the molecules move faster the increased friction causes the substance to become hotter.

When the movement is slowed down the friction is reduced and the substance becomes cooler.

For example, when a copper bar is placed in a flame, rapid vibration of the molecules takes place and the heat is transferred from molecule to molecule along the bar.

To achieve this, a transference of energy has taken place; heat energy from the flame has been imparted to the rod.

When an electric current passes through the element of a radiator, electrical energy is transformed into heat energy.

When an electric current flows through the windings of a motor, most of the electrical energy is transformed into mechanical energy. The loss of efficiency which occurs is due to some electrical energy being wasted in the form of heat.

Heat is regarded as the lowest form of energy to which all other forms of energy tend to degenerate.

4.3 Methods of Transferring Heat. Heat can be transferred in three ways -

(i) Conduction; the gradual moving of heat from the warmer to the colder parts of a substance, by molecular agitation.

(ii) Convection; the process by which liquids and gases become heated by the movement of their molecules.

(iii) Radiation; heat moving through a gas or vacuum without heating the space through which it moves.

4.4 Difference between Heat and Temperature. The word Temperature denotes the degree of hotness or coldness of a substance. When a substance feels hot to touch we say it has a high temperature; when it feels cold, it has a low temperature. The term Heat is an expression of the quantity of energy in that form, that the substance possesses.

For example, if a needle and an iron bar are heated to the same temperature, the degree of heat is the same, but the quantity of heat energy present in both is vastly different, the needle possessing only a small quantity of heat energy compared to the iron bar.

4.5 The Thermometer. Heat is invisible and can be measured only by its effects. One effect is to change the volume of a substance; for example, most substances expand when heated and contract when cooled.

This effect is used in the thermometer, which is an instrument for measuring the temperature, or degree of hotness or coldness of a substance.

The thermometer most commonly used is the liquid type which consists of a glass tube with a small bore, one end of which is enlarged to form a thin walled bulb, which contains the bulk of the indicating liquid of mercury or coloured alcohol

The other end is sealed off after the introduction of the liquid, above which exists a vacuum. This ensures that there is no air resistance to the expansion of the liquid in the tube.

4.6 Thermometer Scales. Two reference points are used to calibrate thermometers

(i) the temperature at which water freezes and turns to ice,

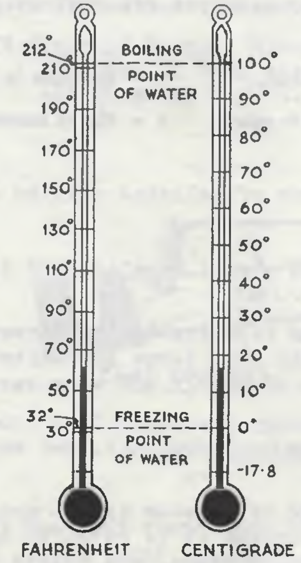
(ii) the temperature at which water boils and turns to water vapour.

The values are marked on the scale and the glass tube is uniformly calibrated in relation to the points. The two most common scales are the Fahrenheit and the Centigrade.

There is no difference between the two thermometers, except in the calibration. We see in Fig. 2, that -

(i) On the Fahrenheit scale, the freezing point of water is marked 32 degrees (32°) and the boiling point 212°.

(ii) On the Centigrade scale, the freezing point of water is marked zero (0°) and the boiling point 100°.



FAHRENHEIT AND CENTIGRADE SCALES.

FIG. 2.

Therefore, 180 divisions of the Fahrenheit (F) scale correspond to 100 divisions on the Centigrade (C) scale, or -

$$1 \text{ division F} = \frac{5}{9} \text{ division C:}$$

$$1 \text{ division C} = \frac{9}{5} \text{ divisions F.}$$

To convert temperature readings from degrees Fahrenheit (F) to degrees Centigrade (C), and vice versa, we use the formulas -

$$C = \frac{5\,(F - 32)}{9};$$

$$F = \frac{9C}{5} + 32.$$

5. THE HEATING EFFECT OF AN ELECTRIC CURRENT.

5.1 We can produce heat by many means; indeed, in the conversion of energy from one form to another, a proportion of energy is always lost in the form of heat.

5.2 Heat is produced when electrons flow in a conductor. When electrons flow in a metallic conductor, they move from atom to atom (and therefore from molecule to molecule), under the control of the e.m.f.

When recaptured by a molecule, some of the energy of motion acquired by the electron may help to set free another electron, the rest being transferred to the molecule, helping to increase its movement. As a result, the molecular movement is increased throughout the conductor, and it becomes heated.

Electrical energy is changed into heat energy whenever current flows through a conductor. This may or may not be a loss of energy depending upon whether the apparatus is designed to deliver heat, or another form of energy.

Also, in expending electrical energy in the production of heat, there is a definite relationship between the quantity of heat produced, and the quantity of energy used in producing it.

5.3 The unit of heat is the Calorie, which is defined as the quantity of heat required to raise the temperature of one gramme of water by 1° centigrade.

In the electrical production of heat, the relationship between electrical energy and heat energy has been found to be -

1 Calorie = 4.2 Watt-sec. (Joules).

1 Watt-sec (Joule) = 0.24 Calorie.

5.4 Factors Producing Heat in a Conductor. In effect, a conductor becomes heated because its molecules tend to oppose electron flow, that is, because of its electrical resistance.

The more electrons that flow, and the longer the time that they flow, the greater will be the heat developed.

It can be proved by experiment that the heat (H) produced by current flowing through a conductor can be found from -

$$H = I^2 Rt$$

where

H - Heat in watt-secs (Joules).

R - Resistance in ohms.

I^2 - Square of the current in amperes.

t - time in seconds.

Since 1 watt-sec = 0.24 calorie this expression in terms of calories will be -

$$H = 0.24\, I^2 Rt$$

5.5 It is not necessary for our study of electricity to have a full knowledge of force, work, power and energy in their application to physics.

However, it is important to realise that terms and units relating to the conversion of one form of energy to another, in physics, can be the same terms and units used in the conversion of electrical energy to another form of energy, and vice versa.

For example, in the study of physics, the power and energy developed by a locomotive, can be expressed respectively in terms of watts or horsepower, and watt-hours or horsepower-hours.

In electrical matters, it is usual to express the power of a motor driven generator in terms of watts or kilowatts, whilst the motor that drives it is rated in terms of horsepower. This is a matter of convenience and common usage, and points to the conclusion that the watt, kilowatt, watt-hour and kilowatt hour, are not necessarily units of power and energy peculiar to electricity, but are expressions that can if necessary be applied to other forms of power and energy.

6. PRACTICAL APPLICATIONS OF HEATING EFFECT.

6.1 The operation of many electrical devices used in home and industry depends upon the heating effect of an electric current. Such things include electric jugs, kettles, stoves, lamps, soldering irons and etc. These devices are in principle simply a length of high resistance wire (the element) which becomes heated with a current flow, and gives off heat, or light energy as the case may be.

6.2 Fuses. The principle of the heating effect produced in a current-carrying conductor, is used to protect circuits against excessive currents, which could damage the apparatus in the circuit, and in some cases, cause fires.

Inserted in series with the circuit to be protected, is a short length of wire (termed fuse wire, or fuse element), of such dimensions that it will carry the normal circuit current without overheating, but will overheat and melt with an excessive current.

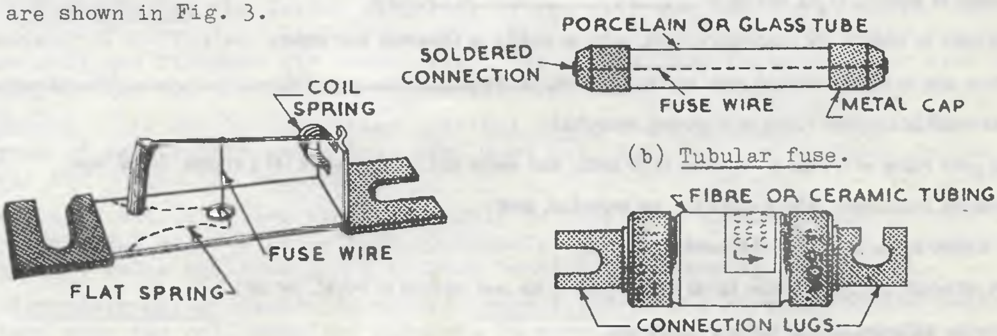
Materials often used for the fuse element, are copper, lead, zinc, aluminium, or some alloy such as tin lead which is used for low current values in preference to copper, as the gauge of copper wire required is too small for practical purposes.

6.3 Current Rating of Fuses. Although most items of electrical apparatus are rated in terms of power (para. 3.2) it is more convenient to rate a fuse by its safe current carrying capacity. In this regard, the current rating of a fuse is the maximum current which it can carry without fusing.

There is no simple relation between the maximum safe working current and the fusing current of a fuse. Some factors which can affect this relationship, are the material and surface area of the fuse wire, the temperature of the surrounding air, and if the fuse is enclosed, the nature of the enclosing material. As a general rule the fusing current is taken to be about twice the rated current value.

For example, an 0.5 A fuse will safely carry 0.5 A continuously but will fuse at approximately 1.0 ampere. It is apparent from this that the correct value fuse must always be used in electrical apparatus. Too low a rating causes overheating and unnecessary "blow-outs"; too high a rating will allow dangerously high currents to pass.

6.4 Types of Fuses. Since various types of apparatus require different currents, fuses are made in many sizes, shapes, and current ratings. Typical fuses used in telecom are shown in Fig. 3.



(b) Tubular fuse.

(a) Rat trap fuse.

(c) Cartridge fuse.

FIG. 3. TYPES OF FUSES.

6.5 The "rat trap" fuse (Fig. 3a) is constructed in such a way that the fuse wire is held under spring tension between the extension of a coil spring on the top of the fuse, and a flat leaf spring underneath the fuse. When the fuse operates, the flat spring connects with an "alarm bar" on the fuse panel and completes the circuit for the operation of a bell and lamp. The coil spring extension raises a coloured bead to indicate which fuse is open.

6.6 The tubular fuse (Fig. 3b) as used in substation protective equipment, consists of a short piece of porcelain or glass tubing, with a metal cap cemented to each end, which plug into spring clips. The fuse wire is threaded through the tube and is soldered to the metal caps at each end.

6.7 A larger type of fuse used for power distribution in telephone exchanges is called the cartridge fuse, (Fig. 3c), which is designed for protection in circuits with relatively heavy currents. It consists of a length of fibre or ceramic tubing at each end of which is fastened a brass cap or lug according to type, enabling the fuse to be either plugged in to metal clips, or bolted in position.

The fuse element itself varies according to type, but can consist of a zinc element joined by copper wire to the brass caps of the cartridge mounting.

The fibre cartridge is packed with asbestos fibre and chalk dust which serves to absorb the spark, and prevents the scattering of the molten metal when the fuse melts.

6.8 Heat Coil. The heat coil is designed to protect apparatus against damage from overload currents which will not cause the operation of a fuse, but if persisting, could cause damage to the apparatus.

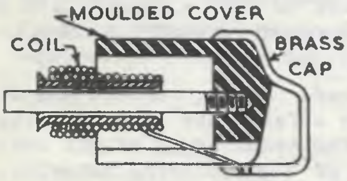


FIG. 4. EARTHING TYPE HEAT COIL.

The typical heat coil (Fig. 4.) consists basically of a coil of fine wire wound on a metal bobbin, mounted on a brass pin, to which it is soldered with a low melting point solder.

The heat coil mounting incorporates a spring arrangement which holds the bobbin under a force.

If the heat generated by current flow is sufficient, the solder melts and the bobbin slides along the pin which is forced against an earthed connection, earthing the circuit, and protecting the apparatus.

TEST QUESTIONS.

1. The factor which tends to move or change the rate or direction of motion of a body is ....

2. .... is done when force causes movement.

3. The energy of anything is its ability to ....

4. Define power in terms of the electrical circuit, using an example to illustrate your answer.

5. The three ways in which electrical power can be determined, are (a).................. (b).................. (c)..................

6. What is meant by the power rating of electrical apparatus?

7. If the power rating of a piece of apparatus is 50 watts, what energy will be consumed in (a) 2 minutes (b) 20 days.

8. Describe the relationship between electrical and mechanical power.

9. What is meant by the efficiency of electrical apparatus?

10. An 85% efficient, 2 H.P. motor runs for 20 hours. What is the cost involved at 1-3/4d. per unit.

11. What is the difference between heat and temperature.

12. Describe a simple thermometer, giving two scales in common use and stating the relationship between the two.

13. What is a fuse?

14. Describe a type of fuse used in telecom. which on operating completes the circuit for an alarm.

15. Sketch and describe a heat coil.

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

PRIMARY AND SECONDARY CELLS.

★ AMENDED 1962

1. INTRODUCTION.

1.1 An electric cell is a device which changes chemical energy into electric energy; electricity is not stored in these cells. There are two main types -

(i) Primary cells,
(ii) Secondary (or Accumulator) cells.

When two or more cells are connected together, the arrangement is called a battery.

1.2 In <u>Primary Cells</u>, the active materials of the cell are used or exhausted during the process of providing electric energy. When the elements of the cells are used, the cell has finished its useful life. We can replace these elements with new ones, but the old elements cannot be restored to their original condition.

Primary cells can be subdivided into <u>wet cells</u> and <u>dry cells</u>. Many different types of wet primary cells have been used but these are now replaced by the dry cell for use in the Department.

Dry cells and batteries are used mainly to supply a relatively low current for intermittent service in telecom equipment, for example, in magneto telephones, in portable radio equipment, and in some testing instruments.

1.3 In <u>Secondary Cells</u> (generally called <u>Accumulators</u>), the chemical action which takes place when the cell supplies current, is reversible; we can restore the elements of the cell to their original state by charging.

Accumulator cells and batteries are used at many telecom stations where a fairly continuous large current is required, for example, as the central battery for the operation of a telephone exchange.

1.4 This paper gives a general understanding of the construction and operation of dry cells and accumulators, and shows how <u>Stray Current Electrolysis</u> (a chemical action similar to that which occurs in the charging of an accumulator) can cause deterioration in the lead sheath of a telephone cable.

2. PRIMARY CELLS.

2.1 Simple Voltaic Cells. 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.

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. The value of the e.m.f. is dependent on the type of dissimilar conductors and nature of the solution.

The following list shows approximate values of e.m.f. from various combinations of conductors and solutions -

Conductors	Solutions	Approx e.m.f.	Conductors	Solutions	Approx e.m.f.
Copper and Zinc.	Sulphuric Acid.	0.8 volt	Copper and Carbon.	Sulphuric Acid.	0.25 volt
Brass and Zinc.	Sulphuric Acid.	0.2 volt	Carbon and Zinc.	Sulphuric Acid.	1.5 volt

Alternatively, solutions of common salt used in each case, produce e.m.f.'s of much lower values than those quoted. The pieces of carbon, copper, zinc, etc., are called plates or electrodes and the solution is termed the electrolyte.

In commonly used primary cells, the electrodes are carbon and zinc and the electrolyte is salammoniac, (ammonium chloride) (Fig. 1).

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.

2.2 Operation of Cell. While the electrodes of the simple cell shown in Fig. 1 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.

They are -
- (i) Some of the zinc electrode is eaten away.
- (ii) Hydrogen bubbles form around the carbon electrode.

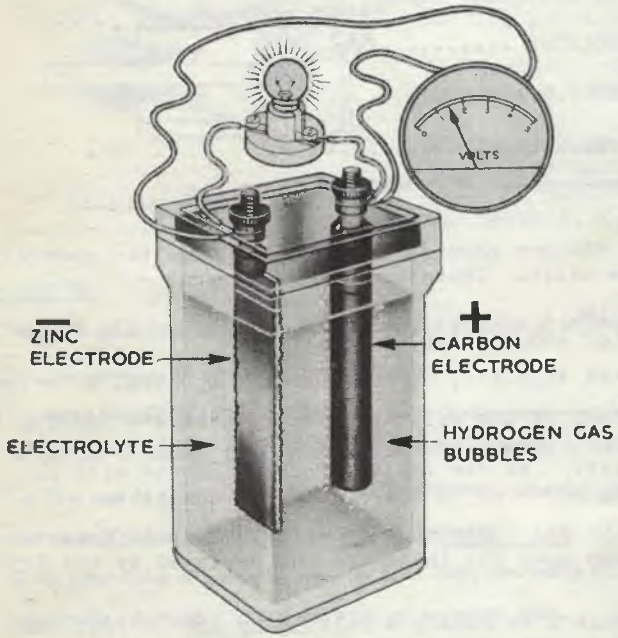


FIG. 1. SIMPLE PRIMARY CELL.

2.3 Chemical Action. The electrolyte of the voltaic cell contains a large number of negatively and positively charged ions which are able to move freely. When the zinc and carbon electrodes are immersed in the electrolyte, a chemical action takes place, and the electrodes each take up a difference of potential to the electrolyte, and a potential difference to each other of about 1.5 volts, the zinc electrode being a negative polarity with respect to the carbon electrode.

When the external circuit is closed electrons will flow through the load as a result of the P.D. between the electrodes.

The chemical action within the cell maintains the P.D. between the electrodes and may be briefly summarised as follows -

In the electrolyte which consists of ammonium chloride (NH_4Cl), there are present positively charged ammonium ions (NH_4), and negatively charged chlorine ions (Cl). When current flows, the chemical action results in the eating away of the zinc plate, as positively charged zinc ions are removed to unite with negative chlorine ions forming zinc-chloride ($ZnCl$) in the electrolyte. The electrons from the zinc ions remain on the zinc plate maintaining its negative potential.

The positively charged ammonium ions are urged towards the carbon electrode where they are neutralised by electrons from the carbon, maintaining it at a positive potential.

The chemical change which takes place results in the formation of ammonia gas which is liberated, and hydrogen gas which accumulates around the carbon rod in the form of a layer of bubbles.

Whilst the cell is delivering current to the external circuit, there is a steady movement of negative ions through the electrolyte to the zinc electrode, and a steady movement of positive ions to the carbon electrode in the opposite direction.

This is termed a convection current which occurs in electrolytes; it is distinct from the conduction current which occurs in conductors.

2.4 Polarisation. As the cell delivers current to an external load and the chemical action continues, the layer of hydrogen around the positive carbon electrode increases. This has the effect of reducing both voltage and current.

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.

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.

2.5 Leclanche Cell (Fig. 2). This type of cell uses the same electrodes and electrolyte as shown in Fig. 1, but eliminates polarisation whilst the cell is working, by using a depolariser to chemically absorb the hydrogen gas, and prevent it from affecting the operation of the cell.

The depolariser in the Leclanche cell is manganese dioxide (MnO_2). In its essential action the manganese dioxide gives up oxygen which combines with the hydrogen to form water.

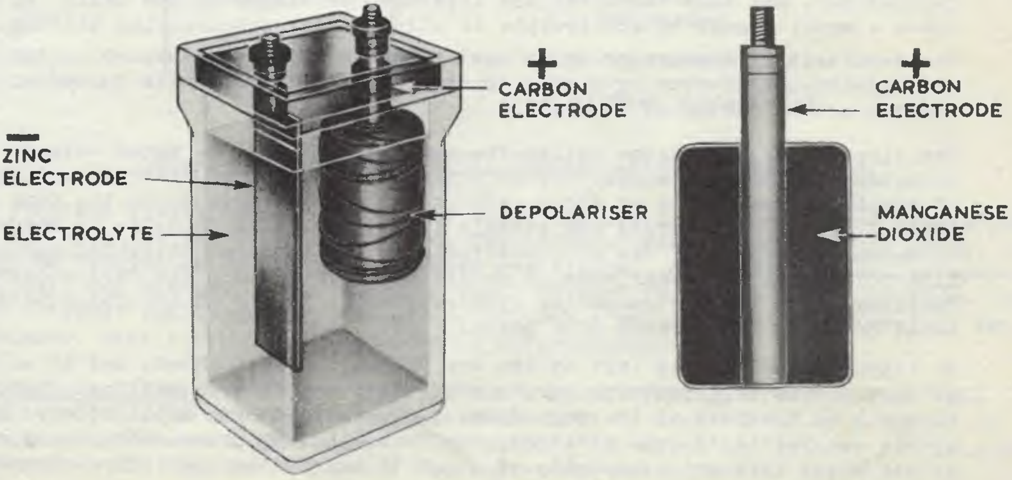


FIG. 2. COMPONENTS OF A LECLANCHE CELL.

2.6 Dry Cell. This cell contains the same components, and has the same chemical action as the Leclanche cell, but the salammoniac 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. 3) is the one most commonly used in the P.M.G.'s Department, principally in magneto telephones. The general description and operation of this cell applies also to other types of dry cell except for minor details of mechanical assembly.

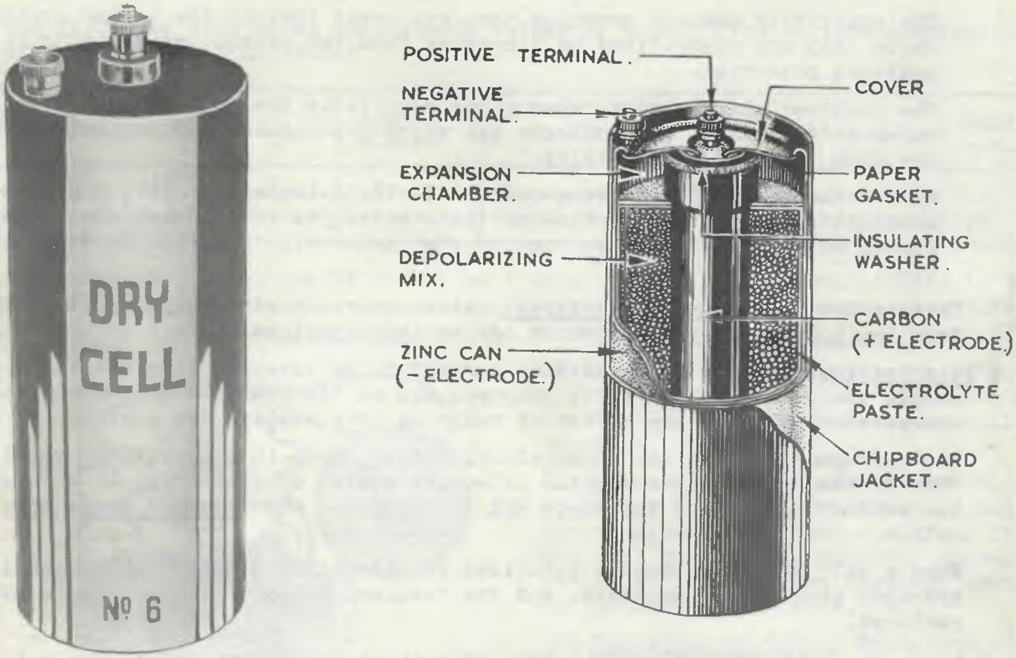


FIG. 3. NO. 6 DRY CELL - SECTIONAL VIEW.

A cylindrical zinc container, which is also the negative electrode, is enclosed in a cardboard outer wrapping to avoid damage and to insulate the electrode from adjacent cells.

The positive electrode is a carbon rod surrounded by a depolarising mixture of manganese dioxide and ground carbon. The latter increases the conductivity of the depolariser, and thus decreases the internal resistance of the cell. In some cases a small amount of electrolyte is added to the depolarising mixture.

The depolarising mixture occupies most of the cell and is secured in the container and insulated therefrom by a star or square shaped washer with turned-up corners, located at the bottom of the cell.

The electrolyte (sometimes called the excitant), fills the space between the depolariser and the container. It is a mixture of ammonium chloride and some form of combining agent such as flour, starch or gelatine made up in the form of a paste. Some manufacturers add a small quantity of zinc chloride to the electrolyte, to reduce corrosion of the zinc electrode by the ammonium chloride, and to maintain high voltage values under working conditions. The actual mix varies between manufacturers, and in some cases the electrolyte is held in an absorbing material instead of being in the form of a paste.

An expansion chamber is left at the top of the cell for gases, and to allow expansion of the cell contents during use. In some cells, a sealing compound of wax or pitch is provided at the top of the cell, instead of a metal cover. Brass terminals are fitted to each electrode for connection purposes. No. 6 dry cells have a long shelf life and a capacity of about 75 Ah; smaller cells are cheaper, but have a much shorter shelf life and lower capacity.

2.7 Local Action - Commercial zinc which is used for the negative pole of most dry cells, contains many impurities such as iron, lead and tin, etc. These impurities together with the pure zinc and the electrolyte, form tiny voltaic cells with closed electrical circuits, and thus the zinc is eaten away, although the cell may not be delivering current to an external circuit (Fig. 4). To prevent local action, the zinc is subjected to a treatment called "amalgamation". Mercury is added to the zinc before casting or is rubbed over its surface. Either of these processes forms a mercury-zinc amalgam film on the surface of the zinc. When the cell is working, the electrolyte is able to act on the zinc in the film, and the plate acts as a normal zinc plate. The impurities which do not dissolve in the mercury are covered with the film, and local action cannot occur.

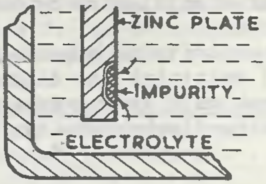


FIG. 4. LOCAL ACTION.

2.8 The Internal Resistance of a Cell, is its total resistance to the flow of current. It is due to the electrodes, electrolyte, and depolariser, which are not perfect conductors. The larger the electrodes and the closer they are together, the smaller the internal resistance.

The average value of internal resistance for a dry cell is approximately 0.5 ohm. This figure increases with age, rising slowly at first, but later as the cell is used, rising rapidly to large values. This is due to -

(i) The effects of polarisation. With age the depolariser becomes ineffective, and hydrogen forms a high resistance layer around the positive electrode.

(ii) Chemical action. Secondary chemical effects take place within the cell, forming compounds which offer high resistance to the current.

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 the 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. 5 shows the equivalent circuit of a dry cell under load.

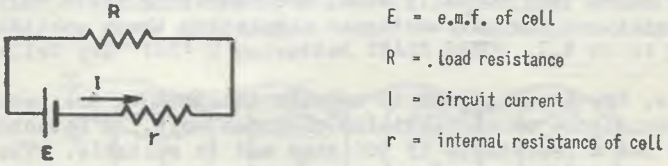


FIG. 5. EQUIVALENT CIRCUIT SHOWING INTERNAL RESISTANCE.

In problems involving cells (or batteries), the e.m.f. figures quoted always refer to the open circuit voltage, and when the internal resistance value is given, it must be treated as an additional series resistance. However, in examples where the cell (or battery) is providing a small current through a high resistance load, the internal resistance of the cell is of such a small ratio to the overall resistance, that it is often neglected in calculations.

2.9 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 high voltages and low currents can be made in fairly compact sizes.

2.10 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 (abbreviated to Ah), 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 Ah.

As the current does not usually stay constant but falls during a discharge, the average current is calculated from readings taken at periods during the discharge.

The larger the size, the greater the capacity of a cell.

2.11 The desirable qualities in a primary cell are -

(i) high and constant terminal voltage;
(ii) no polarisation;
(iii) no local action;
(iv) low internal resistance;
(v) free from objectionable fumes;
(vi) long shelf life;
(vii) high capacity.

There is no cell with all these qualifications, but the dry cell satisfies most requirements, and is the standard primary cell used to operate telecom equipment.

2.12 Shelf Life is a measure of the lasting quality of a dry cell or battery when not in use. Its deterioration over a period of time is due to a number of factors, some of which are temperature, materials used in construction, and method of sealing.

Cells and batteries should always be stored upright, in a cool well ventilated location when not in use.

* 2.13 Testing Dry Cells and Batteries. In general, unless specific tests are laid down by the manufacturer, dry cells and batteries are tested by connecting them in the circuit in which they normally work, and measuring their voltage under actual working conditions (or circumstances simulating these conditions). This method of testing is in E.I. POWER PLANT Batteries C 1201 "Dry Cells".

(2) For example, No. 6 cells used in magneto telephones, are tested with a voltmeter having a resistance of at least 100 ohms per volt. A Detector No. 4 on the 5 volt range has a resistance of 500 ohms and is suitable. The voltage of each cell is measured after supplying current for one minute to its normal load circuit, or a simulated circuit of equivalent resistance. Any cell which shows a reading of 1 volt or less should be discarded.

(3) Similarly, a battery block used to supply current, is discarded when its voltage falls to two-thirds of its nominal rated value, after supplying current for one minute. For cells other than the No. 6 cell, a voltmeter with a resistance of at least 1000 ohms per volt is used.

In some types of telecom equipment, cells and batteries are used mainly to supply a P.D. instead of a current, for example, as bias batteries for thermionic valves. The usual lower limit of voltage for bias batteries is 1.4 volts per cell, and the cell or battery should be discarded when the voltage, measured on a voltmeter of at least 1000 ohms per volt, is 1.4 volts (or less) per cell.

3. GROUPING OF DRY CELLS.

3.1 In telecom circuits, cells can be connected either in series or in parallel, to increase the e.m.f. or current in the circuit. 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.

3.2 To connect cells in series, join the positive terminal of one cell to the negative terminal of the next cell, and so on. Fig. 6 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.

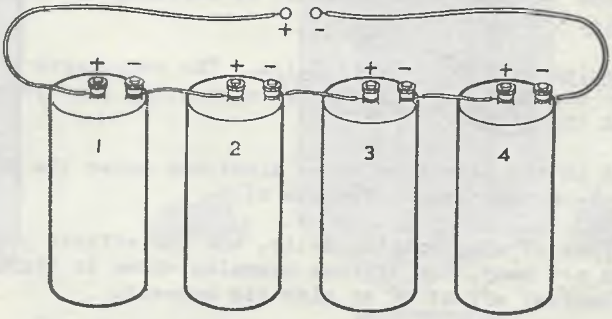


FIG. 6. HOW TO CONNECT CELLS IN SERIES.

3.3 To connect cells in parallel, join all the positive terminals together to a single wire, and all the negative terminals to another wire. Fig. 7 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.

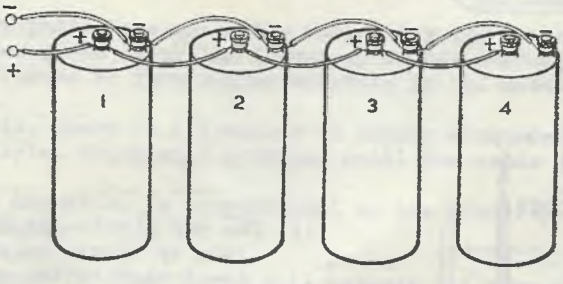


FIG. 7. HOW TO CONNECT CELLS IN PARALLEL.

3.4 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.

4. CHEMICAL EFFECT OF AN ELECTRIC CURRENT.

4.1 Electrolytic Cell. In previous papers, the Magnetic and Heating effects of an electric current have been discussed, and it has been shown that in the voltaic cell, two dissimilar *metals in an electrolyte can provide a source of e.m.f. for current flow in an externally connected circuit.*

Now let us examine the effects produced, when current from an external source is passed through a cell containing two electrodes and an electrolyte.

When a source of e.m.f. is connected to such a cell, current will flow through the cell, and chemical changes will occur in the components of the cell. Experiments show that the nature of the chemical changes which take place, depend on the material used for electrodes, and the type of solution used as the electrolyte.

Such a cell is usually referred to as an electrolytic cell, and the chemical changes which take place as a result of current flow through the cell, are termed Electrolysis.

4.2 Typical examples of Electrolytic Cells. The components of the cell are the container, the electrolyte, and the two conducting electrodes, which are termed the cathode and the anode.

The cathode is the electrode where electrons enter the cell. The anode is the electrode where electrons leave the cell.

Although types of electrolytic cells, and the effects produced by electrolysis within them are many, two typical examples shown in Figs. 8 and 9 will serve to show the chemical effect of an electric current.

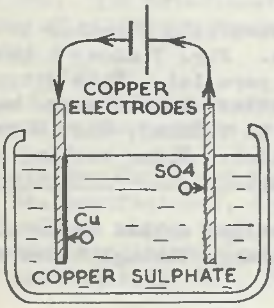


FIG. 8.

(i) The two electrodes are copper (Cu) and the electrolyte is copper sulphate ($CuSO_4$). By electrolysis, copper is deposited on the cathode, the anode is eaten away, and the strength of the electrolyte remains unchanged.

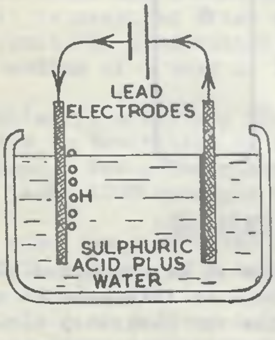


FIG. 9.

(ii) The two electrodes are lead (Pb), and the electrolyte is dilute sulphuric acid ($H_2O + H_2SO_4$). By electrolysis, the anode is coated with lead peroxide, hydrogen gas is given off at the catho and the strength of the electrolyte is increased, by the diminishing water content.

4.3 Chemical Action. The chemical action of the electrolytic cell shown in Fig. 8 will be discussed briefly, but in general the principle is the same for each cell, although the chemical action differs.

When copper sulphate ($CuSO_4$) is mixed with water, the molecules split up into positively charged copper ions (Cu), and negatively charged sulphate ions (SO_4) (Fig. 10).

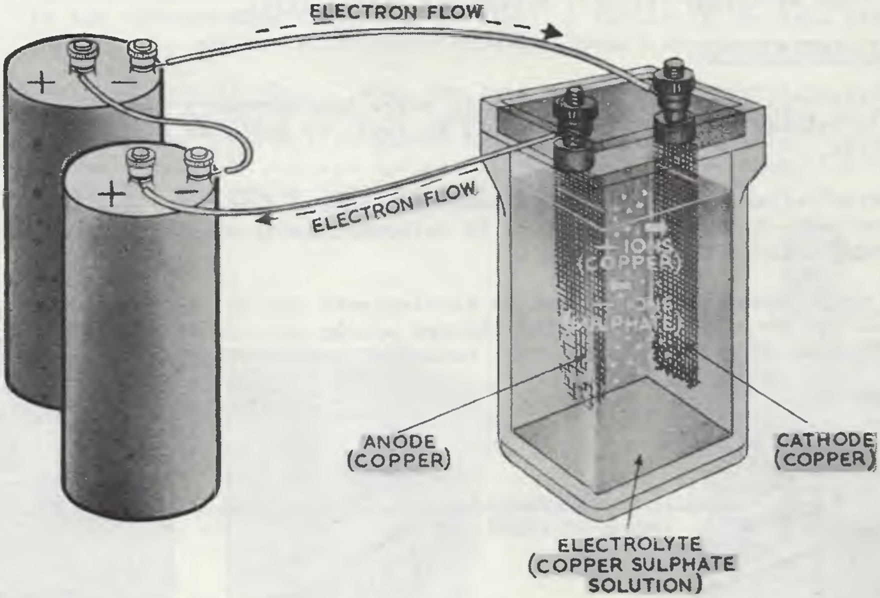


FIG. 10. CHEMICAL ACTION IN AN ELECTROLYTIC CELL.

When the electrodes are connected to a battery, the cathode takes up a negative potential with respect to the anode, and the ions within the electrolyte are in an electric field. The positive ions are attracted to the cathode and the negative ions are attracted to the anode; this constitutes a convection current within the electrolyte.

The positive copper ions on reaching the cathode are neutralised by electrons from the cathode, and are deposited as a layer of pure copper on that electrode.

When the negative sulphate ions reach the anode they are neutralised, and a chemical change takes place resulting in copper being eaten from the anode, and uniting with the sulphate to form copper sulphate in the electrolyte.

Thus, by electrolysis, there is a transfer of copper atoms from anode to cathode through the electrolyte, which will continue until the anode is dissolved.

4.4 The amount of copper deposited is proportional to the quantity of electricity passed through the cell.

A current of one ampere for four hours will deposit the same amount of copper as a current of two amperes for two hours. The type of cell shown in Fig. 10 is used as a current measuring device, to define the ampere in terms of its chemical effect. In this relation the ampere is defined as follows:-

> The ampere is that unvarying current, which when passed through a solution of silver nitrate in water, deposits silver on the cathode at the rate of 0.001118 grams per second.

4.5 Applications of Electrolysis. The chemical effect of an electric current has an important application in telecommunication, with respect to some types of electric cells and batteries. This will be explained in Section 6 relating to Secondary Cells.

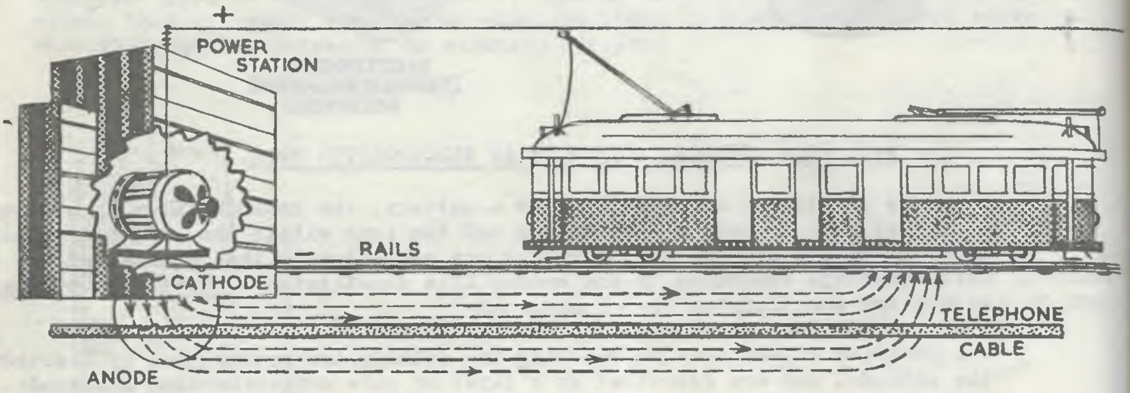
This principle is also widely used in industry for various types of electroplating such as copper, nickel, silver and gold plating.

5. STRAY CURRENT ELECTROLYSIS.

5.1 Electrolysis only occurs in D.C. circuits where the necessary factors are present, namely, a cathode or negative element, an anode or positive element, and an electrolyte.

The chemical effect of electrolysis sometimes causes damage to lead covered underground cables. Although this effect in telecommunication is widespread, conditions resulting in electrolysis vary.

Fig. 11 shows how damage is caused by electrolysis due to stray currents from electric tram (or train) lines, passing through nearby cable sheaths, rather than through the earth return, or the rail return of the traction system.



STRAY CURRENTS IN SHEATH OF TELEPHONE CABLES.

FIG. 11.

In this case the rails are the negative element or cathode, the cable sheath is the positive element or anode, and the earth containing salts etc., is the electrolyte.

As in the "electrolytic cell" positive ions are eaten away from the anode to neutralise negative ions in the electrolyte, with the result that the cable sheath becomes corroded and perforated, moisture enters the cable which breaks down due to the failure of the insulation.

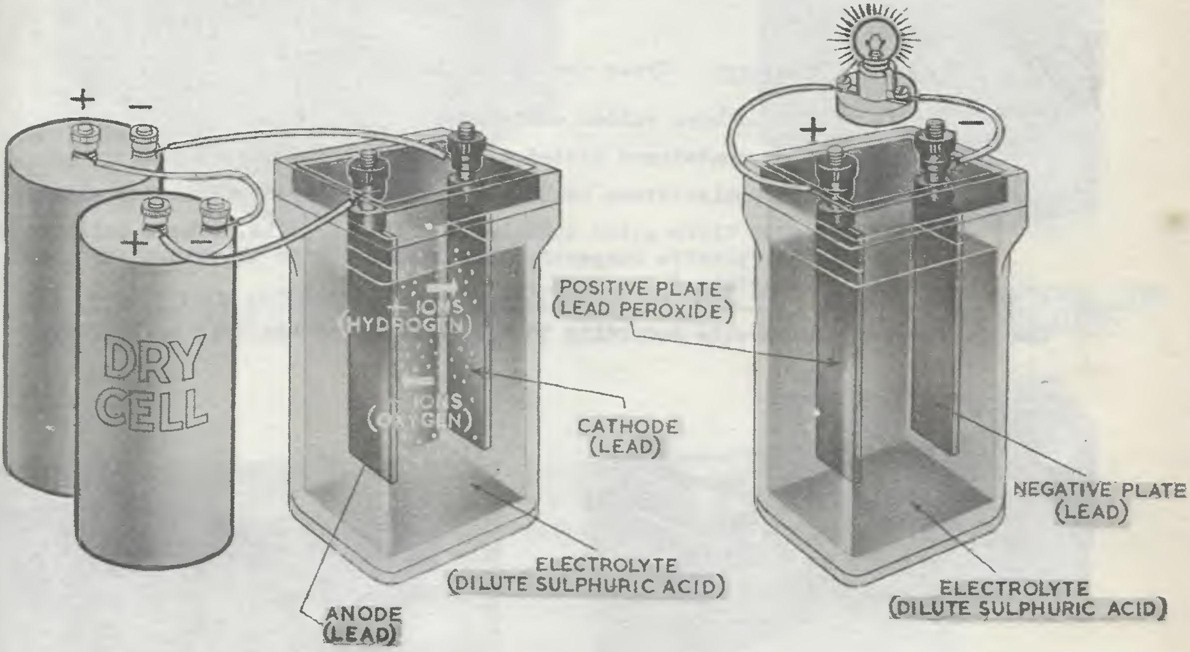
The effects of stray current electrolysis can be prevented in a number of ways; these are described in other books of this Course.

6. LEAD-ACID ACCUMULATOR.

6.1 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.

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.

6.2 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. 12a) the lead sulphate on the cathode is reduced to metallic lead and on the anode the sulphate is chemically changed to lead peroxide (Fig. 12b).



(a) Charging. (b) Discharging.

FIG. 12. SIMPLE ACCUMULATOR CELL.

This cell is in the same category as the electrolytic cells described in paragraph 4.2, for chemical changes have occured due to the passage of an electric current.

When the cell is disconnected from the voltage source it acts as a voltaic cell exhibiting an e.m.f. of about 2.1 volts, and when connected to an external load will deliver current for a short time until discharge (Fig. 12b).

A reverse current will again restore the components to their original condition, and the cell will again act as a voltaic cell. Continued charging and discharging, (a process called forming), will increase the amount of active material on each plate, but in general the chemical components produced in this way are so small that the cell has only a very small ampere-hour capacity, which makes it impractical for normal use.

In considering the charge-discharge cycle, we should note that on charge, when electrical energy is converted into chemical energy the cell acts as an "electrolytic cell", and on discharge, when chemical energy is converted into electrical energy, the cell acts as a "voltaic cell".

6.3 Make-up of a Typical Accumulator. Most accumulator cells used in telecom are of the lead-acid type. The essential components are a container, positive and negative plates, separators and the electrolyte in which the plates are immersed.

6.4 Containers. Cells are provided with open or enclosed containers, depending upon the purpose for which they are designed (Figs. 13 to 19).

Most modern accumulator cells are now of the enclosed container type.

(i) Open Containers consist of -

- (a) Lead lined wooden containers.
- (b) Glass.

(ii) Enclosed Containers. Types now in use include -

- (a) Moulded hard rubber containers.
- (b) Glass containers fitted with bakelite or similar lid.
- (c) Clear polystyrene containers with fused lid of similar material.
- (d) Bonded fibre glass containers with fused lid. (These cells have clear plastic inspection ports inserted in the sides for easy inspection.)

The containers vary in size according to the capacity of the cell or battery.

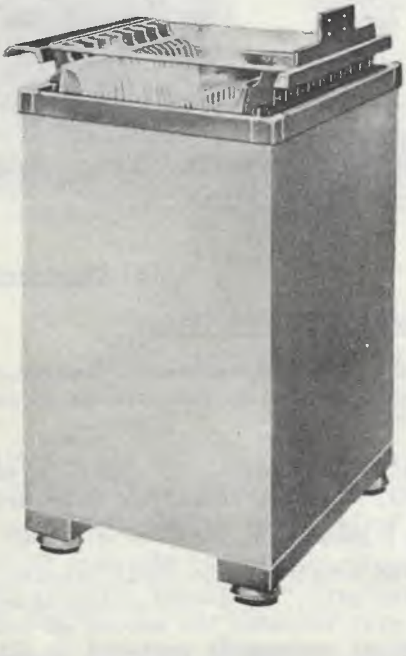


FIG. 13. 2 VOLT OPEN TYPE CELL, LEAD-LINED WOODEN CONTAINER.

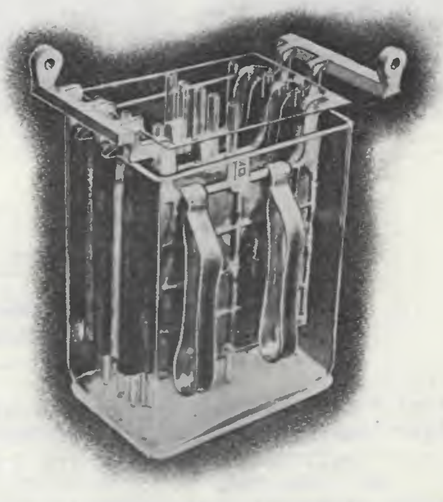


FIG. 14. 2 VOLT OPEN TYPE CELL, GLASS CONTAINER.

FIG. 15. 6 VOLT ACCUMULATOR ENCLOSED TYPE, CLEAR PLASTIC CONTAINER.

FIG. 17. 2 VOLT CELL ENCLOSED TYPE, HARD RUBBER CONTAINER.

FIG. 18. 6 VOLT ACCUMULATOR ENCLOSED TYPE, HARD RUBBER CONTAINER.

FIG. 16. TYPICAL BATTERY INSTALLATION.

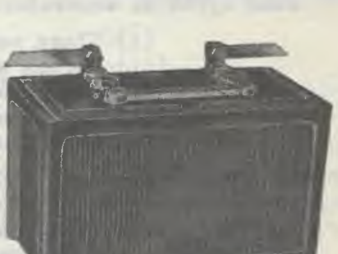
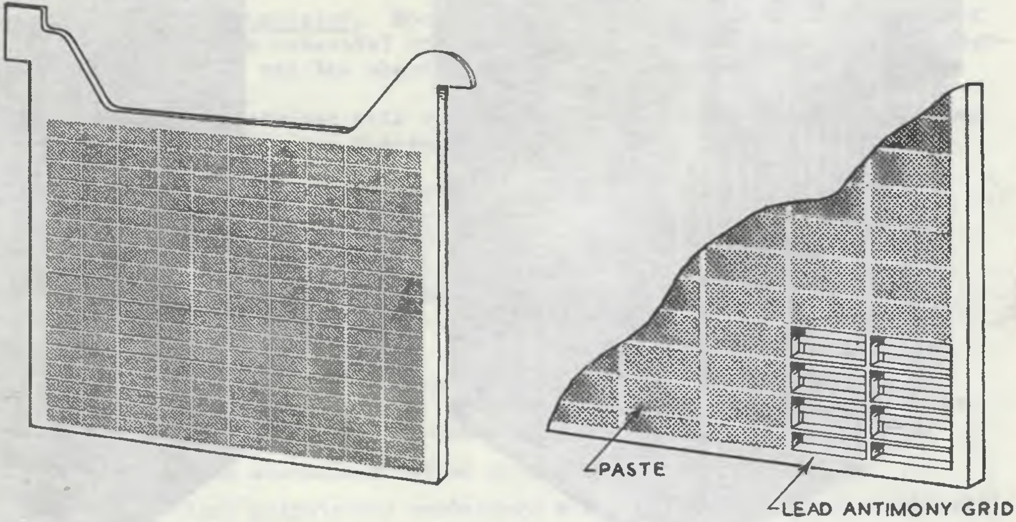


FIG. 19. 4 VOLT ACCUMULATOR ENCLOSED TYPE, HARD RUBBER CONTAINER.

6.5 Plates. The cells used in telecom employ various types of plate construction, full details of which are given in E.I. POWER PLANT Batteries A 2010.

A typical "pasted plate" construction, used for both positive and negative plates, is shown in Fig. 20.



(a) Typical Pasted Plate. (b) Enlarged Section.

FIG. 20. PASTED PLATE CONSTRUCTION.

Essentially the plates consist of a lead alloy framework or grid, which serves to hold the active material.

The lead is commonly alloyed with antimony to provide a greater framework strength, but it has recently been found that antimony tends to cause local action, and a decomposing action on the plates. To overcome this, pure lead grids and new alloys containing an alternative strengthening agent to antimony (such as calcium), are being used.

The active material in the form of a lead oxide paste is firmly pressed into the spaces of the grids, is dried, and then "formed" into its eventual active state of lead peroxide ($Pb\ O_2$) on the positive plate, and spongy lead (Pb) on the negative plate.

6.6 Separators. The separators prevent metallic contact between neighbouring plates in a cell, but allow free circulation of electrolyte.

Some types of separators are:-

(i) Glass rods or tubes.
(ii) Porous wood sheets.
(iii) Micro porous polyvinyl chloride (Porvic).
(iv) Resinite (a synthetic-resin bonded, wood pulp board).
(v) Micro porous rubber (used by some overseas manufacturers).

In conjunction with either the Resinite or the Micro-porous rubber types of separators, a thin mat of fibre-glass is often used. This mat is wrapped around the positive plates, and serves to combat the tendency of the positive plate to shed some of its active material under working conditions.

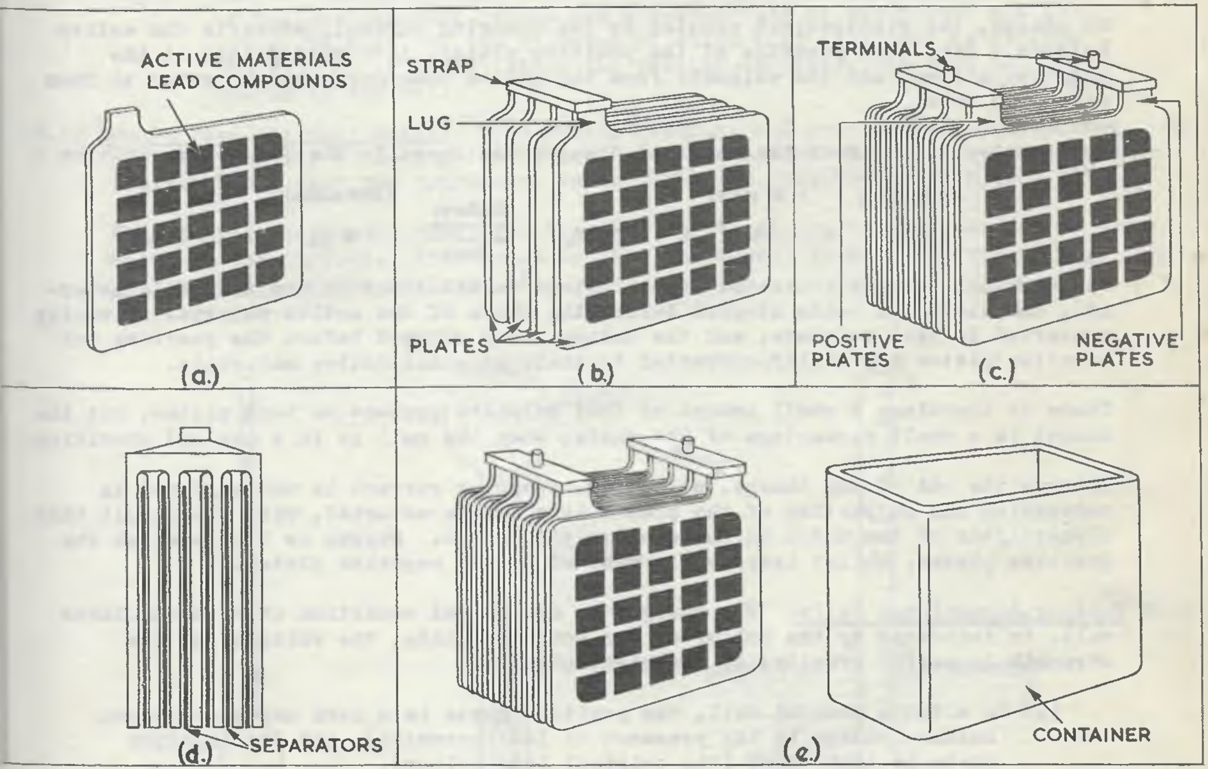
6.7 Electrolyte. The electrolyte is chemically pure sulphuric acid of specific gravity 1.840, diluted with distilled water until the specific gravity lies between 1.200 and 1.300, depending on the type of cell.

In general, a fully charged stationary cell has a specific gravity of 1.210 to 1.215, but enclosed type cells have higher values because of the relatively small quantities of electrolyte used.

6.8 Basic Construction. According to the required cell capacity, a selected number of positive and negative plates (Fig. 21a) are connected together in positive and negative groups (Fig. 21b).

The method of connection is by a lead strap which is "lead burned" to the lugs at the top of the plates.

(Lead burning is a form of soldering using pure lead and a heating flame). Terminals are provided on the lead straps for connection to the external circuit (Fig. 21c).



BASIC CONSTRUCTION OF AN ACCUMULATOR CELL.

FIG. 21.

The negative group usually has one more plate than the positive, so that under working conditions each outside plate is a negative.

In this way the positive plates are worked evenly on both sides, equalising the expansions and contractions of the active material in the positive plates during working conditions, and preventing the buckling of these plates. The negative plates are not subject to this tendency.

The two groups of plates are slipped together (Fig. 21c), and separators are inserted to prevent metallic contacts between the plates (Fig. 21d).

The set of plates and separators is mounted in the container (Fig. 21e) and the electrolyte added.

6.9 **Chemical Action during Discharge and Charge.** In the fully charged state, the active material of the positive plate is lead peroxide (PbO_2), and that of the negative plate is spongy lead (Pb).

On discharge, the sulphuric acid electrolyte combines with the lead in the active material of both positive and negative plates, and lead sulphate ($PbSO_4$) is formed on their surfaces.

As discharging continues, the active material in both positive and negative plates continues to be changed into lead sulphate. The electrolyte becomes diluted by the loss of acid during the chemical change, and the formation of water by the combination of the hydrogen (H) and oxygen (O) in the cell.

On charge, the electrolysis created by the charging current, converts the active materials into lead peroxide at the positive plates, into spongy lead at the negative plates, and the sulphate from the plates combines with the water to form sulphuric acid.

As a matter of interest the chemical changes are shown in the following equation -

$$\underset{(+\text{ ve plate})}{PbO_2} + \underset{(-\text{ ve plate})}{Pb} + 2H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} \underset{(\text{both plates})}{2\,PbSO_4} + 2H_2O.$$

The chemical changes indicated do not extend to the limit of the available material, the discharge being stopped before the whole of the active material is wholly converted to lead sulphate, and the charge being stopped before the positive and negative plates are wholly converted to their original active materials.

There is therefore a small amount of lead sulphate present on both plates, but the amount is a small percentage of the whole, when the cell is in a charged condition.

Towards the end of the charge, all of the charging current is not employed in converting the sulphation of the plates into active material, with the result that electrolysis of the water in the electrolyte occurs. Oxygen is liberated at the positive plates, whilst hydrogen is evolved at the negative plates.

6.10 **Testing Accumulator Cells.** The charged or discharged condition of an accumulator cell, is indicated by the colour of the positive plate, the voltage, or the strength (specific gravity) of the electrolyte.

(i) In a fully charged cell, the positive plate is a dark chocolate brown colour (caused by the presence of lead peroxide), and the negative plate is light grey (the original lead colour).

(ii) The voltage of a fully charged accumulator cell is about 2.2 volts. This falls rapidly when the cell is first discharged, and normally remains steady at about 2 volts. When the cell is almost completely discharged, the voltage again begins to fall; and at about 1.85 volts, the cell is considered discharged. For calculation purposes, the e.m.f. of an accumulator cell is regarded as 2 volts, irrespective of its size.

(iii) Specific Gravity is the ratio between the weights of equal volumes of a substance and water.
Due to the chemical action, the proportion of sulphuric acid (specific gravity 1.8), to water (specific gravity 1.0) in the electrolyte, and, therefore, the specific gravity of the electrolyte, gradually increases during charge and decreases during discharge.
The specific gravity of the electrolyte of a fully charged cell is about 1.215 for open type cells; and about 1.280 for enclosed type cells.
When the specific gravity falls to about 1.175, the cell is considered to be discharged and needs charging. For a constant discharge, the specific gravity falls linearly with time.

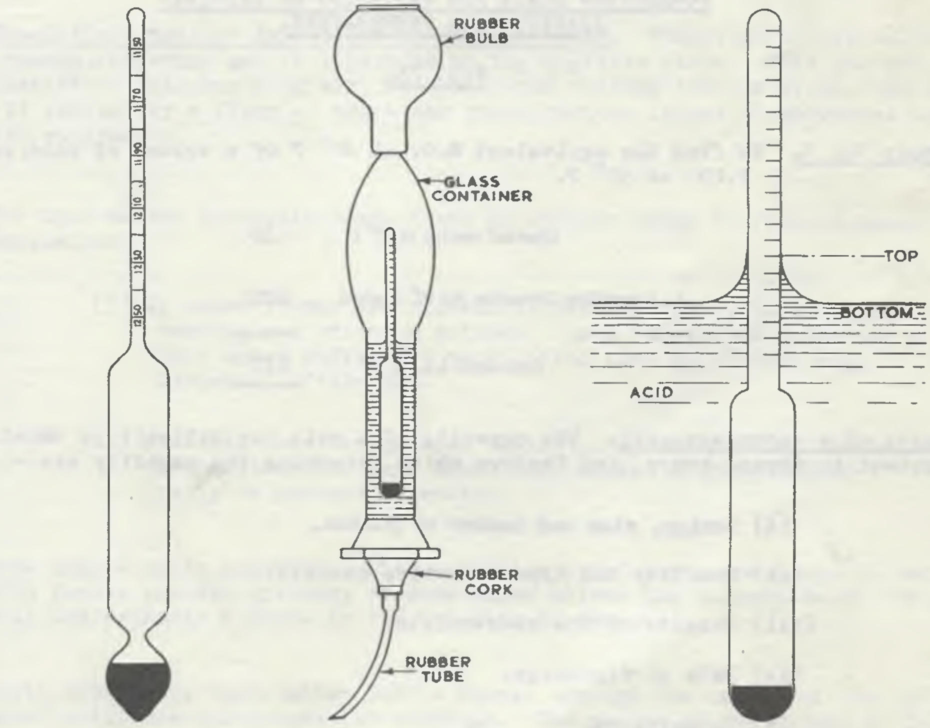
★ 6.11 The hydrometer. There is a direct relationship between the state of charge of the cell and the specific gravity of the electrolyte. In practice, the standard way to test the condition of a cell is to measure the specific gravity of the electrolyte with a hydrometer. Two types commonly used, are -

(i) The floating hydrometer, (Fig. 22a), used with open type cells. It consists of a glass tube with a calibrated scale and a weighted bulb at the lower end. It is placed in the electrolyte of the cell, and sinks more or less into the solution depending on the specific gravity, which is read directly from the scale.

(ii) The syringe hydrometer, (Fig. 22b), used with enclosed type cells, and also with open type cells where the separation between plates is small. The hydrometer float is contained in the enlarged portion of a glass cylinder, which has a rubber tube at the bottom and a rubber bulb at the top by means of which acid is sucked in it from the cell under test. After the reading is taken, the acid is restored to the cell.

6.12 How to read the hydrometer. To simplify records, and for convenient reference, the specific gravity is multiplied by 1,000 and the hydrometer scales marked accordingly. Thus, when the hydrometer reads 1215, the specific gravity is 1.215.

When taking hydrometer readings, the electrolyte clings to the stem of the hydrometer at the surface. This is called the meniscus. To avoid errors, always read to the bottom of the meniscus (Fig. 22c).



(a) Floating Type. (b) Syringe Type (c) Take readings to the bottom of the meniscus.

HYDROMETERS.

FIG. 22.

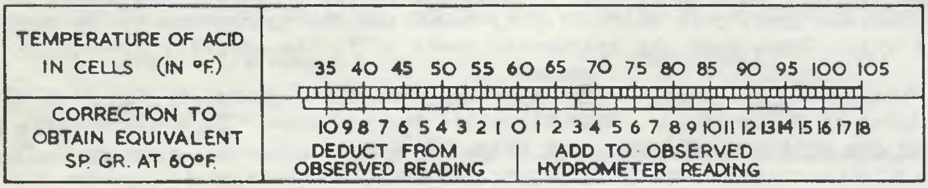
6.13 Specific Gravity temperature correction. In conjunction with specific gravity readings, a thermometer is used to record the temperature of the electrolyte, as the specific gravity of the electrolyte has a large temperature coefficient, and all readings must be corrected for temperature.

A temperature increase decreases the specific gravity; a temperature decrease increases the specific gravity.

For temperatures above or below 60° F, a correction factor of 1 point specific gravity variation for each 2.5° F temperature variation, is applied.

When the temperature is above 60° F, the correction is added to the observed reading, and when below 60° F, the correction is subtracted.

Fig. 23 shows a correction scale and Example No. 1 shows how the scale is used.



CORRECTION SCALE FOR VARIATION OF SPECIFIC GRAVITY WITH TEMPERATURE.

FIG. 23.

Example No. 1. To find the equivalent S.G. at 60° F of a volume of acid, reading 1.203 at 90° F.

Observed reading at 90° F	1.203
Temperature Correction for 90° F added	0.012
Equivalent S.G. at 60° F	1.215

6.14 Capacity of a secondary cell. The capacity of a cell (or battery) is usually expressed in ampere-hours, and factors which determine the capacity are -

(i) Design, size and number of plates.

(ii) Quantity and type of active material.

(iii) Density of the electrolyte.

(iv) Rate of discharge.

(v) Temperature.

6.15 Efficiency of a secondary cell. The ampere-hour efficiency of a secondary cell (or battery), is the ratio of the quantity of electricity available during discharge, to the quantity of electricity required during charge, to restore the components to the fully charged state.

6.16 Internal Resistance of Secondary Cell. The internal resistance of a secondary cell (or battery) varies with -

(i) size and number of plates,
(ii) distance between the plates,
(iii) type of separator,
(iv) state and rate of discharge of the cell,
(v) the temperature of the electrolyte.

Cells in good condition, with glass tube separators, and a plate separation of half-an-inch, have a resistance of the following order -

$$\mathrm{Rb} = \frac{N}{4C}\ \mathrm{OHMS}$$

Where

R_b = Internal resistance of battery
N = Number of cells
C = Ah capacity at 10 hour rate

6.17 Precautions Against Explosions in Battery Rooms. Whilst secondary cells are on charge, hydrogen gas is liberated at the negative plate. This gas can form explosive mixtures with air, either in the battery room or within the cell, and if ignited by a flame or spark can cause serious injury to personnel and damage to equipment.

For this reason precautions are taken in battery rooms to prevent these dangerous explosions -

(i) No naked flames are allowed in battery rooms, for example, smoking and striking matches. Lead burning is permitted only after sufficient ventilation time is allowed for dispersal of the gas.

(ii) Electric arcs are guarded against, for example, all bolted connections are kept tight and covered with petroleum jelly to prevent corrosion.

Some modern cells are fitted with explosion proof vent caps (Fig. 15) which consist of a porous ceramic cylinder or dome which allows the dispersion of the gas but will not transmit a flame to the interior of the cell.

Cells with these vents often have a funnel through the centre of the cylinder for water additions and hydrometer readings. The outlet of the funnel is below the normal electrolyte level, and the explosive proofing is effective only when the electrolyte covers the outlet.

Full precautions to be observed in battery rooms are listed in E.I. POWER PLANT Batteries SP 1010 "Secondary Cells, Prevention of Explosions."

9. TEST QUESTIONS.

1. An electric cell is a device which changes .... into ....

2. State the fundamental difference between primary and secondary cells.

3. The common name for a secondary cell is ....

4. In a simple voltaic cell an e.m.f. is obtained by placing .... in an ....

5. When current flows from a voltaic cell, the visible results are ....

6. The electron flow in a conductor is termed a conduction current. The movement of ....
within a cell is termed a .... current.

7. Polarisation within a cell causes a reduction of .... and ....

8. Polarisation is caused by ....

9. To combat the effects of polarisation, a .... consisting of .... is use

10. What is meant by local action, and what is its remedy?

11. Briefly describe the construction and operation of a primary cell.

12. State the method of testing a No. 6 dry cell.

13. When the plates of a lead-acid cell are fully charged the active materials of positive and negative plates respectively are ...., and ....

14. The electrolyte of an ordinary lead-acid cell is ....

15. Briefly describe a lead-acid cell's action on discharge and charge.

16. Modern cells have enclosed type containers manufactured of (i) .... (ii) ....
or (iii) ....

17. List four types of separators.

18. Describe the basic construction of a lead-acid accumulator.

19. The state of charge of a cell is indicated by the .... of the electrolyte.

20. This is measured by a ....

21. Temperature readings of the electrolyte are also taken. Why is this necessary?

22. The temperature of the electrolyte of a secondary cell is 85°; what significance has this in the final recording of the cell's state of charge.

23. Why are precautions taken against naked flames in battery rooms?

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

MAGNETISM AND ELECTROMAGNETISM.

★ AMENDED 1962

INTRODUCTION.

1.1 In ancient times, the Greeks discovered that a certain kind of rock, found originally near the city of Magnesia in Asia Minor, had the power to attract and pick up pieces of iron. This rock was actually a type of iron ore (now called <u>magnetite</u>), which is a compound of oxygen and iron. It is dug out of the earth as a dark or brown coloured stone, and its power of attraction is called <u>magnetism</u>.

1.2 The first practical use of magnetism was probably the simple magnetic compass, which the Chinese claim to have invented about 2600 B.C. Pieces of magnetite used in the early days for navigation were called lodestones or leading stones.

1.3 Magnetism plays an important part in telecommunications. Electric motors and generators, automatic switches and teleprinters, telephone and telegraph relays, radio pick-ups and microphones, telephone receivers and loudspeakers, measuring instruments and many other items of telecom apparatus make use of magnetism in their operation. The most common method of producing electricity is by the use of magnetism.

1.4 This Paper gives some practical information about magnetism which is so necessary for modern telecommunication. As with electricity, knowledge of its exact nature is incomplete. The information about magnetism in this paper, therefore, is confined to those laws concerning the magnetic properties of substances learned through observation and to the behaviour of these substances under practical conditions.

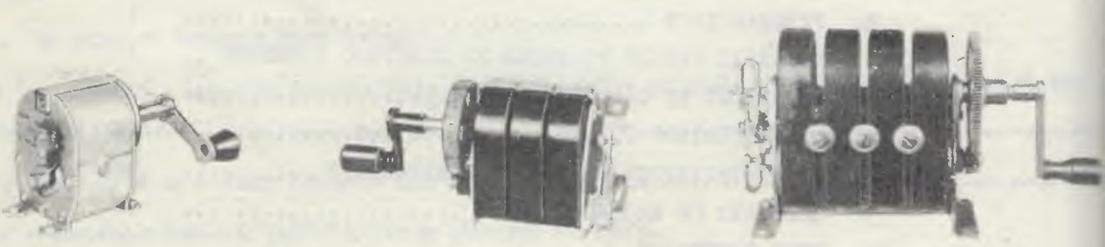
2. MAGNETIC MATERIALS.

2.1 A magnet is a substance which either attracts or repels certain other substances, called magnetic substances. The attracting and repelling property of a magnet is called magnetism. A substance which has this property is said to be magnetised.

Natural magnets are pieces of iron ore which are found magnetised in their natural state. Magnetic substances can be magnetised by artificial means, and these are called artificial magnets. Natural magnets are weak and irregularly magnetised. Artificial magnets can be made strong and evenly magnetised. All the magnets used in telecom are artificial magnets and they are of two types - either permanent magnets or temporary magnets.

2.2 Permanent magnets keep their magnetism for a long period of time unless subjected to heat or jarring, both of which may have a demagnetising effect. They are usually made of hardened steel, cobalt-steel, tungsten-steel, or of iron alloys such as alnico (aluminium-nickel-iron-cobalt), or remalloy (iron-cobalt-molybdenum).

Permanent magnets are used in telephone receivers, loudspeakers, electrical measuring instruments, generators, some types of microphones, telephone bells and many other items of telecom apparatus. A typical permanent magnet is the magnetic compass-needle - a small permanent magnet pivoted so that it can turn horizontally.



TELEPHONE GENERATORS USE PERMANENT MAGNETS.

2.3 Temporary magnets quickly lose their magnetism. They are usually made of soft iron or mild steel or of iron alloys, such as permalloy (iron-nickel), perminvar (cobalt-iron-nickel), or permendur (iron-cobalt and vanadium).

Temporary magnets are used in telecom apparatus, such as relays, electric buzzers, automatic telephone switches, etc. In practice, they get their temporary magnetism from the magnetic effect of an electric current; and are called electromagnets.

2.4 Ferromagnetic Materials. Materials such as iron, steel or cobalt which can be strongly magnetised by a weak magnetising force, are called ferromagnetic materials.

Small amounts of materials such as nickel, chromium, cobalt or tungsten are added to iron and steel to make commercial magnets having great magnetic strength and also other desirable features, as we shall see later.

Other substances, such as air, brass, copper, aluminium, zinc, and glass, are practically non-magnetic. These substances allow magnetism to go through them, however, without themselves becoming magnetised to any extent.

3. MAGNETS.

3.1 Telecom Magnets are made in various shapes, sizes and strengths but are usually in the form of a bar magnet or a horseshoe magnet.

The bar magnet is usually a straight strip or circular rod (Fig. 1a), whilst a horseshoe magnet is bent or cast in a "U" shape, to bring its ends near to each other. This shape allows both ends to combine their force of attraction upon a magnetic substance.

In some cases (for example, in some types of ammeters and voltmeters) soft iron pole pieces are added to the ends of the permanent magnet. These extend the polarities of the permanent magnet and provide an easy method of concentrating the magnetic field in any desired way. (Fig. 1b.)

A horseshoe magnet is usually in one piece, but may consist of two bar magnets joined together by a soft iron "yoke", or one bar magnet with its polarities extended by two soft iron pole pieces (Fig. 1c).

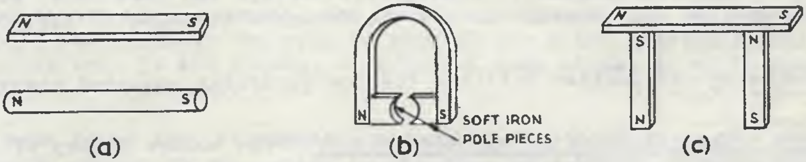


FIG. 1. SOME TYPICAL MAGNETS.

3.2 Magnetic Poles. From the effect of the earth on a bar magnet, for example, a magnetic compass, we conclude that the earth is a large natural magnet. The magnetic effects seem to be concentrated at the magnetic poles, which are points near the geographic poles.

When freely suspended or pivoted on a sharp point, a bar magnet always points in the directions of the earth's north and south magnetic poles. (Fig. 2.) The force that causes this, is due to the earth's magnetism.

Just as the earth has two poles, magnets have two poles, which are those regions of the magnet where the magnetism appears to be concentrated, usually at the ends. When a magnet is placed in a pile of iron filings, the filings cling to the ends or poles of the magnet. (Fig. 3.)

FIG. 2. A MAGNETIC COMPASS.

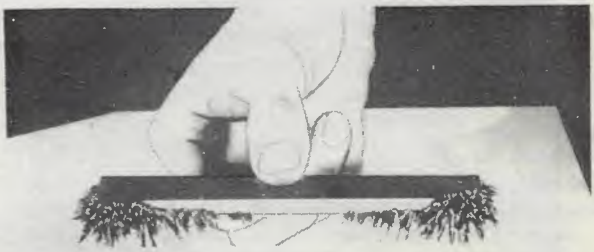


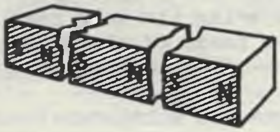
FIG. 3. THE MAGNETIC POLES OF A MAGNET.

In the region midway between the poles, the magnet shows little or no magnetism; this is the neutral zone.

The "north-seeking" pole, more commonly called the north pole (N) of a magnet, is the pole which points to the north when freely suspended. The "south-seeking" or south pole (S) is that pole which likewise points to the south.

4. WHAT IS MAGNETISM?

4.1 A simple theory of magnetism. We cannot get a magnet with only one pole; each magnet has at least two poles - a North and a South. For example, when a bar magnet is broken into two or more pieces, each piece still has a north pole at one end and south pole at the opposite end. (Fig. 4.) Why is this so?



NEW POLES APPEAR WHERE THE MAGNET IS BROKEN.

FIG. 4.

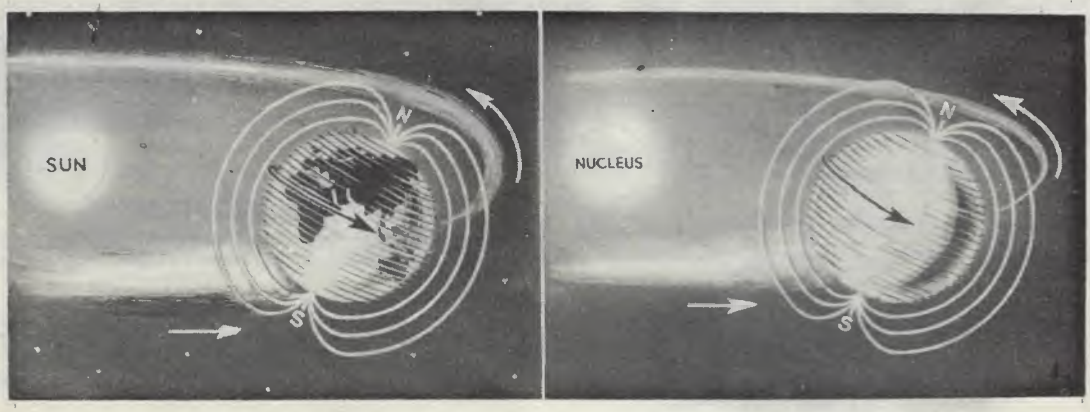
An early theory of magnetism, termed the "Molecular Theory", explained that the molecules of magnetic materials were actually small magnets in random arrangement, which would line up under the influence of a magnetising force. The material as a whole exhibited the properties of a magnet with N and S poles, and if broken would become a number of smaller magnets each with its own polarities.

We know that magnetism is not transferred from one substance to another, but is caused by some rearrangement of polarities within the substance, but it is now considered that the molecule is not the fundamental magnetic particle.

The following explanation outlines the now generally accepted theory of magnetism.

4.2 Magnetism - the effect of moving electricity. The modern theory of magnetism, explains magnetic properties as due to the movement of electrons in matter. The similarity between the magnetism produced by the permanent magnet and that produced by an electric current (Section 9) leads to the conclusion that the same cause operates in each case. Ordered electron movement constitutes an electric current, and it has been suggested that electrons spin around a certain axis in the same way as the earth spins about its axis. For the same reason, (as yet unknown) that the spinning earth has a magnetic field, it is assumed that the spinning electron, travelling in its orbit, produces a magnetic field. (Fig. 5.)

In magnetic materials, it is thought that the combined magnetic effects of the electrons allow the atom as a whole to act as a small magnet. However it is still not clearly understood why the atoms of some substances behave as magnets whilst the atoms of other substances do not.



MAGNETISM - THE SPINNING ELECTRON?

FIG. 5.

4.3 The Domain Theory of Magnetisation. As stated in para. 4.1, the early "Molecular" theory of magnetism considered that the molecule was the basic unit of magnetism, and that the state of magnetisation was the aligning of the small molecular magnets in the direction of the magnetising force.

The modern theory, mentioned in para. 4.2, where the production of a magnetic field depends on the spinning electron, is the basis of the domain theory of magnetism, and experiments support the conclusion that groups of atoms and not molecules are the effective magnetic unit in the structure of magnetic materials. A simplified explanation of the domain theory is as follows -

It has been found from experimental work that unmagnetised iron is a crystalline structure, each crystal of which contains a large number of groups of atoms. Each group of atoms is termed a "Domain", and can contain some 10^{14} atoms.

The domains are large compared with atomic sizes, and using approximate figures, there are about 100,000 such domains in each of the 10,000 crystals comprising one cubic centimetre of ordinary iron.

It appears that in the domain, the basic magnetic unit is the atom, which exhibits a magnetic field due to the spin of some of the outer electrons, but the effective unit in the iron is the domain, or group of such atoms, in which each individual magnetic axis is aligned.

It has been found that in magnetic materials, the domains can be magnetised easily in a number of directions, which in the case of a domain of iron atoms, is six directions.

In iron then, each domain exhibits the property of a tiny permanent magnet, with a north and south pole existing across two of its boundary faces. The direction of magnetisation is haphazard and can be any one of the six directions possible.

From this we can see that when the iron is not subjected to a magnetising force, the random arrangement of the domains' magnetic axes in each crystal results in an unmagnetised state of the material as a whole. When a magnetising force is applied and gradually increased, it causes the axis of magnetism within each domain to change in direction until all are aligned in a direction parallel to the applied field.

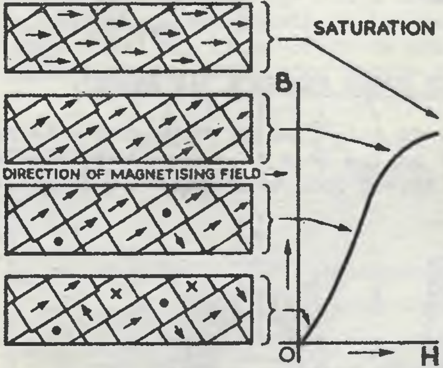


FIG. 6. THE MAGNETISATION OF DOMAINS IN PART OF A SINGLE CRYSTAL OF IRON.

Fig. 6 attempts to show this complex picture in simple form. The squares represent the domains, and the arrows, dots, and crosses, the existing direction of magnetisation within the domains. In the graph the degree of magnetisation is represented by B.

With a continual increase of magnetising force (H), the axis of magnetisation of each domain will change abruptly to a more favourable direction of easy magnetisation until all domains are magnetically aligned with the magnetising force.

These changes as they occur, result in a greater degree of magnetisation of the iron as a whole, until saturation occurs, when all domains are aligned magnetically

It has been proved that the degree of magnetisation does not increase gradually with the smooth increase of magnetising force, but rather increases in a series of jumps, corresponding to the abrupt reorientation of the magnetic axis occuring in each domain.

5. MAGNETIC FIELDS.

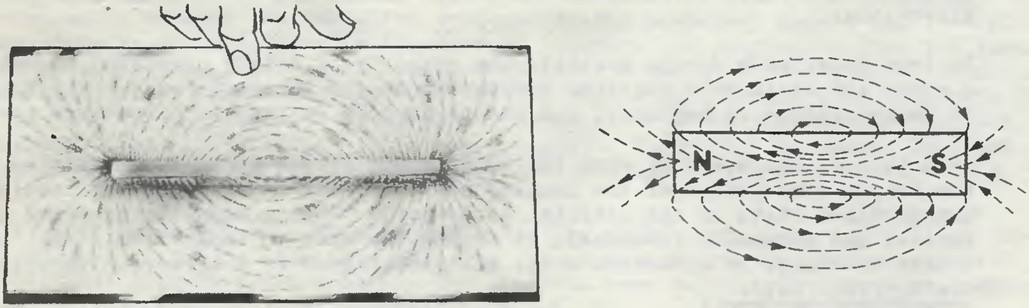
5.1 Magnetism is an invisible force and can be seen only in terms of the effect it produces. The wind, for example, provides tremendous force, yet is invisible. Similarly, magnetic force cannot be seen but its effects can be noted.

The Magnetic Field is that space in the vicinity of a magnet in which the forces of attraction and repulsion are apparent. It is most intense near the poles of the magnet and is weaker at greater distances away.

5.2 Lines of Force. Fig. 7 shows a permanent bar magnet which attracts pieces of iron and exerts a force either of attraction or repulsion on other magnets. These attracting and repelling properties are due to its magnetic field which for convenience we consider to be comprised of magnetic "lines of force".

The pattern and arrangement of these lines of force can be traced out by moving a compass needle around the magnet with the needle tracing the direction of the field's force, or by sprinkling iron filings on a glass plate, or piece of paper on the top of the magnet. The filings form a regular pattern when the glass or paper is gently tapped (Fig. 7a).

From this it is assumed that these lines of force pass through a magnet from the south to the north pole, leave the magnet at the north pole and pass outside the magnet to re-enter at the south pole, thus forming closed loops. This is indicated by the arrows on the lines in Fig. 7b, which shows the pattern of the magnetic field drawn as a map or diagram.



(a) (b)

FIG. 7. MAGNETIC LINES OF FORCE AROUND A BAR MAGNET.

Fig. 8 shows the arrangement of the filings and lines of force for a horseshoe magnet. The magnetic field is strongest at the ends of the magnet; but the external field is not concentrated and is spread generally over the length of the magnet.

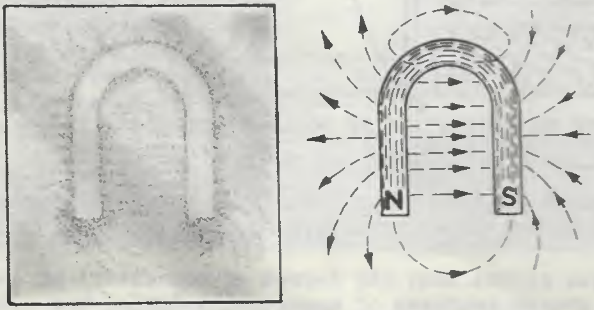


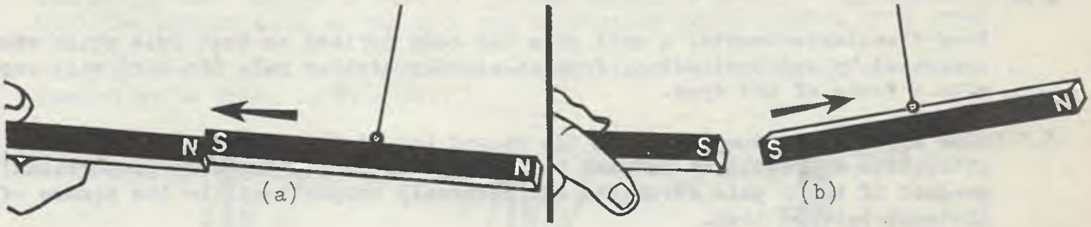
FIG. 8. MAGNETIC LINES OF FORCE AROUND A HORSESHOE MAGNET.

By convention we assume that each line of force makes a complete loop, and like a rubber band can be stretched or distorted, but tends to become as short as possible. Yet each line or loop repels adjacent lines, tending to keep them separated from each other; hence, they never cross.

Remember: This idea of lines of force is simply a convenient assumption to help understand the behaviour of magnets and magnetic substances. Although diagrams of magnetic fields usually represent the lines of force in one plane, it must be remembered that the force of the magnetic field acts throughout the whole of the space surrounding the magnet, and not just along these imaginary lines.

6. LAWS OF MAGNETISM.

6.1 Attraction and Repulsion of Magnetic Poles. From the action of one magnet toward another, it can be seen that the two poles of a magnet are unlike. For example, when a compass needle is placed in different positions near a bar magnet, the north pole of the needle is always attracted to the south pole, but repelled by the magnet's north pole. The south pole of the needle is always attracted to the north pole, but repelled by the south pole of the magnet. The same effects can be observed when the poles of two bar magnets are brought close together. (Figs. 9a and 9b).

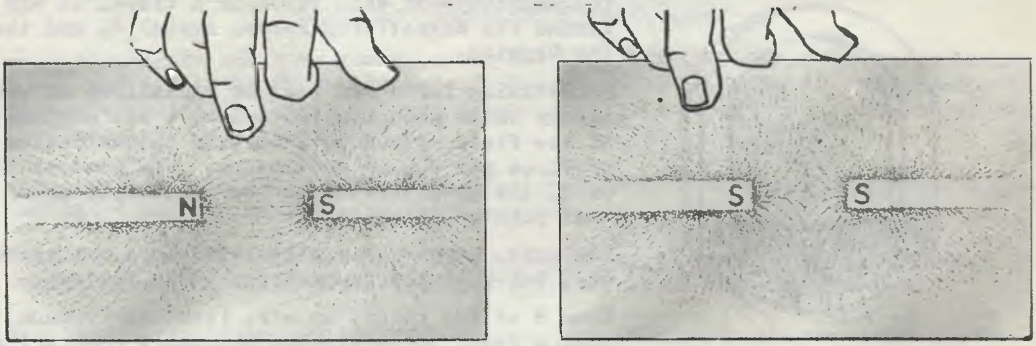


(a) (b)

FIG. 9. PROVING THE FIRST LAW OF MAGNETISM.

This attraction or repulsion between the poles is due to the aiding or opposing of the lines of force of the magnets. For example, when two bar magnets are placed end to end, and iron filings are used to map out the lines of force, the effects are as shown in Fig. 10.

With unlike poles (Fig. 10a), the lines of force from each magnet link up and tend to draw the poles together; the magnets attract one another. With like poles (Fig. 10b), the lines of force are crowded and tend to push the poles apart; the magnets repel. Repulsion occurs when we use either two north or two south poles.



(a) Unlike Poles. (b) Like Poles.

FIG. 10. AIDING AND OPPOSING LINES OF FORCE.

6.2 These effects are summarised in the First Law of Magnetism.

UNLIKE POLES ATTRACT AND LIKE POLES REPEL.

(In this respect magnetic poles behave similarly to static charges of electricity).

6.3 The full study of magnetism and electromagnetism is an extremely abstract and complex study, and a complete knowledge of its wide scope is only required in the field of design and manufacture of equipment.

In the field of telecom, generally we do not have to appreciate the mathematical approach, but it is essential to gain a clear knowledge of certain aspects, which enable us to visualise and understand the principles of operation of equipment using the principles of magnetism or electromagnetism.

To achieve this, some sections of information presented in this paper serve as an introduction to the essential information, and show how some of the terms and expressions used in magnetism and electromagnetism are arrived at.

6.4 The Unit Pole. Most calculations and formulas in magnetism and electromagnetism are based on the effects that are produced by an imagined isolated magnetic pole of a certain strength.

Experiments conducted with two very long thin magnets, which are sufficiently long so that their opposite poles can be disregarded, have shown that the force between two similar poles is inversely proportional to the square of the distance between them.

From these experiments, a unit pole has been defined as that pole which when separated by one centimetre, from an exactly similar pole (in air) will repel it with a force of one dyne.

6.5 These effects are summarised in the Second Law of Magnetism. The force (F) of attraction or repulsion between two magnetic poles, is directly proportional to the product of their pole strengths, and inversely proportional to the square of the distance between them.

Expressed mathematically:-

$$F \propto \frac{M_1 M_2}{d^2}$$

where

F = force in dynes
M_1 and M_2 = pole strengths
d = distance apart
$\propto$ = varies as

6.6 Magnetising Force (Field Strength or Field Intensity). We have learnt from Section 5, that surrounding a magnet there is a field of force which by convention is imagined to be composed of lines of force.

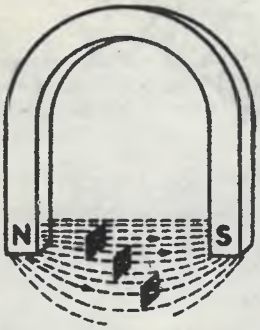


FIG. 11. MAGNETISING FORCE REPRESENTED BY LINES OF FORCE.

The magnitude of this force in a field, at any point is termed its Magnetising Force, symbol H, and the unit is the Oersted.

Magnetising force can best be visualised as being the agency which when applied across a one centimetre length of the field, produces a certain concentration of lines of force per square centimetre. The greater the value of H, the greater will be the concentration of lines at that point. (Fig. 11.)

The unit, oersted, is calculated in a rather theoretical way, but a simple explanation is as follows -

When H at any point, in air, (strictly vacuum) is of such a value as to produce through a one centimetre length of the field, one line of force per square centimetre, then the value of H is one oersted. If H produces 10 lines per square centimetre, then H = 10 oersteds, and so on.

Summarising. Existing in the air space around a magnet is a field of force which is represented by lines of force. The concentration of the lines is numerically equal to the force in oersteds at that point.

7. MAGNETIC INDUCTION.

7.1 We have seen that the force which can be exerted by a magnetic field is termed its "magnetising force", "field strength", or "field intensity". The magnetic field can also be regarded as a region of induction, since changes take place, or are induced, in magnetic materials placed within the field, due to the presence within them of a magnetic force.

For example, when we place the south pole of a bar magnet near (but not touching) an unmagnetised iron nail, the iron at once becomes a magnet by induction.

Under the influence of the magnetising field from the magnet, the polarities of the domains within the iron tend to come into the definite arrangement referred to in Section 4. A north pole is induced at the end nearest to the bar magnet, and a south pole at the other end. (Fig. 12a.)

The magnet, therefore, first magnetises the piece of non-magnetised iron by induction, and then attracts it.

Induction precedes attraction.

Similarly, when the north pole of the bar magnet is used, it induces a south pole into the nearest part of the iron and attraction again results (Fig. 12b).

Other pieces of soft iron can also be magnetised by induction and will attach themselves as shown in Fig. 12c.

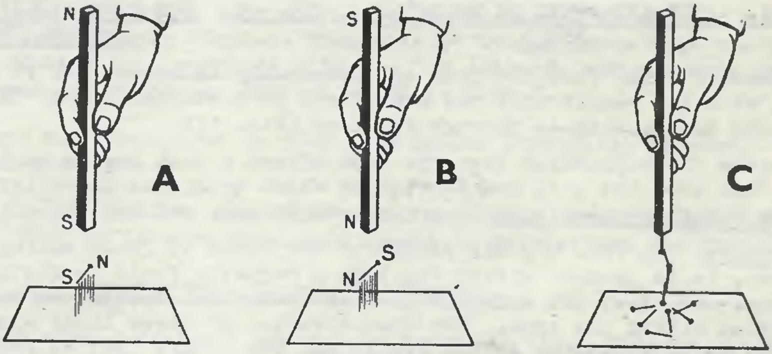


FIG. 12. MAGNETISM BY INDUCTION.

7.2 After the magnet has been removed, the nails will still possess magnetic properties, and will attract each other or other unmagnetised nails. This is due to the material still retaining some magnetic alignment, with a consequent remaining or "remanent" magnetic flux.

Remanence is a measure of the flux density left in a material after it has been saturated and the magnetising force removed.

This remaining flux is also called Residual Magnetism, a term commonly used to denote remaining flux, whether the material has been saturated or not.

When soft iron is magnetised by induction and then removed from the magnetic field, it loses much of its magnetism, but when hard steel is similarly treated, it retains much more of its magnetism. The more permeable the substance, (refer paragraph 8.1), the less the remanence or residual magnetism.

Other terms and definitions which are common to both magnetism and electromagnetism, but have more application to the latter, will be dealt with later in this Paper.

8. PERMEABILITY.

8.1 When a piece of soft iron is placed in a magnetic field, it is found by mapping with iron filings, that the field of the magnet tends to concentrate through the piece of iron rather than through the air (Fig. 13). If however, a piece of hard steel is placed within the field, there is less distortion of the field shape.

This indicates that certain materials appear to have the ability to concentrate the field within them, or to attract lines of force to them.

When the iron is placed in the magnetic field it is subjected to the inductive influence of the field, and the iron itself becomes in effect a bar magnet, possessing its own field (Fig. 14a).

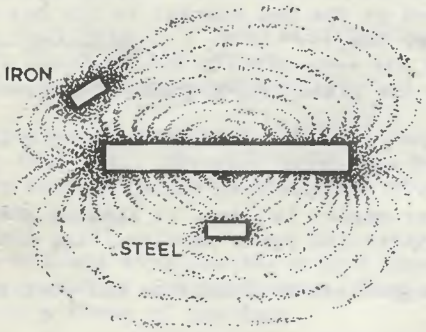


FIG. 13. IRON AND STEEL IN MAGNETIC FIELD.

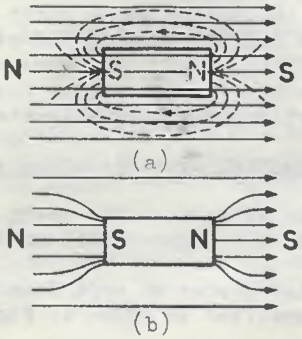


FIG. 14. THE PERMEABILITY OF IRON IS GREATER THAN AIR.

The lines of force from the iron are externally in opposition to the magnetising field, with the result that the main field is distorted due to this opposition, and tends to concentrate through the iron (Fig. 14b).

This gives the impression that the iron offers a much easier path for the lines of force than does the air, and substances which have this characteristic are said to possess a high permeability in comparison to air, and are therefore more permeable.

8.2 Flux Density. In Fig. 14 , the result of the lines of force acting inductively on the iron, is to produce within the iron a magnetic field consisting of the lines of force, and lines of magnetic flux or induction, due to the re-arrangement of polarities within the iron. The concentration of these lines within the iron measured at right angles to the field, and per square cm., is referred to as the Flux Density (Symbol B).

8.3 The Permeability of a substance (in this case iron), is a ratio of the number of lines of force through a unit area of 1 square cm. of a substance, to the number of lines through the same area when the substance is replaced by air, (strictly vacuum), providing that the field within the substance is due solely to the magnetising force (H).

$$\mu = \frac{B}{H}$$

where μ - Permeability

B - Flux Density
H - Magnetising Force

As this relationship can be expressed in terms of flux density ($B = \mu H$) we see that there must be μ times as many lines of flux permeating a region as there are lines of force.

The permeability of air, (strictly vacuum), is taken as unity, and in air, the magnetising force and flux density are numerically equal ($B \doteq \mu H$).

It will be shown later that permeability is not a constant value, but for a given material varies with magnetising force and the state of magnetisation of the material.

The unit of magnetic flux is the Maxwell and the unit of flux density is the Gauss

One gauss ≐ one maxwell per square cm.

8.4 In the preceding paras. the term, "line of force", has been applied to the magnetic field in air, and the term, "line of flux or induction" has been applied to the field produced within a material by the influence of the field.

In common practice, all of these terms mean the same thing, and it is usual to speak of the "lines of flux", or "flux lines", or simply the "flux" or "lines" from a magnet, whether the field of the magnet is acting in air, or through a magnetic material within the field. The total number of lines in a magnetic circuit is expressed by the symbol ϕ (phi).

8.5 Magnetic Screening. In electrical circuits it is often necessary to prevent a magnetic field from affecting nearby apparatus or adjacent circuits.

The apparatus requiring screening or the source of the field is usually enclosed in a can of soft iron (Fig. 15).

Most of the disturbing magnetic lines of force traverse the iron which provides a better path for the field than does air.

The thicker the iron and the greater its permeability the more perfect is the screening effect from the disturbing field.

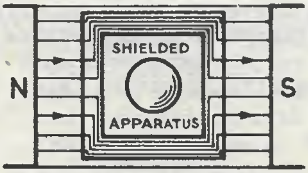


FIG. 15. PRINCIPLE OF MAGNETIC SCREENING.

9. MAGNETIC FIELD PRODUCED BY ELECTRIC CURRENTS.

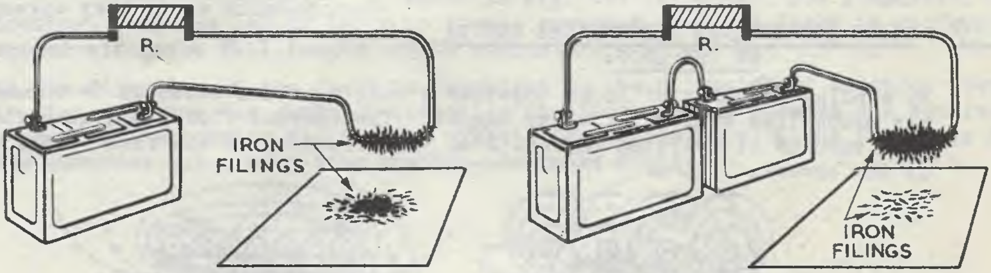
9.1 So far we have considered only the magnetism possessed by natural and artificial magnets. In the paper "Current Electricity" it was shown that one effect of an electric current is a magnetic effect - "an electric current sets up a magnetic field around the conductor through which it flows".

This effect was discovered in 1819 by a Danish physicist, Oersted, one of the electrical pioneers.

The relationship between electricity and magnetism is called electromagnetism and many items of telecom apparatus depend on this effect for their operation.

9.2 Magnetic Field Around a Wire Carrying a Current.

(i) When a wire carrying a current is buried in iron filings, it is found when the wire is lifted that some of the filings cling to its surface (Fig. 16a).



(a) (b)

FIG. 16. ATTRACTION OF IRON FILINGS TO A CURRENT-CARRYING WIRE.

When the current through the wire is increased and the experiment repeated more filings cling to the wire, (Fig. 16b). When the switch is opened the filings will fall from the wire.

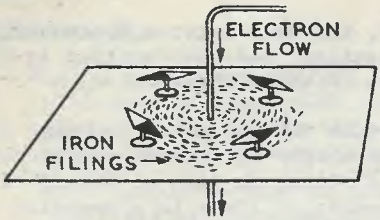


FIG. 17. MAGNETIC FIELD SURROUNDING A CONDUCTOR.

(ii) When the same piece of wire is passed through a hole in a horizontal piece of cardboard and iron filings are sprinkled on the card, the iron filings will take up a pattern of concentric rings when current flows and the card is tapped (Fig. 17).

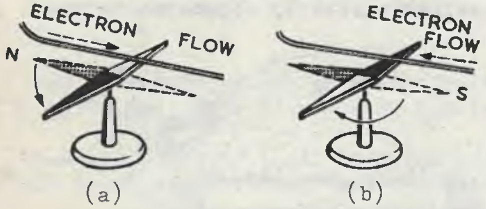


FIG. 18. COMPASS INDICATES A MAGNETIC FIELD.

(iii) When a compass needle is placed near to a conductor carrying a current the needle is deflected at right angles to the wire (Fig. 18a). When the direction of current is reversed in the wire, the compass needle swings in the opposite direction (Fig. 18b).

9.3 From these simple experiments the following conclusions are drawn:-

When a current flows in a conductor -

(i) A magnetic field is set up around the conductor.
(ii) The strength of the field depends on the value of current, being greatest at points near the conductor.
(iii) The field can be mapped in the form of concentric rings, in a plane at right angles to the conductor.
(iv) The direction of the magnetic field depends on the direction of the current.

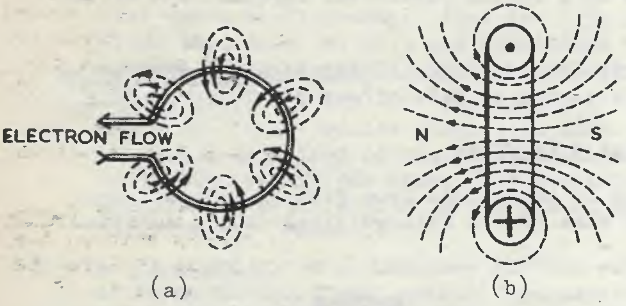


FIG. 19. LINES CONCENTRATE THROUGH THE CENTRE OF THE LOOP.

9.4 Magnetic Field of a Solenoid. If a wire or conductor is formed into a single turn or loop, and a current is passed through it, all the circular magnetic lines of force will pass through the centre of the loop as shown in Fig. 19a.

The magnetic field or field intensity within the loop is more dense than on the outside since all the lines of force are concentrated into a smaller area than outside where they spread (Fig.19b)

By winding a number of loops together a coil termed a solenoid is formed which has properties similar to a bar magnet. The current flow produces a field around each turn as illustrated in Fig. 20a, the direction of the field being indicated by the arrows.

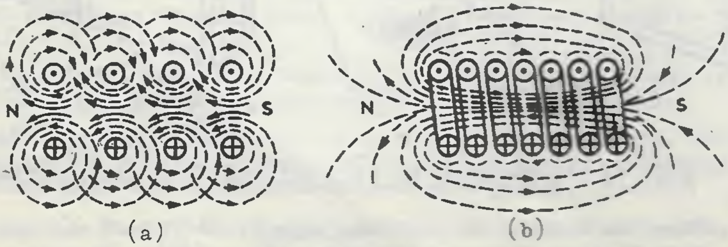


FIG. 20. FIELD OF A SOLENOID.

Within the solenoid the lines of force are in the same direction and combine to form a strong field. In the space between the adjacent turns, the lines are equal in strength but are in opposite directions and therefore neutralise one another.

The resultant field is shown in Fig. 20b, which corresponds to the field pattern of a bar magnet, possessing a North pole where the lines of force leave the coil, and a South pole where they enter.

9.5 The Strength of a Magnetic Field in a Coil. Since the magnetic field depends on the value of current, and the magnetic field of each turn of wire adds to that of the next turn, the field of a coil or solenoid is proportional to the product of the current flowing and the number of turns of wire. This product is known as Ampere-Turns.

9.6 The Effect of an Iron Core. Although the field strength of a solenoid can be increased by an increase of current or turns, these factors do not concentrate the field sufficiently. For practical use in electrical apparatus such as telephone relays, motors, and generators, soft iron or similar magnetic materials are used in conjunction with the coil windings, thereby increasing the flux density to an extent governed by the permeability of the material used.

9.7 Relationship Between Directions of Current and Magnetic Field. Since the modern conception of electricity is based on the Electron Theory and an electric current is considered to be an ordered flow of electrons from a negative potential to a positive potential, it is important to understand that the following rules are stated in terms of electron flow and are not related to conventional current flow.

The rules outlined in this course will therefore apparently be opposite to those quoted in older text books still using the conventional current theory.

9.8 How to find the Direction of the Magnetic Field. A simple way to find the relationship between the directions of the electron flow and the resulting magnetic field in a wire is -

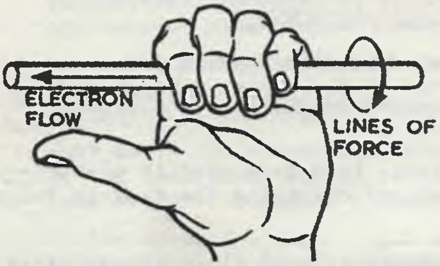


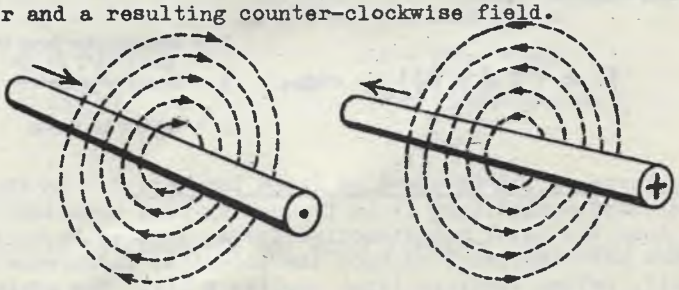
FIG. 21. USING THE LEFT-HAND RULE FOR A CONDUCTOR.

The Left-Hand Rule for a Current-Carrying Conductor. Place the fingers of the left hand around the wire so that the thumb points in the direction of electron flow. The fingers will point in the direction of the magnetic field (N to S)(Fig. 21).

Similarly, the rule can be used to find the direction of the electron flow when the direction of the magnetic field is known.

9.9 The Relationship of Current to lines of force. A simple way to draw the relationship between the directions of electron flow and lines of force is shown in Fig. 22. Although, for simplicity of drawing, only one set of loops is shown, remember that the field is uniformly spread along the full length of the conductor.

As the direction of the field is dependent on the direction of electron movement in the conductor the symbol • indicates an electron flow towards the observer and a resulting clockwise field. The symbol + indicates an electron flow away from the observer and a resulting counter-clockwise field.



(a) (b)

FIG. 22. SHOWING THE RELATIONSHIP BETWEEN LINES OF FORCE AND ELECTRON FLOW.

9.10 The Left-Hand Rule for a Coil Carrying Current. If the fingers of the left hand are wrapped around the coil in the direction of the electron flow, the thumb will point to the North Pole end of the coil (Fig. 23).

Similarly, if the polarity of the coil is known the direction of current flow can be determined by using the same rule.

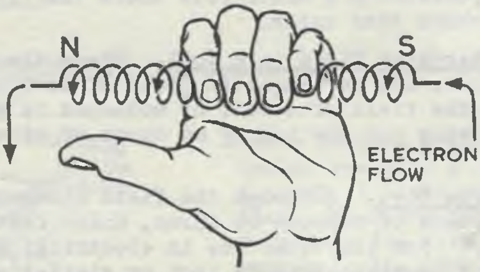


FIG. 23. LEFT-HAND RULE FOR COILS.

10. THE MAGNETIC CIRCUIT.

10.1 In the same way as the factors of an electrical circuit are related by Ohms Law, so are the factors of the magnetic circuit related to the fundamental equation -

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

When a coil of wire carries a current it generates a force (termed Magnetomotive Force), to establish a magnetic field against the opposition (termed Reluctance) offered in the magnetic circuit. Thus the equivalent of Ohms law in a magnetic circuit is expressed as follows -

$$\phi = \frac{F}{S}$$

where

ϕ = magnetic flux in Maxwells.

F = magnetomotive force in Gilberts.

S = reluctance (no units).

10.2 Magnetomotive Force in the practical application, is a term used in electromagnetism, and is the force which establishes and maintains the flux in the magnetic circuit.

It is analagous to e.m.f. in the electrical circuit since it forces magnetic flux through the magnetic circuit.

Experiments show that the total magnetomotive force of a coil (symbol F), is proportional to the product of turns on the coil, and the current carried.

One unit of magnetomotive force is the Ampere-turn, which is the F developed by one ampere flowing through one turn of wire.

Another unit of magnetomotive force is the Gilbert which is equal to the F of $\frac{1}{0.4\pi}$ of one ampere turn.

$$F = 0.4\pi NI.$$

where

F = magnetomotive force in Gilberts

N = number of turns

I = current in amperes

10.3 Magnetising Force (Field Strength or Field Intensity). In the application of magnetism and electromagnetism, it is frequently more important to know the magnetising force than the total magnetomotive force, just as in an electrical circuit it is sometimes more important to know the potential difference across various parts of a circuit, rather than the total applied e.m.f. The analogy is therefore, that in comparison to an electrical circuit, magnetomotive force can be likened to the applied e.m.f., whilst the magnetising force is compared with a potential difference across one part of the circuit.

From Section 6, we found that an H of one oersted at any point in air produces through a one centimetre length, one line of force per square centimetre.

The oersted has the same application in the field of an electromagnet, and related to magnetomotive force, is another name for Gilberts per centimetre length of the magnetic circuit.

$$H = \frac{F}{l}$$

where

H = magnetising force in Oersteds
F = magnetomotive force in Gilberts
l = length of magnetic circuit in cm.

10.4 Reluctance is the opposition offered by a magnetic circuit to the establishment of a magnetic field.

It is analogous to resistance in the electrical circuit, for just as the resistance of a circuit has been expressed as -

$$R = \frac{\rho l}{a}$$

where

R = resistance in ohms
ρ = specific resistance
l = length
a = cross-sectional area.

So is Reluctance expressed as -

$$S = \frac{l}{\mu a}$$

where

S = reluctance
l = length
a = cross-sectional area
μ = permeability.

In the analogy used, although specific resistance represents a proportional increase of resistance in the electrical circuit, permeability represents a proportional decrease in reluctance of a magnetic circuit, since it expresses the ease of establishment of a magnetic flux.

Also, since permeability is not a constant, but generally varies with each flux density, the reluctance of the magnetic circuit depends upon the condition of operation of the magnetic materials within it.

Just as in the electrical circuit, where the total resistance depends on the sum of the individual series resistances, the total reluctance of a magnetic circuit consists of the sum of a number of separate reluctances.

In the case of a magnet with extended pole pieces and an air gap, the reluctances of the magnet, the pole pieces, and the air path, must be added together to give the total reluctance.

10.5 It is beyond the scope of this course to show the derivations of all equations as most are rather theoretical.

However as a matter of interest, the total magnetic flux of a magnetic circuit is stated as follows -

$$\phi = \frac{4\pi N I \mu a}{10 l}$$

where

ϕ = flux in maxwells
N = number of turns
I = current in amps
a = cross-sectional area
l = length
μ = permeability

This expression is derived from the three formulas previously expressed, namely -

$$S = \frac{l}{\mu a}, \quad \phi = \frac{F}{S}, \quad \& \quad F = 0.4\pi NI \text{ Gilberts.}$$

11. MAGNETISATION CURVES.

11.1 When a piece of magnetic material, for example, iron is placed within the field of a permanent magnet, the flux density is increased to an extent governed by the permeability of the iron.

When the iron is placed within a magnetic field which can be varied in intensity (as would be the case if it were the core of a solenoid), the flux density in the iron will vary with a change in magnetising force.

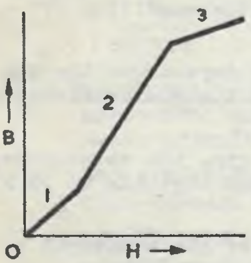
The relationship between flux density and magnetising force can be plotted as a graph, called a "magnetisation" or B-H curve, which has three basic stages (Fig. 24).

The stages, in terms of the "Domain Theory" (Section 4), are as follows -

(i) For a small magnetising force there is no change in the direction of magnetisation of the domains, excepting those nearest in direction to the applied force. The iron will therefore be magnetised to a small degree.

(ii) As the magnetising force increases, the direction of magnetisation of the domains changes abruptly, one by one, to a more favourable direction of easy magnetisation. This results in a greater degree of total magnetisation.

(iii) When each crystal of the iron is magnetised completely in the direction of magnetisation nearest to the direction of the magnetising force, the bend, or "knee" of the curve is reached. A further increase of magnetising force changes the direction of magnetisation slowly and smoothly until it is parallel to the field. At this stage maximum magnetisation occurs and the iron is said to be magnetically saturated.



STAGES OF MAGNETISATION.

FIG. 24.

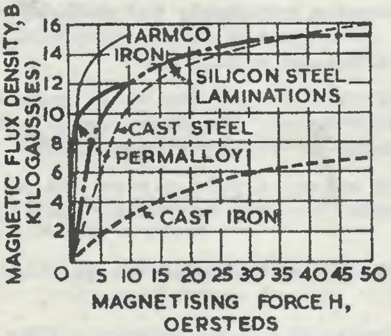


FIG. 25.

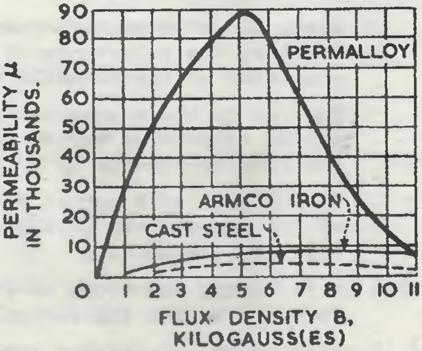


FIG. 26.

11.2 Typical B-H curves for cast iron, cast steel, silicon steel, armco iron, (a pure commercial iron) and permalloy (a nickel iron alloy), are shown in Fig. 25.

The curves show that the magnetic flux density (B) for low values of magnetising force (H) is very much greater in the permalloy than in the armco iron, which makes permalloy useful in telecom work where small values of magnetising force are usual.

11.3 The permeability curves of Fig. 26 have been plotted from data obtained from the B-H curves of Fig. 25 and serve to show the behaviour and comparisons between magnetic materials under working conditions.

If a magnetising force H were applied to an ideal (unfortunately purely imaginary) magnetic material, the flux density of the material would vary directly with a wide range of applied magnetising forces, but this ideal state does not exist and the permeability is dependent on the flux density at which the material is operated.

11.4 Hysteresis. When a piece of iron is subjected to a varying magnetic force the magnetism produced lags behind the magnetising force. This effect is termed Hysteresis. Fig. 27 shows graphically the magnetic effects produced in a piece of soft iron when it is subjected to a complete magnetisation cycle, firstly being saturated in one direction and then in the opposite direction.

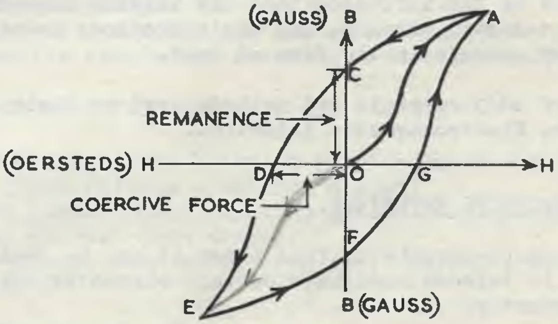


FIG. 27. TYPICAL HYSTERESIS LOOP.

The magnetising force H is increased from zero to a value at which saturation occurs in the iron, and the results are plotted in the form of the curve (OA), which is the familiar B-H curve discussed in paragraph 11.1.

On reduction of the magnetising force, the curve of demagnetisation will not correspond to OA, as owing to the retentivity of the material, there will be a remanent value of flux density in the material, represented by OC. To reduce this flux value to zero, the magnetising force must be applied in the opposite direction as represented by OD.

The further increase of H to saturate the material in the opposite direction (E) and its subsequent reduction to zero, again results in a remanent value of flux, OF.

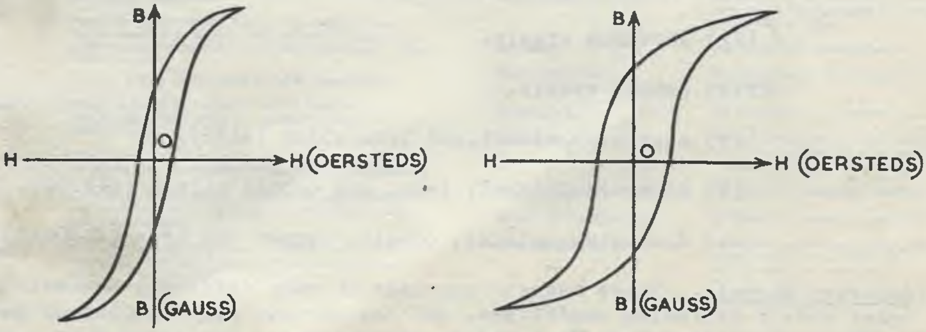
The application of a reversed magnetising force OG finally reduces the remanence to zero, and the continued increase of H completes graphically the closed loop indicating hysteresis.

The electrical energy used up in changing the magnetisation of the iron is known as hysteresis loss and is supplied by the magnetising winding.

For any material, the area of the hysteresis loop indicates the extent of the hysteresis loss, which appears within the material in the form of heat.

The value of reversed magnetising force necessary to reduce the remanent flux value to zero, is termed the coercive force, and is represented graphically by OD and OG.

Hard steel is less permeable than iron and requires a greater magnetising force for saturation. Since it has a higher remanence after saturation, the coercive force for demagnetisation must be greater than that required for iron and the hysteresis loop for steel will therefore be of a greater area than that for iron, indicating a greater hysteresis loss (Fig. 28).



(a) Soft Iron.

(b) Hard Steel.

FIG. 28. HYSTERESIS LOOPS FOR SOFT IRON AND HARD STEEL.

11.5 Eddy Currents. In addition to the loss of energy in magnetic circuits caused by Hysteresis, another form of loss is caused in the magnetic circuit by the flow of circulatory currents called Eddy Currents.

These are caused by the influence that the varying magnetic flux has on the components of the magnetic circuit, and their presence denotes a loss of efficiency and energy which appears in the form of heat.

The formation of eddy currents and methods used in their control will be explained in the paper, Electromagnetic Induction.

12. CHARACTERISTICS OF MAGNETIC MATERIALS.

12.1 From the preceding paragraphs of this paper it can be seen that the magnetic materials used in telecom must have certain characteristics to perform their functions efficiently.

Design characteristics, and manufacturing problems and processes are beyond the scope of this course, but we can examine the required basic characteristics by dividing the magnetic materials into two categories, as described in Section 2.

(i) Permanent Magnets.

(ii) Temporary Magnets.

12.2 Permanent Magnets. The magnetic state of the permanent magnet is determined by the properties of the material of which it is made, the dimensions of the magnet, its pole pieces, and the magnetising procedure.

Its function is to maintain magnetic flux in a magnetic circuit of which it is a part.

The permanent magnet must be capable of retaining a constant magnetomotive force indefinitely, and be able to withstand the effects of mechanical shock, vibration and stray magnetic fields all of which tend to demagnetise it.

In relation to the purpose for which the magnet is designed, its material must therefore possess -

(i) High value of Remanence.

(ii) High value of Coercive Force.

Typical permanent magnets are made from -

(i) Tungsten steels.

(ii) Chromium steels.

(iii) Cobalt steels.

(iv) Aluminium, nickel, and iron alloy (ALNI).

(v) Aluminium, nickel, iron, and cobalt alloys (ALNICO).

(vi) Aluminium, nickel, cobalt, copper and iron (ALCOMAX).

12.3 Temporary Magnets. These magnets are used in many different magnetic circuits and under widely differing conditions, and the various combinations of materials used in their manufacture are designed to give magnetic qualities which are suitable for a specific purpose.

Throughout this course the magnetic requirements and qualities of the various materials will be given in relation to their particular function in telecom, but in general temporary magnets are required to possess the following qualities.

(i) High values of flux density for low values of magnetising force (high permeability).
★ (ii) Low values of remanence and low coercive force.
(iii) High specific electrical resistance to limit eddy currents.

Typical materials used for temporary magnets are -

(i) Pure Commercial irons (Swedish iron or Armco Iron).
(ii) Stalloy (iron silicon aluminium alloy).
(iii) Permendur (iron cobalt vanadium alloy).
(iv) Permalloy (nickel iron alloy).
(v) Mumetal (nickel iron alloy with small percentages of copper and manganese).

13. Glossary of Magnetic Terms.

Air Gap.	A non-magnetic discontinuity in a ferromagnetic circuit whether filled with air, brass, wood, or any other non-magnetic material.
Ambere-Turn (I.T.)	A unit of magnetomotive force. It is a product of the number of turns on a coil and the current in amperes through it.
C.G.S. System.	A system of physical constants, of which the centimetre, gram, and second, are the fundamental units.
Coercive Force (Hc).	The magnetomotive force which must be applied to a magnetic material in a direction opposite to the residual induction to reduce the induction to zero.
Diamagnetic.	A term applied to a substance which has a permeability less than unity.
Domain.	The smallest possible magnet in a magnetic material.
Dyne.	A unit of force. It is the force which acting on a mass of 1 gram for one second, gives it a velocity of one centimetre per second.
Eddy Current.	A current induced in a conducting body by a varying magnetic field.
Electromagnet.	A solenoid with a ferromagnetic (generally iron) core.
Flux.	The term applied to the physical manifestation of the presence of magnetic induction.
Flux Density (B).	The number of lines of flux (Maxwells) per square centimetre in a section, normal to the direction of the flux. Unit: Gauss.
Flux Leakage.	The portion of the flux which does not pass through the useful part of the magnetic circuit.
Flux Linkage (ØN).	The product of the number of turns in a circuit by the average value of flux linked with the circuit.
F.P.S. System.	A system of physical constants, of which the foot, pound, and second, are the fundamental units.
Fringing Flux.	The flux which extends beyond the working area in the air gap of a magnetic circuit.
Gauss.	Unit of flux density. One gauss equals one maxwell per square centimetre.
Gilbert.	A unit of magnetomotive force. The magnetomotive force required to produce one maxwell of magnetic flux in a magnetic circuit of unit reluctance. Also defined as - F or M.M.F. in Gilberts $= 0.4\pi$ ampere turns.
Hard Magnetic Materials.	Refers to magnetic materials which are not easily demagnetised (for example, permanent magnet materials).
Hysteresis.	Term applied to the tendency of a magnetic material to persist in any magnetic state that already exists.
Hysteresis Loss.	The dissipation of energy expended in magnetising and demagnetising a ferromagnetic material through one complete cycle.
Hysteresis Curve or Loop.	Graphical representation of the relationship between the H and resultant B of a ferromagnetic material, when H is carried through a complete cycle.
Keeper.	A piece of magnetically permeable material placed between the poles of a permanent magnet to reduce the demagnetising effects.
Kilogauss.	One kilogauss equals 1000 gauss.
Line of Force.	A line drawn in a magnetic field such that its direction at every point is the direction of the magnetic force at that point.
Line of Flux.	A line drawn in a magnetic field such that its direction at every point is the direction of the magnetic flux at that point.
Magnetic Circuit.	The complete path followed by the useful magnetic flux.
Magnetic Field.	A region where a magnetic effect can be detected.
Magnetic Flux (Ø).	Generally considered to be the total number of lines of magnetic force or induction existing in a magnetic circuit.
Magnetic Poles.	Those portions of a magnet from which the external magnetic effects seem to emanate.
Magnetising Force (H).	The magnetomotive force per unit length at any given point in a magnetic circuit. It may be defined in ampere-turns or in the C.G.S. units, oersteds.
Magnetomotive Force (F). (Sometimes M.M.F.)	The force which produces or tends to produce a magnetic flux. It is the work required to carry a unit magnetic pole around the magnetic circuit against the magnetic field. Unit: Gilbert or Ampere-Turn.
Maxwell.	The C.G.S. unit of magnetic flux. It is the flux produced by an M.M.F. of one gilbert in a magnetic circuit of unit reluctance. Also defined in terms of induced e.m.f. as follows:- One volt potential is produced when a conductor cuts 10^8 maxwells per second.
Oersted.	The C.G.S. unit of magnetising force.
Paramagnetic.	A term applied to a substance which has a permeability greater than unity.
Permeability (μ)	The ratio of the magnetic flux density produced in a medium to that produced in a vacuum by the same magnetising force.
Permeance.	The reciprocal of reluctance.
Reluctance (S).	The property of the magnetic circuit to resist magnetisation.
Reluctivity.	The reciprocal of permeability.
Remanence.	The maximum induction which remains in the material after being magnetised to saturation and the external magnetising force removed.
Residual Magnetism.	Any value of remaining induction.
Soft Magnetic Materials.	Ferromagnetic materials which are easily demagnetised.
Unit Magnetic Pole.	A pole of such strength that when situated one centimetre away from a similar pole in a vacuum repels it with a force of one dyne.

14. TEST QUESTIONS.

1. A magnet is a substance which .... or .... other magnetic substances.

2. What is the difference between natural and artificial magnets?

3. The two types of artificial magnets are (i) .... (ii) ....

4. What is the main characteristic of ferromagnetic materials?

5. The two poles of a magnet are designated ...., and are those regions where ....

6. Describe how a magnetic field may be plotted.

7. State the characteristics of lines of force.

8. In magnetism, like poles .... unlike poles ....

9. The second law of magnetism, expressed mathematically, is ....

10. The symbol and unit of magnetising force are respectively .... and ....

11. Explain the term, magnetic induction.

12. What is meant by (i) Remanence (ii) Residual Magnetism.

13. Sketch and explain the reason for the shape of a plotted magnetic field after a piece of soft iron is placed in it.

14. Define permeability. IS THE RATIO

15. The unit of magnetic flux is .... FM

16. Define Flux Density.

17. Briefly outline the principle of Magnetic Screening.

18. With the aid of sketches, show how the magnetic field of a current-carrying conductor depends on the direction of current.

19. Sketch and describe the magnetic field of (i) a loop of wire (ii) a solenoid.

20. The strength of the magnetic field of a coil depends upon ....

21. Show the relationship between the direction of current, and magnetic field of a conductor. LEFT

22. How can the N pole of a coil be found? LEFT HAND

23. Using an analogy from an electrical circuit, describe the factors of a magnetic circuit. FMM = MAGNETISING FORCE
RES = RELUCTANCE
CURRENT -

24. Sketch and describe a basic B-H curve, in terms of the Domain Theory of magnetism.
SKETCH A HYSTERISIS LOOP &

25. Fully describe what is meant by hysteresis.

26. Outline the desirable features of a permanent magnet. REMAIN PERMANENT

27. The three general qualities required in a temporary magnet are (i) LOW CO FORCE (ii) LOW REMAN (iii) HIGH PERMIBILITY

28. List four typical materials used for temporary magnets.

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

ELECTROMAGNETIC INDUCTION

INTRODUCTION.

1.1 The close relationship that was found to exist between electricity and magnetism, convinced many early experimenters that magnetism could be converted into electricity. In 1831 Faraday succeeded in obtaining an electric current by the use of a changing magnetic flux and formulated the principles of the production of a current by this means.

It is largely due to his pioneering work that we now enjoy the benefits of commercial electric power.

In this paper we will examine the principles and laws of Electromagnetic Induction, and their application to Telecom.

2. INDUCED E.M.F's. AND CURRENTS.

2.1 Faraday's experiments investigating the relationship between electricity and magnetism, resulted in the formulation of his law of electromagnetic induction, which can be stated as follows -

> "When relative motion exists between a magnetic field and a conductor, an e.m.f. is induced in the conductor, and when the circuit is closed a current flows".

For example, Fig. 1 shows a coil of wire wound on a circular former; 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.

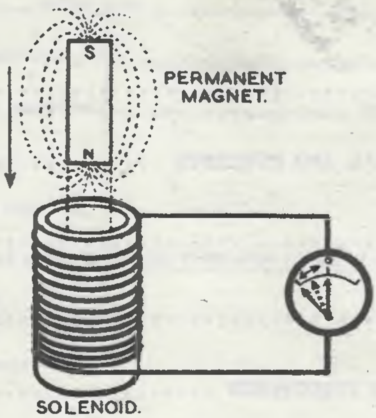


FIG. 1. RELATIVE MOVEMENT INDUCES AN ELECTRIC CURRENT.

When the S pole is inserted, a momentary deflection of the needle occurs in the same direction as when the N pole is withdrawn. Conversely when the N pole is inserted, a deflection occurs in the same direction as when the S pole is withdrawn.

When the coil is moved, and the magnet is stationary, these same induced effects occur. There is, therefore, a relationship between the relative movement and the direction of the resultant e.m.f. and current, as we shall see later.

The principle of this action, which is the basis of Faraday's Law, is that the magnetic field moves with the magnet, and when the magnet is inserted into the coil, the lines of force comprising the magnet's field "link" or "cut" the turns of the coil. This "cutting" sets up an induced e.m.f. across the coil, and a resultant current passes through the completed circuit of coil and meter.

The current only occurs when the magnet or coil is in motion; as soon as the magnet or coil comes to rest, the current stops.

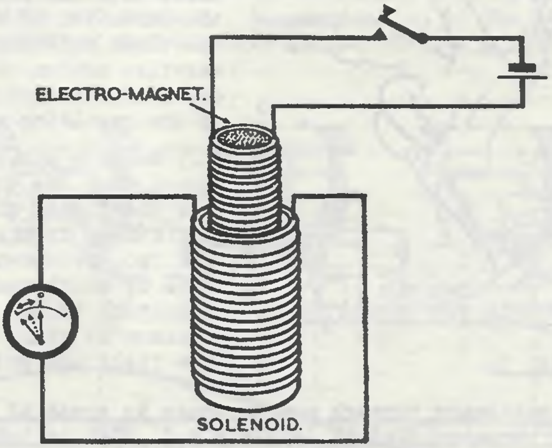
The value of induced e.m.f. and resultant current flow is dependent upon -

(i) The field strength of the magnet; the stronger the field, the greater is the induced effect.
(ii) The number of turns on the coil; an increase in turns increases the induced effect.
(iii) The speed of "cutting"; the faster the relative motion, the greater is the induced effect.

Remember, the induced effect is only transient; it lasts only while the magnet or coil moves.

2.2 When an energised electromagnet is substituted for the permanent magnet, as shown in Fig. 2, similar results are obtained.

Further, when the electromagnet is placed in the coil and a means (for example, a switch) provided to stop and start the current through the electromagnet, a current is induced in the coil without movement of the electromagnet.



ANOTHER METHOD OF INDUCING AN ELECTRIC CURRENT.

FIG. 2.

The closing of the circuit of the electromagnet allows current to flow. This current creates a magnetic field, and as the lines of force are established and expand, they cut the turns of the coil. When the circuit of the electromagnet is opened, the field collapses and the lines of force cut across the turns of the coil in the opposite direction.

As we shall see later, 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.

2.3 We can summarise these effects in the following way -

An induced e.m.f. will occur when -

(i) Relative motion occurs between a magnet and a coil.

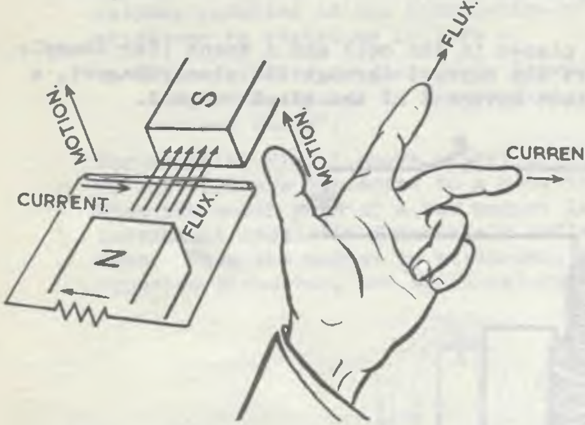
(ii) Relative motion occurs between an energised electromagnet and a coil.

(iii) The current in an electromagnet is stopped, started or varied, and

The magnitude of the induced effect varies as the strength of the magnetic field, and the rate of movement.

These principles are the basis of Electromagnetic Induction, and experiments prove that there are definite relationships between the factors producing it.

2.4 Left Hand (Electron) Rule (for Generators). We found in paragraph 2.1 that ther is a definite relationship between the direction of motion, direction of magnetic field, and the direction of the induced current. This can be determined by the Left Hand Electron Rule (Fig. 3).



LEFT HAND ELECTRON RULE FOR GENERATORS.

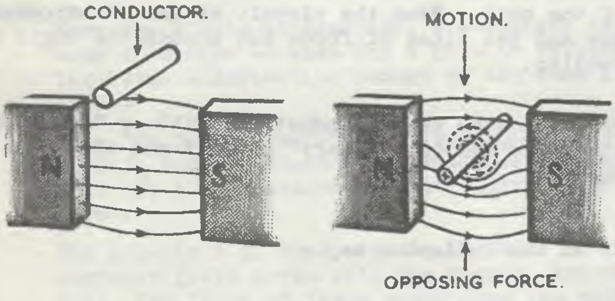
FIG. 3.

When the thumb, first, and second fingers of the left hand are held at right angles to each other like the three boundaries at the corner of a cube, with the first finger pointing in the direction of the field (N to S), the thumb pointing in the direction of relative motion of the conductor, then the second finger indicates the direction of the resulting e.m.f. and current.

2.5 Maximum e.m.f. and current are induced when the direction of motion, and the field, are at right angles. Variations from a right angle between the two, produces a variation in the rate of cutting, and consequently in the magnitude of the induced effect, from maximum at right angles, to zero when the field and motion are parallel.

Although it is customary through common usage to speak of induced currents, it is important to remember that it is the e.m.f. that is induced; a current flow will result if the circuit conditions are suitable.

2.6 Lenz's Law. We have seen that relative motion between lines of force and a conductor produces an induced e.m.f., and if the circuit is closed, a current. However, an examination of the following conditions shows that the magnetic effect of the induced current tends to oppose the originating motion.



(a) (b)

FIG. 4. PRINCIPLE OF LENZ'S LAW.

With the conductor at rest, there is no induced effect, and no magnetic field around the wire, the only field present being due to the permanent magnet (Fig. 4a).

When the wire is moved downwards into the permanent magnet's field, an e.m.f. is induced, and the flux produced by the resultant current, combines with the magnet's field to produce a magnetic effect which opposes the motion of the conductor into the field (Fig. 4b).

From similar experiments, Lenz, a Russian physicist, formulated his law, which is expressed as follows -

Induced currents (and e.m.f's.) are always in such a direction, that their effects tend to oppose the motion which produces them.

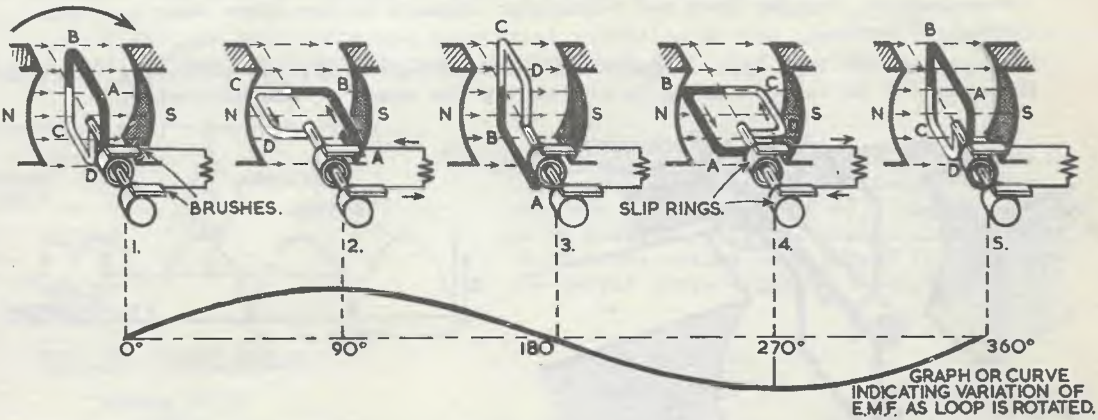
An electric current possesses energy, and a current can only appear through the expenditure of some form of energy, which is in this case mechanical. From this it follows that the greater the induced current, the greater will be the opposition to its creation, and the greater will be the expenditure of energy necessary to produce it.

Both Lenz's and Faraday's laws are important in Telecom theory, and have a wide application in all forms of electrical apparatus.

3. GENERATORS.

3.1 A.C. Generator (Alternator). This generator uses the principle of induction, and a coil of wire is mechanically rotated in the field produced by a permanent magnet or electromagnet. As the coil rotates, it cuts the magnetic field and an alternating voltage is induced across the coil. When the coil is connected to a closed circuit, current flows.

3.2 Fig. 5 shows how this current is generated by the rotation of a single turn of wire ABCD in a magnetic field, with connection made from the coil to the external load by slip rings and brushes. An application of the Left-hand (Electron) Rule shows the direction of current flow at the various positions of the coil of wire.



HOW THE GENERATOR GENERATES A CURRENT.

FIG. 5.

In position 1, both sides of the turn are moving parallel with the lines of force and, therefore, do not cut the field. In this position there is no induced e.m.f.

At 2, side A-B of the turn is moving downwards and the side C-D is moving upwards, and both sides are cutting the field at right-angles. E.M.F's. in series are induced across the two sides of the turn, as shown in Fig. 5, so that the current in the external circuit is in the direction D to A. As the turn moves from 1 to 2, the voltage increases gradually from zero in 1 to a maximum in the direction D to A in the external circuit at 2. This is because the sides of the turn cut a gradually increasing number of lines per unit time as the turn rotates from position 1 to position 2.

At 3, the induced e.m.f. is again at zero, and, at 4, is a maximum in the A to D direction in the external circuit. This is because in position 4 side A-B is now moving upwards across the field and side C-D is moving downwards.

Included in Fig. 5 is a graph of the variation in the value and direction of the induced e.m.f., and, therefore, the voltage applied across the external circuit for one revolution of the coil turn. From this graph, it is seen that the e.m.f. generated across the turn is alternating, one complete cycle being generated for each revolution of the armature.

3.3 In practice, the single loop of wire shown in the diagram is replaced by a coil of many turns of insulated wire, wound upon a soft iron core, called an armature, which is turned by a handle or a motor.

E.M.F's. are generated in each turn of the coil, and so the total e.m.f. produced by the generator is increased in direct proportion to the number of turns. Thus, for the same speed of rotation, a generator with a coil of ten turns generates ten times the e.m.f. of a similar machine with only a single loop.

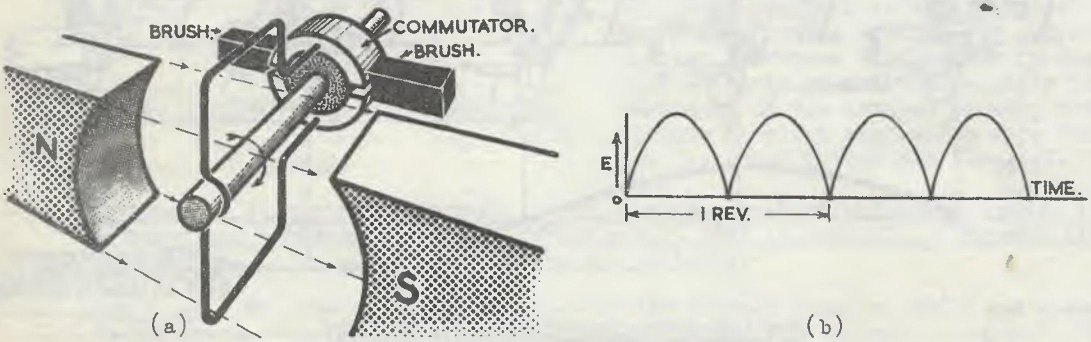
The iron core increases the induced e.m.f. by increasing the intensity of the magnetic field in which the coil rotates.

3.4 Direct Current Generator. The D.C. generator is the same in principle as the A.C. generator, but uses a device called a commutator to convert the induced A.C. of the armature so that a D.C. flows in the external circuit. The machine consists of conductors rotating in a magnetic field, but the coil, instead of being connected to slip rings as in an alternator, is joined to the two halves of a split ring which is mounted on, but insulated from the generator shaft (Fig. 6a).

The split ring is termed a commutator, and acts as an automatic reversing switch which reverses the coil's connections to the external circuit each time the coil current reverses.

The current pick-up and connection to the external circuit is made by brushes, usually of carbon, which are mounted in such a position to the magnetic field, that the connection changes from one commutator segment to the other when the coil current is zero.

The output from this type of generator is unidirectional, but pulsating (Fig. 6b), the speed of pulsations being determined by the speed of the generator.



(a) (b)

FIG. 6. SIMPLE COMMUTATION.

3.5 Commercial machines have a number of coils spaced around the armature with a correspondingly larger number of commutator segments, each of which is a junction point for the connection of two coils. In this way, fluctuations of output are reduced and a practically steady D.C. is obtained.

3.6 In both A.C. and D.C. generators, when a load is connected across the output terminals, the resultant current through the armature produces a field which, by Lenz's law, interacts with the generator's field in such a direction as to oppose the rotation of the armature which is producing it.

As a result, the larger the electrical load, and the heavier the output current, the greater will be the mechanical force required to turn the generator.

3.7 Types of Generators. In telephone instrument generators, the magnetic field is provided by a permanent magnet, but most practical generators have electromagnetic fields. To produce a constant field, the field coils must be connected across a D.C. supply. (A.C. does not produce a constant polarity and is therefore not suitable.)

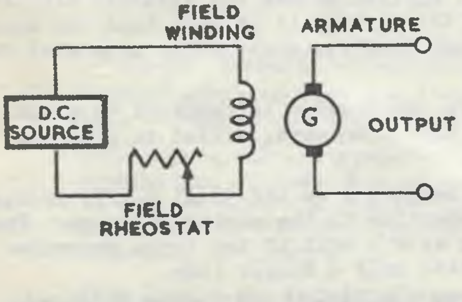


FIG. 7. SEPARATELY EXCITED GENERATOR.

The current in the field coils is called the "excitation current", and may be supplied from a separate D.C. source or by using the D.C. output of the generator itself.

Generators are classified according to the way in which the fields are excited, and these are (i) Separately excited generators, and (ii) Self excited generators.

3.8 Separately Excited Generator. When the field coils of the generator are energised from a separate D.C. source, such as cells or another D.C. generator, it is said to be "separately excited" (Fig. 7).

This type of generator has two independant circuits. One is the field coils and separate D.C. source, and the other is the armature and load resistance. A variable resistance, called the "field rheostat", is generally provided to vary the excitation and the output of the machine.

3.9 Self Excited Generators. When some of the generator output is used for field excitation, the generator is "self excited", and the residual magnetism in the pole pieces is depended upon to provide the initial field for the armature windings to cut. When the induced e.m.f. produces a small current in the armature, portion (or the whole) of the output D.C. passes through the field and builds up the magnetic flux, increasing the generated e.m.f.

Self excited generators are classified according to the type of field connection used; these are Shunt, Series, and Compound connected generators.

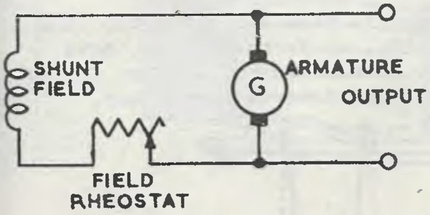


FIG. 8. SHUNT FIELD.

(i) Shunt Field Generator. During rotation under load, the armature current divides between the load and field (Fig. 8). The field which is in parallel with the armature is generally of high resistance, and only a fraction of the output current passes through it.

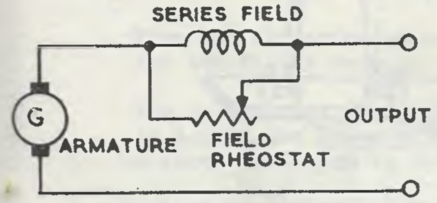
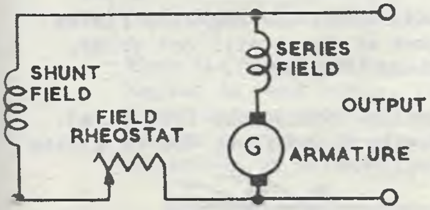
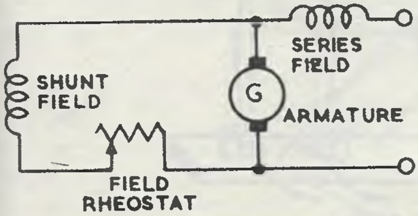


FIG. 9. SERIES FIELD.

(ii) Series Field Generator. The field is connected in series with the armature and load (Fig. 9). With the machine on load all of the output current passes through the field, and the field must be of sufficiently heavy gauge of conductor to carry the full output current without overheating.



(a) Long Shunt.



(b) Short Shunt.

FIG. 10. COMPOUND FIELD.

(iii) Compound Field Generator. This is a combination of shunt and series windings designed to combine the advantages of both types. There are two methods of field connections, the "long shunt" field, where the shunt field is connected across the series field and the armature (Fig. 10a), and the "short shunt" field, where the shunt field is connected across the armature only (Fig. 10b).

Field rheostats are usually used to control the output of the machine by varying the field current.

3.10 The performance of a generator (or motor) depends upon its field characteristics and connections, and each type has its own particular characteristics and applications. These are dealt with in other papers of the Course.

4. MOTORS.

4.1 Mechanical force exerted on a conductor in a magnetic field. We saw in "Magnetism and Electromagnetism" that the direction of a magnetic field can be mapped by utilising the mechanical force that it exerts on a compass needle, in turning it in a direction at right angles to the field.

Since the direction of any magnetic field can be found in this way, we can determine the effects of magnetic fields on one another, by using the two fundamental laws of attraction and repulsion of magnetised bodies.

When two conductors are placed side by side, and are carrying a current in the same direction, the magnetic fields are in the same direction, and combine, forming a stronger magnetic field (Fig. 11a). Since lines of force tend to shorten, there is a force of attraction between the two conductors.

This is demonstrated by the simple experiment shown in Fig. 11b. The two long flexible conductors suspended at both ends, and parallel to each other, have currents in the same direction through them. The combination of the two fields produces a force of attraction, and the two wires bend towards each other.

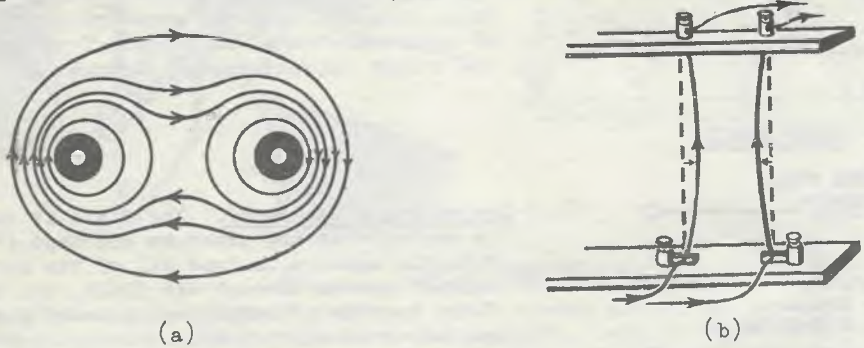

(a) (b)

FIG. 11. SIMILAR DIRECTION OF CURRENT THROUGH PARALLEL CONDUCTORS.

When the current is in opposition through the conductors, the magnetic fields oppose one another, (Fig. 12a), and since the lines of force will not cross, there is a force of repulsion between the conductors (Fig. 12b).

Again, this effect is demonstrated by the two parallel conductors (Fig. 12b). When current flows through the conductors in opposite directions, the repulsion between the two fields forces the conductors apart.

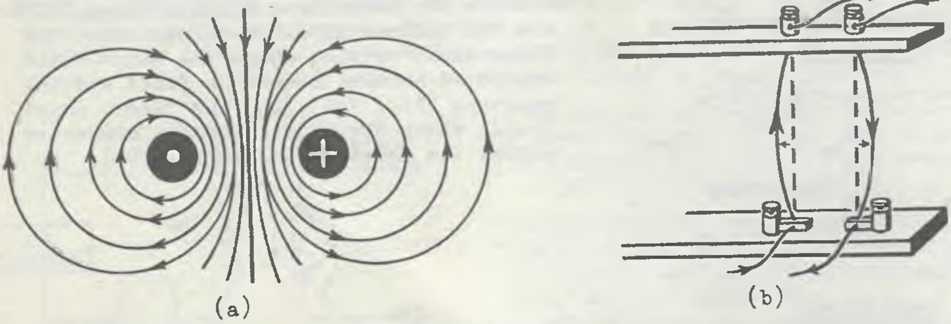

(a) (b)

FIG. 12. OPPOSITE DIRECTION OF CURRENT THROUGH PARALLEL CONDUCTORS.

Summarising. Parallel conductors, each carrying a current, experience mutual forces of attraction or repulsion depending upon whether the currents are in the same or opposite directions through them.

4.2 The same repulsion and attraction between combining fields is produced when a current-carrying conductor is placed between the poles of a permanent magnet.

The two fields, one due to the magnet, and the other due to the current in the conductor, are shown in Fig. 13a. When the conductor is placed in the magnet's field, the combination of the two fields strengthens the field above, and weakens the field below the conductor, with the result that a force is exerted on the conductor, tending to move it downwards (Fig. 13b).

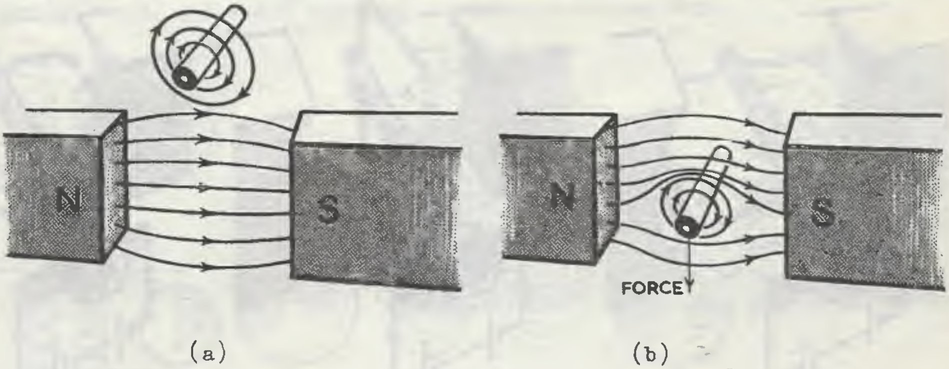


FIG. 13. MOTOR PRINCIPLE.

When the direction of current is reversed, (or the magnet polarity is reversed), the two fields combine to produce a force tending to move the conductor upwards.

The development of a force on a current-carrying conductor in a magnetic field is termed the Motor Principle, as an electric motor depends for its operation on a force developed in this way.

4.3 Right Hand (Electron) Rule for Motors. This relationship between the direction of current, direction of the magnetic field, and the resultant movement of the conductor is determined by the Right Hand Electron Rule (Fig. 14).

When the thumb, first, and second fingers of the right hand are held at right angles to each other, like the three boundaries at the corner of a cube, with the first finger pointing in the direction of the field (N to S), and the second finger pointing in the direction of current, then the thumb indicates the direction of movement of the conductor.

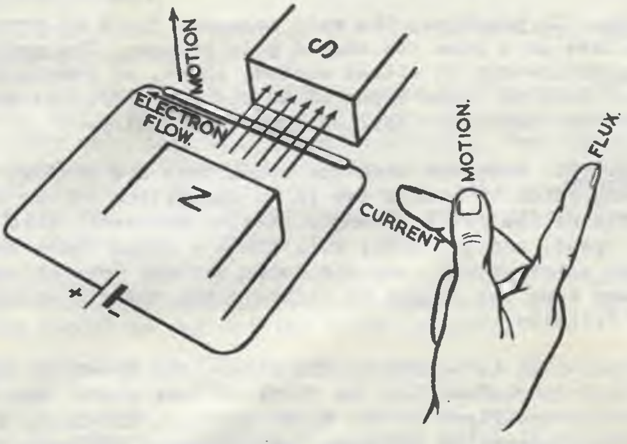
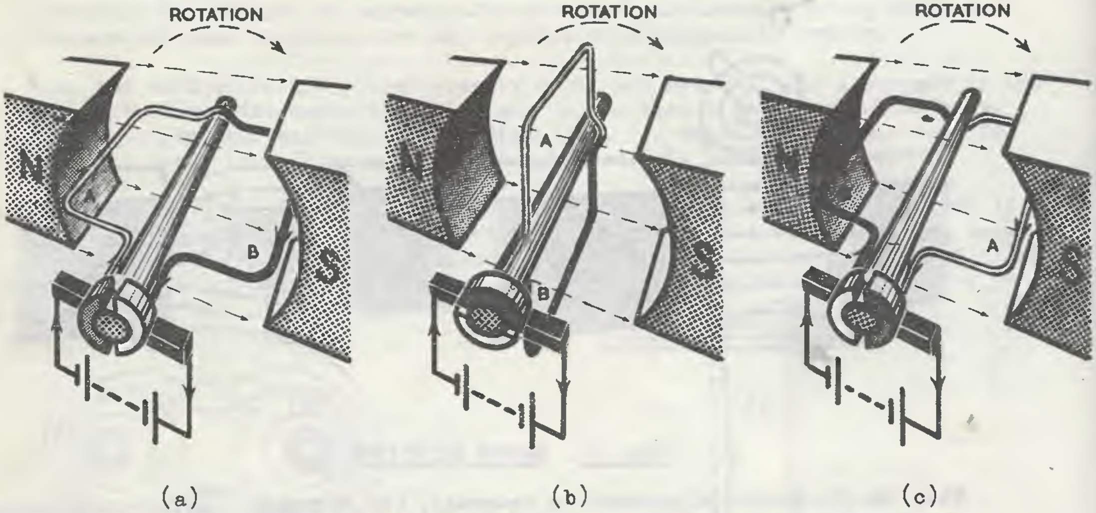


FIG. 14. RIGHT HAND ELECTRON RULE FOR MOTORS.

4.4 Simple Motor. Let us consider a coil AB which is pivoted and free to rotate between the poles of a permanent magnet (Fig. 15a).

The ends of the coil are connected to a two segment commutator, and mounted in such a way that when the coil is vertical the brushes are at the point of changing from one segment to the other (Fig. 15b).



THE SIMPLE MOTOR.

FIG. 15.

When a battery is connected to the brushes and current flows from A to B, the interaction between the coil conductor's field and the magnet's field causes rotation of the coil (Fig. 15a). When the coil reaches the vertical position, the current is zero for an instant (Fig. 15b), and then reverses in direction from B to A as the connections to the battery have been reversed by the commutator.

The force on the coil conductors is thus reversed and the coil continues to rotate in the same direction (Fig. 15c). In this way, continuous rotation is obtained by the conversion of electrical energy into mechanical energy.

4.5 Field Excitation. In practice, the main magnetic field is provided by electromagnets which have as a core the shaped pole pieces. The method of connection of field and armature can be either series, shunt, or compound as shown in paragraph 3.9. Each of these types of motors has different performance characteristics for different applications in industry.

4.6 Armature Back E.M.F. When the armature conductors are moving, there is an e.m.f. induced in them, which by Lenz's law is in opposition to the applied e.m.f. and current. Providing the field strength remains constant, this back e.m.f. increases with speed, and the motor will reach a speed where the applied e.m.f. and back e.m.f. are almost equal, and the motor settles down at that speed; sufficient current is drawn from the source to maintain the motor's speed against the opposition of friction.

When a mechanical load is placed on the motor, the speed of the armature in cutting the field decreases, and the value of back e.m.f. decreases. As a result a greater current flows in the motor circuit, providing a greater expenditure of electrical energy to overcome the increased mechanical load.

5. INDUCTION AND INDUCTANCE.

5.1 Mutual Induction. We saw in Section 2 that when an electromagnet is placed within a coil, and the current through it changed, an e.m.f. is induced in the coil without movement of the electromagnet.

When a current changing in one circuit, induces an e.m.f. in a neighbouring circuit, the effect is known as Mutual Induction, and it is upon this principle that the Transformer operates.

5.2 Let us now re-examine the laws of Faraday and Lenz in their application to the transformer, where the relative motion between the two bodies is that of the moving field, and not a physical movement of either body.

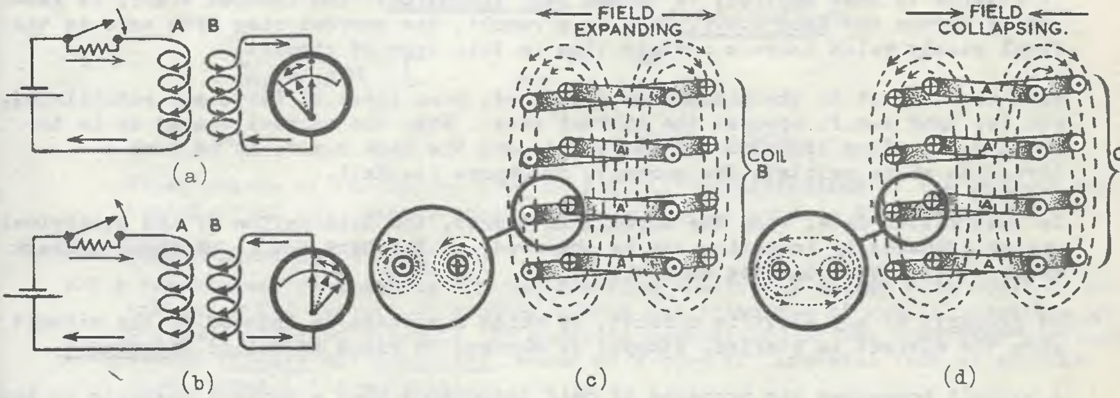


FIG. 16. INDUCING A CURRENT.

Two coils A and B are connected as shown in Fig. 16. When the switch is closed the current increases as the resistor across the switch contacts is short circuited. As a consequence, the existing magnetic field around coil A increases, and in expanding, cuts coil B. By Faraday's Law this relative motion results in an induced e.m.f. and current whilst the flux is changing, and a momentary reading on the meter. (Fig. 16a)

When the switch is opened, the inserted resistance reduces the value of current in A. The magnetic field in collapsing to its new value cuts coil B and induces a transient current in the opposite direction to the first induced effect. Once again the transient current indicated by the meter lasts only while the flux is changing.

As it is the change in flux which produces the induced effect, the same results are achieved when a pulsating D.C. or an A.C. is applied to coil A, instead of the varying D.C. shown.

The principle outlined in Figs. 16a and 16b has its application in the operation of a telephone's speaking circuit.

5.3 The application of Lenz's Law in this example can be seen in Figs. 16c and 16d, which show the coils wound one on the other. The application of the appropriate rules shows that when coil A's current increases, the magnetic flux resulting from the induced current in coil B is in an opposing direction to the flux of coil A. Also when coil A's current decreases, the direction of induced current is such that its flux tends to maintain the originating flux of coil A, again "opposing the motion that creates it".

In the application of the rule of "relative motion", remember that the motion of the field and conductor is relative, and the thumb, will be applied in the rule as though the conductor and not the field is moving.

5.4 Summary. Any variation in flux linkage caused by a changing current of either D.C. or A.C. in one coil, will cause an induced e.m.f. in a coil with which it is magnetically linked; the magnetic effect of any induced current is in such a direction as to oppose the change of current which is producing it.

5.5 Self Inductance and Inductance. We have considered the induced effect produced by one coil on another; now let us examine the induced effects produced in a circuit consisting of a single coil.

When a source of e.m.f. is applied to a coil, and current flows in the coil, the resulting magnetic flux rises and links the turns of the coil, inducing across its turns an e.m.f. which, by Lenz's law, will be in opposition to the applied e.m.f. When the current reaches the Ohm's law value, the flux becomes stationary and the induced effect disappears.

This effect of a current, changing in a coil or conductor, and inducing an e.m.f. in reverse to that applied, is termed Self Induction. The induced e.m.f. is generally termed the Back e.m.f., and as a result, the current rise from zero to the final steady value takes a certain time in this type of circuit.

When the current in the circuit is increased, more lines of force are established, and the back e.m.f. opposes the current rise. When the current ceases or is decreased, the flux linkages are decreased, and the back e.m.f. is in such a direction as to maintain the current, or oppose its fall.

In this latter case, when the circuit is opened, the dissipation of the electrical energy produced by induction can be observed, as the back e.m.f. produces a spark across the switch contacts when they open.

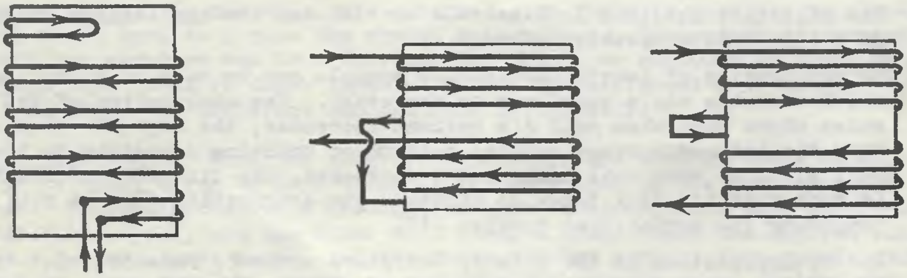
5.6 The property of any electric circuit, by which a voltage is induced in the circuit when the current is started, stopped or changed in value is called Inductance.

A circuit possesses the property of Self Inductance when a current changing in the circuit, induces a back e.m.f. in the same circuit.

A circuit possesses the property of Mutual Inductance when a current changing in the circuit, induces an e.m.f. in a neighbouring circuit.

5.7 Unit of Inductance. The unit of inductance is the Henry, and a circuit has an inductance of 1 Henry when a current with a rate of change of one ampere per second induces in it an e.m.f. of one volt.

5.8 Non-Inductive Resistance (N.I.R.). In some types of apparatus, it is necessary to introduce a resistance coil possessing negligible inductance. Such a winding is termed a non-inductive resistance. The self inductance of a wire can be neutralised by doubling the wire back on itself and winding from the centre of the length of wire (Fig. 17a). The magnetic effect of the current in one direction through the winding is equal and opposite to that produced by the same current in the opposite direction, resulting in a non-inductive winding.



(a)

(b)

FIG. 17. NON-INDUCTIVE RESISTANCES.

Another method used when the length of wire is inconveniently long is to wind the wire in the form of two separate equal coils, connecting the windings so that the magnetic effect of one is neutralised by the magnetic effect of the other (Fig. 17b

5.9 Inductive Reactance. Since any change in current value through a coil produces a back e.m.f. in opposition to the applied e.m.f., this opposition reduces the effect of the applied e.m.f. in producing a current through the coil.

Also, the magnitude of back e.m.f. depends on the rate of change; therefore, the faster the rate of change, the greater the magnitude of the back e.m.f., and the slower will be the rise of current in the coil to the final value.

This opposition to the current, caused by the self induced or back e.m.f. in an A.C. circuit, is called Inductive Reactance. (Essentially the same effect is also produced in a pulsating D.C. circuit.)

Inductive reactance is expressed as follows -

$$X_L = 2\pi f L$$

where

X_L = Inductive reactance in ohms

2π = 6.28

f = frequency in c/s

L = inductance in henries.

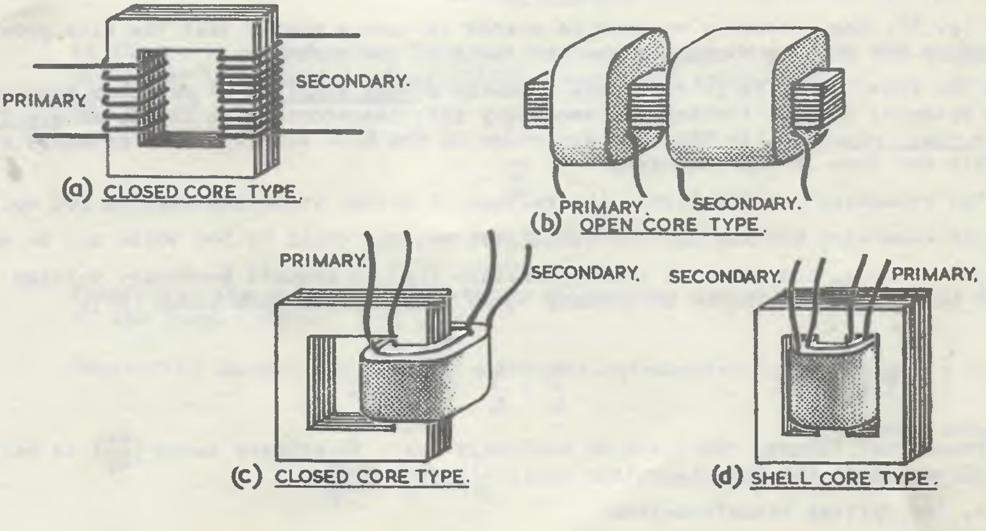
Other papers of the Course provide a fuller understanding of the effects and behaviour of inductance, capacitance, and resistance in A.C. circuits.

6. TRANSFORMERS - SIMPLE THEORY.

6.1 A transformer is a device for transferring electrical energy from one A.C. (or varying D.C.) circuit to another, using the principle of mutual induction in a common magnetic circuit. It consists essentially of two insulated windings, termed Primary and Secondary, wound on a core of laminated iron or similar high permeability material.

When an alternating (or varying) e.m.f. is applied to the primary, a higher or lower alternating voltage is available from the secondary. When the voltage at the secondary is higher than that applied, the transformer is said to be a step-up transformer; when it is lower it is a step-down transformer.

6.2 Construction. Fig. 18 shows some basic transformer designs.



(a) CLOSED CORE TYPE.

(b) OPEN CORE TYPE.

(c) CLOSED CORE TYPE.

(d) SHELL CORE TYPE.

FIG. 18. TYPES OF TRANSFORMERS.

The shell type (Fig. 18d) is the one most commonly used, as its design is more efficient, with less magnetic losses than the other types shown.

6.3 Basic Principle. The principle of the transformer is that of mutual induction. The A.C. (or varying D.C.) in the primary coil sets up a varying magnetic flux in the magnetic circuit. This variation of flux results in an induced alternating e.m.f. in the secondary circuit, having the same frequency as the applied current.

6.4 Voltage Transformation. Let us consider a transformer with 100 primary turns, and 200 secondary turns (Fig. 19).

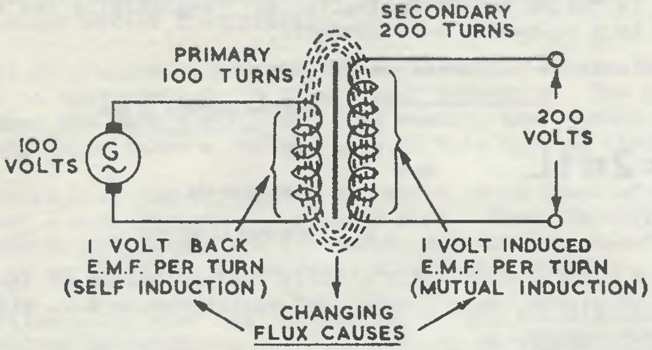


FIG. 19. STEP-UP TRANSFORMER.

Assuming there are no losses, and the secondary winding is open circuit, then when an alternating potential of 100 volts is applied across the primary winding, the current which flows through the primary will be due to the difference between the applied voltage, and the e.m.f. of self induction.

In a well designed transformer with these conditions, the voltage of self inductance (back e.m.f.) so closely approximates the applied e.m.f., that only a small current (magnetising current) flows. It is useful for study purposes at this stage to consider that the back e.m.f. equals the applied e.m.f. We may assume then that the back e.m.f. of the primary is 100 volts, that is, the magnetic field induces an alternating e.m.f. of 1 volt per turn in the primary winding, in opposition to the applied e.m.f.

In Fig. 19, the secondary winding is placed in such a manner that the flux produced by the primary winding links the turns of the secondary.

Now the flux, which is in this case inducing a back e.m.f. of 1 volt per turn in the primary, is also linking the secondary and, therefore, will induce an e.m.f. of mutual induction (in the same direction as the back e.m.f. of the primary) of 1 volt per turn in the secondary.

As the secondary has 200 turns, the voltage of mutual induction will be 200 volts.

If the secondary winding had 500 turns, the voltage would be 500 volts and so on.

In other words, the ratio of primary voltage (lp) to induced secondary voltage (Es) is equal to the ratio of primary turns (Np) to secondary turns (Ns).

That is – $\frac{E_p}{E_s} = \frac{N_p}{N_s}$ or $E_s = E_p \times \frac{N_s}{N_p}$

6.5 In transformer theory, the ratio of secondary turns to primary turns $(\frac{Ns}{Np})$ is called the turns ratio (or transformation ratio) (symbol T).

Thus, for voltage transformation –

E_p = primary voltage

$$E_S = T E_P$$

where E_s = secondary voltage

T = turns ratio

6.6 Current Transformation. Now let us consider a transformer with 200 primary turns and 100 secondary turns connected to a 200 volts supply (Fig. 20).

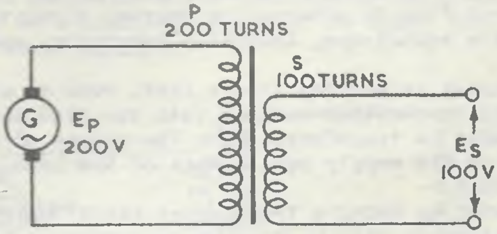


FIG. 20. STEP-DOWN TRANSFORMER.

The changing magnetic flux which induces a back e.m.f. of 200V across the primary, or 1 volt per turn by mutual induction, will induce 1 volt per turn of the secondary winding or 100 volts across it.

When a 50 ohms load resistance is connected across the secondary the resulting current will be -

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

$$= \frac{100}{50}$$

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

Neglecting losses, the power output from the secondary will be -

$$P = E \times I$$

$$= 100 \times 2$$

$$= \underline{200 \text{ watts.}}$$

As the power output comes from the source of supply, that is, the primary circuit, the power input must be (neglecting losses) 200 watts. Therefore, the primary current is -

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

$$= \frac{200}{200}$$

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

From this, the ratio of currents in the primary and secondary, is the inverse of the turns ratio.

Neglecting losses, this can be expressed mathematically as follows -

$$E_p I_p = E_s I_s$$

$$\text{or } \frac{I_s}{I_p} = \frac{E_p}{E_s} = \frac{N_p}{N_s}$$

where

I_p = Primary current

I_s = Secondary current

T = Turns ratio

$$\therefore I_S = \frac{I_P}{T}$$

6.7 Impedance Transformation. Besides transforming voltages and currents, an important use of the transformer is that of impedance transformation.

Impedance, as we shall see fully in other papers of the course, is the total opposition to current flow in alternating current circuits, and takes into account the circuit's resistance, inductive reactance, and capacitive reactance.

When a source of supply is working into a load, such as a generator energising a bell, or a telephone transmitter working into the line and the instrument at the far end, maximum power is transferred from the source of supply to the load, when the impedance of the supply equals that of the load.

This is often achieved by using a transformer which "matches" the two impedances. For example, the induction coil (a form of transformer) in the circuit of a telephone, matches the telephone transmitter to line and far instrument for efficient transmitting, and matches the receiver to line and far instrument for efficient reception. Such matching is necessary, because in telecom, powers of a few milliwatts are quite common.

6.8 To understand the necessity for impedance transformation, we must first examine the factors associated with maximum transference of energy from a source to its load.

Let us now consider the following simple calculations of a 24 volt generator, having a resistance of 3 ohms, connected to various load resistors, as set out in Table 1.

The power in the load can be found from

$$P = I^2R. \text{ (watts)}.$$

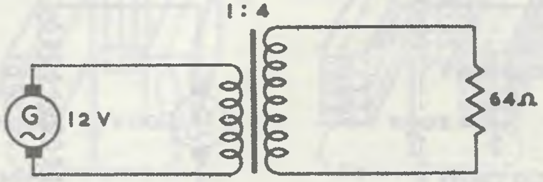
Load Value.	Circuit Current.	Power In Load.	Power in Generator.
1 Ohm	$\frac{24}{(1+3)}$ = 6 amps.	36 watts.	108 watts.
2 Ohms	$\frac{24}{(2+3)}$ = 4.8 amps.	46.1 watts.	69.1 watts
3 Ohms	$\frac{24}{(3+3)}$ = 4 amps.	48 watts.	48 watts.
4 Ohms	$\frac{24}{(4+3)}$ = 3.4 amps.	47.1 watts.	35.3 watts.
5 Ohms	$\frac{24}{(5+3)}$ = 3 amps.	45 watts.	27 watts.

TABLE 1.

From these results it can be seen that maximum power is transferred to the load when the generator and load impedances are "matched", that is, when the load resistance equals the generator resistance (in this case - 3 ohms).

6.9 Where the A.C. generator and load impedances are unequal and maximum power is required in the load, the transformer is used to match the generator and the load.

Consider an A.C. generator which develops 12 volts across its terminals whilst supplying power to a load resistance of 64 ohms, via a step up transformer having a turns ratio of 4.



Primary Voltage E_p = 12 volts.

Secondary Voltage E_s = 48 volts.

∴ Load Current I_s = 0.75 amperes.

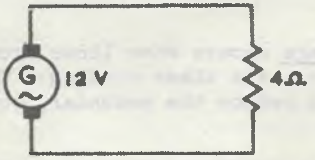
and Power in Load P_s = 36 watts.

Assuming no losses - Primary Power P_p = 36 watts.

∴ Primary Current I_p = 3 amperes.

Since I_p = 3 amperes and E_p = 12 volts, then the effective load on the generator = 4 ohms.

We can therefore derive an equivalent circuit for the generator load -



From this example we can see, that due to the action of the transformer, the 64 ohm secondary load is "reflected" back from the secondary to the primary circuit, and appears as an equivalent load of 4 ohms.

If we assume the resistance of the generator as 4 ohms, then maximum power is transferred from the generator to the load via the impedance matching transformer.

6.10 The ratio of load to reflected resistance corresponds to the square of the turns ratio, that is

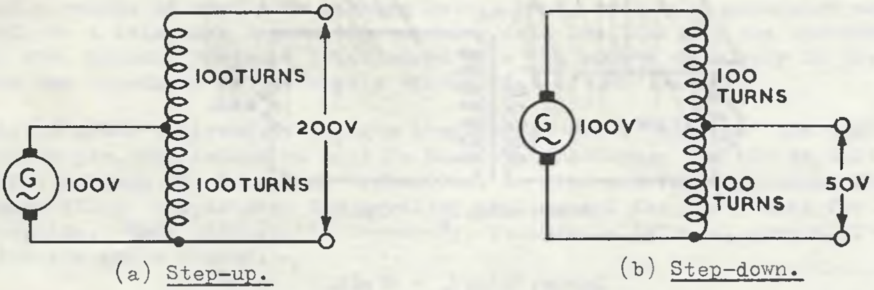
$$\frac{64}{4} = T^2. \ (16).$$

The impedance transformation ratio of a transformer can be found from

$$T^2 = \frac{Z_S}{Z_P}$$

where
T = Turns ratio
Z_s = load impedance of secondary
Z_p = impedance offered by primary to supply under load conditions.

6.11 Auto-transformer. In the conventional transformer, the primary and secondary windings are electrically separate, but in the auto-transformer the secondary winding is connected to the primary winding (Fig. 21), the whole forming a single winding with appropriate tappings. When the primary winding forms part of the secondary winding it is a step-up transformer (Fig. 21a); when the secondary forms part of the primary winding, it is a step-down transformer (Fig. 21b).



(a) Step-up. (b) Step-down.

FIG. 21. AUTO-TRANSFORMER.

The transformation of electrical energy from the primary supply to the secondary load is partly by transformer action, and partly by electrical conduction from one circuit to the other, but for all practical purposes the auto-transformer is the same in its magnetic action, and can be used for exactly the same purposes, as an equivalent two winding transformer; that is, for voltage, current, and impedance transformation.

6.12 Transformer Losses. Although the transformer is the most efficient of all electrical devices, with efficiencies of above 95% not uncommon, its efficiency is reduced by -

(i) Winding Loss. This is called "copper loss" or "I^2R loss" and is due to loss of electrical energy in the windings of the transformer due to their resistance; this appears in the form of heat.

(ii) Core Losses.

(a) Magnetic Leakage occurs when lines from one energised winding do not link or cut the other winding. The effect of magnetic leakage is to reduce the secondary voltage for a given primary voltage.

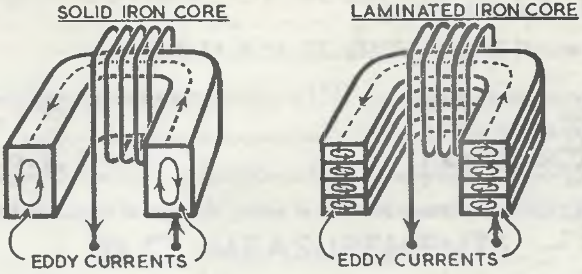
To overcome magnetic leakage, the transformer coils are wound one on another, and an efficient magnetic circuit used.

(b) Hysteresis Loss refers to the energy lost in reversing the direction of magnetisation within the core material with each alternation; this appears in the form of heat. This loss is reduced by using a special core material such as silicon steel or permalloy in which the effect of hysteresis is not marked.

(c) Eddy Currents. Let us consider the magnetic action in a transformer with a solid soft iron core. The core is actually a single turn secondary winding of very low resistance which has a low value of voltage induced in it by the varying magnetic field.

As the direction of induction is at right angles to the main field, circular currents of a large value flow in the core (Fig. 22a). These currents, called "Eddy Currents", as well as possessing a field in opposition to the main field, also cause a considerable loss of energy in the form of heat in the core.

To overcome the effect of eddy currents, the core is constructed of thin laminations, each one insulated from the next by oxide or varnish, and bolted tightly together to prevent vibration caused by the changing magnetic field (Fig. 22b).



(a) Solid Core. (b) Laminated Core.

FIG. 22. LIMITING EDDY CURRENTS.

By using laminations, the core is continuous in the direction of the field, but is broken up into many high resistance paths for the eddy currents.

To further decrease the effect of eddy currents, core materials of high electrical resistance with high permeability, such as silicon steel and permalloy, are used.

6.13 It is important to realise that with an extension of knowledge of A.C. theory, other factors not yet explained will cause some modification of this outlined basic approach to transformer theory.

NOTES.

7. TEST QUESTIONS.

1. State Faraday's Law of electromagnetic induction.

2. Describe two simple experiments illustrating this law.

3. An induced e.m.f. will occur when (i) ....
(ii) .... (iii) ....

4. The value of the induced e.m.f. depends on (i) ....
(ii) .... (iii) ....

5. Describe a method by which the relationship between direction of motion, direction of field, and direction of induced current, may be determined.

6. What is meant by Lenz's Law?

7. Describe the principle of the A.C. generator, using diagrams to illustrate your answer.

8. The iron core of the generator's armature increases the value of induced e.m.f. by increasing the ....

9. Describe fully why a telephone generator is hard to turn when a short circuit is placed on its output terminals.

10. Briefly explain the principles of a D.C. generator.

11. In generator theory what is meant by (i) Separate Excitation (ii) Self Excitation.

12. List 3 types of self excited generators.

13. Parallel current-carrying conductors experience mutual forces of .... or ....
depending upon whether the currents are ....

14. Using diagrams to illustrate your answer, describe the "Motor Principle" of a current-carrying wire in a magnetic field.

15. Describe the Right Hand Electron Rule for motors.-

16. Briefly describe the operation of a simple motor under (i) no load conditions (ii) full load conditions.

17. What is meant by (i) Mutual Inductance (ii) Self Inductance.

18. Define the unit of inductance.

19. How can coil windings be made non-inductive?

20. Briefly describe the construction of a transformer.

21. Describe the simple operation of a (i) Step-Up Transformer (ii) Step-Down Transformer.

22. In transformer theory, the ratio of secondary to primary turns is called .... with the symbol ....

23. For voltage, current and impedance transformation, the following formulas should be used -
(i) .... (ii) .... (iii) ....

24. What is an Auto-Transformer?

25. In transformer theory what is meant by "Winding Loss"?

EXPLAIN
26. How ~~does~~ Magnetic Leakage affect the efficiency of a transformer?

27. (i) What is the action and effect of Hysteresis Loss in a transformer? USE [illegible]
(ii) How is this loss reduced? BY USING LOW [illegible] & CO[illegible] FORCE

28. Sketch and describe the effects of eddy currents in a transformer.

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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D.C. MEASUREMENTS.

1. INTRODUCTION.

1.1 The three quantities which we deal with most in electrical work are -

(i) Current (rate of electron flow).
(ii) Voltage (electrical force which causes the flow).
(iii) Resistance (opposition to the flow).

We must be able to measure these quantities accurately in order to design, build, test, and maintain telecom equipment.

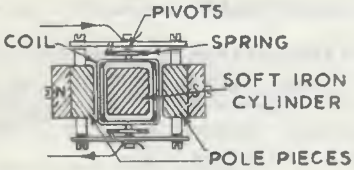
To do this we use instruments which are known by the purpose for which they are used. An AMMETER measures current; a VOLTMETER measures voltage; and an OHMMETER measures resistance.

We know that a current flowing in a circuit converts electrical energy into other forms of energy, such as chemical, heating, magnetic, etc. Since the magnitude of conversion can always be related to the magnitude of the current causing it, we use one or more of these effects as the principle of operation of our measuring instruments. Practically, the effects we use are -

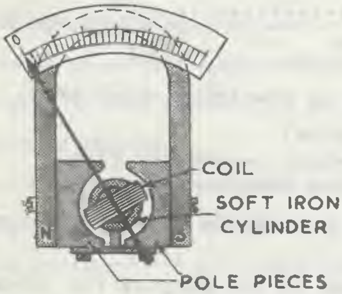
(i) Electromagnetic, the magnetic effect of an electric current.
(ii) Electrothermo, the heating effect, and
(iii) Electrostatic, the force existing between electrically charged conductors.

These three effects can be used to measure electric current and e.m.f., simply by measuring the intensity of the effect produced by the passage of the current to be measured. In practice, however, the electromagnetic effect is used most, and this paper outlines the basic principles, construction, and operation, of the two most common types of instrument using this principle of operation, and the associated apparatus used for D.C. measurements. Other types of meters using various principles of operation, and suitable for use in A.C. and/or D.C. circuits, will be described in another Paper of the Course.

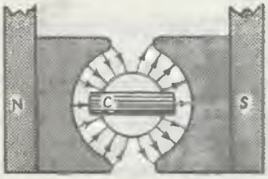
(a) Typical Moving Coil Instrument.



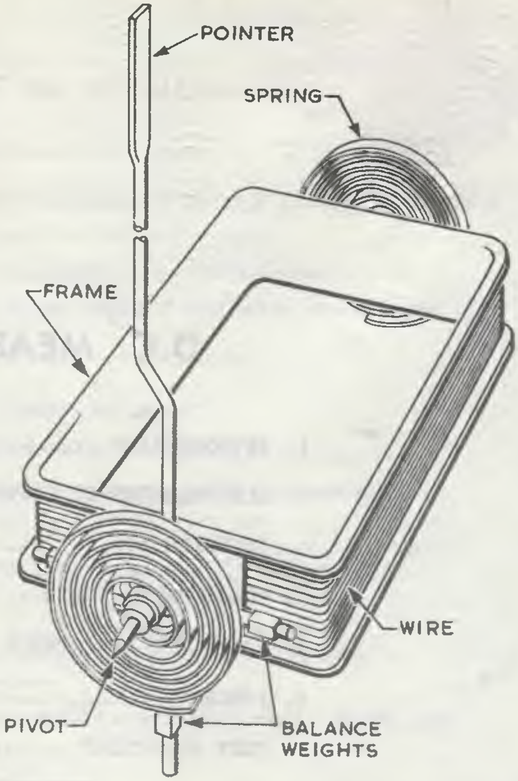
(b) Instrument Components.



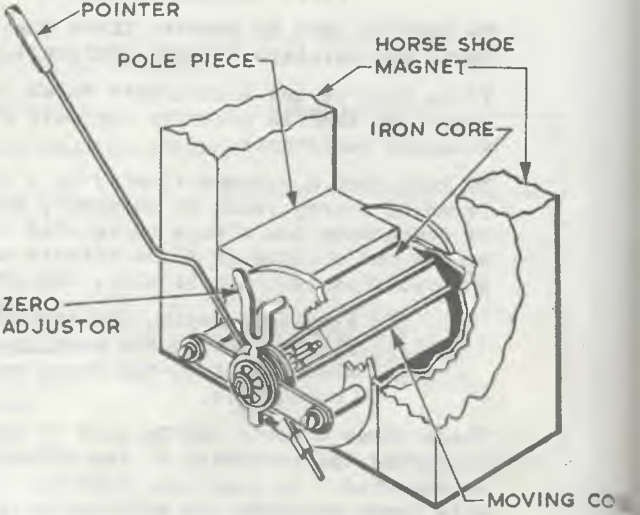
(c) Components (Face View).



(d) Radial Field Produced by Soft Iron Cylinder.



(e) Enlarged View of Moving Coil.



(f) Sectional View.

FIG. 1. MOVING COIL INSTRUMENT.

2. ELECTROMAGNETIC INSTRUMENTS.

2.1 There are several types of instruments which depend on electromagnetism for their operation. The types described in this Paper are -

(i) Moving Coil.
(ii) Moving Iron.

2.2 Moving Coil Type. This type of meter is by far the most common of the electrical measuring instruments.

Minor constructional details vary between manufacturers, and also according to the purpose for which the meter is designed, but the simple principle to be outlined is the basis of this type of instrument. Constructional details are shown in Fig. 1.

The meter consists of a powerful horseshoe permanent magnet with soft iron pole pieces providing a circular shaped air gap. Mounted in the centre of the air gap is a cylindrical soft iron core which is smaller in diameter than the bore of the pole pieces, leaving a small annular air gap between the pole pieces and the iron core (Figs. 1b and 1c).

The soft iron cylinder lowers the reluctance of the air gap between the pole pieces, and because of its shape tends to concentrate the field radially, increasing its intensity, and providing a uniform distribution of flux in the air gap (Fig. 1d).

A light rectangular coil of many turns of fine wire is wound on an aluminium or similar non-magnetic, metallic former, and is provided with hardened steel pivots which rest in jewelled bearings (Fig. 1e).

The coil is mounted so that it is free to pivot in the annular air gap of the magnet assembly (Fig. 1f).

The current to be measured (or part of it) passes through the moving coil; it is led to and from the coil by means of two light springs, similar to the hair springs of a watch. One end of each spring is attached to the moving coil, the other to the frame of the instrument, and to compensate for temperature changes affecting the zero position of the meter, the springs are mounted with their spirals in opposite directions.

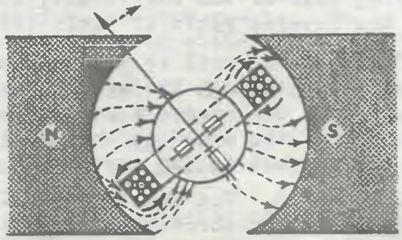
The springs provide the opposing force against which the moving coil acts, and also return the meter to zero.

Attached to the coil is the long hollow aluminium pointer, which moves over a graduated scale, calibrated in the units which the instrument is designed to measure.

A zero adjuster is provided, so that the front spring can be rotated to position the pointer on the zero mark.

2.3 Operation. The operation of the instrument follows the "motor principle" of a current-carrying wire in a magnetic field, the movement of the coil occurring as a result of the interaction between the magnet's field and the field of the moving coil.

The permanent magnetic field strength remains constant whilst the field strength of the moving coil changes with a change in current flow.



The interaction between the two fields provides a force which turns the coil on its pivots against the force exerted by the springs (Fig. 2).

When the electrical and mechanical forces are equal, the rotation stops and the pointer indicates the reading on the graduated scale.

Since the restoring force of the springs is proportional to the angle of deflection, and the magnetic field is proportional to current flow, the deflection of the pointer is directly proportional to the current, and the graduated scale is even, or linear.

The metallic former on which the coil is wound, acts as a short circuited turn in the magnetic field, and the eddy currents set up in it when the coil moves, by Lenz's law, make the instrument "dead beat", by "damping" the action. The flux due to eddy currents in the former opposes the coil's movement, and the pointer moves somewhat slowly to its final steady deflection, enabling a reading to be taken immediately.

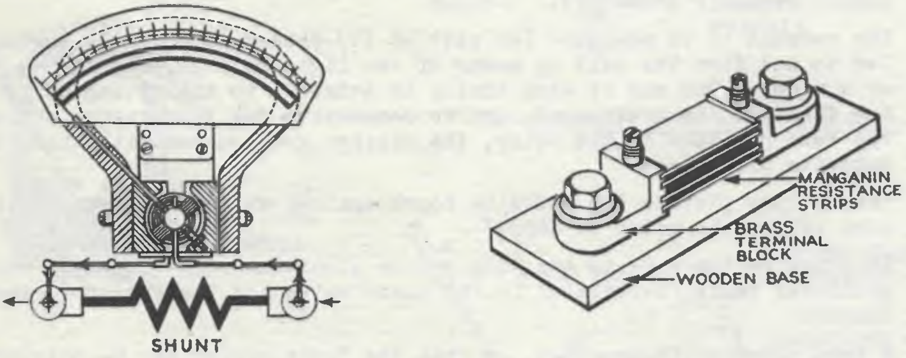
A meter with an undamped movement generally has a non-metallic former, and the needle oscillates for a considerable time before a final steady reading is attained.

2.4 Moving Coil Ammeters. One of the most important requirements of any type of measuring instrument, is to perform its function without any substantial change of values in the circuit where it is operating.

Since an ammeter measures the current in a circuit, it must be connected in series with the circuit, and have a low resistance to avoid introducing any substantial voltage drop, which would alter the value of current it is to measure.

The current value through the moving coil necessary to produce a full scale deflection of the pointer, depends on the pole strength and the coil winding. Many moving coil meters give a full scale deflection with 1 mA or less. In practice, however, meters are constructed which give full scale deflection with a current of up to 0.25 amperes through the coil.

For currents above this, an ammeter "shunt" is used, and this arrangement is shown in Fig. 3.



(a) Connections. (b) Typical Shunt.

MOVING COIL, AMMETER.

FIG. 3.

The shunt is placed in parallel with the moving coil of the instrument, and by Ohms Law, the current divides between the two in the inverse ratio of their resistances.

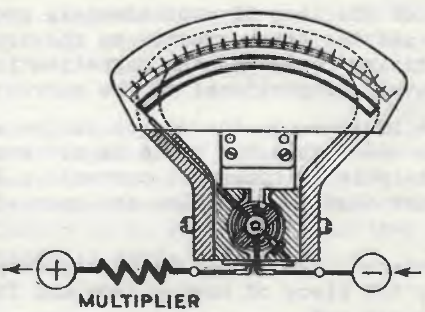
Suppose, for example, that the resistance of the moving coil is 9 times the resistance of the shunt, then the current which flows through the movement of the meter is 1/9th of that which flows through the shunt. If one ampere were flowing then 1/10th ampere would go through the movement and 9/10ths would go through the shunt, and the meter would thus register 1/10th of the current in the circuit.

The "multiplying power" of the shunt is said to be 10. The shunt is usually permanently associated with the meter, and the meter is calibrated to read directly with the shunt in use.

2.5 Some ammeters, particularly portable ones, are supplied with several shunts of different values, to enable the instrument to cover several ranges of current. The different ranges are selected either by means of a switch, or by external terminals, suitable labelled, and different graduated scales are provided on the face of the meter for use on each current range.

Shunts are often made from flat manganin strips, which are fastened into heavy copper blocks. Manganin has a low temperature co-efficient of resistance, and the accuracy of the meter is thus not affected by temperature changes. The leads between the shunt and meter movement form part of the resistance of the movement, and the meter, therefore, must be calibrated with the leads associated.

2.6 Moving Coil Voltmeters. A voltmeter measures the potential difference between points in a circuit, and is connected in parallel with the load to be measured. It must have such a high resistance, that it avoids disturbing the circuit conditions by shunting the circuit current to any appreciable extent. A moving coil voltmeter is actually a moving coil milliammeter in series with a high resistance (Fig. 4). The meter deflection is proportional to the current flowing through it, and this in turn, is proportional to the difference of potential between its terminals. The deflection is, therefore, proportional to the applied voltage and the scale is calibrated to read this voltage direct. The resistance connected in series is made of manganin or some similar material with a low temperature co-efficient, and its value is so large that it completely "swamps" the resistance of the moving coil. Changes in the resistance of the moving coil due to temperature changes, therefore, have a negligible effect on the total resistance of the instrument. Moving coil voltmeters, therefore, have a very small temperature error.



MOVING COIL INSTRUMENT AS A VOLTMETER.

FIG. 4.

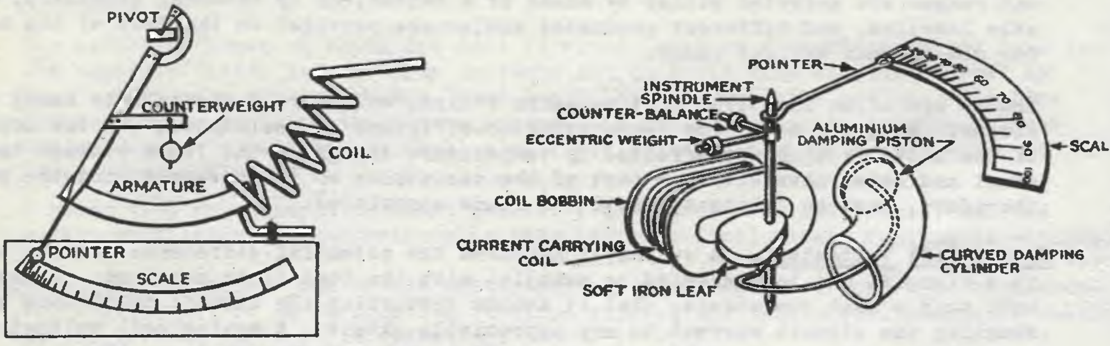
2.7 The range of a voltmeter is altered by altering the value of its series resistance. Thus, when an instrument reading up to 100 volts has its resistance doubled, the deflection is halved and 200 volts are needed for full scale deflection, that is, doubling the resistance doubles the voltage range. This resistance is consequently known as a "multiplier".

Voltmeters are often equipped with several different multipliers, which give a variety of voltage ranges. As in the case of the ammeter, the different ranges are usually selected either by a switch or terminals.

2.8 Since the rotation of the moving coil movement is dependant on a unidirectional current through the coil, this instrument is suitable for use on D.C. only, and not A.C. Also, when used as a voltmeter or ammeter, care must be taken to connect the terminals, which are labelled + and -, to the correct polarity of the supply.

The positive polarity of the supply connects to the + terminal, and the negative polarity of the supply connects to the - terminal.

2.9 Moving Iron Instruments. The principle of moving iron instruments is shown in Fig. 5.



(a) Armature Type. (b) Leaf Type.

FIG. 5. MOVING IRON METERS.

The current to be measured passes through a coil, and the resulting field, by induction, magnetises the soft iron armature or leaf, which is drawn into the coil, causing the pointer to move over the scale.

The movement of the iron is due to the principle that a piece of iron, in a non-uniform magnetic field, is drawn to the strongest part of the field.

As the magnetisation of the iron is approximately proportional to the current providing the field, and the force exerted on the iron is proportional to the product of the magnetising force and the magnetisation of the iron, the pull on the iron is approximately proportional to the current squared.

The deflection of the instrument, therefore, varies approximately as the square of the current, which means that the scale is not evenly divided, and there is little movement of the pointer for small currents. It is characteristic of moving iron instruments that their scales are cramped, and practically useless at the lower end.

The instrument is rendered "dead-beat" by an air damping arrangement consisting of a piston worked by the piece of moving iron and fitting loosely into a bent hollow tube closed at one end.

2.10 Another form of moving iron instrument depends for its action on the force of repulsion between two rods of soft iron similarly magnetised. The two rods are situated within the coil, and when a current passes, both rods become magnetised in the same direction. The repulsion exerted between them is used to deflect a needle over a graduated scale.

2.11 Moving iron instruments are more robust and cheaper, but less accurate than the moving coil instrument. Since the fixed coil can be wound with heavy wire, currents up to 100 amperes or more are carried by the meter movement. However, above 100 amperes, shunts, or when on A.C. work, current transformers are normally used. The current transformer has advantages over the shunt, in that relatively heavy currents can be measured without overheating.

Moving iron voltmeters differ from the ammeters, in that they require less current for full scale deflection, and that they have a high resistance or multiplier in series with the fixed coil.

2.12 In considering Fig. 5, it can be seen that when energised, the soft iron movement is drawn into the coil, irrespective of the direction of the current. Similarly, in the second type of meter described, the repulsion between the soft iron rods exists with both directions of current.

The moving iron instrument, therefore, is not polarised, and can be used on both A.C. or D.C.

2.13 **Sensitivity.** The sensitivity of meters is expressed in several ways, but is dependent on the constructional features of the instrument. The magnet's field strength, the turns and resistance of the coil, the springs, and the efficiency of the pivots, are some factors which govern sensitivity.

With these features in mind, to achieve sensitivity, the designer aims at maximum deflection for minimum current, having in mind the cost, and the purpose for which the instrument is intended.

The sensitivity of voltmeters and ammeters is therefore generally based on the current through the movement which provides full scale deflection. That is to say, an ammeter may be designed to give full scale deflection with 1 mA, 10 mA and so on.

Voltmeters, particularly those of the moving coil type, are rated in ohms per volt. For example, when an 0-1 moving coil milliammeter is used with multipliers, as a voltmeter with full scale readings of 1 volt, 10 volts, and 100 volts, the total resistance of the instrument for each scale, (from Ohms Law) is 1000Ω, 10,000Ω, and 100,000Ω respectively.

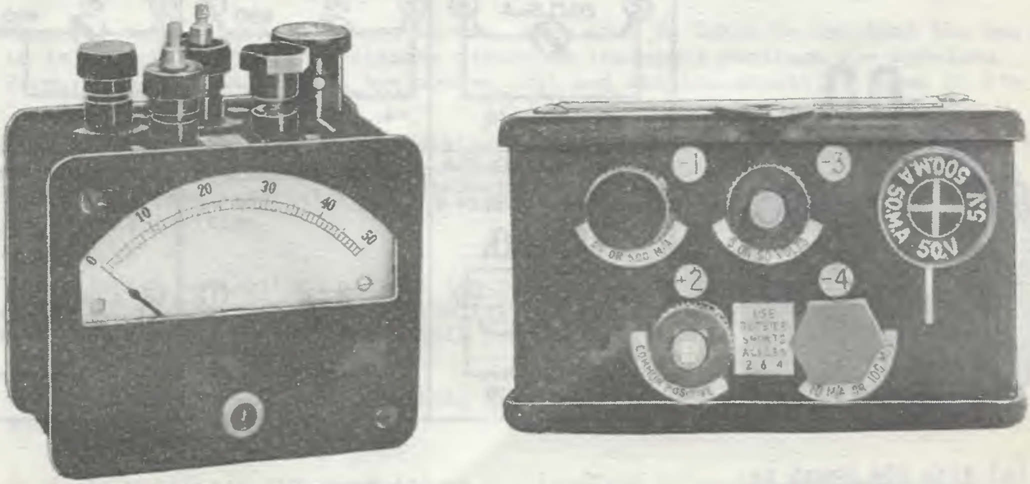
The sensitivity of this meter is 1000 ohms per volt, for with each additional volt added to full scale reading, the resistance of the multiplier must be increased by 1000Ω, to limit the current through the movement to 1 mA. Conversely, the current sensitivity of a voltmeter may be found from an expression of its ohms per volt. For example, the current giving full scale reading on a 100 ohms per volt meter, (from Ohms Law), is 10 mA.

Since a voltmeter is a parallel connection, and must take some current from the circuit across which it is measuring, the higher its "ohms per volt", the higher will be the resistance connected in parallel, the more sensitive must be its meter, and the less the circuit conditions will be disturbed.

In practice, the values range between 50 and 1,000 ohms per volt, with some meters of particularly high sensitivity, having values up to 20,000 ohms per volt.

3. DETECTOR NO. 4.

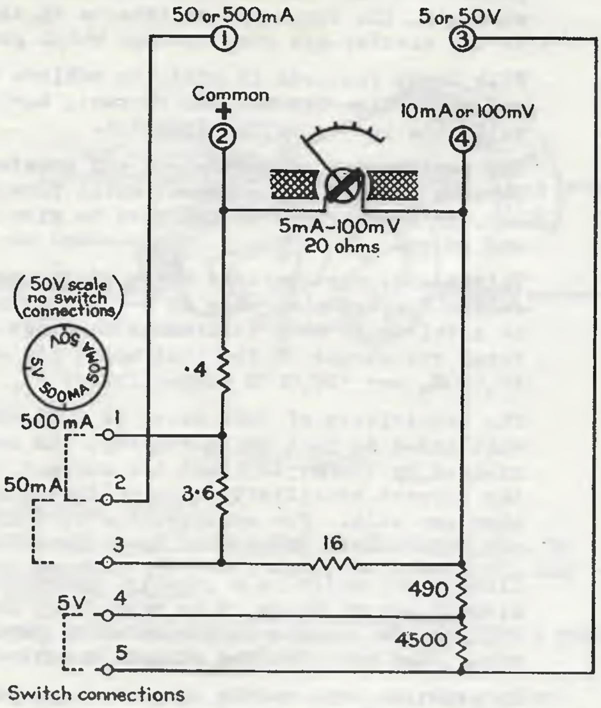
3.1 To telecom men, electrical instruments are of great interest, for there is probably no other branch of engineering where a wider range of instruments and a greater variety of measurements are used. Of particular interest is a moving coil type of portable voltmeter-ammeter, the Detector No. 4 (Fig. 6). Although this instrument is shortly to be replaced by another having greater facilities, it is at present universally used.



(a) Face View.   (b) Top View.

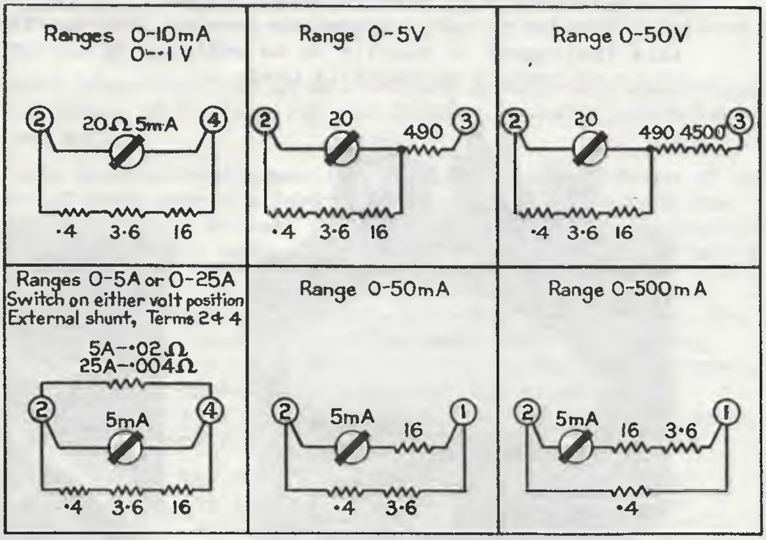
FIG. 6. DETECTOR NO. 4.

(a) With Resistance Coils.



(b) Schematic Circuit.

(c) With 25A Shunt in Position.



(d) Basic Circuits.

FIG. 7. DETECTOR NO. 4.

3.2 Over the years, different manufacturers have introduced minor modifications of circuitry and switching to the Detector No. 4, but basically the instrument has not changed.

Terminals, and switching facilities provide for current ranges of 10 mA, 50 mA, and 500 mA, and voltage ranges of 100 mV, 5 volts, and 50 volts. Some details of a late model of the Detector No. 4 are in Fig. 7b.

This particular model uses a 0-5 mA, 20Ω moving coil system permanently shunted on the voltage ranges, to give the standard 0-10 mA, 10 ohm movement at the terminals.

For current measurement, the 5 mA movement is used in conjunction with a "ring" or universal shunt, to give the required current ranges (Fig. 7d).

The detector is provided with a 5 ampere and 25 ampere shunt and two 10,000 ohm resistance coil multipliers. The shunts fit conveniently across the moving coil terminals 2 and 4. The resistance coils are screwed together in series on the extended threads of terminals 2 and 3 which accommodate one or both of the coils, according to the required range.

Each added coil increases the range of the instrument by 100 volts; thus, 150 volts are measured with the addition of one coil and 250 volts with the addition of two coils.

Both resistance coils fitted to terminal 3 are shown in Fig. 7a. Terminal No. 2 preferably is used for this purpose, when the negative pole is earthed, and Terminal No. 3 when the positive pole is earthed; the reason being that it is desirable, when using the instrument with the higher voltages, that the internal connections should approximate to earth potential.

Associated with the detector is a contact spike, which is housed in the back of the instrument, but when required for use it is screwed into the socket at the base and becomes a positive terminal.

When the terminals 2 and 4 are in use, care must be taken to see that the switch is in one of the "volt" positions otherwise incorrect readings are obtained. Terminal No. 4 connects to the moving coil and caution should be taken in its use.

The compound switch has four positions, which are 50 mA, 500 mA, 5 volts and 50 volts, respectively. When multipliers are used, the switch is in the 50 volt position. When external shunts are used (Fig. 7c) the switch is in either the 5 or 50 volt position.

The internal connections and the theoretical connections in Fig. 7d are self-explanatory. An instruction plate, giving scale readings, deflections to be used, etc., is mounted on the instrument.

The frame former of the moving coil system is of insulated silver and is wound with insulated copper wire.

On early models, an 0.5 ampere fuse was inserted in series with the wiring to No. 4 terminal. This provided some protection when the instrument was overloaded due to wrong terminal connections, and/or incorrect switch position.

3.3 Ranges of the type of Detector No. 4 shown in Fig. 7 are as follows -

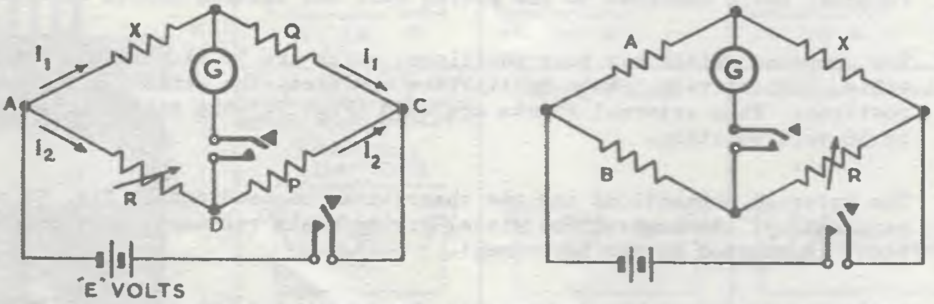
Range	Terminals	Value per division.	Resistance in ohms.	Shunts or resistances in use.
Current -				
0-10 mA.	2 and 4	0.2 mA.	10.00	Permanent internal shunt on 5 mA movement
0-50 mA.	2 " 1	1.0 mA.	3.6	Internal Shunt.
0-500 mA.	2 " 1	10.0 mA.	0.396	" "
0-5 A.	2 " 4	100.0 mA.	0.02 (approx.)	External Shunt.
0-25 A.	2 " 4	500.0 mA.	0.004 "	" "
Volts -				
0-0.1 V.	2 and 4	0.002 V.	10	Direct on shunted moving coil.
0-5 V.	2 " 3	0.100 V.	500	Internal resistance.
0-50 V.	2 " 3	1.0 V.	5,000	" "
0-150 V.	2 " 3	3.0 V.	15,000	External "
0-250 V.	2 " 3	5.0 V.	25,000	" "

The calibrated scale range of the instrument as an ammeter lies between 0.2 mA and 25 A, and as a voltmeter between 2 mV and 250 volts. When used as a voltmeter, the resistance is 100 ohms per volt. When readings of over 250 volts are required, the range may be increased by 100 volts or upwards by the addition of the requisite 10,000 ohms multipliers.

A rectifier attachment is available to allow the detector to be used for A.C. work.

4. WHEATSTONE BRIDGE.

4.1 The measurement of resistance is an important feature in practical electrical measurements, and the Wheatstone Bridge (in one of its forms) is one apparatus for this purpose; a simplified circuit is shown in Fig. 8a. In this P, Q and R are three known resistances whose values can be varied at will, and X is the unknown resistance whose value is to be found. A battery (say, two dry cells) is joined across the points A and C, with a key in series, and a sensitive centre zero galvanometer (moving coil milliammeter) is joined across points B and D, and has a key in series. The Wheatstone Bridge is often drawn and labelled as shown in Fig. 8b but the principle is the same as that described for Fig. 8a.



(a) (b)

FIG. 8. SCHEMATIC CIRCUITS WHEATSTONE BRIDGE.

4.2 When the battery key is pressed, current flows in the two arms of the bridge, and there will be a P.D. across resistors X and R. Points B and D therefore, will be at positive potentials with respect to point A, the values being determined by the resistances of X and R.

4.3 When the galvanometer key is pressed, one of the following occurs -

(i) A current flows from B to D, and the instrument shows a deflection, say, to the right of the centre zero. In this case B is negative with respect to D.

(ii) A current flows from D to B, giving a deflection to the left; D is negative with respect to B.

(iii) There is no current between D and B, and no deflection of the instrument. Points B and D are at the same positive potential with respect to point A.

To balance the bridge, condition (iii) is aimed at, and the variable resistance "R" is adjusted until there is no deflection when the key is pressed.

Under this condition, the value of the unknown resistance is calculated as follows -

Since there is no P.D. existing across points B and D, the P.D. from A to B must equal the P.D. from A to D.

Similarly the P.D. from C to B must be the same as that from C to D.

As each of these P.D.'s is an IR drop, it can be written that -

$$I_1X = I_2R$$

and $$I_1Q = I_2P$$

$$\therefore \frac{X}{Q} = \frac{R}{P}$$

and $$X = R\frac{Q}{P}$$

In practice Q and P are known as "ratio arms" and according to the range of resistance to be measured, are adjusted to have some definite ratio, for example 1 : 1, 10 : 1 or perhaps 1 : 10. By finding the value of R in ohms, and multiplying by the ratio $\frac{Q}{P}$, the value of the unknown resistance is found.

4.4 Instruments using the wheatstone bridge principle are supplied by manufacturers in various forms, but all use the basic principle outlined in para. 4.2.

The face layout and schematic circuit of a typical wheatstone bridge is shown in Figs. 9 and 10.

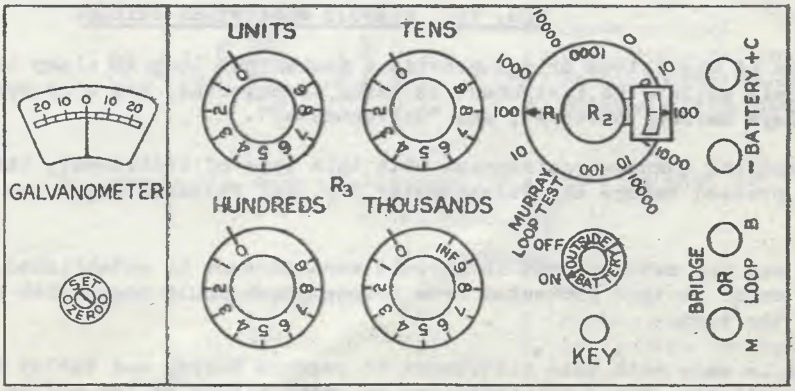


FIG. 9. FACE LAYOUT, WHEATSTONE BRIDGE.

4.5 The variable resistance range is provided by a number of coils connected to four selecting switches, which enables a range of from 0-9999 ohms to be selected in 1 ohm steps.

The resistance range is coupled with two ratio arms to form the bridge, each arm consisting of four coils, of resistance 10,000 ohms, 1000 ohms, 100 ohms, and 10 ohms.

The combinations of variable resistance range and ratio arms, enables a range of from 0.001 ohm to 9,999,000 ohms to be measured.

The press button key, when pressed, completes the galvanometer and battery circuits, and when released short circuits the galvanometer. This enables rapid successive readings to be made, and "damps" the meter's movement when the instrument is moved or carried about.

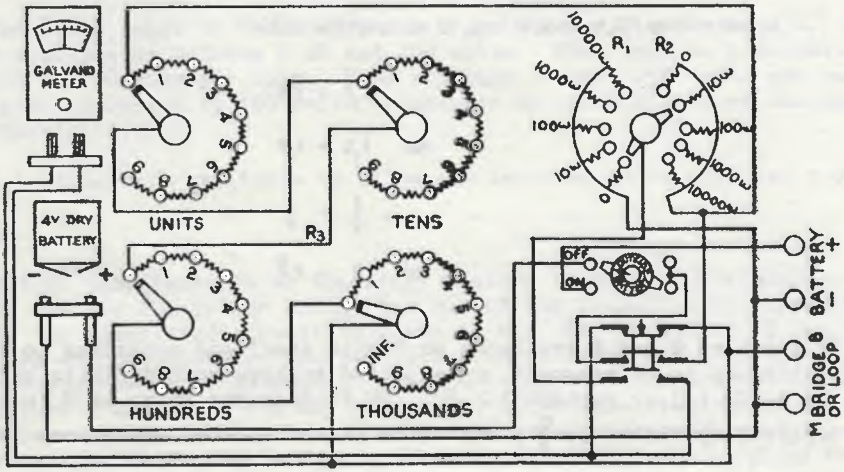


FIG. 10. CIRCUIT WHEATSTONE BRIDGE.

4.6 Some types of wheatstone bridge provide a mechanical lock to clamp the meter movement firmly whilst the instrument is being transported, and also provide two press button keys marked "Battery", and "Galvanometer".

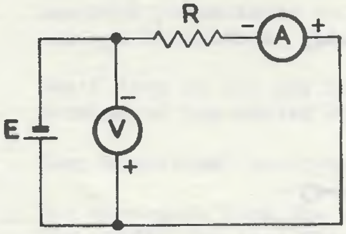
When measuring unknown resistances with this type of instrument, the Battery key must be pressed before the Galvanometer key, and released after the Galvanometer key.

In this way the meter is not in circuit when current is established or stopped, and the meter is thus protected from surges which could occur with reverse operation of the keys.

4.7 Provision is made with this instrument to perform Murray and Varley Loop Tests on telephone lines. These are explained in other papers of the course.

5. MEASURING RESISTANCE.

5.1 Ammeter-Voltmeter Method. One of the simplest ways of measuring an unknown resistance, is to use a voltmeter and ammeter (or milliammeter), connected to a source of e.m.f. (Fig. 11).



AMMETER-VOLTMETER METHOD.

FIG. 11.

The method consists in measuring the P.D. produced across the apparatus, due to its resistance, when the measured current flows through it.

The resistance can then be found from the application of Ohm's Law -

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

R = unknown resistances
E = P.D. across unknown resistance
I = current

The two factors important to correct calculations, are the values of P.D. and current, related to the unknown resistance. To avoid disturbing the circuit conditions, which could result in incorrect readings and calculations, the voltmeter and ammeter must be respectively, very high and very low resistance.

5.2 Voltmeter Method. Another simple method of determining the value of an unknown resistance, is the voltmeter method. The Wheatstone Bridge method is slow, and the value of the resistance to be measured is limited by the ratio arms available and the resistance of the unknown resistance.

For example, the maximum resistance it is possible to measure with the bridge described in Section 4 is 9.999 MΩ.

Voltmeters can be adapted to provide measurements for a range of resistance values from zero to about 80 MΩ.

To find the resistance value when an unknown resistance is connected in series with a voltmeter and battery.

(i) Measure and note the supply voltage, with the voltmeter of known ohmic resistance. This deflection is called "D".

(ii) Connect the unknown resistance in series with the voltmeter, and note the meter reading. This deflection is called "D_1".

(iii) Calculate the value of the unknown resistance from the formula -

$$R = V\left(\frac{D}{D_1} - 1\right)$$ where

R = unknown resistance
V = Total voltmeter resistance
D = Deflection without resistance
D_1 = Deflection with resistance

Thus, when $D = 50$ V, and $D_1 = 20$ V, measured with a 150,000 ohms meter, then

$$R = 150{,}000 \times \left(\frac{50}{20} - 1\right)$$

$$= \underline{225{,}000 \text{ ohms}}.$$

★

An alternative formula often used is -

$$R = R_M\left(\frac{V_1 - V_2}{V_2}\right)$$ where

R = unknown resistance
R_m = Total voltmeter resistance
V_1 = Deflection without resistance
V_2 = Deflection with resistance.

5.3 Ohmmeter. An ohmmeter is an instrument which measures the resistance of a circuit or apparatus directly on a calibrated scale, without the need for any calculations. A simple circuit of an ohmmeter is shown in Fig. 12.

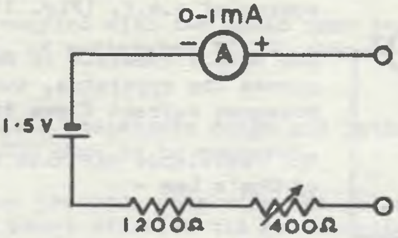


FIG. 12. SIMPLE OHMMETER.

The values of the fixed resistance and rheostat are such, that when terminals A and B are short circuited, a full scale deflection of the meter can be obtained by an adjustment of the rheostat.

The unknown resistance replaces the short circuit between A and B, and the meter deflection will then be proportional to the current, reading less than the full scale deflection, which is marked zero on the ohms' scale.

Since the applied e.m.f. is constant, the current and deflection depends upon the value of the unknown resistance, and the scale of the instrument is calibrated directly in ohms.

Different ranges of resistance can be provided by increasing the value of the fixed resistance, but the battery voltage must always be sufficient to calibrate the meter to full scale reading of zero ohms.

5.4 Universal Test Meter. The universal test meter (often termed multimeter) is a combined voltmeter, ammeter, and ohmmeter, built around a sensitive moving coil movement, the full scale deflection of which may vary from 50μA to 10 mA, according to the type and manufacturer.

The ranges of volts, amperes, and ohms are generally selected by multi-position switches, that switch the appropriate components into circuit.

Multimeters often have A.C. voltage and current scales, and include a mechanical, spring-operated cut out, which is operated by the pointer swinging above full scale deflection, and tripping a lightly balanced relay. In this way, the instrument is protected, as a small overload is sufficient to operate the safety device.

5.5 Classification of Electrical Measuring Instruments. Instruments are many and varied in types and design, and perform many functions, with degrees of accuracy suited to the requirements of the equipment in which they operate.

They are generally classified in relationship to the degree of accuracy of the instrument, namely -

(i) Sub-standard Instruments are laboratory instruments of great accuracy, which have been calibrated against an international standard.

(ii) Precision Instruments are instruments having a high degree of accuracy, and are used for testing work. They are often fitted with knife edged pointers and mirror scales and are generally meant to be used horizontally.

(iii) Industrial Instruments are designed and constructed for mounting on a panel, or for portable use. They are used for general testing where a high degree of accuracy is not required.

For example, the maximum permissible scale inaccuracy for a moving coil voltmeter with a scale length of 5" or over, in each of the above gradings, is respectively, (i) 0.2% (ii) 0.3% and (iii) 2.0% (panel mounting), 1.5% (portable).

6. PRECAUTIONS.

6.1 The intelligent use of electrical measuring instruments, depends upon skill and care, as well as an understanding of the theory of each test made. There are numerous precautions to be taken, some of which are learned (or realised) only through experience, but some important precautions are listed below.

Don't drop or jar any instrument, as this can permanently damage the delicate suspension of the moving system, causing inaccurate readings, or complete failure.

Keep electrical instruments free from dampness.

For accuracy, read the scales of electrical instruments with the eye directly over the needle, so that the line of vision is perpendicular to the scale.
Some instruments are equipped with small mirrors beneath the needle, to guard against reading the scale at an angle. When the image of the needle in the mirror is directly beneath the needle, the eye is perpendicular to the scale. An error caused by the eye not being perpendicular to the scale is called a "parallax error".

Be sure that when at rest, the needle of the instrument stands on the zero of the scale. Most instruments are equipped with a device to correct the zero position of the needle.

Delicate instruments are usually equipped with some device for clamping the needle when not in use. This often prevents damage from jarring. Instruments not equipped with a clamping device may have their coils "dampened" by short-circuiting their terminals. Remove the short circuit before using the instrument.

All connections to terminals etc. must be tight and have zero resistance. Do not use high resistance wires for leads.

Make a mental estimate or rough calculation of the value you expect to read from your knowledge of the circuit conditions, as a check against your method of connection and use of the instrument.

Do not connect instruments to circuits where the values to be measured are likely to be greater than the scale reading.

In any case, for safety, always take the first reading with the meter switched to the highest appropriate range available.

Millivoltmeters and milliammeters are designed for measuring millivolts and milliamperes, not volts and amperes.

Always insert ammeters in series with the circuit to be measured, never across any branch or part of the circuit.

Ohmmeters must not be used on energised circuits. P.D.'s caused by current through the circuit components will cause inaccurate readings, and could damage the instrument.

In any Wheatstone Bridge test, do not operate the galvanometer and battery key, except when endeavouring to obtain a bridge balance.

In making Wheatstone Bridge measurements, see that the circuit under test is absolutely cleared of all bridged or other apparatus not permanently associated with the circuit and essential for giving simple continuity.

Errors are often encountered in Wheatstone Bridge measurements on long cable and open wire circuits due to foreign potentials caused by induction, ground potentials, etc. To correct for these, reverse the polarity of the testing battery and make a second measurement. The average of the two measurements is then recorded as the correct one.

7. TEST QUESTIONS.

1. One of the useful effects used in the measurement of current is Electromagnetism. Two other effects also used are (i) .... (ii) ....

2. Sketch and describe the basic construction and principle of operation of the Moving Coil Instrument.

3. The provision of a soft iron cylinder lowers the .... between .... and ensures that the permanent magnet field is .... and ....

4. The moving coil is wound on a .... former.

5. The current is led to the moving coil by ....

6. The principle governing the action of the moving coil is known as the ....

7. Describe how the instrument's action is "damped".

8. What is meant, when a shunt is said to possess a multiplying power of 10.

9. One of the most important characteristics of a shunt is ....

10. What is a multiplier?

11. When connecting an ammeter or voltmeter in circuit the + and − terminals should be connected respectively to ....

12. The scale of the moving coil instrument is ....

13. State why this is so.

14. Sketch and describe the construction and operation of a moving iron instrument.

15. The scale of the moving iron instrument is ....

16. State why this is so.

17. Why is the moving iron instrument suitable for A.C. and D.C.

18. What is meant by the "Sensitivity" of an instrument.

19. What current is required for full scale deflection of a 20,000 ohms per volt voltmeter.

20. List the D.C. scales available on a fully equipped Detector No. 4.

21. With the aid of a simple circuit, describe the principle of operation of a Wheatstone Bridge.

22. Describe the voltmeter method of determining an unknown resistance.

23. What is an Ohmmeter?

24. How are voltmeters and ammeters classified?

25. An "error due to parallax", means ....

26. How is this guarded against?

27. List ten important precautions in the use of measuring instruments.

END OF PAPER.

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COURSE OF TECHNICAL INSTRUCTION

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CAPACITANCE.

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1. INTRODUCTION.

1.1 The discovery of static electricity led to a number of important inventions amongst which were the Electroscope, the Wimshurst Machine, and the Leyden Jar.

Of these the Leyden Jar was the most important as it was the forerunner of the Capacitor which is so widely used in all electrical circuits.

Capacitors, which were formerly termed Condensers, are many and varied in sizes, type, and shape, and are necessities in all types of telecom circuits from telephone equipment to radio and television.

This paper deals with the basic construction, operation, and effects of capacitors in electric circuits.

2. THE ELECTRIC FIELD.

2.1 In previous papers it has been shown that when a P.D. is applied to a circuit in which a continuous current can flow, a magnetic field is set up which influences certain materials placed in its proximity.

Just as a current flow sets up a magnetic field composed of magnetic lines of force, so does a charge or voltage set up an electric field, considered to be composed of electric lines of force.

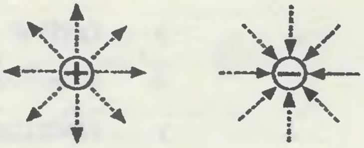
2.2 The electric field (or electrostatic field) is that space around a charged substance in which an electric force is apparent.

The insulating substance occupying the space of the electric field opposes the electric force set up by the charge, and is said to be electrically strained.

Electric fields and magnetic fields have many points in common.

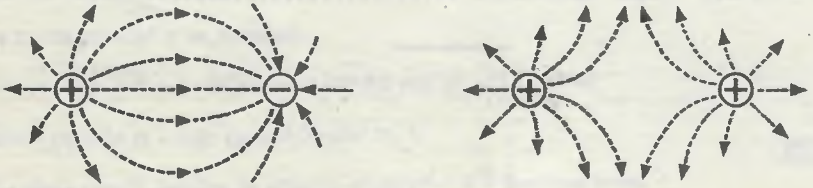
2.3 Lines of Force. We can imagine an electric force as due to "lines of electric force" or, simply, "lines of force". These lines radiate in all directions from an electric charge. We assume that the lines start from a positive charge (Fig. 1a) and end on a negative charge (Fig. 1b).

The attraction or repulsion between charged substances is due to the aiding or opposing of the lines of force. With unlike charges (Fig. 2a), the lines link up and tend to draw the substances together. With like charges (Fig. 2b), the lines are crowded and tend to push the substances apart.



(a) (b)

FIG. 1. LINES OF FORCE.



(a) (b)

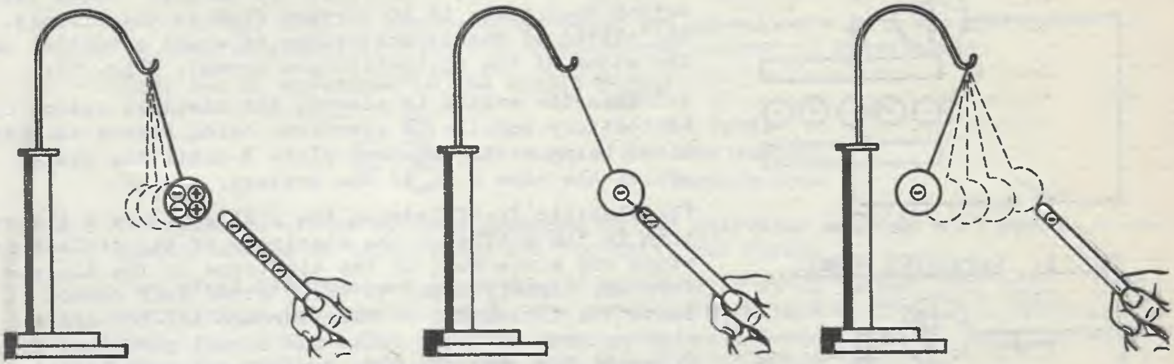
AIDING AND OPPOSING OF LINES OF FORCE.

FIG. 2.

Remember: This idea of lines of force is simply a convenient assumption to help us understand the behaviour of electrically charged substances. Although diagrams of electric fields usually represent the lines of force in one plane, we must remember that the force of the electric field acts throughout the whole of the space surrounding the charged substance, and not just along these imaginary lines.

2.4 The air or any other insulating material occupying the space around a charged body is called the dielectric, the derivation of the word meaning that electrical influences can take place across or through it. It will be seen later that the dielectric plays a major part in the effects produced by an electric field.

2.5 Influences of the Electric Field. An experiment which shows the influence that an electric field has on objects within its proximity, is one in which a suspended neutrally charged pith ball is placed in proximity to a charged ebonite rod. The negatively charged rod will first attract the pith ball and then when contact has been made, will repel it.



(a) Electrostatic Induction and Attraction. (b) Transfer of Charge by Conduction. (c) Repulsion.

FIG. 3. INDUCING A PERMANENT CHARGE ON A PITH BALL.

Electrons on the pith ball are repelled by the rod's negative charge, so that the side of the pith ball nearest the charge becomes positively charged, as in Fig. 3a. As "unlike charges attract" the pith ball is attracted to the rod. The induction of the charge affects both the dielectric and the pith ball, and precedes the attraction which takes place.

When contact is made, electrons pass from the rod and the pith ball's positive ions become neutralised (Fig. 3b). When the rod and side of the ball are at the same negative potential the two bodies will repel one another, as "like charges repel". (Fig. 3c).

Experiments with a positively charged glass rod and pith ball produce the same result, showing the influence that an electric field has on objects within it.

2.6 Plotting the electric field. If a very high voltage is applied to two conducting plates and pieces of hard rubber filings are sprinkled on a piece of paper which is placed over the plates, when the paper is lightly tapped, the rubber filings will align themselves as shown in Fig. 4.

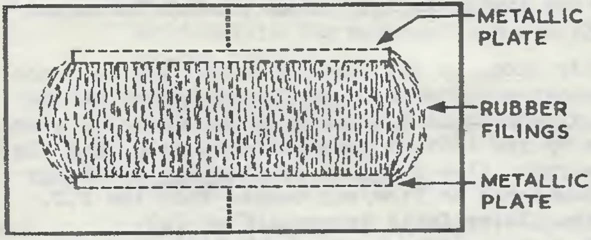


FIG. 4. USING HARD RUBBER FILINGS TO SHOW ELECTRIC FIELD.

The reason for this reaction is that the rubber filings provide a better conducting path for this field than does the air between the plates. The electric lines of force produced by the high voltage tend to follow the rubber particles and exert a force on them, so that they line up in the same way that iron filings line up when influenced by the magnetic lines of force from a magnetic field.

The shape of the electric field as shown in Fig. 4 indicates that the lines of force are not continuous as in a magnetic field but pass from the positively charged plate to the negatively charged plate.

The effects produced by electrostatic induction due to the electric lines of force from an electric field, have a similarity to magnetic induction produced by magnetic lines of force from a magnetic field, as in both cases the field affects certain objects within its influence, by induction.

3. THE CAPACITOR.

3.1 In its simplest form the capacitor consists of two conducting plates separated by a thin layer of air.

When 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. 5).

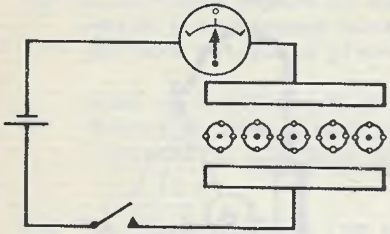


FIG. 5. CAPACITOR NORMAL.

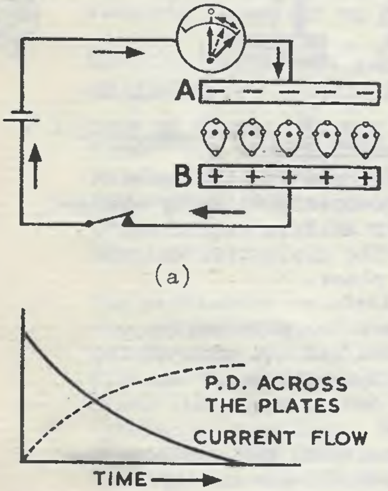
3.2 When the switch is closed, the chemical action of the battery results in electrons being passed to plate A and being withdrawn from plate B until the plates are at the same P.D. as the battery.

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. 6a. In this condition the dielectric exhibits surface charges and is said to be "polarised".

The limited electron movement in the dielectric is commonly called a <u>displacement current</u> which 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. Fig. 6b indicates that the current ceases to flow when the plate P.D. equals oppositely the applied voltage.

It should be noted that the rate of current flow into the capacitor is at its maximum when the P.D. across the plates is at a minimum. The rate of current falls as the P.D. across the plates is raised, and ceases when the capacitor is fully charged.

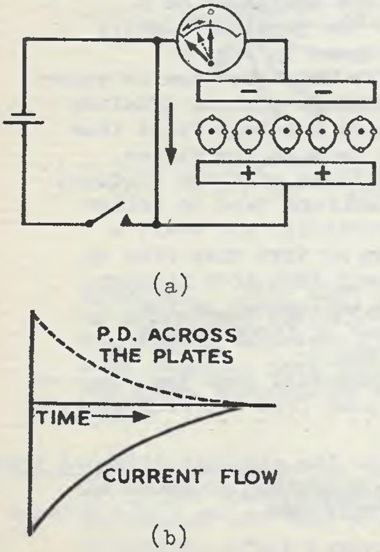


(b)

FIG. 6. CAPACITOR CHARGING.

3.3 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. 7a).

The ammeter shows by its reverse deflection that the discharge current flows out of the capacitor in the opposite direction to the charging current. It also indicates by its initial maximum deflection that the rate of current flow is greatest when the discharge current commences to flow, and ceases when the P.D. between the plates falls to zero (Fig. 7b).



(b)

FIG. 7. CAPACITOR DISCHARGING.

3.4 From this it can be said that -

(i) A capacitor can be charged.
(ii) The charge causes a displacement of electrons within the insulating dielectric material resulting in the dielectric surfaces being "polarised".
(iii) The charge will remain when the energising source is disconnected.
(iv) The stored charge will flow out of the capacitor when a circuit is provided and the dielectric will restore to normal.

4. THE UNIT OF CAPACITANCE.

4.1 Capacitance is defined as the ratio of the charge of a capacitor to the P.D. between its plates. The unit of capacitance is a Farad. A capacitor is said to possess a capacitance of one farad when a charge of one coulomb raises the potential difference between the plates by one volt.

A farad may also be expressed as being the capacitance of a capacitor in which an applied e.m.f. of 1 volt will store one coulomb of electricity.

This can be expressed in the simple formula -

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

where,
E = P.D. in volts.
Q = charge in coulombs.
C = capacity in farads.

4.2 A comparison of the effects produced in the following analogy will assist in the understanding of capacitance and its unit, the farad.

Two tanks of different sizes have a quantity of water poured into them. If the quantity is the same for each, the water in each tank will be at a different level as shown in Fig. 8. The large tank has a lower level or "head" of water than the smaller tank, for the same quantity of water.

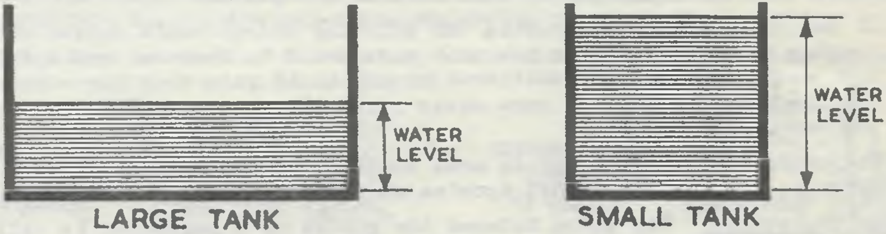


FIG. 8. THE SAME QUANTITY OF WATER PRODUCES DIFFERENT LEVELS OR HEADS OF WATER.

If the analogy is related to the charge that is passed into a capacitor, in comparison with the voltage that it produced across the plates, it will be understood that:-

When similar charges are passed into two capacitors of unequal capacitance the voltage produced across the larger capacitance will be less than that produced across the smaller capacitance.

It must also be understood that when similar voltages are applied across two unequal capacitances, a greater charge must flow into the larger capacitance in comparison to the smaller, before the P.D. across the plates is raised to the value of the applied voltage.

The farad is not an expression of the amount of charge that a capacitor can hold, but is the measure by which the voltage is raised when a certain charge passes into it.

4.3 Submultiple Units. A capacitor possessing a capacitance of one farad is too large both physically and electrically to be of practical use in electrical circuits.

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

(i) Microfarad (symbol μF, previously MF).
(ii) Micromicrofarad (symbol μμF, previously MMF) sometimes called picofarad (symbol pF).

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

The micromicrofarad is equal to $\frac{1}{10^{12}}$ (10^{-12}) or one million-millionth of one farad.

4.4 Conversion of submultiple units. Problems involving capacitors generally require the capacitance to be stated in terms of a farad.

To convert microfarads to farads, divide by 10^6.

To convert micromicrofarads to farads, divide by 10^{12}.

5. FACTORS AFFECTING CAPACITANCE.

5.1 The capacity of a capacitor is related to its constructional details and the whole can be expressed in the following statement.

The capacity of a capacitor varies directly as the cross-sectional area of the plates and the nature of the dielectric, and inversely as the distance between the plates.

$$C \propto \frac{AK}{d}$$

where,

C = capacity in farads.
A = area of the plates in contact with the dielectric.
K = dielectric constant.
d = distance between the plates.

5.2 Area of the Plates. The area of the plates in contact with the dielectric material determines the extent to which a charge can be spread over their surfaces.

When a capacitor is charged, the charging source causes transferred electrons to spread uniformly over one plate, making it negative, and electrons to be drawn from the other plate, making it positive.

These combined charges act on the dielectric, and the intensity of the charge on the plates determines the rise of P.D. across them.

Thus, when the capacitor is charged, and its P.D. equals the applied voltage, there exists a certain charge per unit area on the plates.

If the plate area were doubled the existing charge would spread uniformly over the greater area. The charge per unit area would be lessened and a fall of capacitor P.D. would result. An additional charge would pass from the source to maintain the charge intensity and once again raise the capacitor P.D. to equal the applied voltage.

Therefore, doubling the plate area doubles the electron charge for a given applied voltage, or in other words, doubles the capacitance.

5.3 The Dielectric. The space between the plates of a capacitor is called the dielectric, and may be occupied by air or any insulating material.

In relation to air, most materials pass electric lines of force more easily. This is shown by the example in paragraph 2.6 with the field between the plates of a capacitor traced out by hard rubber filings.

The dielectric material acts in much the same way as materials used in magnetic circuits, as the concentration of the field within it is dependent on the nature of the material used.

5.4 Dielectric Constant (Permittivity). The ratio between the lines of force produced in a dielectric by a given charge, to those produced when air (strictly vacuum) is used in its place is called that material's dielectric constant or permittivity, and is a measure of the extent to which the dielectric may be polarised.

For given plate sizes and spacings, the capacitance of a capacitor will increase in the direct ratio of the dielectric constant of the dielectric material used, to that of air as unity.

This means that when the air dielectric of a capacitor is replaced by mica, the capacity is increased about five times, and when replaced by dry paper the capacity is approximately doubled, for the dielectric constants of mica and paper are quoted as about 5.0 and 2.0 respectively in comparison to air (more correctly vacuous space) as unity.

5.5 Distance Between the Plates. When a capacitor is charged, and the plates are moved together, the effect of the electric field produces an increased attraction on the planetary electrons of the dielectric atoms, and increased polarisation of the surface of the dielectric occurs.

This increased surface polarisation reduces the effect of the charges on the plates which correspondingly reduces the P.D. between them.

If the capacitor is connected to a source of electricity a further charge will pass into the capacitor to raise the P.D. between the plates to that of the source.

When the plates are brought closer together the P.D. between them falls and the capacity increases.

When the plates are separated the P.D. between them rises and the capacity decreases.

5.6 Dielectric Strength. The limiting factor of the efficiency of a capacitor in preventing a current through it, is the insulating dielectric material. When the capacitor is charged, the field by induction strains the dielectric and causes displacement of electrons within it. The higher the charge, the higher the P.D. between the plates, and the greater the straining of the dielectric.

If an increase in charge raises the voltage above a critical value, the displacement of electrons within the dielectric will become a current flow from plate to plate, and the capacitor breaks down. The voltage at which breakdown occurs across a 1 mm. slab of the dielectric material is known as the material's dielectric strength.

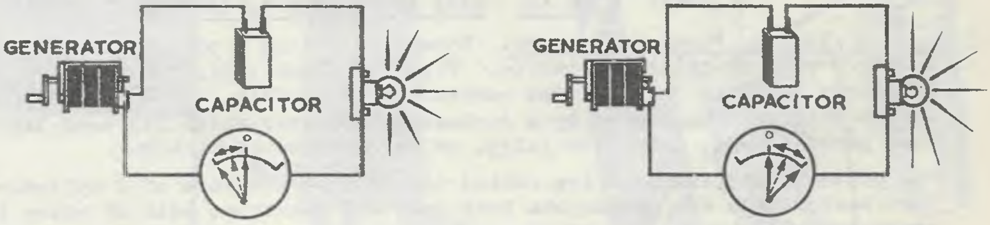
For example, the dielectric strengths of air, mica and ebonite are given as about 4,300 volts, 60,000 volts and 50,000 volts respectively.

The maximum working voltage is usually indicated on the capacitor by the manufacturer. This value should never be exceeded.

6. CAPACITOR IN AN A.C. CIRCUIT.

6.1 Although experiments prove that a D.C. will charge a capacitor but will not pass through it, other experiments show that when a capacitor is included in an A.C. circuit, the effect produced in the circuit is as though the A.C. passes through the capacitor, to operate other components in the circuit.

For example, a generator, an ammeter, a suitable lamp, and a capacitor are connected in series as shown in Fig. 9.



(a) (b)

FIG. 9. CAPACITOR IN AN A.C. CIRCUIT.

When the generator is operated and the voltage rises to a maximum, the capacitor is charged, and when the voltage falls the capacitor discharges, to then be charged in the opposite direction by the next half cycle of A.C. which is of opposite polarity. When the voltage falls the capacitor will then discharge.

This continual charging and discharging takes place through the lamp and ammeter causing the lamp to glow and the ammeter to register the different directions of current. The current has the effect of passing through the capacitor, although it is only charged and discharged for each half cycle of current. (Figs. 9a & 9b).

This effect is used in telecommunication circuits, where a capacitor is connected in series with the bell in a telephone, to prevent a passage of D.C. through the bell, and yet allow the bell to operate when the alternating ringing potential is applied to the telephone from the exchange.

6.2 Capacitive Reactance:- We have seen how inductance offers an opposition, termed inductive reactance, to the flow of an A.C., which varies directly as the frequency of the current and the inductance of the circuit.

Similarly a capacitance offers an opposition to the flow of an A.C.

This is termed capacitive reactance which varies inversely as the frequency of the current and the capacitance of the circuit.

Capacitive reactance is expressed as follows:-

$$X_C = \frac{1}{2\pi f C}$$

where

X_c - capacitive reactance in ohms.
2π - 6.28
f - frequency in c/s.
C - capacitance in farads.

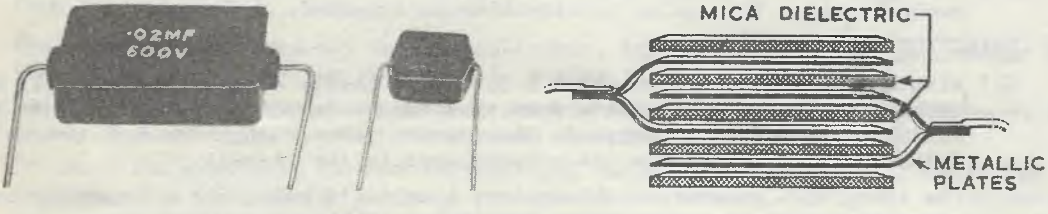
Later papers of the course will provide a fuller understanding of the effects and behaviour of capacitance, inductance and resistance in A.C. circuits.

7. PRACTICAL TYPES OF CAPACITORS.

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

Their symbols are:-

7.2 Mica Dielectric Fixed Capacitors. If a capacitor were made with two plates it would be large and cumbersome. To overcome this a number of small metallic plates are connected together. These are interleaved with another combination of small plates also joined together. A dielectric of mica is inserted between the plates. (Fig. 10b.) This gives the effect of a two plate capacitor in a small space (Fig. 10a). As mica possesses a high dielectric strength, a mica dielectric is generally used when a capacitor needs to withstand high voltages.

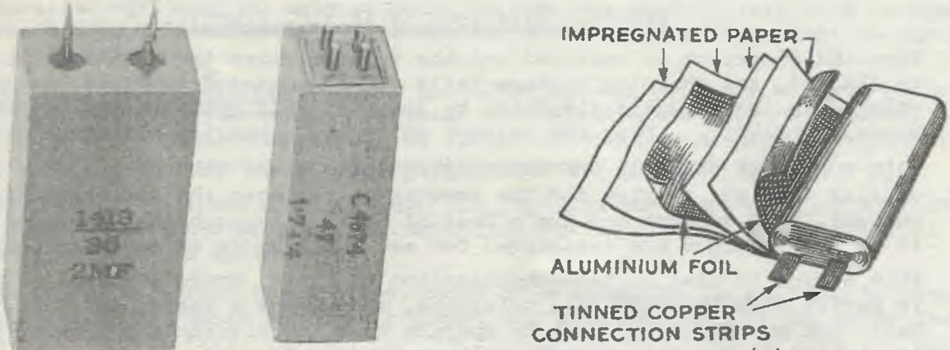


(a) (b)

FIG. 10. MICA DIELECTRIC CAPACITORS.

7.3 Paper Dielectric Fixed Capacitors. Capacitors using a paper dielectric are commonly used in telecom circuits. Fig. 11a shows typical capacitors used in telephone circuits. The plates consist of long, thin, tin or aluminium foil sheets which are separated by a dielectric of paper which has been impregnated with paraffin wax, petroleum jelly, or chlorinated naphthalene.

The plates and dielectric are rolled together in the form of a cylinder which is then sealed in a can to exclude both dust and moisture, both of which tend to break down the insulation of the dielectric under working conditions.



(a) (b)

FIG. 11. PAPER DIELECTRIC CAPACITORS.

7.4 Electrolytic Fixed Capacitors. This type of capacitor depends for its action on the principle that two suitable electrodes in an electrolyte will allow a current to pass in one direction, but very little current in the opposite direction. In construction these capacitors may be of either the "Wet" or "Dry" types.

(i) Wet Electrolytic Capacitors. In its simplest form this type of capacitor consists of two aluminium plates which are in contact with an electrolyte of boric acid. The electrolytic action of a current which is passed between the plates through the electrolyte, during manufacture, forms a thin oxide on the surface of the positively connected plate. This insulating oxide acts as the dielectric of a capacitor and permits little or no current to pass when the capacitor is connected in circuit in the same polarity.

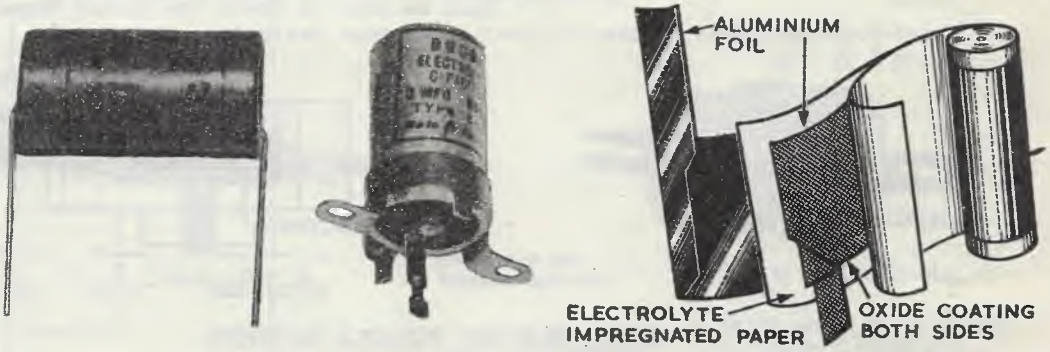
Since the dielectric is maintained by electrolytic action the electrolyte must have contact with the negative side of the voltage source, and the oxide coated plate must be connected to the positive source.

(ii) "Dry" Electrolytic Capacitors. The electrolyte used in this type of capacitor is not "dry" in the strict sense, but is a thick viscous substance held in some absorbing material such as paper or cloth.

The plates are generally of annealed aluminium foil separated by the electrolyte impregnated paper or cloth, the whole being rolled together in a compact roll which is inserted in a container and sealed (Fig. 12). The plate with the oxide coating is the positively connected terminal, and the other negative.

Unless of special design electrolytic capacitors can only be used in circuits where there are unidirectional currents, as a reverse polarity could break down the dielectric, and damage or ruin the capacitor.

In electrolytic capacitors the dielectric of oxide coating is less efficient as an insulator than mica or paper, and small leakage currents must be tolerated; also the coating and electrolyte deteriorate after a period of service. However, the advantages of large capacitance for a small space, and economy of cost, cause these capacitors to be widely used.



(a) (b)

FIG. 12. TYPICAL "DRY" ELECTROLYTIC CAPACITORS.

FIG. 13. TYPES OF CAPACITORS USED IN TELECOM.

7.5 Variable Capacitors.

(i) Air Dielectric Variable Capacitors (Fig. 14). The most common type employs a number of fixed and moving vanes or plates, usually made of brass or aluminium. These mesh with one another according to the capacitance required, and are separated by an air dielectric.

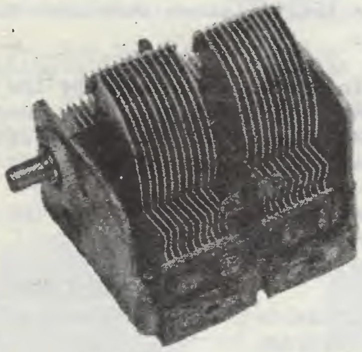


FIG. 14. AIR DIELECTRIC VARIABLE CAPACITOR.

When the rotary plates are fully meshed between the stationary plates, the capacitance is at its maximum as the plate area is then at its greatest. As the movable plates are withdrawn from mesh the capacitance decreases.

The number of plates in combination determines the capacitance required, and common values in use range from 25 to 1000 μμF.

(ii) Mica Dielectric Variable Capacitor. (Fig. 15). This capacitor usually has a maximum value of less than 50 μμF and consists of a number of metallic plates with sheets of mica between them. A screw adjustment is used to force the plates together and vary the plate spacing to the capacitance desired.

(a) (b)

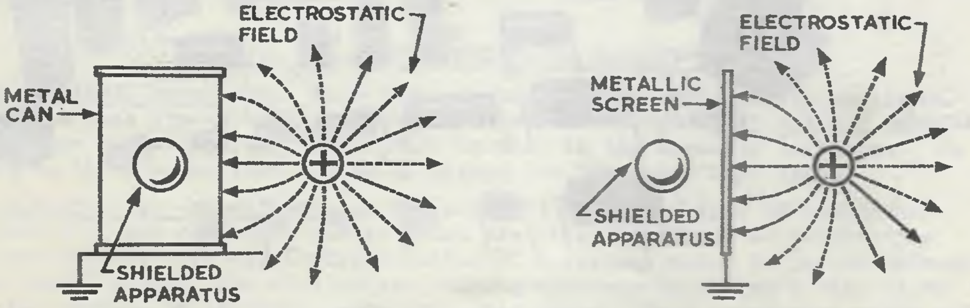
FIG. 15. MICA DIELECTRIC VARIABLE CAPACITOR.

8. ELECTROSTATIC SCREENING.

8.1 In telecom circuits it is sometimes necessary to prevent an electric field from inducing charges on nearby apparatus or adjacent circuits.

To do this an earthed electrostatic screen is used. This usually consists of a metallic can or screen which wholly or partially encloses the apparatus from the effects of induction, or encloses the apparatus which produces the electric field.

In both cases the lines of force have no effect on the protected apparatus for they terminate on the earthed metal screen.



(a) Field terminates on earthed can. (b) Field terminates on earthed screen.

FIG. 16. FORMS OF ELECTROSTATIC SCREENING.

9. CAPACITORS IN SERIES AND PARALLEL.

9.1 When capacitors are connected in series or parallel the method of finding the total capacitance is opposite to that used in finding the total resistance of series or parallel resistors. Just as conductances represent the ease with which current flows, so does capacitance represent the ease with which electric flux is established.

Fig. 17 shows that connecting capacitors in series effectively increases the dielectric space, which decreases the total capacity to less than the smallest capacity in the combination.

When capacitors are connected in parallel, the effect produced is of one large capacitor with a plate area equal to the sum of the plate areas of the component capacitors. (Fig. 18).

9.2 Capacitors in Series.

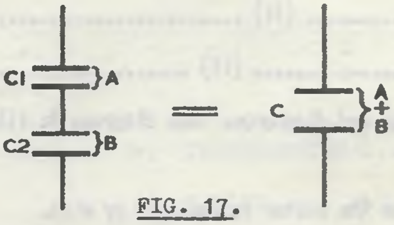


FIG. 17.

Thicker dielectric decreases capacitance.

Formula for Series Capacitors.

$$C = \frac{C1 \times C2}{C1 + C2}$$

or

$$C = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}} \text{ etc.}$$

9.3 Capacitors in Parallel.

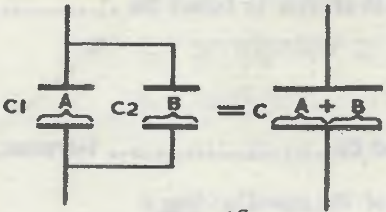


FIG. 18.

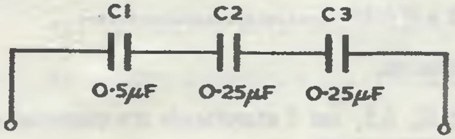
Larger plate area increases capacitance.

Formula for Parallel Capacitors.

$$C = C1 + C2 + C3 \text{ etc.}$$

In both cases C1, C2 and etc. must be expressed in similar units or subunits of capacitance.

9.4 Example (i). Calculate the total capacitance when three capacitors of 0.5 μF, 0.25 μF, and 0.25 μF, are connected in series.

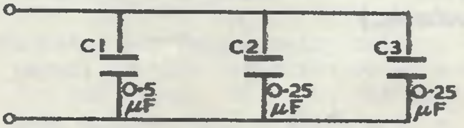


$$C = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

$$C = \frac{1}{\frac{1}{0.5} + \frac{1}{0.25} + \frac{1}{0.25}}$$

Answer:- $C = 0.1\mu F$.

9.5 Example (ii). Calculate the total capacitance when three capacitors of 0.5 μF, 0.25 μF, and 0.25 μF, are connected in parallel.



$$C = C1 + C2 + C3$$

$$C = 0.5 + 0.25 + 0.25$$

Answer:- $C = 1\mu F$.

10. TEST QUESTIONS.

1. The electric field between charged bodies is considered to be composed of ....which pass from the .... charged body to the .... charged body.
2. The space or material surrounding a charged body is termed ....
3. Describe the effects produced when a positively charged body is placed in close proximity to a neutrally charged pith ball.
4. The unit by which capacitance is measured is called the ....
5. Explain the relationship between the charge passed into a capacitor in comparison with the P.D. produced across its plates.
6. The submultiple units of capacity are (i) .... (ii) ....
7. Their relationships to the unit are respectively (i) .... (ii) ....
8. Briefly describe the action of a simple capacitor during charge and discharge. Use diagrams to illustrate your answer.
9. What effect is produced in a capacitor if the air space between the plates is replaced by mica.
10. This effect is due to the .... of mica.
11. The P.D. required to cause an electron flow through a 1 m.m. slab of mica is termed the .... of mica.
12. Briefly explain what is meant by Capacitive Reactance.
13. Capacitive reactance decreases as the .... and the .... increases.
14. As the capacitance is dependent on the constructional features of the capacitor then -
    (i) The capacitance will .... if the size of the plates is ....
    (ii) When the plates are moved apart, the capacitance ....
    (iii) The capacitance will .... if the insulating material between the plates is changed for another material possessing a greater ....
15. Briefly explain what is meant by Electrostatic Screening.
16. Calculate the capacitance when three capacitors of 10, 0.5, and 2 microfarads are connected -
    (a) in series (0.385 microfarads)
    (b) in parallel (12.5 microfarads)
17. What is the capacitance when the 10 microfarads capacitor is placed in series with the paralleled 0.5 microfarads and 2 microfarads capacitors. (2 microfarads.)

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

INTRODUCTION TO A.C. THEORY

★ AMENDED 1962

1. INTRODUCTION.

1.1 Modern Telecommunications are based on Alternating Current theory, and this paper is a simple introduction to this subject.

1.2 Geometry and Trigonometry help us understand A.C. theory, and the introductory paras. of this Paper revise some aspects of these subjects to provide a basis for our study. However, the use and understanding of some of the terms will only achieve full significance at a more advanced stage of study.

2. RADIAN.

2.1 The distance from the centre of a circle to any point on the circumference is called the radius.

A line drawn from a point on the circumference to another point on the circumference, passing through the centre, is called the diameter.

For measurement of angles within the circle, the circumference is divided into 360 equal parts or degrees.

Each degree is divided into 60 minutes, and each minute is divided into 60 seconds.

We therefore measure angles in degrees, minutes and seconds.

2.2 There is another way of measuring angles.

When we measure on the circumference of a circle an arc equal in length to its radius, and join the ends of the arc to the centre, we form an angle which is equal to 57.296 degrees.

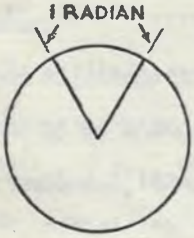


FIG. 1.

This angle is called a radian, since it encloses a length of circumference equal to the radius of the circle.

When the circumference of a circle is divided by its diameter, we obtain 3.14 (approx.) which is always denoted by the Greek letter π (pi). (π is often expressed as $3\frac{1}{7}$.)

As the radius is equal to half the diameter, the circumference is equal to 2π times the radius.

From this it follows that there are 2π radians in 360°.

3. ANGULAR MOTION AND VELOCITY.

3.1 To measure the distance travelled by a horse galloping down the "straight six" is an easy task, as the path it takes is almost a straight line. It is just as easy to measure the velocity of the horse and express it in yards per second, or miles per hour.

The speed of a horse on a merry-go-round can similarly be expressed in miles per hour; it can also be measured in revolutions per given time, or by the number of radians, or certain angles, covered in a given time.

When the velocity is measured in linear units (miles per hour), it is referred to as linear velocity.

When the velocity is measured in angular units, (radians) it is referred to as angular velocity, the symbol for which is the Greek letter ω (omega).

Thus, when the circumference of a circle is travelled "f" times per second, the angular velocity is $2\pi f$ radians per second.

Therefore -

$$\omega = 2\pi f$$

where

ω = angular velocity in radians/second
2π = 6.28 (approx.)
f = revs. per second

We shall see later that this expression has important applications in A.C. theory.

4. TRIGONOMETRICAL RATIOS.

FIG. 2.

4.1 When a circle is divided into four equal parts, the intersecting diameters form four equal angles of 90° each. In trigonometry the quarters are counted in the order shown in Fig. 2.

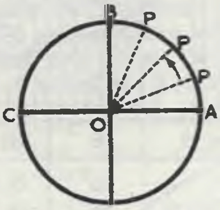


FIG. 3.

When the line OP in Fig. 3 moves from OA to OC, the angle formed increases from 0° at OA to 90° at OB, and 180° at OC.

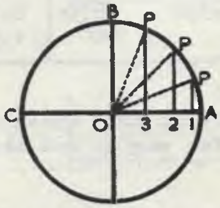


FIG. 4.

With the growth of the angle POA to 90°, the distance from point P to the line OA, also grows, as shown by the dotted lines P1, P2 and P3. (Fig. 4.)

4.2 There is a definite relationship between the increase of the distance P1 with the increase of angle POA, and P1, P2 and P3, or any distances between them, can be used as a measure of angle POA.

4.3 Let us now consider Figs. 5 and 6. Just as the ratio of $\frac{\text{circumference}}{\text{diameter}}$ of any circle is always equal to π (or 3.14), so is this ratio of $\frac{PC}{OP}$ always a definite number for a given angle in a right-angled triangle.

In trigonometry this ratio of $\frac{PC}{OP}$ or $\frac{\text{Opposite}}{\text{Hypotenuse}}$ is termed the Sine of the related angle. In common practice Sine is abbreviated to Sin, and the related angle is denoted by the lower case of the Greek letter Theta, the symbol for which is θ.

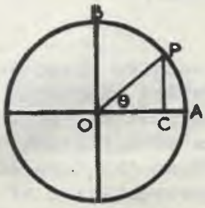
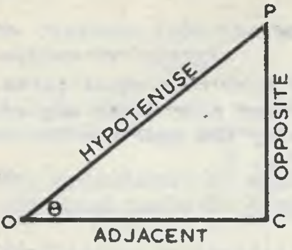


FIG. 5.

4.4 In a right-angled triangle the ratios $\frac{OC}{OP}$ and $\frac{PC}{OC}$ are also definite quantities for every angle, in the same way as the sine of an angle.

These are known respectively as Cosine (Cos.) and Tangent (Tan.)

4.5 These three relationships are expressed as follows -



$$\text{Sin}\,\theta = \frac{\text{OPPOSITE}}{\text{HYPOTENUSE}}$$

$$\text{Cos.}\,\theta = \frac{\text{ADJACENT}}{\text{HYPOTENUSE}}$$

$$\text{Tan.}\,\theta = \frac{\text{OPPOSITE}}{\text{ADJACENT}}$$

FIG. 6.

4.6 Table of Sines. Each angle has its own value of sin θ, and these values vary from zero at the point when OP coincides with OA, to unity at the point where OP coincides with OB (Fig. 7). From this sin $0^\circ = 0$, and sin $90^\circ = 1$, and the sine of the intermediate angles vary between these points as set out in Table 1.

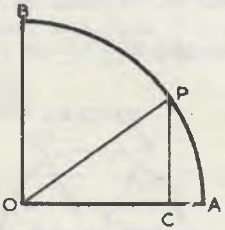


FIG. 7.

θ	Sin θ	θ	Sin θ	θ	Sin θ
0°	0.	30°	0.5	60°	0.8660
5°	0.0872	35°	0.5736	65°	0.9063
10°	0.1736	40°	0.6428	70°	0.9397
15°	0.2588	45°	0.7071	75°	0.9659
20°	0.3420	50°	0.7660	80°	0.9848
25°	0.4226	55°	0.8192	85°	0.9962
				90°	1.0

TABLE 1.

Standard tables for all trigonometrical ratios are available in most suitable text books and in other books of this course, including values for angles not shown in Table 1.

5. DEVELOPMENT OF SINE WAVE.

5.1 We saw in para. 3.1 that angular motion is represented by the rotating radius of a circle, the angular velocity of which can be measured in radians/sec. ($\omega = 2\pi f$.) The sines of all the angles through which the radius passes in its 360° movement can be calculated, and the angular motion of the radius can be represented as a graph shown in Fig. 8.

The circumference of a circle is divided into twelve numbered equal parts, and the line AB, which is equal in length to the circle's circumference is similarly divided.

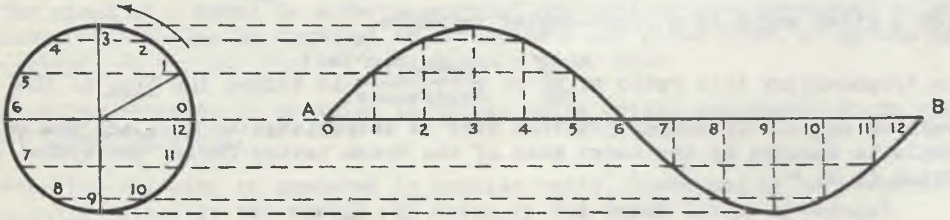


FIG. 8. PLOTTING A SINE WAVE.

Imagine that the radius of the circle rotates in an anticlockwise direction, then from position 0 to position 6 the sines of the angles traversed vary from zero to unity, and back to zero. By periodically projecting the position of the rotating radius across to AB we arrive at a number of lines of different lengths which show the variation of height of the moving radius. When the tops of the lines are joined by a smooth curve, we obtain a graphic representation of these variations. This is termed a Sine Wave or Sine Curve, and is the graph of a trigonometrical function, for it shows graphically the variation in magnitude of the sine of an angle, while the angle grows from 0° to 360°.

5.2 Just as the angular motion of a rotating radius is represented by the graphical sine wave, so can the output voltage (or current) of an A.C. generator be represented by a sine wave. When a conductor rotates with a constant angular velocity in a uniform magnetic field, it cuts the field at varying rates depending on the instantaneous direction of motion. Maximum e.m.f. (E_{max}) is induced when it cuts directly across the lines of force, and minimum e.m.f. when it moves parallel to the lines. (Fig. 9.)

Intermediate or instantaneous values are proportional to the sine of the angle through which the conductor has rotated from the zero value.

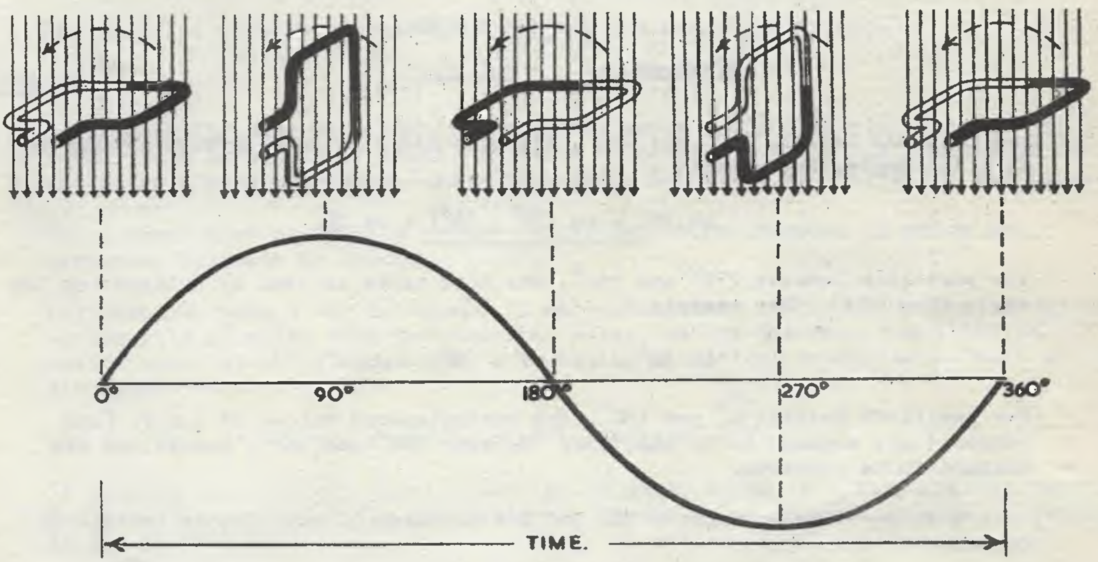


FIG. 9. GENERATION OF A SINE WAVE.

5.3 Although the base line is divided into segments representing electrical degrees, it must also be remembered that it also represents the time in which the various values are attained, from the commencement of the sine wave.

5.4 In a generator therefore, the sine value for any degree of rotation is the factor by which the maximum voltage (or current) is multiplied, to give the instantaneous voltage (or current) at that degree of rotation.

Instantaneous e.m.f. (e) is expressed as -

$$e = E_{max.} \times \sin.\theta$$

Similarly, the instantaneous current (i) is related to the maximum current (I_{max}) by the equation -

$$i = I_{max.} \times \sin.\theta$$

5.5 Examples. The maximum voltage developed by a simple A.C. generator is 2 volts. What is the instantaneous e.m.f. generated when the conductor has rotated to the 60° position? (Sine $60^\circ = 0.8660$, from Table 1.)

$$e = E_{max} \times \sin\theta$$

$$= 2 \times 0.8660$$

Instantaneous e.m.f. $= \underline{1.732 \text{ volts.}}$

For rotational degree positions between 90° and 180°, the sine table is used by subtracting the angle from 180°. Assuming the conductor rotates to the 135° position in the previous example, the instantaneous induced e.m.f. –

$$\begin{aligned} e &= E_{max} \times \sin\theta \\ &= 2 \times \sin\ (180^\circ - 135^\circ) \\ &= 2 \times \sin 45^\circ \\ &= 2 \times 0.7071 \\ \underline{\text{Instantaneous e.m.f.}} \quad &= \underline{1.414 \text{ volts.}} \end{aligned}$$

5.6 For positions between 180° and 270°, the sine table is used by subtracting 180° from the angle, for example –

$$\sin 210^\circ = \sin\ (210^\circ - 180^\circ) = \sin 30^\circ.$$

For positions between 270° and 360°, the sine table is used by subtracting the angle from 360°. For example –

$$\sin 300^\circ = \sin\ (360^\circ - 300^\circ) = \sin 60^\circ.$$

For positions between 0° and 180°, the instantaneous values of e.m.f. (and current) are assumed to be positive. Between 180° and 360°, the values are assumed to be negative.

5.7 It is also possible to measure the angle θ in terms of revolutions instead of degrees.

Since 1 revolution equals 2π radians, then $\theta = 2\pi ft$ radians, and as $2\pi f$ is usually expressed as ω, the instantaneous voltage and current can be found from –

$$\mathbf{e = E_{max.} \times sin.\omega t} \quad \text{and} \quad \mathbf{i = I_{max.} \times sin.\omega t}$$

<u>For example</u> – Find the instantaneous voltage (e), 2 milliseconds after zero voltage, when $E_{max} = 2$ volts, and $f = 50$ c/s.

$$\begin{aligned} e &= E_{max} \sin\omega t. \\ e &= 2 \times \sin\left(\frac{6.28 \times 50 \times 2}{1000}\right) \\ &= 2 \times \sin 0.628 \text{ radians.} && (0.628 \text{ radians} = 36^\circ) \\ &= 2 \times \sin 36^\circ && (\sin 36^\circ = 0.5878) \\ \underline{\text{Instantaneous voltage.}} \quad &= \underline{1.1756 \text{ volts.}} \end{aligned}$$

5.8 <u>Cycle</u>. Fig. 9 shows that one complete revolution of the rotating conductor produces an alternating e.m.f. (and current) which rises from zero to a maximum and falls to zero, then rises to maximum in the opposite direction and again falls to zero. In the sine wave graph the alternation above the line is termed positive, and the alternation below the line is termed negative.

The complete set of positive and negative values is called a <u>cycle</u>, and is made up of two <u>half cycles</u>, one positive and the other negative.

5.9 Frequency. The number of complete cycles produced in one second is the frequency of the alternating e.m.f. or current.

For example, when the coil of Fig. 9 rotates at 3000 revs. per minute, the alternating e.m.f. has a frequency of 50 cycles per second (c/s). (Expressed in ★ angular velocity this is $2\pi 50 = 314$ radians per second.)

The time duration of 1 cycle is called its period and indicates the time in seconds or fraction of a second taken for 1 cycle to elapse.

For example, when the frequency is 50 c/s the period is $\frac{1}{50}$ sec.

6. VECTORS.

6.1 Vector Quantity. Certain quantities can be expressed accurately in numerical terms, such as pounds of fruit, or yards of material, but other quantities can not be so simply expressed unless both their magnitude and direction are known.

These quantities are called vector quantities, some examples of which are distance, velocity or force.

For example, when a car is driven 10 miles, and then another 10 miles, it is not necessarily 20 miles from the starting point, as the distance travelled is a vector quantity which takes into account the directions travelled as well as the distance.

How far then is the car from the starting point?

If we know that the car first travelled 10 miles North, and then another 10 miles East, we can represent the magnitude and direction of these distances by two lines AB and BC (Fig. 10).

The distance AC then represents the distance from the starting point at A.

The lines AB, BC and AC, together with their respective direction indicating arrows, represent the magnitude and direction of the distances travelled and are called vectors.

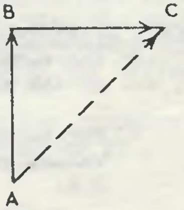


FIG. 10. VECTORS SHOW MAGNITUDE AND DIRECTION.

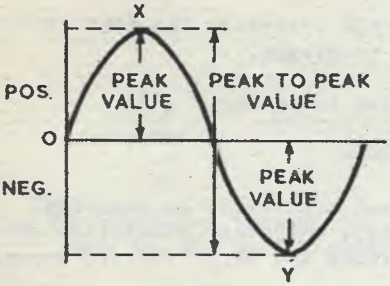
6.2 Vectors are a simple way of representing alternating voltage and current. For example, in the production of the sine wave of Fig. 8, the rotating radius is referred to as the vector of the sine wave, and it is often more convenient to consider the wave from the point of view of the vector rather than the actual sine wave form.

6.3 For convenience and uniformity, vectors are usually assumed to rotate in an anticlockwise direction. However, it is important to understand that a generator, (which the vector may represent), will produce an e.m.f. irrespective of its direction of rotation.

6.4 When vectors are used to indicate effective or R.M.S. value of alternating voltage and current, they are marked E and I and when used to indicate maximum or peak value they are marked E_{max} and I_{max}. (See Section 7.)

7. VALUES OF ALTERNATING VOLTAGE AND CURRENT.

7.1 During each cycle an alternating voltage (or current) passes through a large range of values from zero to maximum, and there are three values generally associated with A.C. theory.



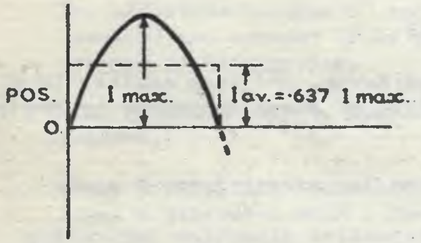
PEAK VALUE.

FIG. 11.

(i) Peak or Maximum Value. This is the maximum instantaneous value occurring during one sine wave shown at points x and y in Fig. 11.

The peak value must be taken into account when considering the insulation in high voltage circuits. Normal measuring instruments indicate 0.707 of the peak value (para. (iii)), but the insulation must withstand 1.414 times the measured voltage, twice per cycle.

The difference between the peaks of positive and negative values is called peak to peak value; this is twice the peak value. In A.C. practice this value is not often used.

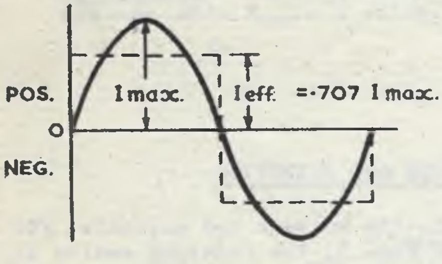


AVERAGE VALUE.

FIG. 12.

(ii) Average Value. The average value is the average of all the instantaneous values of the sine wave for one half cycle (Fig. 12).

Average Value = 0.637 Peak Value.



EFFECTIVE VALUE.

FIG. 13.

(iii) Effective Value. This is the value which produces the same heating effect as a continuous current of the same amount (Fig. 13).

For example, a current of 5 amperes effective value, has the same heating effect as 5 amperes D.C.

Effective Value = 0.707 Peak Value.
Peak Value = 1.414 Effective Value.

The effective value is the one usually used to express alternating voltages and currents, and the scales of most measuring instruments are calibrated to read this value.

7.2 The term R.M.S. value is often used instead of effective value, but the derivation of the term will be explained in a more advanced paper on A.C. theory.

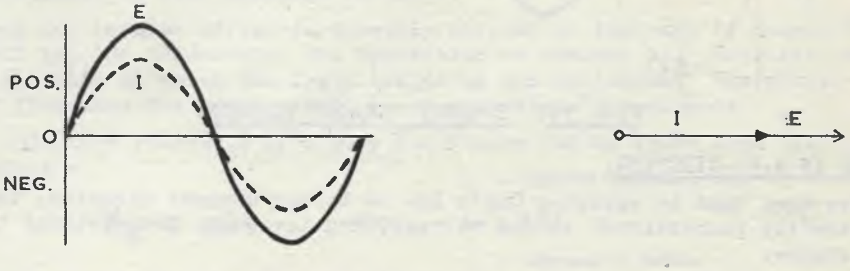
7.3 Average value (0.637 Max) and Effective value (0.707 Max) apply only to sine waves. We shall see that alternating voltages and currents can assume other than sine wave patterns, and in this case, Average and Effective values have a different relationship to the Maximum value than those stated.

8. PHASE RELATIONSHIP.

8.1 Voltage and Current "In Phase". When an alternating potential is applied to a circuit, the resultant alternating current has the same frequency as the applied potential. In some types of circuit the voltage and current waves reach their maximum and zero values at the same time.

In this case the voltage and current are said to be "in phase" and Figs. 14a and b show this condition graphically and vectorially, assuming that the magnitude of the voltage graph is greater than the resulting current graph.

Consequently the voltage and current vectors correspond in direction but not in magnitude.



(a) (b)

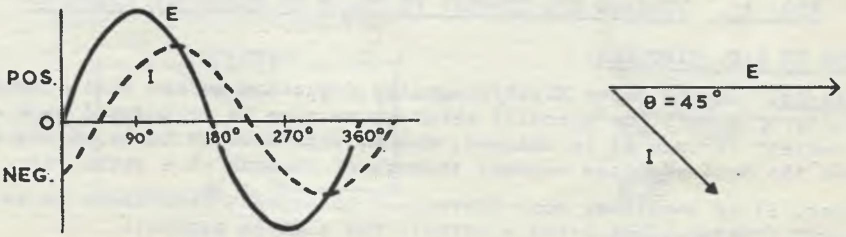
FIG. 14. VOLTAGE AND CURRENT IN PHASE.

It is conventional to show voltage vectors with normal arrowheads, and current vectors with enclosed arrowheads (Fig. 14b).

8.2 Phase Difference. In many A.C. circuits the voltage and current are not in phase, and the maximum and zero values of current in the circuit can occur either before or after the relative voltage values. When this occurs the voltage and current are said to be "out of phase". This phase difference can be either expressed in degrees or time.

8.3 Current "Lags" Voltage. When the maximum and zero values of current occur after the relative voltage values, the current is said to "lag" the voltage. (It would be equally correct to say that the voltage "leads" the current, but it is usual to express the "out of phase" factor in terms of the relationship of the current to the voltage, instead of the voltage to the current.)

Figs. 15a and b show this condition graphically and vectorially with an example of the current lagging the voltage by 45°.



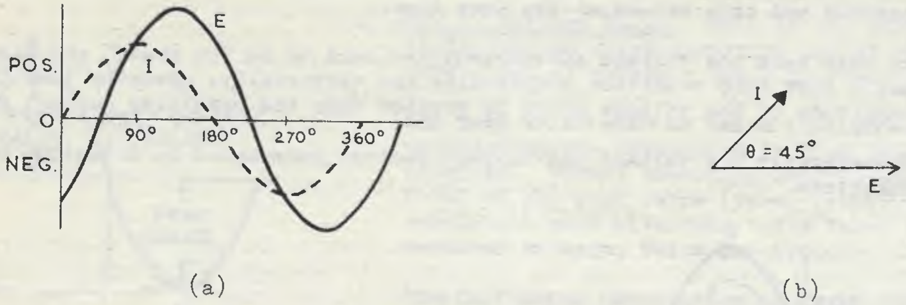
(a) (b)

FIG. 15. CURRENT "LAGS" VOLTAGE.

Remember - Vectors conventionally rotate anticlockwise, therefore the I vector "lags" the E vector by 45° in the direction shown.

8.4 Current "Leads" Voltage. When the maximum and zero values of current occur before the relative voltage values, the current is said to "lead" the voltage.

Figs. 16a and b show this condition graphically and vectorially with an example of the current leading the voltage by 45°.



(a) (b)

FIG. 16. CURRENT "LEADS" VOLTAGE.

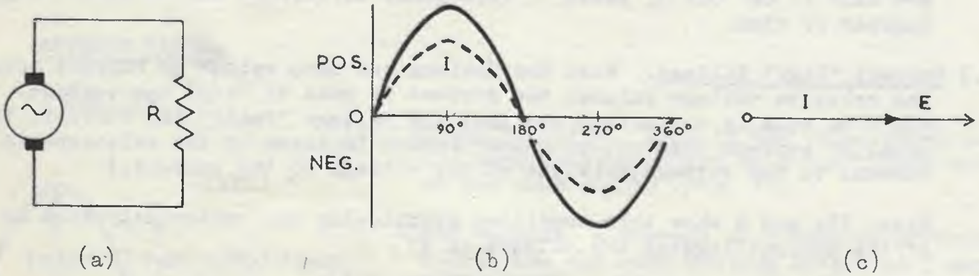
9. RESISTANCE IN A.C. CIRCUITS.

9.1 We have seen that in applying Ohm's Law to Direct Current circuits, the current is directly proportional to the voltage, and inversely proportional to the resistance.

When an alternating potential is applied to a circuit containing purely resistance (Fig. 17a), that is a circuit having no inductance, or capacitance, the current at any instant is directly proportional to the instantaneous voltage.

9.2 Thus, in alternating current circuits, Ohm's Law still applies, providing the load is purely resistive.

9.3 As the values of voltage and current have the same frequency, and achieve their maximum and zero values together, they are therefore "in phase" in resistive circuits. This is shown graphically and vectorially in Figs. 17b and c.



(a) (b) (c)

FIG. 17. VOLTAGE AND CURRENT IN PHASE IN RESISTIVE CIRCUITS.

10. INDUCTANCE IN A.C. CIRCUITS.

10.1 Inductance. In the paper Electromagnetic Induction we saw that inductance is the property of a coil (or circuit) which gives rise to an induced back e.m.f. when the current through it is changed, and is expressed in terms of the e.m.f. induced across the coil when the current through it changes at a given rate.

However, it is sometimes more convenient to express inductance in terms of the linkages created (flux lines × turns), for a given current.

As a matter of interest this is expressed in the following formula.

$$L = \frac{\Phi N}{I \times 10^8}$$

where

L = inductance in henries.
Φ = flux.
N = turns.
I = current.

10.2 When inductances are connected in series, parallel, or series parallel, and there is no mutual induction between the coils, the equations for finding the equivalent inductance are the same as those for resistors similarly connected, with inductance values substituted for resistance values.

10.3 Inductive Reactance. As stated, the property of inductance produces an effect which tends to oppose the establishment of, or change in value of, a current in a circuit, by causing an opposing e.m.f. to retard its increase, or by causing an assisting e.m.f. to retard its decrease.

This means that any coil possessing inductance offers an opposition to a changing current distinct from that due to the D.C. resistance of its windings.

The opposition offered by the inductance of a coil is termed its Reactance or Inductive Reactance, and since it represents an opposition to current, it, like resistance, is also measured in ohms.

Since any induced effect is directly related to the rate of change between the field and the conductors, the opposition to current will increase in proportion to the rate at which the field builds up and collapses. Therefore, the higher the frequency the greater will be an inductance's reactance.

10.4 The inductive reactance of a pure inductance can be found from the following formula -

$$X_L = \omega L$$

where

X_L = Inductive Reactance in ohms.

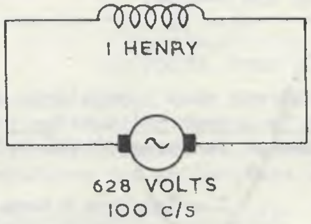
$\omega = 2\pi f$.

L = Inductance in henries.

In practice it is impossible to obtain a purely inductive coil as its windings must possess some D.C. resistance, but when this D.C. resistance is negligible, it is ignored in simple calculations.

10.5 An illustration of the effect of increased frequency on the current flow in an inductive circuit is provided by the following examples.

(i) Find the value of current when a 100 c/s alternating voltage of 628 volts is applied to an inductance of one henry.



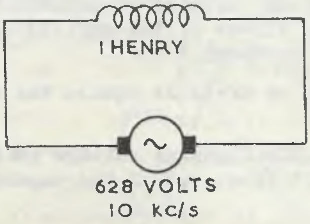
$$I = \frac{E}{\omega L}$$

$$= \frac{628}{6.28 \times 100 \times 1}$$

$$= \frac{628}{628}$$

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

(ii) Find the value of current when the frequency of the current in the previous problem is increased to 10 kc/s.



$$I = \frac{E}{\omega L}$$

$$= \frac{628}{6.28 \times 10{,}000 \times 1}$$

$$= \frac{628}{62{,}800}$$

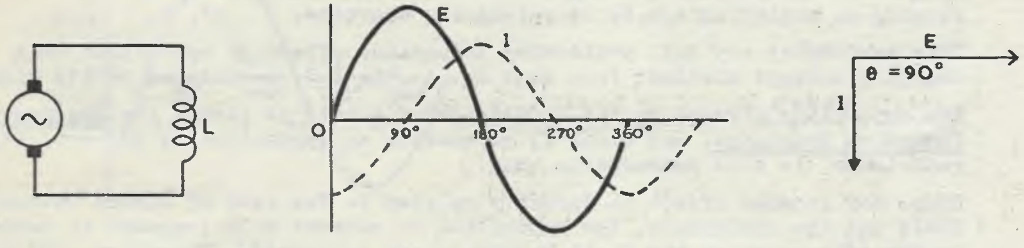
$$= \underline{0.01 \text{ ampere.}}$$

In this particular circuit an increase in the frequency from 100 c/s to 10,000 c/s results in a reduction of current from 1 ampere to 0.01 ampere. Therefore, in an inductive circuit, an increase in frequency causes an increase in inductive reactance and a decrease in current.

10.6 Current Lags in Inductive Circuits. In a circuit possessing inductance (Fig. 18a), the current always lags behind the applied voltage.

Graphically and vectorially, this is represented in Figs. 18b and c, which show the phase relationship between voltage and current in a purely inductive circuit.

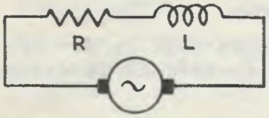
The current lags the voltage by one quarter cycle or 90°.



(a) (b) (c)

FIG. 18. CURRENT LAGS BY 90°.

10.7 For circuits possessing inductance and resistance (whether the resistance is in the windings of the inductance or is separate) the total opposition to current is termed Impedance. This can be found from the formula -



$$Z = \sqrt{R^2 + X_L^{\ 2}}$$

where

Z = Impedance in ohms.
R = Resistance in ohms.
X_L = Inductive Reactance in ohms.

10.8 The addition of resistance to an inductive circuit reduces the angle of lag of the current, and as all inductances must possess some resistance, the angle of lag in practice will always be less than 90°.

10.9 This and other important aspects of the behaviour of inductance in A.C. circuits are covered fully in more advanced papers of the Course.

11. CAPACITANCE IN A.C. CIRCUITS.

11.1 Capacitance. In the paper Capacitance, we saw that capacitance is the property of a capacitor (or circuit) which gives rise to a back voltage due to the storage of electric charges within it, and is estimated in terms of the P.D. between its plates caused by a given charge.

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

where

C = Capacitance in farads
Q = Charge in coulombs
E = Volts.

When a voltage is applied to an uncharged capacitor, maximum current flows at the start of the charge, and as it charges, an opposing or counter voltage is built up across its plates. This reduces the effect of the applied voltage, and the rate of current into the capacitor is decreased.

The opposing voltage continues to build up until it equals the applied voltage, when the charging current ceases.

When the applied voltage is decreased, the opposing voltage is greater than the applied voltage, and a discharge current flows out of the capacitor, in the opposite direction.

11.2 Capacitive Reactance. When an alternating (or varying) potential is applied to a capacitor, it charges and discharges at the frequency of the applied voltage. The opposition offered by the opposing voltage across the capacitor's plates limits current flow from the applied source, and this opposition to an alternating (or varying) current is termed the capacitor's Reactance or Capacitive Reactance (X_c).

Like inductive reactance, capacitive reactance is measured in ohms and is dependent upon frequency, but it decreases with frequency and capacitance, whereas inductive reactance increases with frequency and inductance.

11.3 The capacitive reactance of a purely capacitive circuit can be found from the following formula -

$$X_C = \frac{1}{\omega C}$$

where

X_C = Capacitive reactance in ohms.

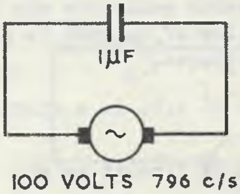
$\omega = 2\pi f$.

C = Capacitance in farads.

In practice it is impossible to obtain a purely capacitive capacitor as its construction and connections possess some D.C. resistance, but this is ignored in simple calculations.

11.4 An illustration of the effect of increased frequency on the current in a capacitive circuit is provided by the following examples.

(i) Find the current when an alternating voltage of 100 volts at a frequency of 796 c/s is applied to a capacitance of 1μ F (Assume ω = 5,000 radians).

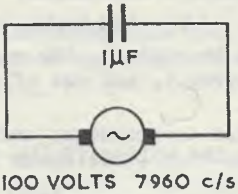


$$I = \frac{E}{X_C} = \frac{E}{\frac{1}{\omega C}} = E\omega C$$

$$= 100 \times 5{,}000 \times 1 \times 10^{-6}$$

$$= \underline{0{,}5 \text{ ampere.}}$$

(ii) Find the current flow when the frequency of the current in the previous problem is increased to 7,960 c/s (ω = 50,000 radians).



$$I = E\omega C$$

$$= 100 \times 50{,}000 \times 1 \times 10^{-6}$$

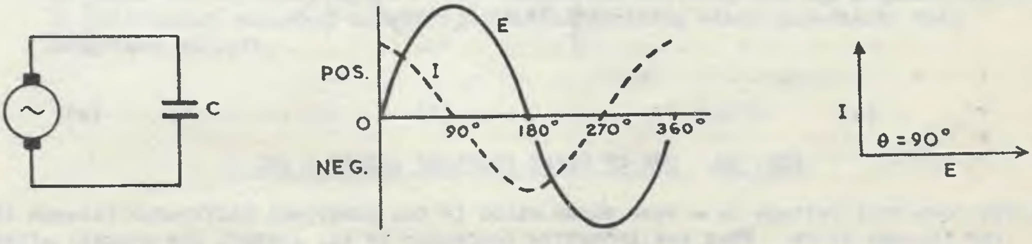
$$= \underline{5 \text{ amperes.}}$$

In this particular circuit, an increase in the frequency of the A.C. from 796 c/s to 7,960 c/s rosults in an increase of current from 0.5 ampere to 5 amperes. In a capacitive circuit, therefore, an increase in frequency causes a reduction in capacitive reactance and an increase in the current.

11.5 Current Leads in Capacitive Circuits. In a circuit possessing capacitance (Fig. 19a) the current leads the voltage as the reactance of its counter voltage does not cause current to cease until the counter and applied voltages are equal.

Graphically and vectorially this is represented in Figs. 19b and c, which show the phase relationship between voltage and current, in a purely capacitive circuit.

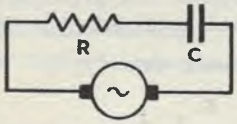
The current leads the voltage by one quarter cycle or 90°.



(a) (b) (c)

FIG. 19. CURRENT LEADS BY 90°.

11.6 For circuits possessing capacitance and resistance (whether the resistance is in the capacitor construction or is separate) the total opposition to current is termed Impedance. This can be found from -



$$Z = \sqrt{R^2 + X_C^2}$$

where
Z = Impedance in ohms.
R = Resistance in ohms.
$X_c = \frac{1}{\omega C}$

11.7 The addition of resistance to a capacitive circuit reduces the angle of lead of the current, and as all capacitances must possess some resistance, the angle of lead will always be less than 90°.

11.8 This and other important aspects of capacitance in A.C. circuits are covered fully in more advanced papers of the Course.

12. CIRCUITS WITH RESISTANCE, INDUCTANCE AND CAPACITANCE.

12.1 Circuits often include both inductance and capacitance as well as resistance.

In a direct current circuit the resistance restricts the flow of current, but as we have seen, in an A.C. circuit the flow of current is also restricted by the reactances of the inductance and capacitance.

12.2 This total effect which limits the flow of A.C. in a circuit is termed the circuit's impedance, the symbol for which is Z.

We can then restate Ohm's Law for an A.C. circuit as -

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

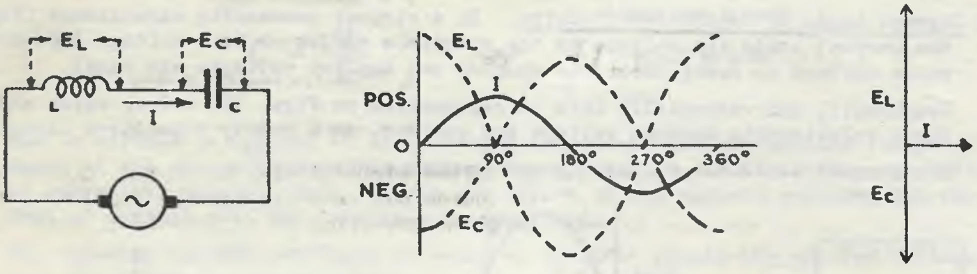
where
I = Circuit current in amperes
E = Applied e.m.f. in volts
Z = Total impedance in ohms.

12.3 In Fig. 20a when an alternating voltage is applied, the same value of current flows through each component in the series circuit, and out of phase voltages are set up across the inductance and capacitance.

The current (I) in the inductance lags the voltage (E_L) by 90°.

The current (I) in the capacitance leads the voltage (E_C) by 90°.

Figs. 20b and c show that the two voltages are exactly in opposition (or 180° out of phase), and therefore tend to cancel out.



(a) (b) (c)

FIG. 20. OUT OF PHASE VOLTAGES ACROSS L AND C.

12.4 The resultant voltage is a wave whose value is the numerical difference between the two voltage waves. When the inductive reactance is the larger, the overall effect is that of an inductive circuit with a lagging current. When the capacitive reactance is the larger, the overall effect is that of a predominantly capacitive circuit with a leading current.

Figs. 21a and b show these conditions graphically and vectorially, assuming that the inductive reactance is large with respect to the capacitive reactance.

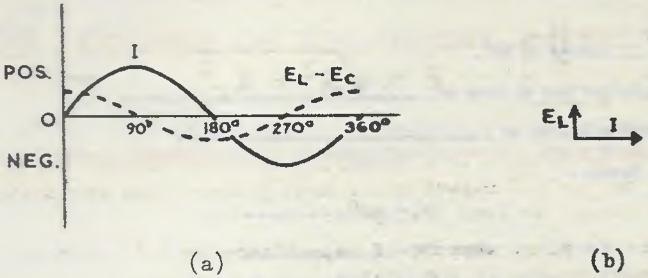


FIG. 21. RESULTANT OF OUT OF PHASE VOLTAGES ACROSS L & C.

12.5 In practical A.C. circuits of this type, series resistance is always present either as part of the inductance or capacitance, or separate within the circuit as shown in Fig. 22.

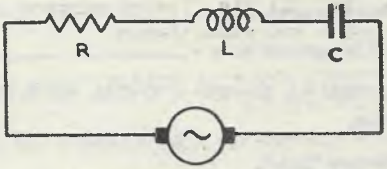


FIG. 22. RESISTANCE, INDUCTANCE & CAPACITANCE IN SERIES.

The impedance must therefore take into account the circuit's resistance and the resultant reactance from opposing effects produced by the inductance and the capacitance.

12.6 We can therefore define impedance as being the total opposition offered to current in an A.C. circuit, which takes into account the circuit's overall resistance and reactance.

For series A.C. circuits containing resistance, inductance and capacitance, the impedance can be calculated from the following formula.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where

Z = Impedance in ohms.

R = Resistance in ohms.

X_L = Inductive reactance in ohms.

X_C = Capacitive reactance in ohms.

12.7 In this paper it is not possible to outline advanced aspects of A.C. theory but we shall see in other papers of the Course how vectors, and the formulas outlined in this paper, are used to solve problems involving other aspects of this important subject.

13. TEST QUESTIONS.

1. For measurements of angles within a circle, the circumference is divided into .... equal parts known as ....

2. Define the Radian.

3. There are .... radians in 360^0.

4. Velocity measured in miles per hour is known as ....

5. Velocity measured in radians is known as ....

6. Complete the following formula -

ω = ...

$\omega = 2\pi .f.$ where 2π = ...

... = ...

7. What is meant by the "Sine of an angle"?

8. Sin 0^0 = ... Sin 90^0 = ...

9. Develop a graph which shows the variation in magnitude of the sine of an angle, while the angle grows from 0^0 to 360^0.

10. This graph is called ....

11. In a generator, instantaneous e.m.f. (e) is expressed as e = ...

12. When the maximum voltage generated by a simple A.C. generator is 10 volts, what is the value of instantaneous e.m.f. when the conductor has rotated to the 60^0 position.

13. Sketch and describe what is meant by the term "Cycle".

14. If the armature of a simple A.C. generator revolves at 1,000 revs. per minute what is the frequency of the alternating e.m.f.

15. With the aid of a diagram, explain what is meant by "vector quantity".

16. In alternating current theory, what is meant by -

    (i) Peak or Maximum Value.
    (ii) Average Value.
    (iii) Effective Value.

17. Normally quoted Average & Effective values apply only to alternating voltages (and currents) possessing a .... pattern.

18. What is meant by (i) "In Phase" (ii) "Out of Phase".

19. Draw one type of circuit where the term "In Phase" applies.

20. In a purely inductive circuit the current ...L.............. the voltage by .... degrees.

21. The formula for inductive reactance (symbol ...X_L...), is ....

22. Correct these statements -

    (i) Inductive reactance increases? / does not change? / decreases? with increase of frequency.

    (ii) Capacitive reactance increases? / does not change? / decreases? with increase of frequency.

23. The formula for capacitive reactance (symbol ....), is ....

24. In a purely capacitive circuit the current .... the voltage by .... degrees.

25. Show your conclusions to questions 20 and 24 graphically and vectorially.

26. What is meant by "Impedance".

27. The formula for impedance (symbol ....), is ...$\sqrt{R^2 + (X_L \sim X_C)^2}$...

END OF PAPER.

THE AUSTRALIAN POST OFFICE

COURSE OF TECHNICAL INSTRUCTION

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

BASIC ELECTRONICS

---

1. INTRODUCTION.

1.1 The discovery of the principle of the vacuum tube by Edison in 1883 (and its subsequent development by later experimenters) was one of the most important events in telecom history.

Hundreds of different types of vacuum tubes are manufactured today, and have countless applications in telecom, and in all branches of industry.

When first attempting the study of vacuum tubes, the bewildering array of the many types manufactured, each with their own characteristics of design, construction and performance, tends to make the subject seem a difficult one to understand.

However, all types operate on the same fundamental principles, which when understood, resolve the subject into a study of the constructional features, and the electrical characteristics resulting from these features.

This paper introduces the basic theory of the two simplest types of vacuum tube, the Diode and the Triode.

2. ELECTRON EMISSION.

2.1 In earlier studies we have seen that the atoms and electrons of a substance are in a constant state of agitation and motion, and possess kinetic energy due to this motion.

Also, we found that the electrons constituting a conduction current are termed "free", inasmuch as they are able to pass in ordered motion from one atom to the next, under the control of an e.m.f.

Under ordinary conditions these electrons are confined within the conductor, being held by the attractive force of the positively charged nuclei. To escape from the surface of the material, the electron must do work to overcome the attractive force, and it is possible by external means to impart sufficient energy to electrons of some materials, so that they tend to leave the surface of the material.

2.2 The forcible emission of electrons from a body, as a result of increasing the electron's kinetic energy sufficiently to overcome the restraining force, is termed Electron Emission.

It can be achieved in the following ways -

(i) Thermionic Emission. When a metal is heated to very high temperatures electrons are given off.

(ii) Secondary Emission. When a beam of electrons strikes a metallic object with sufficient force, electrons, termed Secondary Electrons, are given off.

(iii) Cold Cathode Emission. When certain materials in the cold state (such as lithium coated nickel) are surrounded by an inert gas and subjected to a strong electric field, electrons are drawn from the material.

(iv) Photo-electric Emission. A beam of light directed on certain materials, such as caesium or selenium alloy, will result in the liberation of electrons from the material.

2.3 The diode and triode depend upon the principle of thermionic emission for their action. The other types of emission, and their application to telecom theory and practice, are considered in other papers of the Course.

2.4 Electron Flow across Space. When a material is heated, heat energy is transferred to the atoms of the material. With a sufficient rise in temperature the electrons' kinetic energy is increased, and they achieve such a velocity that some are emitted from the surface of the material (Fig. 1).

The nucleus from which each is emitted will then be positively charged and will attract the electron (or another) back to the material.

Considering this effect over the surface of a heated material, there will exist at any instant a cloud of electrons, being emitted from and attracted back to the material.

This cloud of electrons is called a space charge and its effect is to limit the electron movement from the material by repulsion from its collective negative polarity. (Fig. 2.)

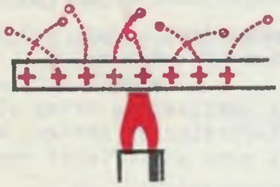


FIG. 1. ELECTRON EMISSION FROM HEATED MATERIAL.

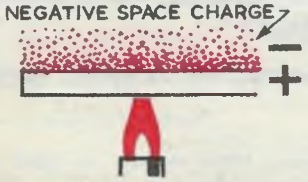


FIG. 2. ELECTRON SPACE CHARGE.

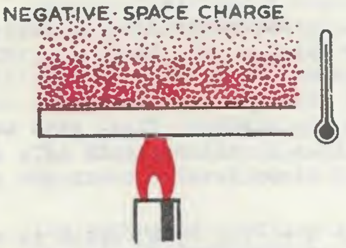


FIG. 3. INCREASED TEMPERATURE INCREASES SPACE CHARGE.

The value or amount of space charge is determined by the balance between the tendency of the heated conductor to emit electrons, and that of the space charge to repel them.

An increase in temperature increases the space charge (Fig. 3).

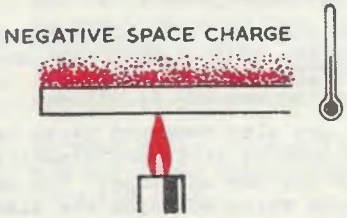


FIG. 4. DECREASED TEMPERATURE DECREASES SPACE CHARGE.

A decrease in temperature decreases the space charge (Fig. 4).

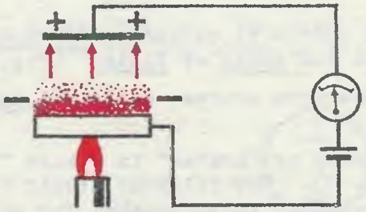


FIG. 5. ELECTRON FLOW ACROSS SPACE.

2.5 When a plate which is positively charged with respect to the electron emitting source is placed near to it, electrons are attracted from the space charge, and a small current is observed on the meter.

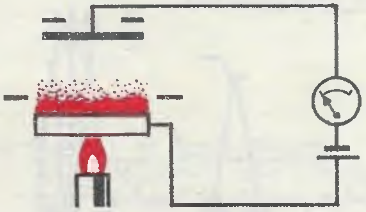


FIG. 6. CURRENT CEASES WHEN POLARITY IS REVERSED.

2.6 When the plate's polarity is reversed with respect to the electron emitting source, the current ceases (Fig. 6).

2.7 Summarising -

(i) When a conductor is heated, electrons are emitted and form a space charge around the conductor.

(ii) When a positively charged conductor is placed near the electron emitting source, a current flows across the space between the two elements.

(iii) The current ceases when the plate's polarity is reversed.

(iv) We call a device with these characteristics a Rectifier, since it will pass current in one direction only, from negative to positive.

3. DIODE.

3.1 Instead of using a heating flame, as shown in the rather theoretical example of Section 2, we can produce thermionic emission by electrically heating a conductor. However, when a positively charged plate is placed near the emitting source, any electron flow is extremely small and practically useless, as the molecules of air between the two elements impede the electron flow, even across a minute gap. When the components are enclosed in a container, such as a glass envelope (Fig. 7), and the air evacuated, current flows freely across the gap from negative to positive.

This arrangement constitutes the simplest form of Electron Tube, which is the Diode, or two element tube.

Since the tube will pass current in one direction only, and has an evacuated container, the names "Valve" and "Vacuum Tube", are often used.

3.2 Typical Constructional Features. The parts of the electron tube which directly control the flow of current are called the electrodes or elements. Electron tubes are classified according to the number of electrodes (Table 1).

Number of Electrodes.	Classification.
2	Diode
3	Triode
4	Tetrode
5	Pentode

TABLE 1.

There are also compound types of tubes which combine different classifications within the one envelope. For example, one type which contains the electrodes of two diodes and one pentode is called a duo-diode-pentode. These are dealt with in other papers of the Course.

In the diode, the electrode from which emission occurs is called the Cathode, and the electrode which attracts electrons is called the Anode or Plate. (Fig. 7.)

In practice, electron tubes have two types of electron source, called Directly and Indirectly Heated Cathodes.

In the directly heated cathode, the heating element or "heater" is a wire "filament" of tungsten, nickel, or nickel alloy (Fig. 8). The filament itself is the electron emitting source and often has to be heated to incandescence for sufficient emission. When lower temperatures are required, a filament of thoriated tungsten, which emits electrons freely at lower temperatures, is used.

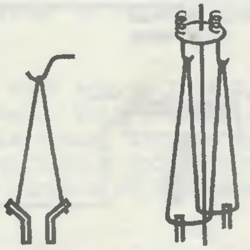


FIG. 8. DIRECTLY HEATED CATHODES.

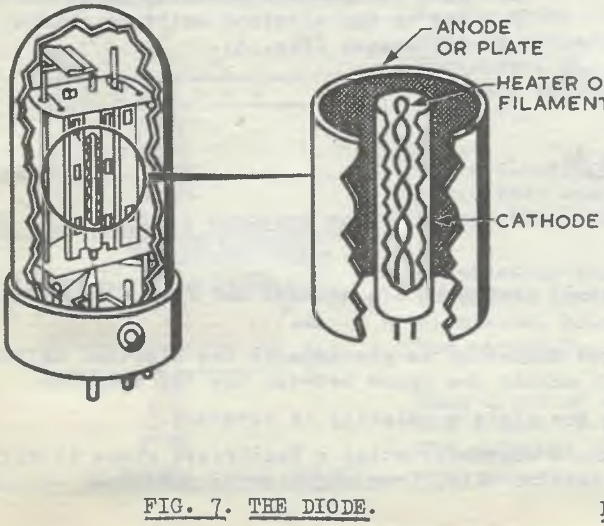


FIG. 7. THE DIODE.

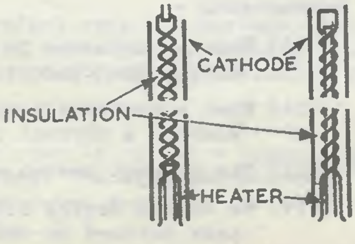


FIG. 9. INDIRECTLY HEATED CATHODES.

The indirectly heated cathode is a cylinder or sleeve of nickel, which surrounds, but is electrically separate from the heating filament (Fig. 9). The cathode cylinder is itself coated with a material such as a mixture of barium and strontium oxides, which emits electrons freely at low temperatures. As a consequence, the cathodes of indirectly heated tubes have only to be heated to a dull or cherry red.

The filaments of these tubes are generally of tungsten wire, coated with magnesium oxide, which acts as an insulation between heater and cathode.

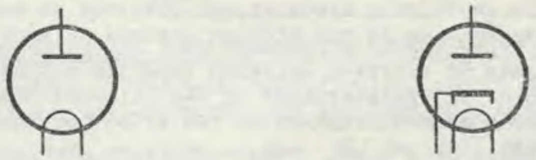
The anodes of electron tubes vary according to type, but are commonly of nickel or nickel plated iron for low power tubes, and carbon and tantalum for high power tubes.

The electrodes of the tube are sealed in either a glass or metal evacuated envelope from which the last trace of gas is removed by a process known as "Gettering". This involves evaporating a small quantity of magnesium or barium in the envelope after sealing, which absorbs any remaining gas in the tube, and results in the characteristic silvered appearance of glass electron tubes.

In some tubes, connection is made to the electrodes by flexible conductors, which are air tight sealed through the tube, and are soldered to hollow pins moulded into its base.

In many recent tubes, the conductors themselves are of sufficiently heavy gauge to form the pins to which connection is made when the tube is plugged into the appropriate socket.

3.3 Diode Symbols. The symbols for the diode, with directly and indirectly heated cathodes are shown in Fig. 10.



(a) Directly heated. (b) Indirectly heated.

DIODE SYMBOLS.

FIG. 10.

3.4 Control of Anode Current. The electron flow from cathode to anode is called the anode current, and its magnitude depends on the rate of electron emission from the cathode, and the potential of the anode.

(i) Filament Current. Thermionic emission from any cathode depends on the temperature at which it operates, and this in turn depends on the magnitude of the heating current. Increasing and decreasing the cathode's temperature by varying the filament current will similarly vary the anode current.

However, in practice the filament voltage and current are not varied, as the manufacturer determines the desirable current and working temperature for satisfactory operation, and stipulates the correct supply voltage for the filament connection.

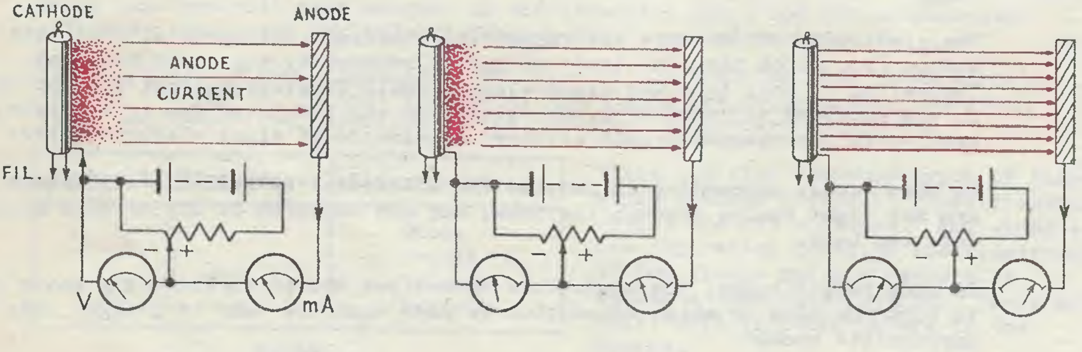
(ii) Anode Potential. When the anode is made positive with respect to the cathode, there is an electric field between anode and cathode, and electrons are drawn to the anode from the negative space charge surrounding the cathode.

Fig. 11 shows that variations of anode potential produce variations in anode current.

With the voltmeter indicating a small anode voltage supplied from the voltage divider network, the milliameter shows a small anode current (Fig. 11a).

An increase in the positive potential applied to the anode, results in an increased anode current (Fig. 11b).

Anode potential can be increased to the point at which the anode attracts electrons as fast as the cathode can emit them, and a further increase of anode voltage will not increase anode current. This is called the saturation point of the tube (Fig. 11c).



(a) (b) (c)

FIG. 11. ANODE POTENTIAL CONTROLS ANODE CURRENT.

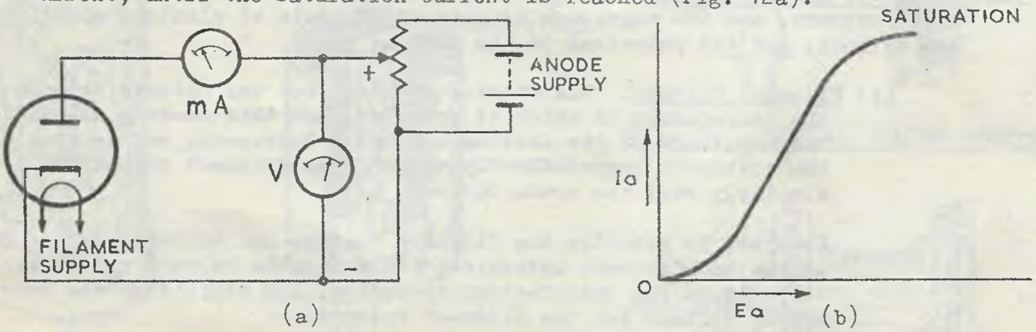
In practice, the anode of a diode is not operated at such a high voltage that changes of anode voltage do not produce changes in anode current.

Summary - The rate of electron emission from the cathode is dependent on its temperature, which is predetermined by the filament's supply voltage and current. The value of anode current depends on the extent of the anode's positive polarity.

3.5 Characteristic Curve of a Diode. The characteristic curve of a diode shows how its anode current (I_a) varies with anode voltage (E_a); Fig. 12a shows a circuit used to plot such a curve. (I_a and E_a are sometimes shown as I_p and E_p.)

The anode voltage is varied by means of the voltage divider across the anode's supply, and the current is measured by the milliameter.

For every increase of anode volts there is an increase in the influence of the electric field between anode and space charge, and a resultant increase in anode current, until the saturation current is reached (Fig. 12a).



(a) (b)

FIG. 12. PLOTTING THE CHARACTERISTIC CURVE OF A DIODE.

The variations of anode voltage and anode current are plotted as a characteristic curve (Fig. 12b), from which can be obtained the operating characteristics of the diode for any applied anode voltage.

4. DIODE AS A RECTIFIER.

4.1 We know that in the diode, anode current flows only when the anode is positive with respect to the cathode. This feature is used in circuits to obtain D.C. from an A.C. input. When the alternating potential of an A.C. generator is applied to the anode in such a direction as to make it positive with respect to the cathode, the diode conducts current. As a result, half wave rectification occurs, with each positive half cycle producing current through the load, and each negative half cycle being suppressed or lost. (Fig. 13.)

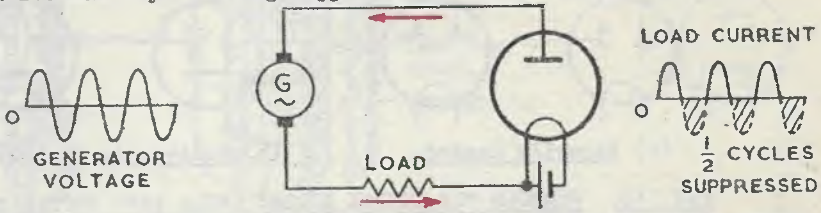


FIG. 13. HALF WAVE RECTIFICATION USING DIRECTLY HEATED DIODE.

In practical circuits where an indirectly, (or directly) heated diode is used for rectification, as in battery charging, a step down transformer with suitable ratio windings provides both the current for rectification and the filament current (Fig. 14).

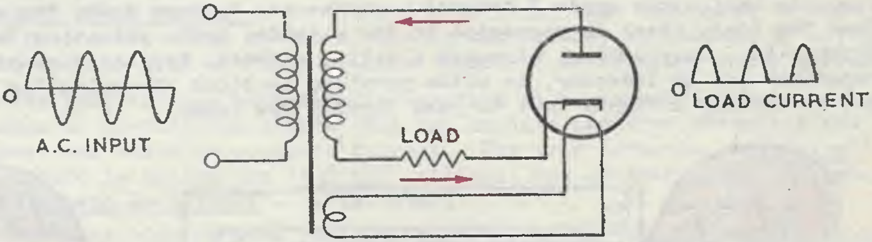


FIG. 14. HALF WAVE RECTIFICATION FROM COMMERCIAL SUPPLY USING INDIRECTLY HEATED DIODE.

4.2 Full Wave Rectification. Full wave rectification occurs when the two half cycles of the A.C. input are effective through the load as a unidirectional current.

Two diodes can be used, as shown in Fig. 15, for full wave rectification.

Consider an instant when the connection to the anode of Diode A is positive. Current flows through the load and Diode A in the direction indicated by the dotted arrows. For this half cycle, the negative potential applied to Diode B results in no current flow in that part of the circuit.

At the next half cycle Diode B's anode becomes positive, and current passes through B and the load resistance in the same direction as the previous half cycle. For this half cycle A's anode connection is negative and no current flows in that part of the circuit.

In this way, each cycle of A.C. input is rectified to two pulses of unidirectional current, through the load.

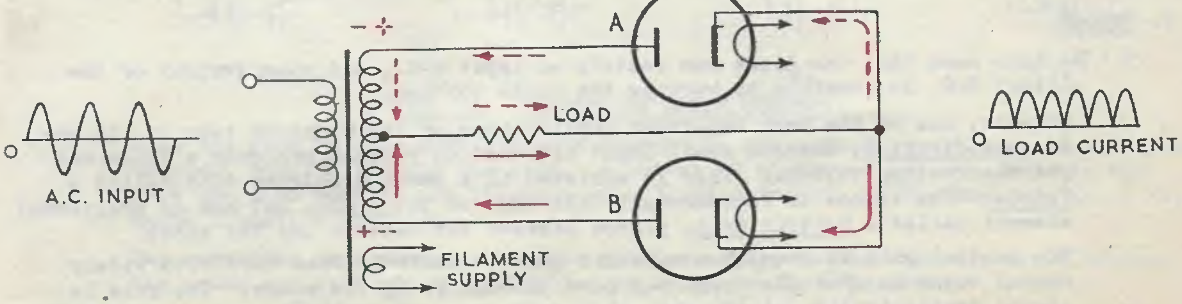
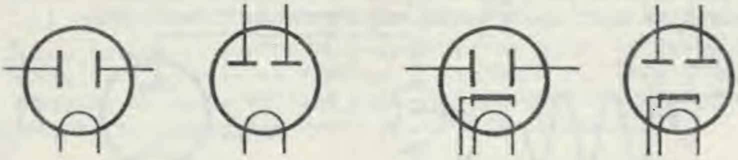


FIG. 15. FULL WAVE RECTIFICATION USING TWO DIODES.

4.3 The Double Diode. Full wave rectification as described in para. 4.2 is usually achieved in practice by using a single electron tube which contains the elements of two diodes in the same evacuated envelope, but uses a common cathode.

This tube is called a Double (or Duo) Diode, or, sometimes a Full Wave Rectifier, and it can be either directly, or indirectly heated. Typical circuit symbols used for Double Diodes, are shown in Fig. 16.



(a) Directly Heated. (b) Indirectly heated.

FIG. 16. SYMBOLS FOR DOUBLE DIODES (FULL WAVE RECTIFIERS).

A typical circuit using a directly heated double diode for full wave rectification is shown in Fig. 17.

The common cathode supplies electrons for both anodes. During one half cycle anode A becomes positive and draws electrons from the cathode, and during the opposite half cycle anode B becomes positive and in turn draws the electrons. Thus the load, which is connected to the cathode, has a pulsating D.C. passing through it. In practical circuits a filter circuit, typically consisting of a capacitor and an inductor, is often provided to block the pulsating component and allow only a steady D.C. to pass through the load.

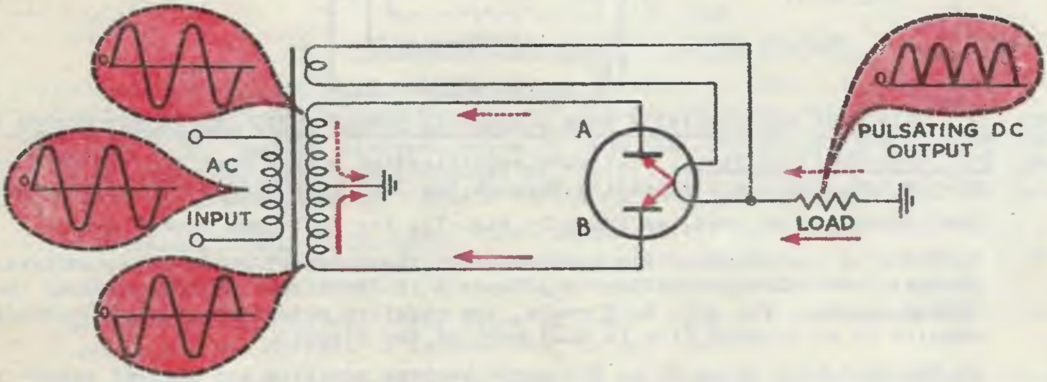


FIG. 17. FULL WAVE RECTIFICATION.

Certain points of the circuit are connected to earth. This is done in practice by connecting these points to the metallic chassis on which the equipment is mounted, thus saving on the number of conductors required.

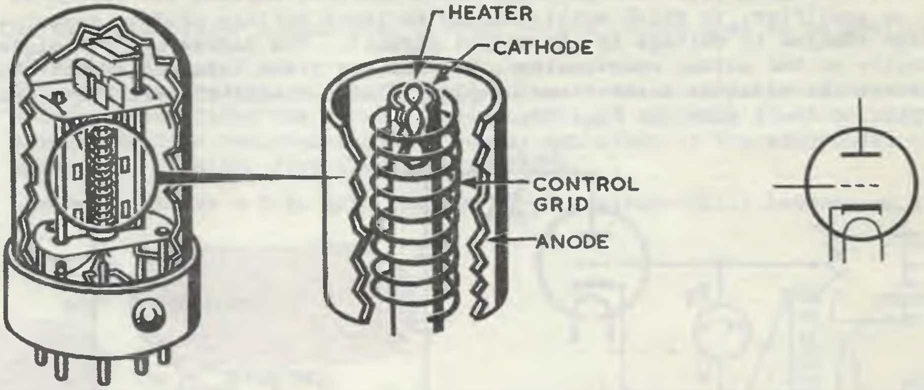
5. TRIODE.

5.1 We have seen that the diode can rectify an input A.C., and some control of the output D.C. is possible by varying the anode voltage.

However, one of the most important applications of the electron tube is its use in amplification, where a small input alternating voltage produces a large output alternating voltage. This is achieved in a three electrode tube called a Triode. The triode is fundamentally the same as the diode, but has an additional element called a Control Grid, placed between the cathode and the anode.

The control grid is usually a metallic mesh, or coil of fine wire with widely spaced turns so that electrons may pass through it to the anode. The grid is placed nearer to the cathode than the anode, so that small changes of potential applied to the grid exert a large influence on the electron stream from cathode to anode.

5.2 The typical construction and symbol of a triode are shown in Fig. 18.



(a) Construction. (b) Symbol.

FIG. 18. THE TRIODE.

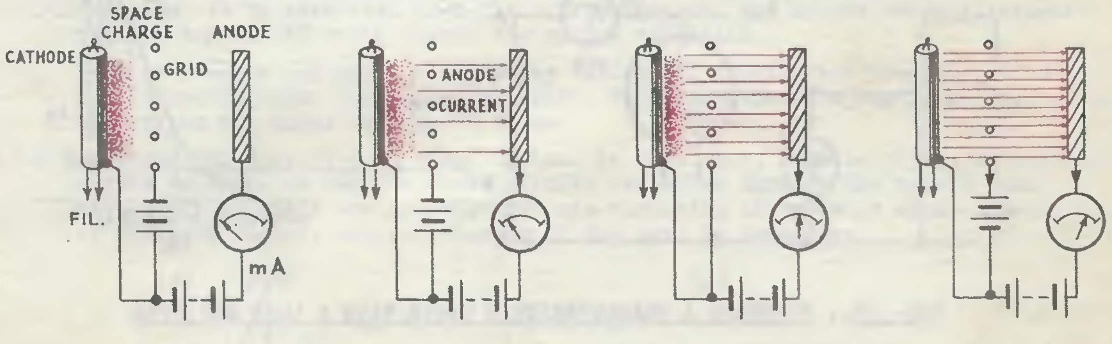
5.3 Control of Anode Current. In the diode we found that the anode current depends on anode potential. Fig. 19 shows that in the triode, variations of voltage applied to the control grid are an additional means of controlling anode current.

When the grid is made sufficiently negative with respect to the cathode, it balances or cancels the effect that the anode's positive potential has on the cathode, and there is no anode current. The grid potential (or "bias") at which this occurs is called the "cut-off" voltage, and at this point the tube is said to be "biased to cut-off". (Fig. 19a.)

When the grid bias is more negative than this, the tube is "biased beyond cut-off".

When the grid bias is made less negative (less than cut-off), a small anode current results (Fig. 19b).

When the negative grid bias is reduced further, or made zero, a still greater anode current flows (Fig. 19c).



(a) (b) (c) (d)

FIG. 19. CONTROL OF ANODE CURRENT.

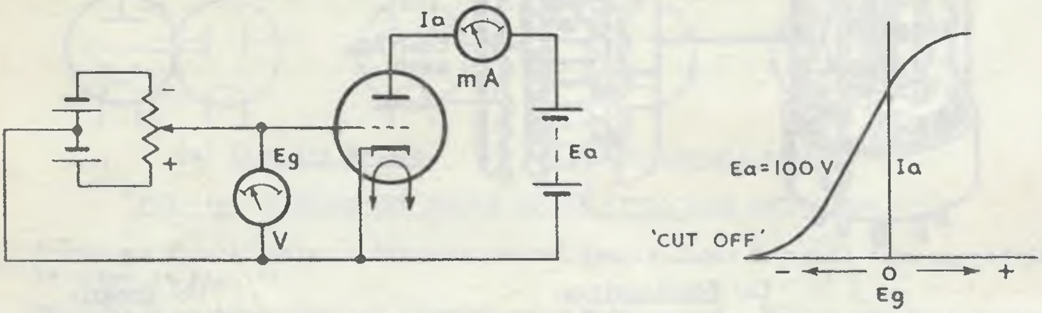
When the grid is made positive with respect to the cathode, an increased electron movement results towards the grid. A number of electrons are attracted to the grid and pass back to the filament as a "grid current", in the same way as in the anode circuit's operation.

The remainder pass through the open grid structure to the electric field between the anode and grid and are attracted on to the anode (Fig. 19d).

Progressively increasing the positive bias results in saturation, when further increases of positive bias do not vary the anode current.

6. TRIODE AS AN AMPLIFIER.

6.1 The control which grid bias has over anode current, enables the triode to be used as an amplifier, in which small changes in input voltage produce comparatively large changes in voltage in its output circuit. The degree of control depends largely on the actual construction, but for any given tube the effect which grid voltage has on anode current can be plotted as a characteristic curve, using a typical circuit shown in Fig. 20a.



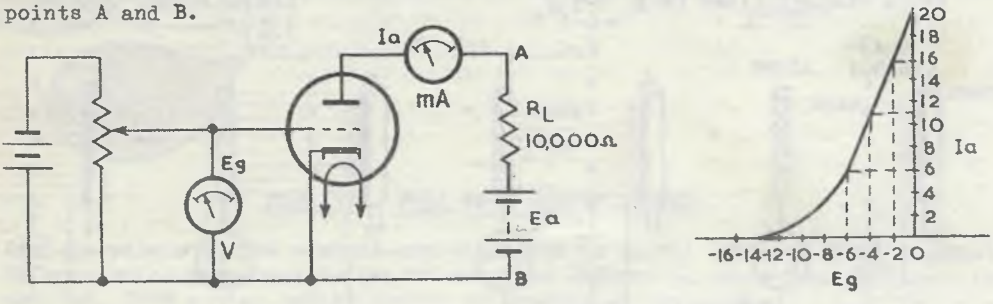
(a) (b)

FIG. 20. PLOTTING THE CHARACTERISTIC CURVE OF A TRIODE.

For a particular value of anode voltage, anode current readings (I_a) (sometimes I_p) are recorded and plotted against variations of grid bias (E_g) in a range of from, "biased to cut off" with maximum negative bias, to saturation when the battery bias is reversed and the grid is positive with respect to the cathode. (Fig. 20b.)

6.2 Let us now examine the circuit and resultant characteristic curve when a 10,000 ohms load resistor (R_L) is connected in series with the anode supply of 200 volts (Fig. 21a). As it is usual to apply only negative bias to the grid of a triode used in this type of circuit, the curve is plotted from variations of grid potential, from cut off to zero. (Fig. 21b.)

The variations of anode current produced by grid voltage changes, causes variations of voltage drops across R_L, and a consequent variation of P.D. between points A and B.



(a) (b)

FIG. 21. PLOTTING A CHARACTERISTIC CURVE WITH A LOAD RESISTOR.

When E_g = - 2V, Ia = 16 mA. ∴ P.D. across R_L = 0.016 x 10,000 = 160 volts

∴ P.D. between A and B = 200 - 160 = 40 volts

When E_g = - 4V, Ia = 11 mA. ∴ P.D. across R_L = 0.011 x 10,000 = 110 volts

∴ P.D. between A and B = 200 - 110 = 90 volts

When E_g = - 6V, Ia = 6 mA. ∴ P.D. across R_L = 0.006 x 10,000 = 60 volts

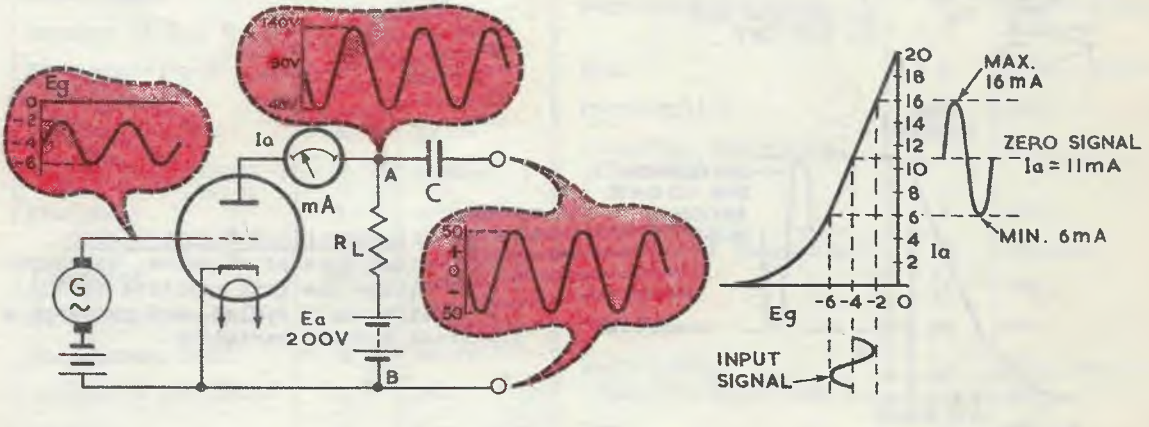
∴ P.D. between A and B = 200 - 60 = 140 volts

6.3 This is the principle of the operation of the triode as an amplifier, where a small variation in grid voltage of 4 volts, has produced the comparatively large change of 100 volts (from 40-140 volts) across the output of the triode.

6.4 Let us now consider a practical circuit with a triode used as an amplifier. (Fig. 22a.)

Two voltages are applied to the grid. One is the steady bias from the bias battery which fixes the normal anode current of the tube at 11 mA, and the P.D. across the load resistance at 110 volts; the other is the sinusoidal alternating voltage of 2 volts, from the A.C. generator.

The resultant is a D.C. grid voltage varying sinusoidally between -2 and -6 volts.



(a) (b)

FIG. 22. THE TRIODE AS AN AMPLIFIER.

From the characteristic curve (Fig. 22b) the anode current varies sinusoidally between 16 mA to 6 mA, and the voltage drop across the load resistor also varies sinusoidally between 160 and 60 volts.

The P.D. between points A and B therefore varies between 40 and 140 volts, and the provision of a capacitor in the triode's output circuit, enables the A.C. component to be separated from the D.C. component, and appear as an alternating peak voltage of 50 volts across the output terminals.

In this example the input alternating voltage of 2 volts has been amplified to an alternating peak voltage of 50 volts, therefore the tube may be considered as amplifying the input voltage 25 times.

6.5 Necessity for Correct Grid Bias. We saw in para. 6.2, that to obtain an amplified output voltage, we use the anode current variation through the tube's load resistor. We shall now see that if this variation is to be an exact duplication of the grid signal, correct biasing of the grid is necessary.

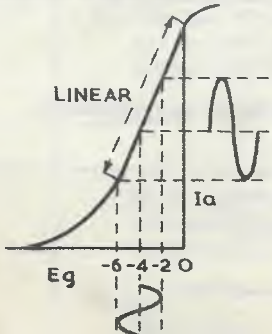


Fig. 23. Correct Bias. With a fixed bias of -4 volts the input signal provides a grid "swing" from -6 volts to -2 volts. As the operating portion of the E_g I_a curve is linear, the amplified output signal duplicates the input signal.

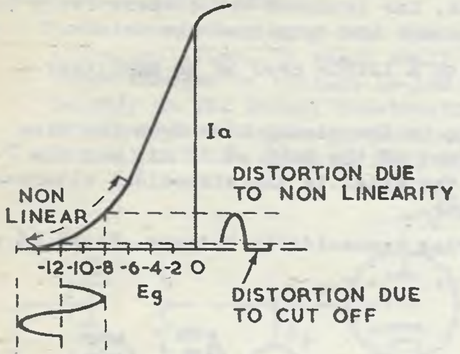


Fig. 24. Excessive Negative Bias. With a fixed bias of -12 volts, the input signal drives the grid into cut-off during the negative half cycle, and produces a distorted anode current variation.

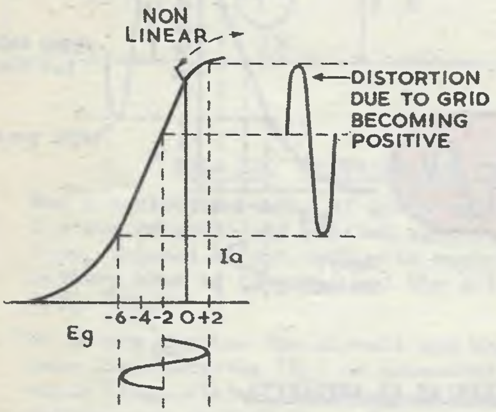


Fig. 25. Insufficient Negative Bias. With a fixed bias of -2 volts, the input signal drives the grid positive during the positive half cycles, and produces a distorted current variation.

6.6 Distortion will also result with the correct grid bias if the input signal is too large. In this case the grid is driven into both the positive and cut off regions, again producing distortion of the anode current variation.

6.7 The examples of the use of the triode in this paper are typically that of a single tube used as an audio frequency amplifier. However other papers of the Course cover the use of electron tubes in other types of amplifiers, where grid bias is not always fixed in the linear portion of the E_g I_a curve.

7. TEST QUESTIONS.

1. When a conductor is heated, ... are emitted and form a .... around the conductor.
2. This principle is known as ....
3. Describe the construction of a Diode.
4. The parts of the electron tube which directly control the current flow are called .... or ....
5. What is (i) An indirectly heated cathode? (ii) A directly heated cathode?
6. Sketch the circuit symbols of a diode.
7. Describe how anode current is controlled in a diode.
8. With the aid of a sketch, describe the typical circuit operation of a duo-diode used for full wave rectification.
9. Describe the construction of a triode.
10. A triode is "biased to cut-off" when ....
11. State what happens when the grid of a triode is made positive with respect to the cathode.
12. Draw a typical circuit from which the characteristic curve of a triode can be determined.
13. Sketch and describe a practical circuit using the triode as an amplifier.
14. Why is it necessary to use correct grid bias for a triode used as an audio frequency amplifier?

END OF PAPER.

APPENDIX.

TERMS, SYMBOLS AND UNITS.

Term	Symbol	Unit	Term	Symbol	Unit
Angular Velocity	ω	radian	Magnetic Flux Density	B	gauss
Capacitance	C	farad	Magnetic Reluctance	S	no official unit
Capacitive Reactance	X_c	ohm	Magnetisation, (Intensity of)	J	-
Conductance	G	mho	Magnetomotive Force	F	ampere-turn, gilbert
Current (A.C., D.C.)	I	ampere	Mass	m	pound, gramme
Electromotive Force (e.m.f.)	E	volt	Permeability	μ	(ratio)
Energy	W	joule	Potential Difference, (Electric)	V	volt
Force	F	newton	Power	P	watt
Frequency	f	cycles per second	Quantity of Electricity	Q	coulomb
Impedance	Z	ohms	Reactance	X	ohm
Inductance, Mutual	M	henry	Resistance	R	ohm
Inductance, Self	L	henry	Resistivity (Specific Resistance)	ρ	ohms per unit cube
Inductive Reactance	X_L	ohm	Time	t	second
Length	ℓ	foot, metre	Turns, number of	n	
Magnetic Field (Magnetising Force)	H	oersted			
Magnetic Flux	ϕ	maxwell			

ABBREVIATIONS FOR COMMON ELECTRICAL UNITS. (Used after numerical values.)

Ampere	A	Ohm	Ω
Ampere-hour	Ah	Microhm	μΩ
Coulomb	C	Kilohm	kΩ
Cycles per second	c/s	Megohm	MΩ
Kilocycles per second	kc/s	Volt	V
Megacycles per second	Mc/s	Microvolt	μV
Decibel	db	Millivolt	mV
Farad	F	Kilovolt	kV
Microfarad	μF	Megavolt	MV
Micromicrofarad	μμF	Volt-Ampere	VA
(Picofarad)	(pF)	Watt	W
Henry	H	Microwatt	μW
Millihenry	mH	Milliwatt	mW
Microhenry	μH	Kilowatt	kW
Joule	J	Megawatt	MW
		Watt-Hour	Wh

PREFIXES FOR MULTIPLES AND SUBMULTIPLES.

Prefix	Abbreviation	Meaning	Prefix	Abbreviation	Meaning
Micro-micro (or pico)	μμ (p)	$\frac{1}{10^{12}}$ (10^{-12})	Deka	dk	10 (10^{1})
Micro	μ	$\frac{1}{10^{6}}$ (10^{-6})	Hekto	h	100 (10^{2})
Milli (or Mil)	m	$\frac{1}{10^{3}}$ (10^{-3})	Kilo	k	1,000 (10^{3})
Centi	c	$\frac{1}{100}$ (10^{-2})	Mega (or Meg)	M	1,000,000 (10^{6})
Deci	d	$\frac{1}{10}$ (10^{-1})			

GREEK ALPHABET. Letters of the Greek Alphabet are universally accepted as designations for some electrical and mathematical terms. The alphabet and relative terms are shown in the following table:-

Name of Letter	Capital Case	Lower Case	Used to indicate
Alpha	A	α	Angles. Area. Coefficients. Attenuation constant. Current gain transistors (common base).
Beta	B	β	Angles. Magnetic flux density. Coefficients. Wave length constant. Current gain transistors (common emitter).
Gamma	Γ	γ	Conductivity. Specific gravity.
Delta	Δ	δ	Variation. Density.
Epsilon	E	ϵ	Base of natural logarithms.
Zeta	Z	ζ	Impedance. Coefficients. Co-ordinates.
Eta	H	η	Magnetic Field Strength. Efficiency.
Theta	Θ	θ	Temperature. Phase angle.
Iota	I	ι	
Kappa	K	κ	Dielectric constant. Susceptibility.
Lambda	Λ	λ	Wave length.
Mu	M	μ	Micro. Amplification factor. Permeability.
Nu	N	ν	Reluctivity.
Xi	Ξ	ξ	
Omicron	O	o	
Pi	Π	π	Ratio of circumference to diameter = 3.1416.
Rho	P	ρ	Resistivity.
Sigma	Σ	σ	Sign of summation.
Tau	T	τ	Time constant. Time Phase displacement.
Upsilon	ϒ	υ	
Phi	Φ	ϕ	Magnetic flux. Angles.
Chi	X	χ	
Psi	Ψ	ψ	Dielectric flux. Phase difference.
Omega	Ω	ω	Ω = ohms. ω = angular velocity = 2π f.

COMPARISON TABLE OF WIRE GAUGES (COPPER WIRE).

S.W.G.

Gauge S.W.G.	Standard Diameter (In)	Weight. Per 1000 yds. (lbs)	Resistance. Per 1000 yds. (ohms)
50	0.0010	0.0090	30568
49	0.0012	0.0130	21228
48	0.0016	0.0232	11941
47	0.0020	0.0363	7642
46	0.0024	0.0523	5307
45	0.0028	0.0712	3899
44	0.0032	0.0930	2985
43	0.0036	0.1177	2359
42	0.0040	0.1453	1910.4
41	0.0044	0.1758	1578.9
40	0.0048	0.2093	1326.7
39	0.0052	0.2456	1130.5
38	0.0060	0.3270	849.1
37	0.0068	0.4200	661.1
36	0.0076	0.5246	529.2
35	0.0084	0.6409	433.2
34	0.0092	0.7688	361.2
33	0.0100	0.9083	305.7
32	0.0108	1.0594	262.1
31	0.0116	1.2222	227.2
30	0.0124	1.3966	198.80
29	0.0136	1.6800	165.27
28	0.0148	1.9895	139.55
27	0.0164	2.443	113.65
26	0.018	2.943	94.35
25	0.020	3.633	76.42
24	0.022	4.396	63.16
23	0.024	5.232	53.07
22	0.028	7.121	38.99
21	0.032	9.301	29.85
20	0.036	11.772	23.59
19	0.040	14.533	19.105
18	0.048	20.93	13.267
17	0.056	28.48	9.747
16	0.064	37.20	7.463
15	0.072	47.09	5.897
14	0.080	58.13	4.776
13	0.092	76.88	3.612
12	0.104	98.24	2.826
11	0.116	122.22	2.272
10	0.128	148.82	1.8657
9	0.144	188.34	1.4741
8	0.160	232.5	1.1941
7	0.176	281.4	0.9868
6	0.192	334.8	0.8292
5	0.212	408.2	0.6801
4	0.232	488.9	0.5679
3	0.252	576.8	0.4814
2	0.276	691.9	0.4013
1	0.300	817.5	0.3396
1/0	0.324	953.5	0.2912
2/0	0.248	1100.0	0.2524
3/0	0.372	1256.9	0.2209
4/0	0.400	1453.3	0.1910
5/0	0.432	1695.1	0.1637
6/0	0.464	1955.5	0.1419

B & S.

Gauge B & S.	Standard Diameter (In)	Weight. Per 1000 yds. (lbs)	Resistance. Per 1000 yds. (ohms)
44	0.0020	0.0355	7962
43	0.0022	0.0448	6312
42	0.0025	0.0564	5007
41	0.0028	0.0712	3969
40	0.0031	0.0898	3147
39	0.0035	0.1132	2495.4
38	0.0040	0.1428	1978.8
37	0.0045	0.18	1569.3
36	0.0050	0.2207	1244.4
35	0.0056	0.2863	987
34	0.0063	0.3609	782.7
33	0.0071	0.4551	620.7
32	0.0080	0.5739	492.3
31	0.0089	0.7239	390.3
30	0.0100	0.9126	309.6
29	0.0113	1.1508	245.49
28	0.0126	1.4511	192.27
27	0.0142	1.8300	154.41
26	0.0159	2.3076	122.43
25	0.0179	2.8998	97.11
24	0.0201	3.669	77.01
23	0.0226	4.626	61.08
22	0.0253	5.835	48.42
21	0.0285	7.356	36.24
20	0.0320	9.276	30.45
19	0.0359	11.697	24.153
18	0.0403	14.751	19.155
17	0.0453	18.6	15.192
16	0.0508	23.454	12.048
15	0.0571	29.574	9.552
14	0.0641	37.29	7.575
13	0.0720	47.04	6.009
12	0.0808	59.31	4.764
11	0.0907	74.76	3.78
10	0.1019	94.29	2.997
9	0.1144	118.89	2.376
8	0.1285	149.94	1.885

NATURAL SINES.

	0'	6'	12'	16'	24'	30'	36'	42'	48'	54'	Differences.				
											1'	2'	3'	4'	5'
0°	0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	14
5	0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	11	14
11	1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
36	5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10
											1'	2'	3'	4'	5'
	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Differences.				

NATURAL SINES.

	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Differences.				
											1'	2'	3'	4'	5'
45°	7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2	4	6	8	10
47	7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9
54	8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0
											1'	2'	3'	4'	5'
	0'	6'	12'	18'	24'	30'	36'	42'	48'	54'	Differences.				

TABLE OF NATURAL SINES.

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