TITLE:- GENERATION OF DIRECT CURRENT
LECTURER:- G. Hegnis
DATE:- 6/7/81
EQUIPMENT:-

When the atoms of any materials are 'electrically balanced' i,e. no potential difference is present, electron flow will not take place. What is needed for this to happen is that some form of external energy must be applied to a given quantity of atoms, such that it will separate some of their negative electrons from their positive nuclei. In this way, the external energy applied will give rise to electrical energy.
The six sources of external energy which are capable of separating the negative electrons from the positive nucleus of an atom are:-

1. Heat
2. Friction
3. Chemical action
4. Light
5. Pressure
6. Magnetism

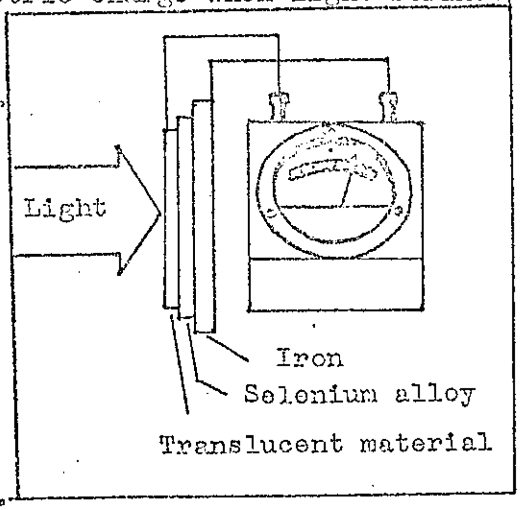
(1) HEAT The most common way of using heat for this purpose is to apply it to the junction of two dissimilar metals e.g. if an iron wire and a copper wire are twisted together to form a junction and heat applied to the junction, an electric charge will result.
The amount of charge will depend upon the difference in temperature between the junction and the opposite ends of the two wires. The greater this differenco, the greater the charge.
This type of junction is called a thermo-couple. It will produce electrical energy for as long as heat is applied to it.
In practice thermo couples are riveted or welded together to make them more efficient.
Large quantities of power are not presently obtainable by this method.
Thermo couples are used in devices whose function is to measure heat.

(2) FRICTION If two different materials are rubbed together, electrons may be forced out of their orbits in one material, transferred to the other material and retained there. The material which aquires electrons takes on a negative charge, and the material which loses electrons acquires a positive charge.
The resulting distribution of charge is known as "static electricity". Both materials retain their static charges until something occurs to discharge them.
Materials which easily acquire static charges include glass, amber, hard rubber, waxes, flannel, silk, rayon and nylon. When a hard rubber rod is rubbed with fur, the fur loses electrons to the rod which becomes negatively charged, the fur becoming positively charged.
When materials are charged with static electricity they behave in an abnormal way e.g. if two pieces of material with unlike charges (one positive, one negative) are suspended close together, they are drawn towards one another by force of attraction.
Alternatively it will be found that if the materials have like charges (i.e. both positive or negative), they will tend to repel one another.
If two materials, carrying opposite charges are brought together, the excess electrons in the negatively charged material move to the positively charged material and tend to cancel that charge, if there are sufficient electrons they will cancel it altogether.
If materials with strong enough charges are used, the electrons may jump from the negative material to the positive material before they are in control, in which case the discharge can be seen in the form of a spark.
Lightning is an example of the discharge of static which accumulates in a cloud as it moves through the air.

(3) CHEMICAL ACTION This is the kind of chemical action which takes place in "electric cells" and "batteries".

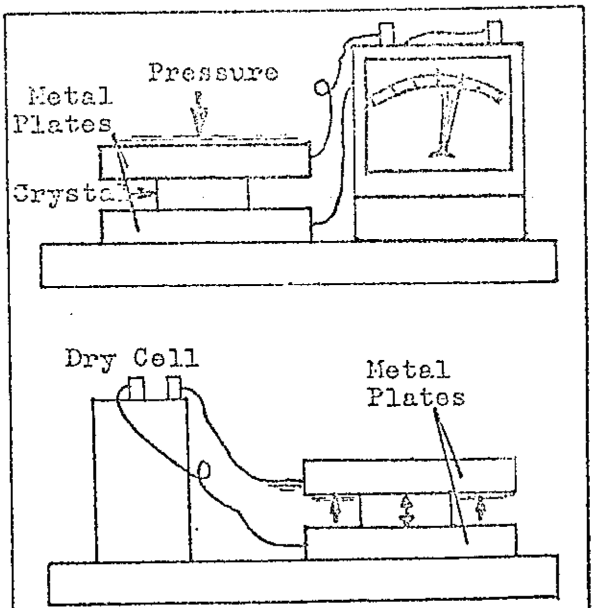
Batteries are usually used for emergency and portable electric power and their types and uses are so varied that they will be discussed separately in a separate lecture.

(4) LIGHT A common way producing electricity from light is using a special kind of cell which contains photo sensitive material, which has the property of developing an electric charge when light strikes it. This "photo cell" is a kind of metallic sandwhich shaped like a disc and composed of three layers of different material. One outside layer is made of iron: the other is a film of semi transparent material which allows light to pass through it. The inside layer is made of a selenium alloy. When light is focused on the selenium alloy through the translucent film, a charge is created between the film and the layer of iron. A meter connected across these layers will measure the amount of the charge created.



Such a cell forms the exposure meter used by a photographer to measure the amount of light present in his studio. Another type of cell produces electrical power by directing the light of the sun on to special photo electric cells which can convert the light itself into useful power. Cells of this kind are called "Solar cells".

(5) PRESSURE Whenever you speak into a telephone or any other similar type of microphone, the pressure waves of the sound energy which your voice generates make a diaphragm move. This diaphragm movement gives rise to an electric charge in the following way:-



There exist in nature certain materials whose crystals develop an electric charge when pressure (as from a moving diaphragm) is exerted on them. Quartz, Tourmaline, and Rochell salts are examples. The size of the charge will depend upon the amount of pressure exerted. It is also possible to convert electrical energy back into mechanical energy by placing an electric charge across the crystal which will then expand or contract by a small amount depending on the amount and type of the charge applied. The mechanical energy so created can be put to use.

(6) MAGNETISM This is by far the most commonly used method of generating electrical power.
Magnetism itself, however, is not used as the direct source of external energy. In a manner which will be gone into depth in a later lecture, large quantities of power are produced in generators as the result of an action which takes place between the windings in the generator and some powerful magnets called field poles which are placed in a special way inside it. This action takes place when the generator is rotating.
The generator itself is driven by water power, steam turbine or internal combustion engine.
The steam for the turbine can be produced by burning oil or coal to heat a conventional boiler, or it may be produced by a modern nuclear reactor.

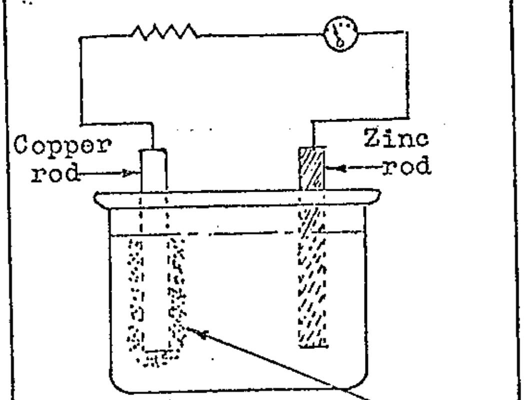
TITLE:- BATTERIES

LECTURER:-

DATE:-

EQUIPMENT:- Dry cell, Lead-acid cell, NIFE cell, Hydrometer, Voltage tester.

If a rod of copper, and a rod of pure zinc, are partially immersed in dilute sulphuric acid, no action occurs until the free ends are connected by a conducting wire, in which case, a current is found to pass from the copper to the zinc along the wire.
The zinc rod gradually dissolves and forms zinc sulphate in solution, whilst hydrogen gas is liberated in the vicinity of the copper rod. A difference of potential is set up between the two metals. Other pairs of metals and fluids may be used, but it is necessary that one of the two metals be acted upon by the chemical action of the fluid. This fluid is called ELECTROLYTE.



Bubbles of Hydrogen gas causing Polarisation

The table below shows how various metals develop a difference in electrical potential, when placed in some active Electrolyte, which is usually dilute sulphuric acid (H_2SO_4). Each metal has been placed in such an order that the first is always positive to that of the one following. Obviously the greatest P.D. will be developed between the first and the last.

1. Carbon (+)
2. Platinum
3. Gold
4. Silver
5. Copper
6. Antimony
7. Bismuth
8. Nickel
9. Iron
10. Lead
11. Tin
12. Cadmium (-)
13. Zinc.

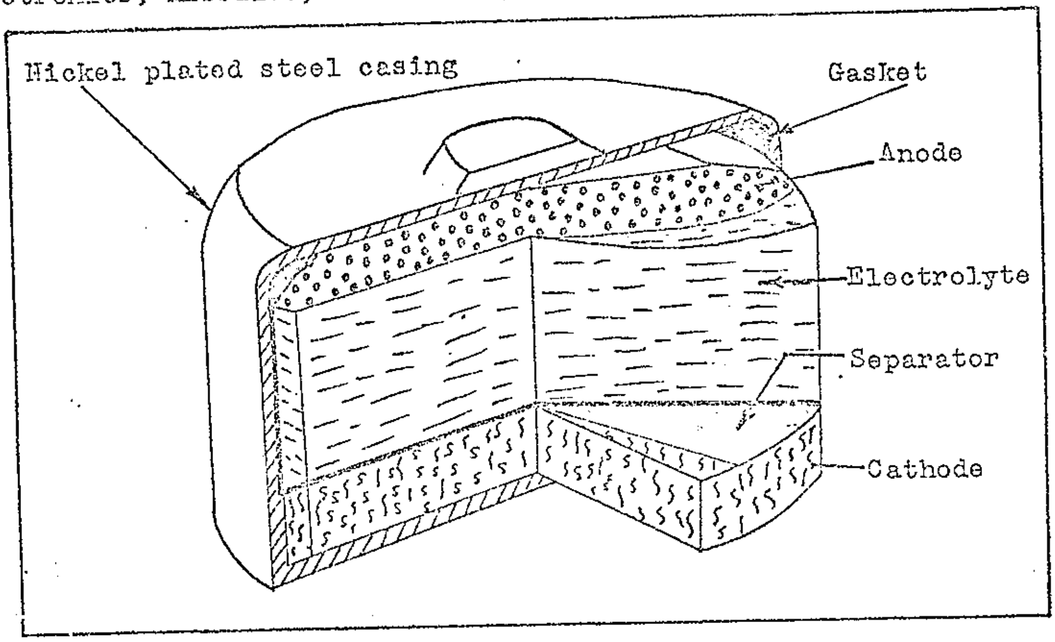
Polarisation: Primary cells The simple copper-zinc cell is of little practical use since it's current weakens rapidly when the cell is working. This defect is due to the layer of hydrogen bubbles, which adhere to the surface of the copper plate. These bubbles reduce it's effective area, and since the hydrogen is a thin insulating film, the internal resistance of the cell is increased. Moreover, since hydrogen collects at one electrode and oxygen at the other, a new cell is produced with the combination H_2 to H_2SO_4 to 0, which is capable of giving a current in the reverse direction. This is a typical polarisation E.M.F. in which new "poles" are produced. To overcome this difficulty, the hydrogen must be removed.

Local action: Common zinc contains many impurities, such as iron, lead, arsenic etc. These, together with the zinc being in contact with the acid, give rise to a number of local currents all over the surface of the plate, the result being that the plate is consumed without any advantage being gained. This "local action" is prevented by "amalgamating" the plate i.e., coating the surface with mercury.
The mercury dissolves the zinc, forming a uniformly soft amalgam, which covers up the impurities; as the zinc is consumed, the impur-

ities fall to the bottom of the cell.

Shelf life: This is the time that a cell can be kept in storage without use and yet remain serviceable. Two factors govern shelf life; namely, drying up of the electrolyte, and the amount of "local action".

Mercury cells: A type of dry cell known as a mercury cell, has been developed, which has about four times the capacity of a zinc - carbon cell.
The mercury cell has a +ve electrode (anode) which is constructed from amalgamated zinc, and the -ve electrode (cathode) of mercury oxide. A steel casing is used to enclose the cell. Mercury cells produce a voltage in the range of 1.2 to 1.4 volts and maintain this voltage very well throughout their life. They can be made in extremely small sizes and are of great value, where space is limited. The example of this is in their application in hearing aids, medical electronics, missiles, satellites, computers etc.



Batteries: A combination of cells, which are connected in series or parallel, is called a Battery. Series connection of a battery of cells provides a total voltage, which is equivalent to the sum of the individual cell's voltages. The current capacity, however, is the same as that of one cell.
Parallel connections provide a total voltage, which is the same as the individual cell voltage. The current, however, is equal to the sum of the capacities of each cell.

Secondary cells: These have 2 big advantages when compared to primary cells;

(1) They may be recharged when exhausted.
(2) Much greater current capacity may be obtained.

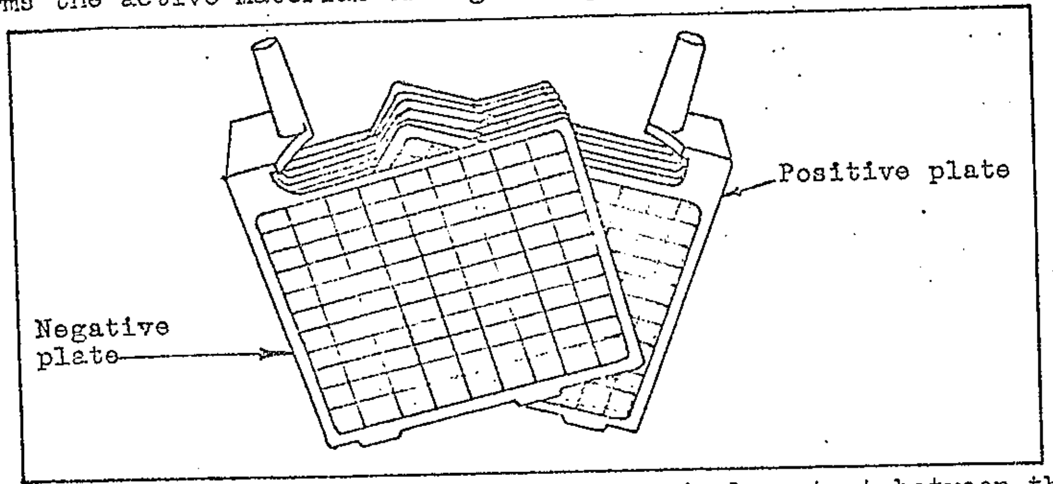
One disadvantage of the secondary cell is its relative lack of portability. This results from two factors:-

(1) Comparatively weighty and bulky.
(2) The electrolyte is liquid and danger of spillage.

Lead-acid battery

Construction: The container is moulded from very hard rubber or plastic material, and divided into compartments, each of which houses a cell element. Each compartment has element rests moulded into the bottom, to provide support for the elements and to form cavities to avoid a short circuit caused through the fall of metallic sediment between plates.
Plates: Are made in grid form, from a mixture of lead and antimony. The grid network is then filled with pastes which form the active materials of the cell. Pure spongy lead, which is grey in colour,

forms the active material of negative plate.



Separators: These are used to prevent physical contact between the plates, and must be sufficiently porous to allow free circulation of electrolyte, but at the same time it must prevent electrical contact, or transfer, of active plate materials through the separator.

Electrolyte: Or liquid in a lead-acid cell, consists of dilute sulphuric acid. Commercial sulphuric acid has a specific gravity of 1.8 and more. Being used in a lead-acid cell, it must be diluted with distilled water, to reduce its specific gravity to between 1.250 - 1.300.

Specific Gravity: The term "specific gravity" is used to compare the weight of a liquid, with the weight of an equal volume of water. For example, if the specific gravity of electrolyte is 1.250, then a given volume of the electrolyte, will weigh 1.25 times the weight of an even volume of water.

Operation: The operation of the lead-acid cell depends on chemical changes which take place between the electrolyte and the plates, during the process of charging or discharging the cell.

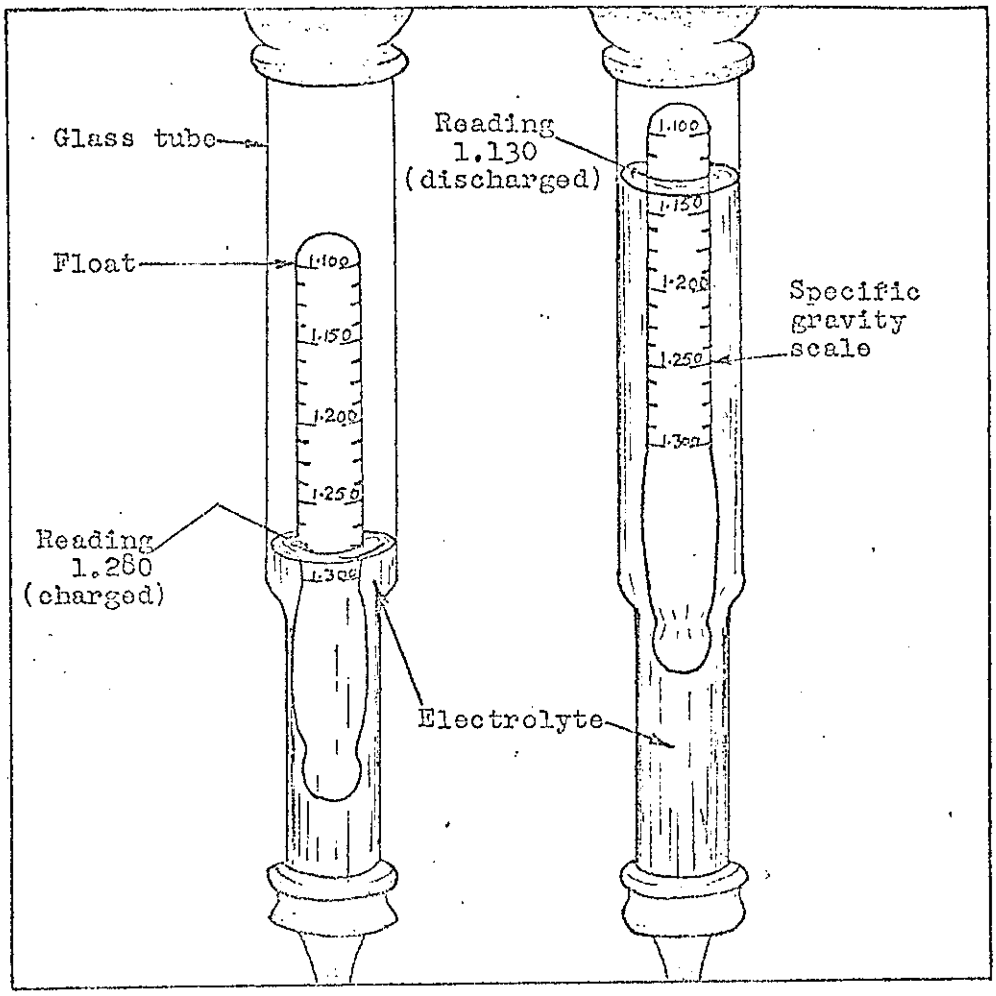
(1) Charging: When direct current is passed through the cell, a chemical change is caused in both the +ve and -ve plates. As the charging proceeds, both the specific gravity of the electrolyte, and the terminal voltage of the cell, will gradually increase. Hydrogen and oxygen bubbles will be given off freely from electrolyte as the cell approaches full state of charge. This process is known as "gassing" of the cell.

(2) Discharging: When current is drawn from a cell, the chemical action is reversed. The electrolyte gradually decreases in specific gravity. At the same time, the terminal voltage of the cell decreases.

(3) Measuring the charge: It has been mentioned that both specific gravity of electrolyte and terminal voltage increase during charging. Two tests which are based on these facts, are used to measure battery charge -

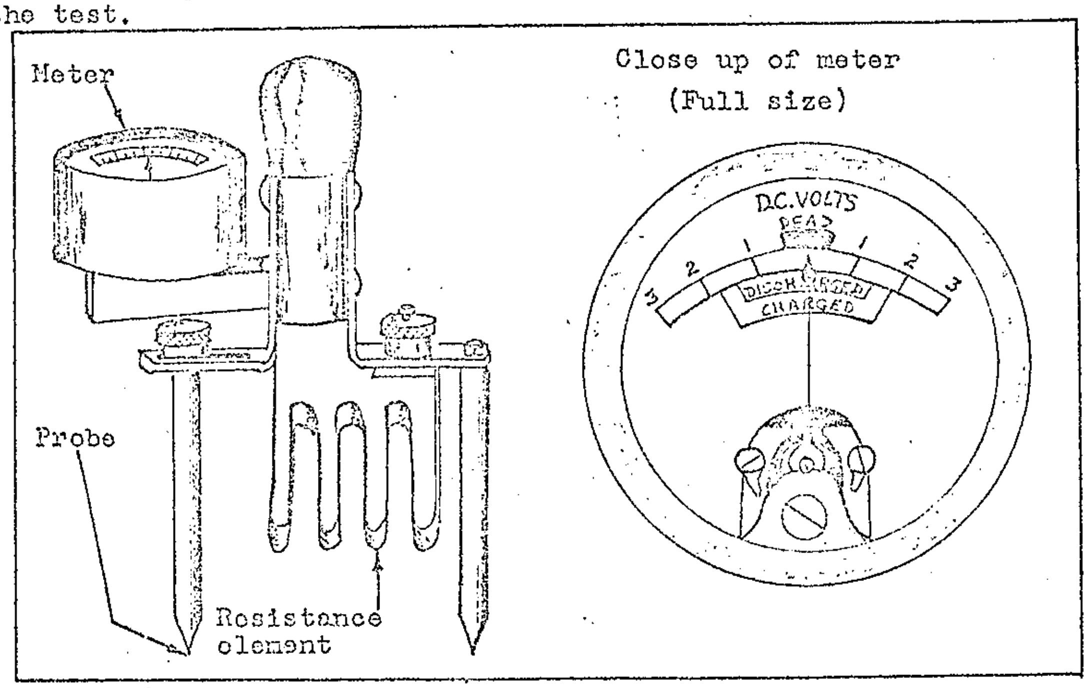
(a) Hydrometer test:

The hydrometer consists of a shaped glass tube, into which the electrolyte may be drawn by squeezing a rubber bulb which is fitted to the end of the tube. A graduated float, which is free to move inside the tube, will float in the electrolyte, at a depth, which depends on the specific gravity of the electrolyte. The specific gravity is indicated by the graduation, which is level with the electrolyte surface.



(b) Voltage test:

The hydrometer test alone is not a complete guide to the condition of a lead-acid battery. In addition, it is necessary to measure individual cell voltages under loaded conditions. This test may be carried out by using the cell tester. Two pointed probes are used, to make contact with the terminal posts of each cell. Loading is provided by the resistance element connected between the probes. The voltmeter is of the "centre zero" type and therefore it is not necessary to reverse the probe to suit the cell polarity. Reasonable cell condition is indicated if the voltage, on load, does not fall below approx. 1.6 volts, and remains at a steady value during the test.



Alkaline Batteries: The active elements used, are iron and nickel oxide, and the electrolyte is a solution of alkaline, potassium hydroxide. This type of cell is known as a nickel-iron cell because of the material used in the plates. The name is often abbreviated to N.I.F.E. The original cell had the disadvantage that it tended to lose its charge when left idle. By substituting cadmium for most of the iron in the -ve plate, this disadvantage has been largely overcome.

(1) The container: Each individual cell is contained in a nickel-plated case, which is rectangular in shape.

(2) The plates: +ve plates, which are formed from nickel, hold the active material of nickel oxide. Nickel oxide is a very poor conductor, and it is necessary to add fine nickel flakes to the mixture to improve its conductivity.
Negative plates, which are formed or iron, hold finely divided cadmium as the active material.

(3) The Separators: Ebonite rods fit into specially formed grooves in the plate surfaces and act as separators between the plates.

(4) The Electrolyte: This consists of an alkaline solution of potassium hydroxide. It acts only as a conducting medium, and does not change in composition or specific gravity during charge and discharge. The electrolyte tends to change its chemical composition very readily, and therefore only distilled water should be added, when required. A complete change of electrolyte should be made annually.

(5) Operation: The general action of the cell is a transfer of oxygen from the -ve to the +ve plate during charge. When discharge occurs, the transfer of oxygen is in the opposite direction. Voltage under load is about 1.2 volts per cell and is used to give an indication of the state of charge of a battery of alkaline cells. Remember that the specific gravity of the electrolyte does not change during charge or discharge periods. It is NOT possible, therefore, to use a hydrometer to measure state of charge.

(6) Comparison of lead-acid & N.I.F.E. batteries:

a) Capacity: A NIFE battery has slightly less weight for a given capacity, than a lead-acid battery.
b) Terminal voltage on load: A NIFE battery requires more cells in series, for a given terminal voltage, than a lead-acid battery. Voltage on load, per cell, is approx. 1.8 for lead-acid, and approx. 1.3 for N.I.F.E.

c) Discharge rate: N.I.F.E. cells have greater internal resistance than lead-acid cells. They are therefore not as suitable in application, such as the starting of vehicle engines where large currents are required for short periods.
d) Charge & discharge rates: Sustained high charge or discharge currents and overcharging do not affect a N.I.F.E. battery, but will seriously affect a lead-acid battery.
e) Leaving in a discharged state: A lead-acid battery must not be left in a discharged state for any appreciable length of time. This precaution does not apply to the N.I.F.E. battery.
f) Cost: A N.I.F.E. battery is much more expensive than the lead-acid, but its longer life offsets the greater initial cost, also the N.I.F.E. requires less maintenance than the lead-acid type.

Summary

1. Two main types of electro-chemical cells.
   (a) Primary cells which cannot be recharged.
   (b) Secondary cells which can be recharged.

2. The simple voltaic cell consists of plates of zinc and copper,

immersed in a dilute solution of sulphuric acid. It has two serious disabilities -
(a) Local action.
(b) Polarization.

3. Dry cells are used where small current output and portability are required. The main types -
(a) The familiar cylindrical type.
(b) The flat type used in high voltage batteries.
(c) Mercury cells, which are available in very small sizes.

4. Cells may be connected in series or parallel to form batteries.
(a) Series connection gives high voltage rating.
(b) Parallel connection gives high current rating.

5. The following points apply to lead-acid batteries -
(a) Control of charge and discharge rate is important.
(b) Do not leave in a discharged state.
(c) Explosive mixture of gases is given off during charging.
(d) Are suitable for auto-motive starting.
(e) Test with hydrometer and voltage per cell, on load.

6. The following applies to N.I.F.E. batteries -
(a) Are more robust and withstand more abuse than lead-acid type.
(b) Voltage per cell is less than lead-acid type.
(c) Not suitable for auto-motive starting.
(d) Test by reading volts per cell, on load.

Safety

If it should be necessary to prepare electrolyte -

- NEVER POUR WATER INTO CONCENTRATED ACID -

A large amount of heat is evolved, when concentrated sulphuric acid and water are mixed, particularly when the quantity of acid is large and the quantity of water is small. The heat generated can (and has) cause an explosion, due to the volume of steam, and a very serious accident can result with concentrated acid sprayed in all directions.

Do not use a naked flame or anything which may cause a spark, when working near a battery being charged - Oxygen and Hydrogen gases are given off and they form a highly explosive mixture.

Wear appropriate protective clothing and safety equipment - If electrolyte spills on skin, the effects can be neutralized by swabbing with a solution of bi-carbonate of soda and water.

Avoid leaving tools etc. near a battery - short circuits cause sparks. Metal watch bands, bracelets, rings, neck chains etc. have also caused accidents.

Unscrew the filling caps when charging batteries.
Ensure that the filling cap vent hole is clear.

Have water readily available, for use when electrolyte has been accidentally splashed on the skin or clothing. Extreme care should be taken in flushing electrolyte from the eye. Volumes of water applied quickly, continuously and copiously, will prevent serious injury to the skin. Quick medical treatment is necessary, to assure proper care and treatment. Apply a strong neutralizer, such as baking soda when acid is spilled on the floor, baking soda will neutralize the acid and make it safe to clean or flush from the floor.

<u>Booster (Jumper) Leads</u>:- The safest way to use jumper leads, is to use one continuous lead for the positive connection, and one lead with a safety connector in the centre, for the negative connection.

<u>Connecting method</u>:

(1) Connect the positive, to positive lead of the respective batteries.

(2) <u>Disconnect the safety connector</u> in the centre of the negative lead.

(3) Connect separate half leads to each battery.

(4) Connect the safety connector in the centre of the lead to complete the connection, keeping the connector clear of the body of the vehicle.

(5) All connections must be firm and clean, and the leads must be completely insulated between each connection.

TITLE:- CURRENT, VOLTAGE, RESISTANCE

LECTURER:-

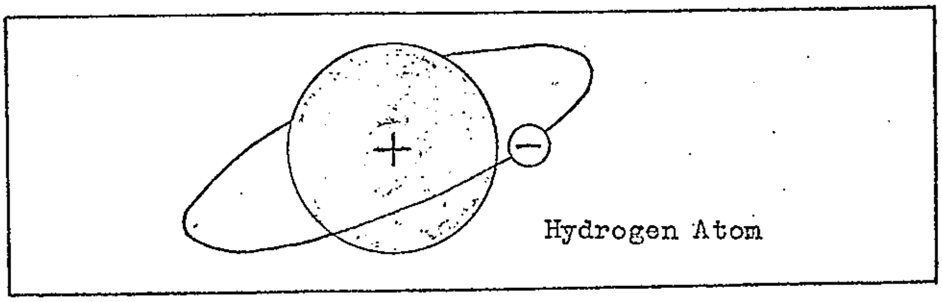
DATE:-

EQUIPMENT:-

Atomic theory:-
all matter is composed of ATOMS of many different sizes, degrees of structural complexity, and weight. But all atoms are alike, in consisting of a NUCLEUS, and of a varying number of ELECTRONS, which move about that nucleus. A good way of understanding what the electron is like, is to examine closely the composition of a drop of water. If you take this drop of water and divide it into two drops, divide one of these two drops into two smaller drops, and repeat this process about a thousand times, the drop will be so small that you will need the best microscope made today, to be able to see it. This tiny drop of water, will still have all the chemical characteristics of water. It can be examined and will be found that there is no chemical difference between this microscopic drop, and an ordinary glass of water.
As the droplet of water is divided into smaller droplets, each will still have all the chemical characteristics of water, eventually you will have a droplet so small, that any further sub-division, will cause it to lose the chemical characteristics of water. This last bit of water is called a MOLECULE. If you examine the water molecule under high magnification, you will see that it is composed of three parts, closely bonded together.
Two of these parts are identical, and are atoms of hydrogen; the third is an atom of oxygen, which is the largest.

Molecule structure:-
While water is made up of only two kinds of atoms - oxygen and hydrogen, the molecules of many materials are more complex in structure.
Cellulose molecules, the basic molecules of which wood is made, consists of three different kinds of atoms - carbon, hydrogen and oxygen. All materials are made up of different combinations of atoms, to form molecules of the materials. There are only about 100 different kinds of atoms, and these are known as ELEMENTS: Oxygen, Carbon, Hydrogen, Iron, Gold, Nitrogen are all elements.
The human body, with all its complex tissues, bones, teeth etc., is made up of only 15 elements, and only six of these are found in reasonable quantities.

Atom structure:-
Referring back to the molecule of water, if we were to take one of the smaller atoms, (Hydrogen) and submit it to enormous magnification, it would look like this:-



You will see that this particular atom is like a sun, with one planet spinning around it. The "sun" represents the nucleus of the atom, and the "planet" is the single electron, which is all that a hydrogen atom has. This electron (like all electrons to be found anywhere in the universe) carries a NEGATIVE charge of electricity,

while the nucleus is POSITIVE in charge.
In all atoms, the negatively-charged electrons, circle round their positively-charged nucleus, at distances which are very great, compared with the sizes of nucleus and of the electrons themselves.
The result is that most of the bulk of any atom, tiny though that is, consists of empty space.
You will get an idea of the kind of scale involved, if you think of the nucleus as a liner in the middle of the English Channel, and of the electrons in the outer orbit of the atom, as bathers on the beaches of Dover and Calais.
The nucleus of an atom itself, contains a number of particles called PROTONS, each carrying a POSITIVE charge of electricity. The number of protons in the nucleus, exactly equals the number of electrons, in orbit around it; with the result, that the atom is, in normal conditions, electrically balanced.

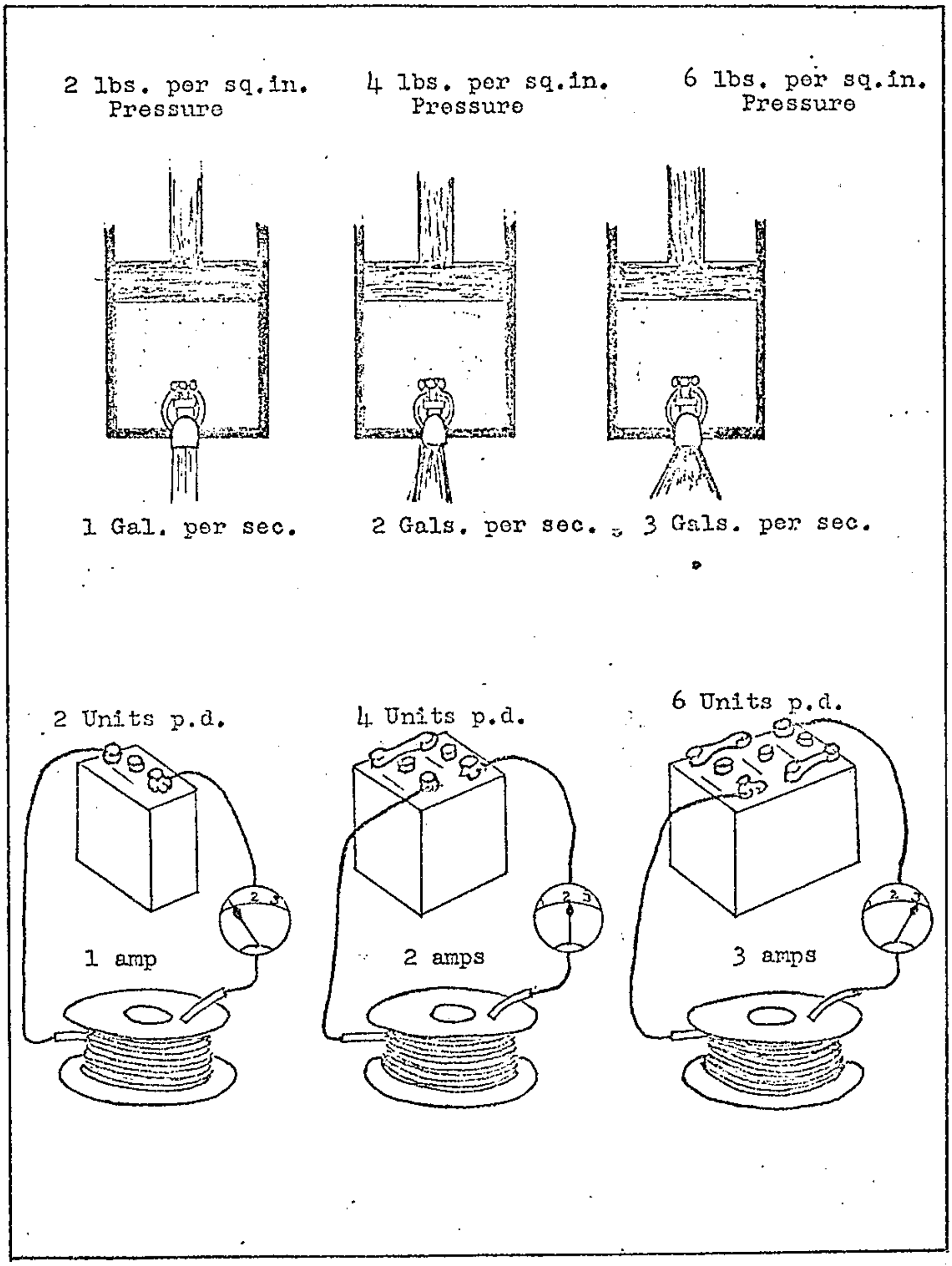
Electric current:-
All atoms are bound together by powerful forces of attraction existing between the nucleus and its electrons. Electrons in the outer orbits of an atom, however, are attracted to their nucleus less powerfully, than are electrons, whose orbits are nearer the nucleus. In certain materials (they are known as "electrical conductors") these outer electrons, are so weakly bound to their nucleus, that they can easily be forced away from it altogether, and left to wander among other atoms at random. Such electrons are called "free electrons"; and it is the movement of free electrons which makes an electric current.

Electric charges:-
Electrons which have been forced out of their orbits, create a deficiency of electrons in the atoms which they leave, and will cause a surplus of electrons, at the point where they come to rest.
A material suffering a deficiency of electrons, becomes POSITIVELY charged; and one possessing a surplus, becomes NEGATIVELY charged.
What happens is that when an atom loses an electron, it loses a negative charge. The part of the atom left behind, therefore ceases to be electrically balanced; for its nucleus remains as positive as before, but one of the balancing negative charges has gone. It is therefore positively charged.

Effect of current:-
Metals and other solid conductors possess free (unbound) electrons, in addition to those associated with the molecules. These free electrons move as if they were particles of a gas dissolved in the metal. When a positive e.m.f. is applied, each electron gains a component velocity, which, on account of its negative charge, is in the direction opposite to the e.m.f.
The drift of electrons constitutes a current. In their motion, the electrons collide with the molecules and give up part of their momentum. This loss is supposed to account for the joulean (I^2R) heat, set free in the conductor.

Voltage:-
You know that current begins to flow in a material, whenever most of the electron movement within the material ceases to be random, and starts to take place in a single direction. You also know, that this movement (always from negative to positive) will continue, only as long as a difference in charge between two points in the material exists; and that this difference in charge, can only be created in the first place by energy from an external source, causing electrons to move in such a way that there will be either an excess, or a deficiency of them at a given point.
The next point to grasp is this:- Whatever the source of the external energy used - heat, pressure, magnetism etc. - This external energy, is changed into POTENTIAL ELECTRICAL ENERGY, the instant the difference in charge is created. Moreover, the amount of electrical energy in the charge created, will always be exactly equal to the amount of source energy needed, to create the change.

The potential electrical energy created, gives rise to what is called "electromotive force", generally written and spoken of as "e.m.f." It is e.m.f. which causes current to flow; and when current is flowing, electrical energy is used up (or dissipated) in making the electrons move from negative to positive.



Resistance:-
A resistor is a material which resists (or insulates) the flow of current. The resistance of a material is dependent on the number of "free" electrons in the material. In substances called "conductors" the outer-shell electrons can be more or less freely interchanged between atoms. In other substances, called "insulators", all the

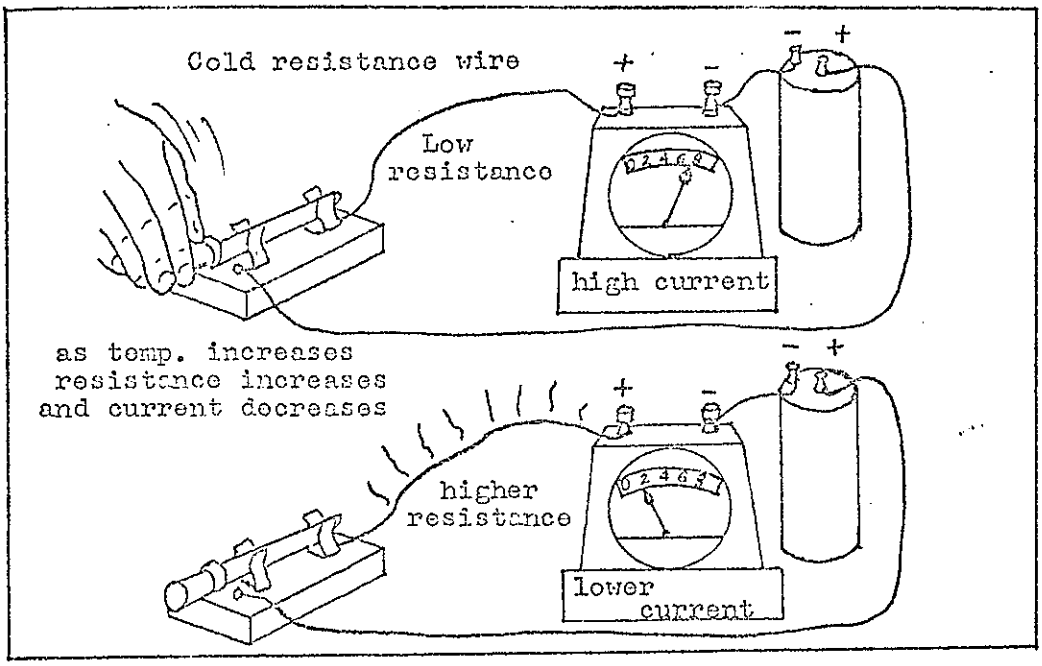
electrons are more or less firmly bound to their parent atoms, so that little or no relative interchange of electron charges is possible.
The resistance of any object depends on four factors -
(a) The material of which it is made.
(b) Its length.
(c) Its cross sectional area.
(d) Its temperature at a given time.

(a) The material of which a wire is made, determines the number of "free" electrons it has available, to carry current flow. Given four wires, identical in length and cross-sectional area all at the same temperature, but each of a different material i.e., silver, copper, aluminium and iron - you would find that each offered a different amount of resistance.
An equal e.m.f. applied to all of them, would produce a different amount of current flow through each.
The silver would conduct best, with copper, aluminium, and iron, offering increasing degrees of resistance in that order.

(b) The second factor affecting the resistance of a wire conductor is its length. A "free" electron needs more e.m.f. applied to it, to make it travel over a long distance, than it does to make it travel over a short distance. Assuming an equal e.m.f. applied, it follows that the electron stream will travel less easily, over a long length of wire, than it will over a shorter one. In other words, current flow is lower, for a given e.m.f. applied over a longer length of wire, than it's is over a shorter length. This means that the effective resistance of the longer wire is greater.

(c) The third factor affecting resistance is its cross-sectional area. To understand what cross-sectional area means, imagine a wire cleanly cut across any part of its length. The area of the cut face of the wire, is the cross-sectional area.
The greater this area is, the lower will be the wire resistance; and the smaller this area is, higher will be the wire resistance.
To see how this works, suppose that you were to connect an iron wire, four inches long and 1/100 inch in diameter, in series with an ammeter. As soon as you connect this across a battery, a certain amount of current will flow. You can see though, the current has narrow wire to travel through.
If you were to remove the iron wire, and replace it with another wire of the same length, but twice the cross-sectional area, the current would double. This happens, because you now have a wider path for the current to flow through. The larger the cross-sectional area therefore, the lower the resistance; and the smaller the cross-sectional area, the higher the resistance.

(d) The fourth factor affecting the resistance of a conductor, is its temperature.
In most materials, the hotter the material, the more resistance it will offer to current flow. Conversely, the colder the material, the less resistance it will offer.
The reason is, that heat makes the free electrons in a material vibrate. When they are in this state, they resist electrical pressure applied. This effect can be observed, by connecting in series, a battery, a switch, a length of resistance wire, and an ammeter. When the switch is closed, current flows through the wire; and soon the wire begins to heat up. The hotter the wire gets, the lower the meter reading will fall. The reason is, increasing resistance to the flow of current. Only when the wire has reached its maximum heat, does the resistance stop increasing, and the meter reading remain steady.

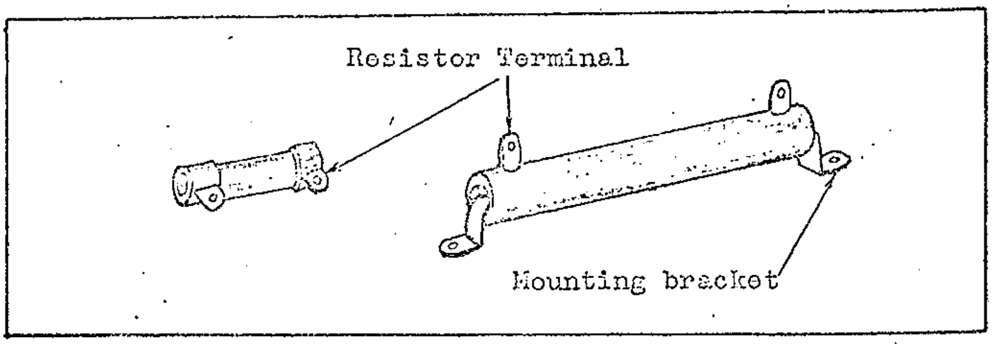


The effect of temperature on resistance varies in different metals. In such materials as copper and aluminium, it is very slight. It must be noted however, that some materials, such as carbon, and electrolytic solutions, actually lower their resistance as they get hotter.

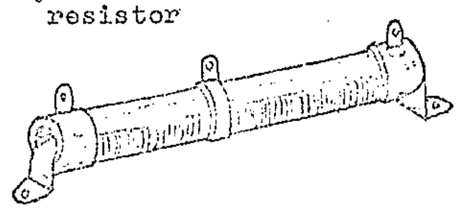
The unit of Resistance:-
The basic unit of resistance is the "ohm". One ohm, is the value of the resistance which will allow exactly one ampere of current to flow, when exactly one volt of e.m.f. is applied.
Imagine an experiment in which you connected a copper wire across an e.m.f. of one volt, and then adjusted the length of the wire, until the current flow through the wire became exactly one ampere. The resistance of the length of wire, would be exactly one ohm. If you substituted wire, made of material other than copper;iron or silver for example, you would have to alter the length, or the cross-sectional area of the wire. The standard abbreviation for the ohm is the Greek letter . A resistor is always indicated in circuit diagrams by the symbol:

This is one of the most commonly used symbols in work with electricity and electronics.

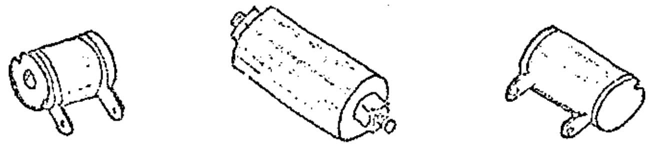
All electrical equipment contains a certain amount of resistance. Often however, this inherent resistance is not enough, to control the flow of current as closely as needed. The solution, then, is to put extra resistance in the circuit deliberately.
Devices used to introduce extra resistance into a circuit, are called resistors. All resistors are made either of special resistance wire, of graphite (carbon) composition, or a metal film. Wire wound resistors are usually used to control large currents, while carbon resistors control currents which are relatively small. Vitreous enamelled, wire-wound resistors, are constructed by winding resistance wire on a porcelain base, attaching the wire ends to metal terminals, and coating wire and base with powdered glass, and baked enamel, to protect the wire and conduct heat away from it.



Wire wound resistors may have fixed "taps", which can be used to change the resistance value in steps, or sliders, which can be adjusted to change the resistance to any fraction of the total resistance.

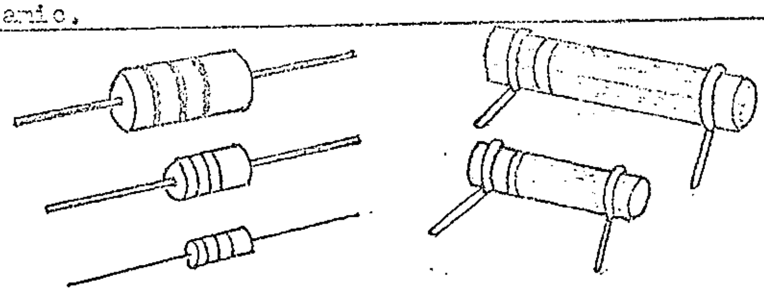


When the value of the resistor has to be very accurate, as in test instruments, precision wound resistors of manganin wire are used.



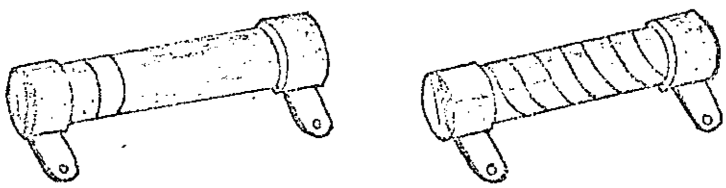
Precision wire-wound resistors

Carbon resistors are constructed of a rod of compressed graphite and binding material, with lead wires attached to each end of the rod. The rod is then either painted, or covered with an insulating coating of ceramic.



Carbon resistors

Some carbon resistors are made by coating a porcelain tube with a carbon film, and in some cases, the film is coated in a spiral, similar to winding a wire around the tube. The carbon coating is covered with baked enamel for protection and to conduct heat away from the carbon film, so that it does not overheat and burn out.

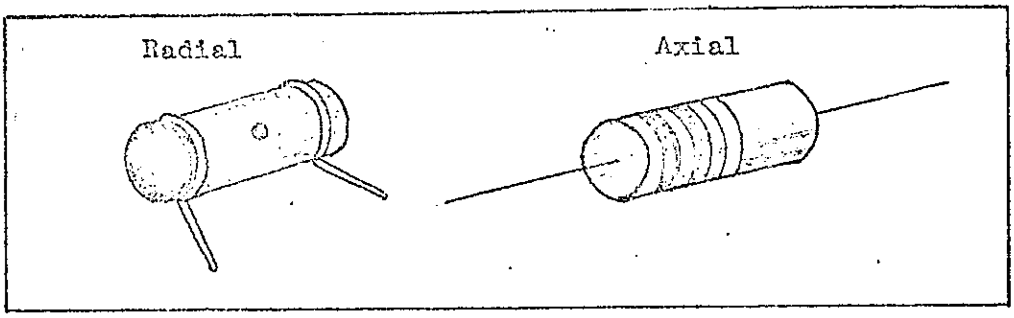


Large carbon resistors

Resistor colour code:-

You can find the resistance value of any resistor, by using an ohmmeter, but in some cases it is easier to find the value by its marking. Most wire-wound resistors, have the value printed in ohms on the body. Many carbon resistors also have their values printed on them, but sometimes, due to their mounting position, or heat, it

is impossible to read the resistance value. To make the value easier to identify, a colour code marking is used.
Carbon resistors are of two types, radial and axial, which differ only in the way in which the wire leads are connected, to the body of the resistor. Both types use the same colour code, but the colours are painted in a different manner, on each type. Radial lead resistors are rarely found in modern equipment, although they were widely used in the past.



Radial resistors are coded with the "body-tip-spot" system. Axial resistors are coded with the "end-to-centre band" system. In each colour code system of marking, three colours are used, to indicate the resistance value in ohms, and a fourth colour is sometimes used to indicate the "tolerance" of the resistance.

Resistor tolerance:-
It is very difficult to manufacture a resistor to an exact value; but luckily, resistors rated within about 20% above or below the exact value of resistance required, will do quite well for most purposes.
Such resistors are said to have 20% tolerance. When a resistor provides an effective value of resistance, within 10% or 5% of the value marked on it, it is said to have 10% or 5% tolerance as the case may be.

COLOUR	1st DIGIT	2nd DIGIT	MULTIPLIER	TOLERANCE %
Black	0	0	1	Gold ± 5
Brown	1	1	10	
Red	2	2	100	Silver ± 10
Orange	3	3	1,000	
Yellow	4	4	10,000	No band ± 20
Green	5	5	100,000	
Blue	6	6	1,000,000	RED ± 1
Violet	7	7	10,000,000	
Gray	8	8	100,000,000	
White	9	9	1,000,000,000	
Silver			.01	
Gold			.1	

General Review

Free electrons:-
The electrons of some substances are so loosely bound to their nuclei, that it takes little force to break the bond (conductors).

Electric charge:-
If the atoms of a substance lose some of its electrons, that substance loses its electrical balance, and becomes positively charged. Conversely, if the atoms of a substance gains electrons, that substance becomes negatively charged. (Remember that - ALL ELECTRONS

ARE NEGATIVE IN CHARGE). It is a fundamental law of physics that LIKE CHARGES REPEL, AND UNLIKE CHARGES ATTRACT.

Conductors & Insulators:-
Some substances, such as silver, copper and aluminium, have electrons so loosely bound to their nuclei, that even the heat of room temperature, is enough to supply the small amount of force needed to set them free. Such substances are called conductors.
The atoms of other (mainly non-metallic) substances, have their electrons so tightly bound to their nuclei, that a great force is needed to set them free. Substances normally having no "free" electrons (glass, mica, porcelain, rubber etc.) are called insulators.

Electric current:-
Flows when all the "free" electrons in a material are moving in the same general direction. Electrons, being negative, move always away from NEGATIVE TOWARDS POSITIVE.

Potential difference and Electromotive force:-
No current can flow between two points in a material, unless there is a difference in charge between them. This "difference in electrical pressure" between the two points, is called "potential difference".
The external energy which is used, to create p.d., is instantly converted into an equal amount of electrical energy, once it is enabled to cause electrons to flow, is called "electro-motive force".

Resistance:-
Is the term used, to describe the ability of a material, to impede the flow of current.

Current - e.m.f. - resistance:-
When a source of e.m.f. of one volt, is connected across a resistor of one ohm, a current of one ampere will flow.

TITLE:- RELATIONSHIP OF VOLTAGE, CURRENT AND RESISTANCE
LECTURER:- Gerry Heynis
DATE:- 22-6-81
EQUIPMENT:-

The relationship between voltage, current and resistance was studied last century by the German mathematician George Simon Ohm. His statement on the relationship, now known as OHMS LAW, is one of the fundamental equations in all physics and is constantly used not only in the electrical trade, but with anything in which the flow of electric current is involved.
This fixed relationship is that given a constant resistance in a circuit, current flow will increase as the voltage applied to the circuit is increased. Also - Given a constant voltage applied to the circuit, current flow will decrease as the resistance of the circuit is increased.
A common way to express this relationship is to say: The current flowing in a circuit is directly proportional to the applied e.m.f. and inversely proportional to the resistance.

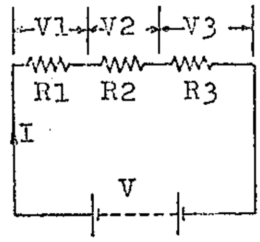
This can be set out as an equation, thus: $\text{CURRENT}(I) = \frac{\text{VOLTAGE }(V)}{\text{RESISTANCE}(R)}$

This can be re-framed by using simple algebra: $V - IR$

or $R = \frac{V}{I}$

This equation, in one of the three above forms, can be used to find unknown quantities in series, parallel or complex circuits where the other two quantities are known.

Series Circuits
A series circuit is formed when the circuit components are connected "end to end" in such a way that there is only one path for current flow.
When a number of resistances are connected to form a series circuit, the total resistance is the sum of the individual resistances.
In a series circuit, the same current flows through every part of the circuit, and the total applied voltage is the sum of the individual voltage drops.



$V = V1 + V2 + V3$

$R_T = R1 + R2 + R3$

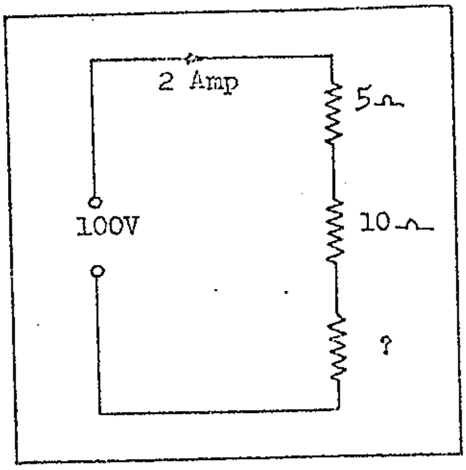
Another law, Kirchhoffs Second Law relates to these voltage drops and states that "In any closed path in a network, the algebraic sum of the IR products is equal to the e.m.f. in that path".
Equations can be formed from these facts so that in Fig. 1

Current	-	I TOTAL = I1 = I2 = I3
Voltage	-	V TOTAL = V1 + V2 + V3
Resistance	-	R TOTAL = R1 + R2 + R3.

These three facts, used in conjunction with Ohm's Law, enable the values of complete circuits or parts of circuits to be calculated.

Example
A circuit contains three resistors connected in series across 100 volts, the current is 2 amps. R1 & R2 are 5 ohms and 10 ohms respectively.
(1) Find the resistance of the entire circuit
(2) the value of the third resistor
(3) Voltage drops across each of the three resistors

(1) $Rt = \frac{Vt}{It} = \frac{100}{2} = \underline{50 \text{ ohms}}$



(2) $Rt = R1 + R2 + R3$

$\therefore R3 = Rt - R1 - R2$
$R3 = 50 - 5 - 10$
$\underline{R3 = 35 \text{ ohms}}$

(3) $V1 = I1 \times R1$
$= 2 \times 5$
$\underline{V1 = 10 \text{ volts}}$

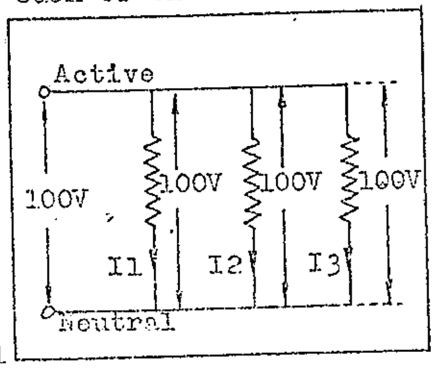
$V2 = I2 \times R2$
$= 2 \times 10$
$\underline{V2 = 20 \text{ volts}}$

$V3 = I3 \times R3$
$= 2 \times 35$
$\underline{V3 = 70 \text{ volts}}$

Parallel circuits

A parallel circuit is formed when the circuit components are connected "side by side" so that more than one path exists through which current can flow.

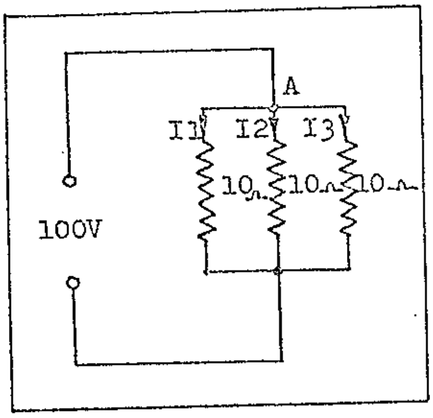
When components are placed in parallel in a circuit and a voltage supplied to the circuit, the voltage across each of the branches is equal to the supply voltage because each of these components is connected to both active and neutral (Fig. 1). In general, it can be said that in a parallel circuit, the voltage across each of the branches is the same. The current through each component however, will vary according to the resistance value of each component.



Consider the idea of roads connecting two towns A and B. Which system will carry the greatest traffic from A to B, a one road series, or a 3 road parallel network? Obviously the parallel network. With equal quality of construction, one road might carry 15 cars per minute; with only one series road then only 15 cars per minute would be carried but the 3 road parallel network would carry 45 cars per minute.

In Fig. 3 there is a three branch parallel circuit with equal branch resistances of 10 ohms. The applied voltage is 100 volts. The current in each branch can be calculated using Ohm's Law.

$I1 = \frac{E}{R1} = \frac{100}{10} = 10 \text{ amps}$



Since voltage and resistance are the same in the other two branches their current is also 10 amps.

$\therefore$ The total load current must be 30 amps. Thus it can be said that the total current in a parallel circuit is the sum of the currents in all branches i.e.

I TOTAL = I1 + I2 + I3.

This still holds true when resistances are not equal in value.

There is another law known as Kirchhoffs First Law which concurs with what has just been shown, it states that: "The sum of all the currents flowing towards a junction always equals the sum of all the currents flowing away from that junction". In Fig. 3 the current flowing towards point A is I , and the currents flowing away are I1, I2, I3. Therefore this law is proving $I_T = I1 + I2 + I3$.

From Ohm's Law $I = \frac{V}{R}$ and if $\frac{V}{R}$ is substituted for I in the above equation it becomes

$$\frac{V}{R_T} = \frac{V}{R1} + \frac{V}{R2} + \frac{V}{R3}$$

If both sides of the equation are now divided by V it then becomes:

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

This is the formula used to find the total resistance in a parallel circuit.
The total resistance in a parallel circuit is always less than the resistance of the lowest single resistor. This may be seen easier by referring back to Fig. 3. If only one 10 ohm resistor had been in circuit, the total current would only have been 10 amps, but when the other two were added the current rose to 30 amps. This, from Ohm's Law indicates a drop in total resistance, since the current and resistance are inversely related.
When, and only when, each parallel connected resistance has the same ohmic value, the total resistance can be calculated by dividing the resistance of one by the number of parallel resistances. This can be proven.

<u>Examples</u> (1) Two 5 ohm resistors in parallel

$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} = \frac{1}{5} + \frac{1}{5} = \frac{2}{5} \quad \text{or} \quad 5 \text{ ohms} \div 2 = \underline{2\tfrac{1}{2} \text{ ohms}}$$

$$R = \frac{5}{2} = \underline{2\tfrac{1}{2} \text{ ohms}}$$

(2) Five 10 ohm resistors in parallel

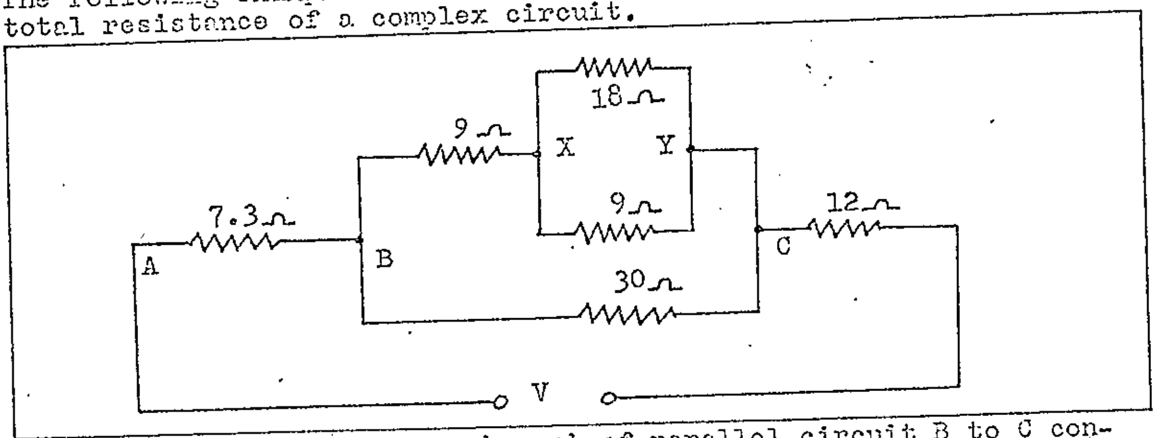
$$\frac{1}{R_T} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4} + \frac{1}{R5}$$

$$\frac{1}{R_T} = \frac{1}{10} = \frac{1}{10} = \frac{1}{10} = \frac{1}{10} + \frac{1}{10} \quad \text{or} \quad 10 \text{ ohms} \div 5 = \underline{2 \text{ ohms}}$$

$$\frac{1}{R_T} = \frac{5}{10}$$

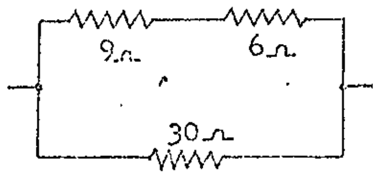
$$R_T = \frac{10}{5} = \underline{2 \text{ ohms}}$$

<u>Complex Circuits</u>
The following example is set out to indicate how to calculate the total resistance of a complex circuit.



It will be noticed that one branch of parallel circuit B to C contains a parallel circuit X to Y in series with a 9 ohm resistor.

Whenever one parallel circuit is contained within another parallel circuit, the inner parallel group must be replaced with its equivalent series resistance, before attempting to calculate the equivalent resistance for the outer parallel group.



$$\frac{1}{R_{x-y}} = \frac{1}{18} + \frac{1}{9}$$
$$= \frac{1+2}{18}$$
$$= \frac{3}{18}$$

$R_{x-y} = 6$ ohms

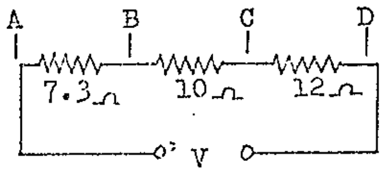
Redrawing the parallel group B. C:-

R TOTAL of 9 ohm and 6 ohm leg = 15 ohms

$$\frac{1}{R_{B-C}} = \frac{1}{15} + \frac{1}{30} = \frac{2+1}{30} = \frac{3}{30}$$

$R_{B-C} = 10$ ohms

Drawing equivalent series circuit:-



R TOTAL $= 7.3 + 10 + 12$
$= 29.3$ ohms

If equivalent circuits are drawn and lettered as shown no difficulty should be experienced with most practical circuit applications. If voltage or some other information was given in the foregoing example the rest of the circuit quantities could be found using Ohm's Law.

TITLE:- ELECTRICAL ENERGY AND POWER

LECTURER:-

DATE:-

EQUIPMENT:-

Power

Whenever a force of any kind causes motion, work is said to be done. A force which is exerted without causing motion however does not cause work to be done.
When a voltage exists across a closed electrical circuit, electrons are caused to move and hence current to flow. Thus when a voltage causes electrons to move, work is done in moving them.
The rate at which the work of moving electrons from point to point is done, is called electric power. It is represented by the symbol "P".
The electrical energy consumed in making the electrons move against the frictional resistance of the circuit is converted into heat energy. This rate of energy conversion is what is meant by power.
The basic unit in which electric power is measured is the watt.
The rate at which work is done in moving electrons through a circuit depends on how many electrons there are to be moved, and the speed at which they are made to travel.
In other words, the power consumed in a circuit is determined by the voltage measured across it multiplied by the current flowing through it.
Expressed as a formula this gives $P = VI$.
By using Ohm's law this formula can be expressed in terms of current and resistance.
Since $V = IR$, the V in the power formula can be replaced by IR, and the power calculated without the Voltage being known:

Substituting IR for V: $P = (IR)I = I \times R \times I = \underline{I^2R}$

similarly $I = \frac{V}{R}$. If this is substituted in the formula, power used can be found with only the voltage and resistance being known:

Substituting $\frac{V}{R}$ for I: $P = V\left(\frac{V}{R}\right) = \frac{V \times V}{R} = \underline{\frac{V^2}{R}}$

Energy

One watt is the rate of working which if continued for one second, would require the expenditure of one practical unit of energy (one Joule).
Thus it can be said: Joules = watts x seconds.
Because of this relation, the term "watt-second" is sometimes used instead of "joule".

Commercial units For industrial purposes the above units are too small and other larger units have been adopted.
The commercial unit of power is the KILOWATT(KW) which, as its name suggests, is equal to 1000 watts.
The commercial unit of energy or work is the KILOWATT HOUR (K.W.H.), and represents the energy expended when a power of one kilowatt operated for one hour. This is the "unit" by which electrical energy is purchased.

Power in series circuits The total power in a resistive circuit is the sum of the power used in all the individual resistors.
If any two of either the applied voltage, the current, or the total resistance can be found, then one of the power formulae previously mentioned would give the total power consumed.

Power in parallel circuits The total power taken by a parallel circuit is also equal to the sum of the power taken by all the individual resistors in the circuit.
It can be found by multiplying the total circuit current by the voltage across the circuit.
If either total current or applied voltage is unknown, total power can still be found by calculating total circuit resistance.

The correct variation of the power formula can then be used to find total power.

Heating effect of Current

As has been stated previously, the electrical energy consumed in making the electrons overcome the frictional resistance of the circuit is converted into heat energy. This heat energy can be put to good use: e.g. water heater, oven, electric kettle, electric cooker, etc.

There are two units of heat, (1) The calorie (2) The British Thermal Unit (B.Th.U).

1 calorie = 0.00397 B.Th.U's. $\left(\frac{1}{252}\right)$

1 B.Th.U. = 252 calories.

1 calorie is the heat energy required to raise the temperature of 1 gram of water by 1 degree celcius.

1 B.Th.U. is the heat energy required to raise the temperature of 1 lb. of water by 1 degree fahrenheit.

$\therefore$ H(calories) = Weight (grams) x Temp. Rise (degrees C) and

H(B.Th.U's) = Weight (lbs.) x Temp. Rise (degrees F)

In certain problems it is necessary to convert from degrees C to degrees F or vice versa.

$$\text{degrees C} = (\text{degrees F} - 32)\frac{5}{9}$$

$$\text{degrees F} = \frac{(\text{degrees C} \times 9)}{5} + 32$$

It may be also necessary to know other factors -

i.e. 1 gallon of water weighs 10 lbs. or 4.54 Kg.
1 cubic foot of water weighs 62.5 lbs. or 28.4 Kg.
1 cubic foot of water = 6.25 gallons.

examples

(a) How many calories of heat energy are required to heat 5 kg of water from 0 degreesC to 20 degrees C.

H = 5000g x 20 degrees = 100,000 calories.

(b) How many B.Th.U's of heat energy are required to heat 10 gallons of water from 0 degrees C to 100 degrees C.

10 gallons = 100 lbs   H = 100 lbs x 212 degrees F
= 21,200 B.Th.U.s

If we go one step further, we can calculate how much electrical energy is required, and what size heating elements would be suitable

The unit of electrical energy is the joule.
1 joule = 1 volt x 1 amp x 1 second = E.I.t.

For calculations, heat energy has to be convertible into electrical energy. Electrical energy = heat energy x joules equivalent

Very careful experiments by the English physicist Joule in 1843 established a definite relationship between heat energy and electrical energy in the form:

J x heat energy = Electrical energy
where J is a constant 4.18

$\therefore$ E.I.t. = calories x 4.18

or calories = $\frac{\text{E.I.t.}}{4.18}$ = E.I.t. x 0.24

Calculate the electrical energy required in examples (a) and (b).

(a) $E.I.t. = 100,000 \times 4.18$ watt seconds

$$= \frac{100,000 \times 4.18}{3600 \times 1000} = \underline{0.116 \text{ KWH}}$$

(b) $E.I.t. = 21,200 \times 252 \times 4.18$ watt seconds

$$= \frac{21,200 \times 252 \times 4.18}{3600 \times 1000} = \underline{6.203 \text{ KWH}}$$

Example

Calculate the capacity in gallons of a water heater fitted with a 3 KW heating element which will increase the temperature of water from 40 degrees F to 200 degrees F in 5 hours.

$$E.I.t. = \text{Calories} \times 4.18$$
$$W \times t = X \text{ lbs} \times 160 \times 252 \times 4.18$$
$$3000 \times 60 \times 60 \times 5 = X \text{ lbs} \times 160 \times 252 \times 4.18$$
$$X \text{ lbs} = \frac{3000 \times 60 \times 60 \times 5}{160 \times 252 \times 4.18} \text{ lbs}$$
$$X \text{ gallons} = \frac{3000 \times 60 \times 60 \times 5}{160 \times 252 \times 4.18 \times 10} \text{ gallons}$$
$$= \underline{32.1 \text{ gallons}}$$