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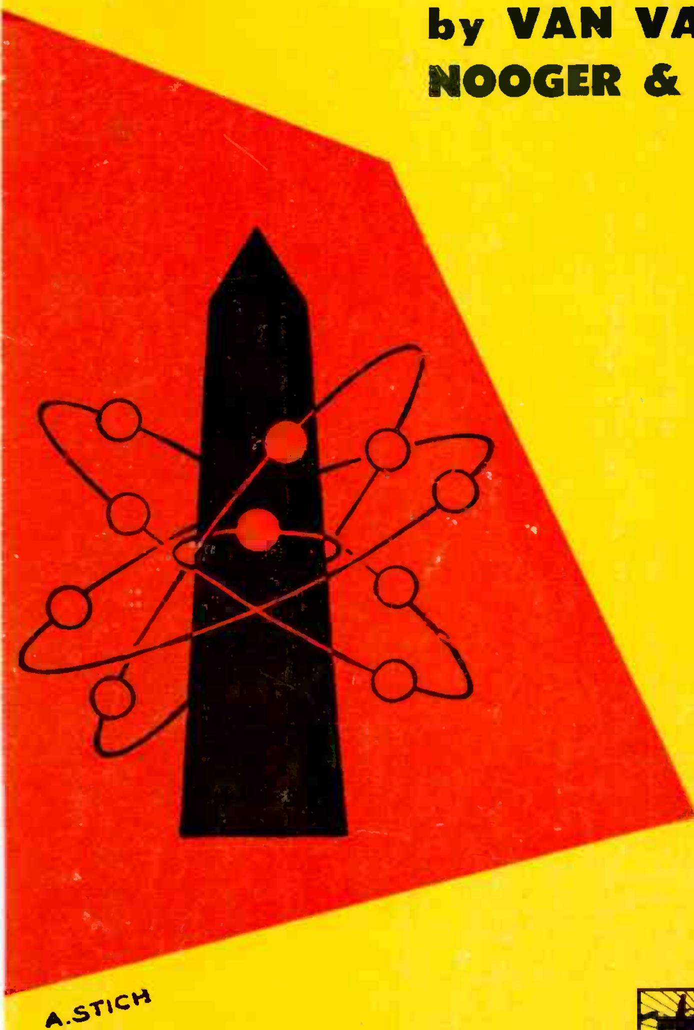
basic electricity

by VAN VALKENBURGH, NOOGER & NEVILLE, INC.



VOL. 1

WHERE ELECTRICITY COMES FROM

ELECTRICITY IN ACTION

CURRENT FLOW, VOLTAGE, RESISTANCE

MAGNETISM, DC METERS

RIDER

basic electricity

by VAN VALKENBURGH, NOOGER & NEVILLE, INC.

VOL. 1

JOHN F. RIDER PUBLISHER, INC., NEW YORK
a division of HAYDEN PUBLISHING COMPANY, INC.

First Edition

Library of Congress Catalog Card No. 54-12946

Printed in the United States of America

PREFACE

The texts of the entire Basic Electricity and Basic Electronics courses, as currently taught at Navy specialty schools, have now been released by the Navy for civilian use. This educational program has been an unqualified success. Since April, 1953, when it was first installed, over 25,000 Navy trainees have benefited by this instruction and the results have been outstanding.

The unique simplification of an ordinarily complex subject, the exceptional clarity of illustrations and text, and the plan of presenting one basic concept at a time, without involving complicated mathematics, all combine in making this course a better and quicker way to teach and learn basic electricity and electronics. The Basic Electronics portion of this course will be available as a separate series of volumes.

In releasing this material to the general public, the Navy hopes to provide the means for creating a nation-wide pool of pre-trained technicians, upon whom the Armed Forces could call in time of national emergency, without the need for precious weeks and months of schooling.

Perhaps of greater importance is the Navy's hope that through the release of this course, a direct contribution will be made toward increasing the technical knowledge of men and women throughout the country, as a step in making and keeping America strong.

Van Valkenburgh, Nooger and Neville, Inc.

New York, N. Y.
October, 1954

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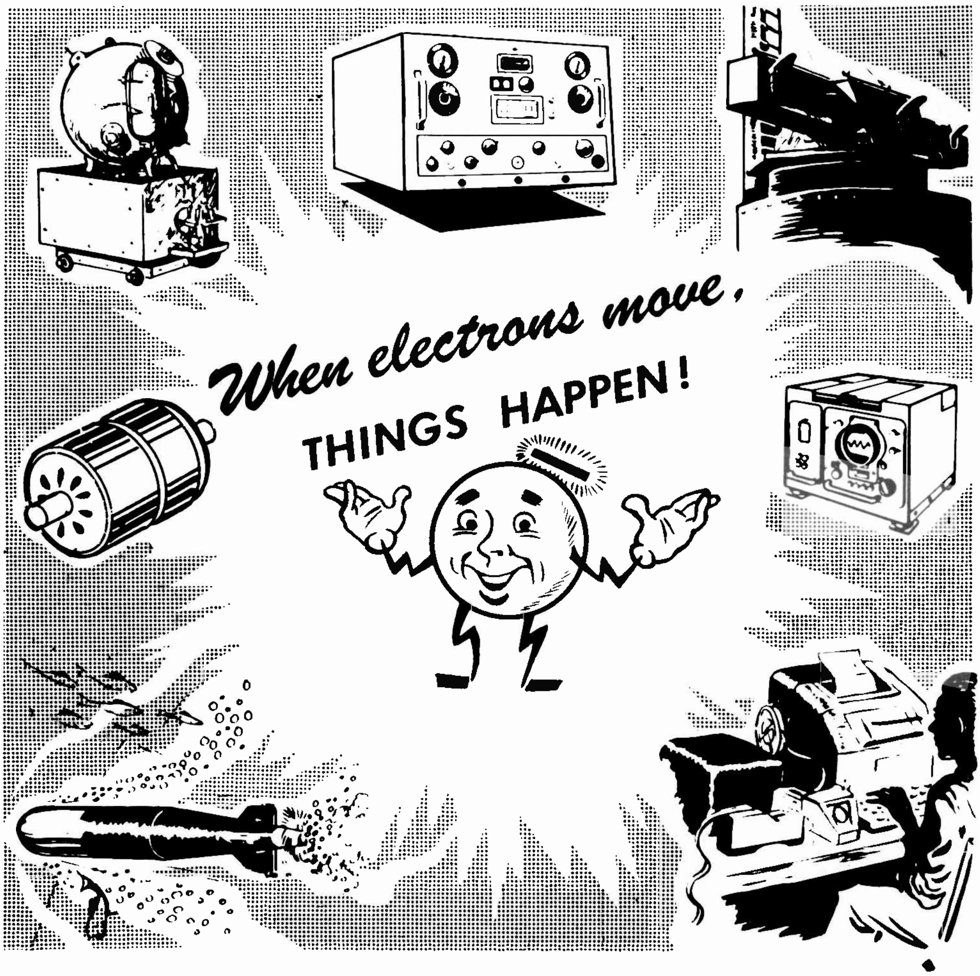
WHAT ELECTRICITY IS

The Electron Theory

All the effects of electricity can be explained and predicted by assuming the existence of a tiny particle called the "electron." Using this "electron theory," scientists have been able to make predictions and discoveries which seemed impossible only a few years ago. The electron theory not only is the basis of design for all electrical and electronic equipment, it explains chemical action and allows chemists to predict and make new chemicals, such as the synthetic "wonder drugs."

Since assuming that the electron exists has led to so many important discoveries in electricity, electronics, chemistry and atomic physics, we can safely assume that the electron really exists. All electrical and electronic equipment has been designed using the electron theory. Since the electron theory has always worked for everyone, it will always work for you.

Your entire study of electricity will be based upon the electron theory. The electron theory assumes that all electrical and electronic effects are due to the movement of electrons from place to place or that there are too many or too few electrons in a particular place.

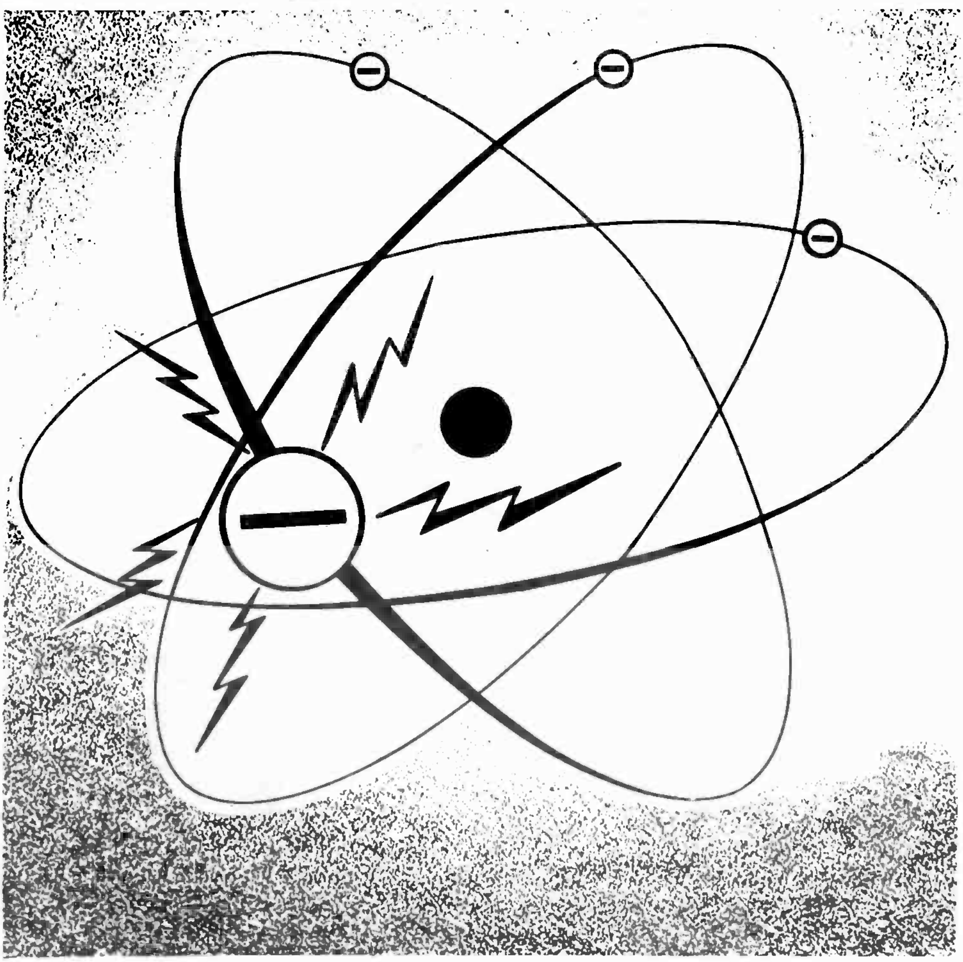


The Electron Theory (continued)

You have heard that electricity is the action of electrons in moving from point to point, or the excess or lack of electrons in a material. Before working with electricity, you will want to know exactly what an electron is and what causes it to move in a material. In order for electrons to move, some form of energy must be converted into electricity. Six forms of energy can be used and each may be considered to be a separate source of electricity.

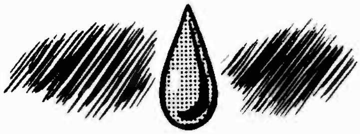
However, before studying the kinds of energy which can cause an electron to move, you first must find out what an electron is. Because the electron is one part of an atom, you will need to know something about the atomic structure of matter.

THE ELECTRON IS ELECTRICITY

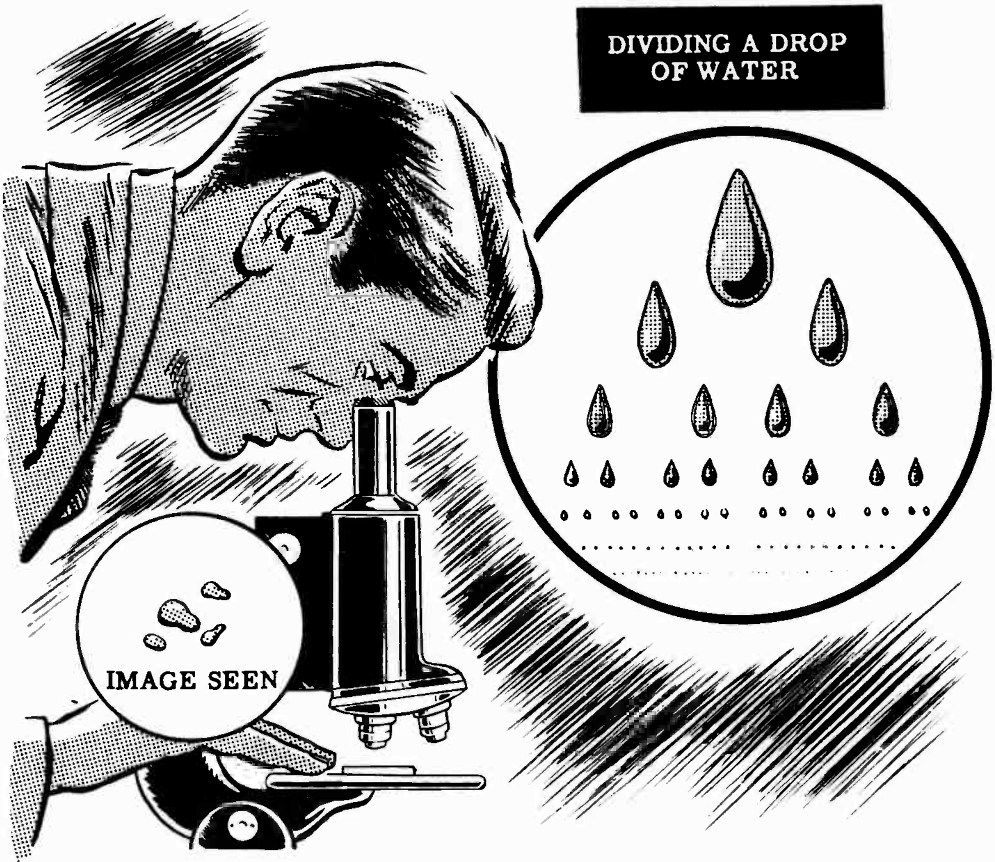


The Breakdown of Matter

You have heard that electrons are tiny particles of electricity, but you may not have a very clear idea of the part electrons play in making up all the materials around us. You can find out about the electron by carefully examining the composition of any ordinary material—say a drop of water.



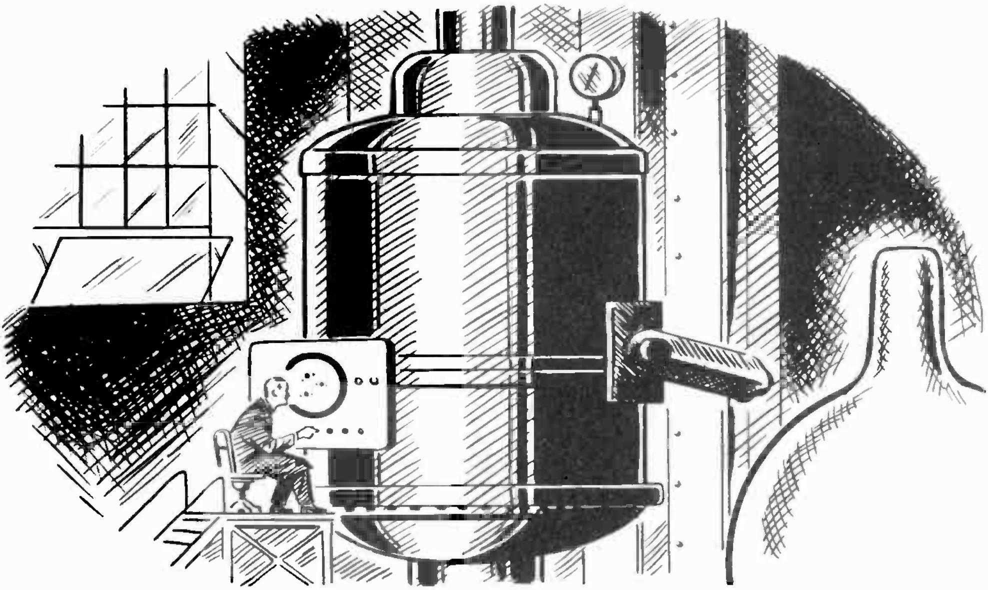
If you take this drop of water and divide it into two drops, divide one of these two drops into two smaller drops and repeat this process a few thousand times, you will have a very tiny drop of water. This tiny drop will be so small that you will need the best microscope made today in order to see it.



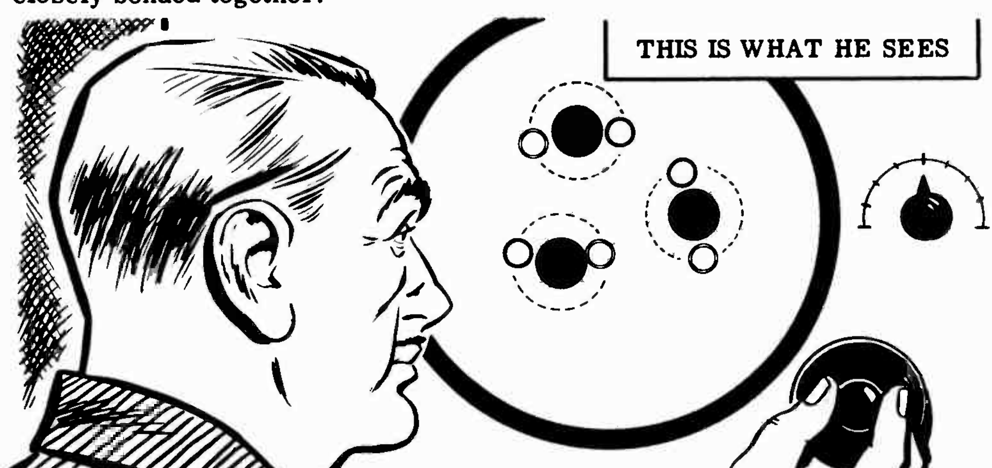
This tiny drop of water will still have all the chemical characteristics of water. It can be examined by a chemist, and he will not be able to find any chemical difference between this microscopic drop and an ordinary glass of water.

The Breakdown of Matter (continued)

Now if you take this tiny drop of water and try to divide it in half any further, you will not be able to see it in your microscope. Imagine that you have available a super microscope which will magnify many times as much as any microscope presently existing. This microscope can give you any magnification you want, so you can put your tiny drop of water under it and proceed to divide it into smaller and smaller droplets.



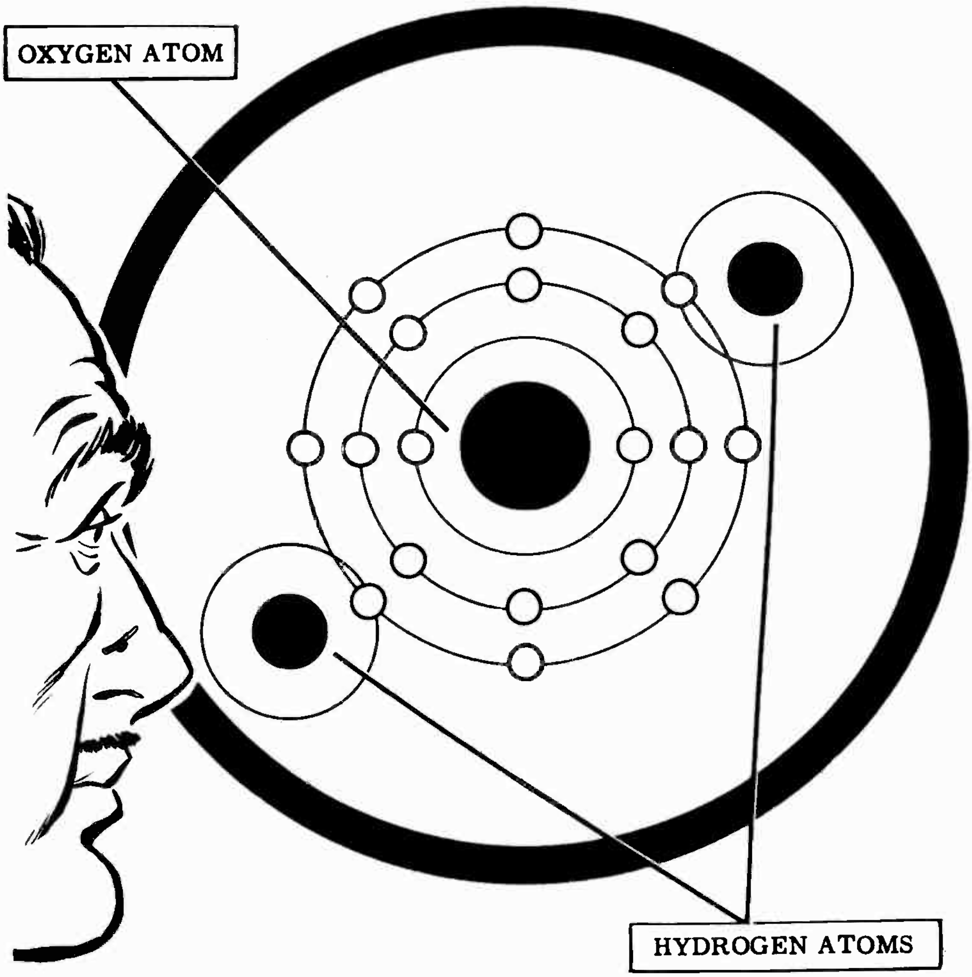
As the droplet of water is divided into smaller and smaller droplets, these tiny droplets will still have all the chemical characteristics of water. However, you eventually will have a droplet so small that any further division will cause it to lose the chemical characteristics of water. This last bit 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.



The Structure of the Molecule

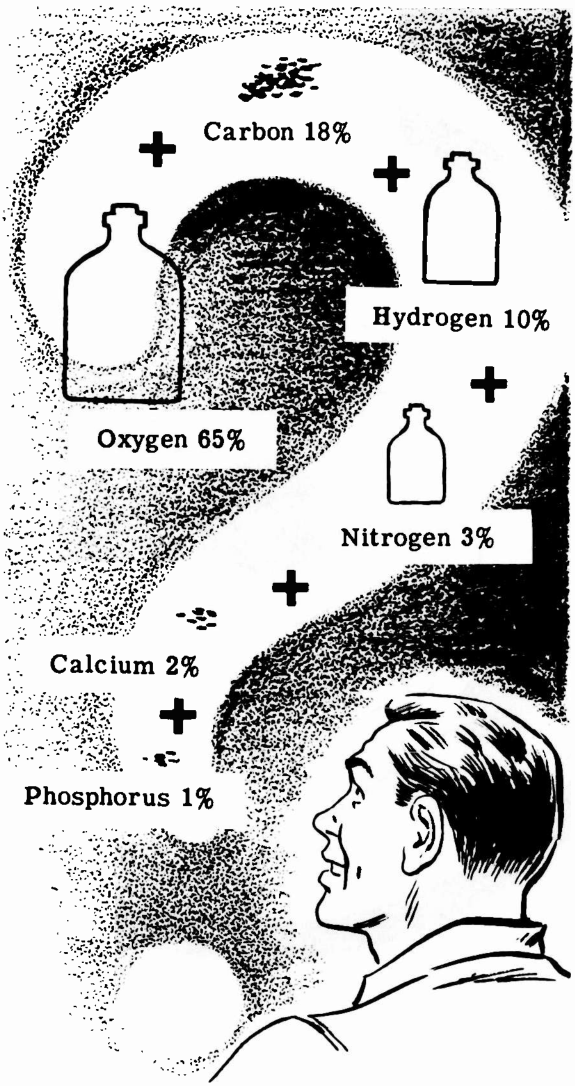
When you increase the magnifying power of the microscope, you will see that the water molecule is made up of two tiny structures that are the same and a larger structure that is different from the two. These tiny structures are called "atoms." The two tiny atoms which are the same are hydrogen atoms and the larger different one is an oxygen atom. When two atoms of hydrogen combine with one atom of oxygen, you have a molecule of water.

THE WATER MOLECULE



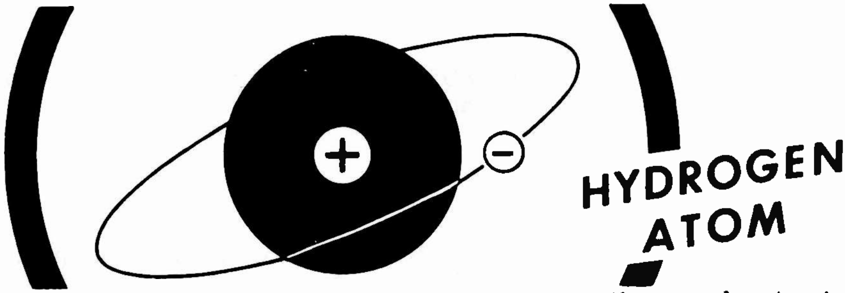
The Structure of the Molecule (continued)

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, consist 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.



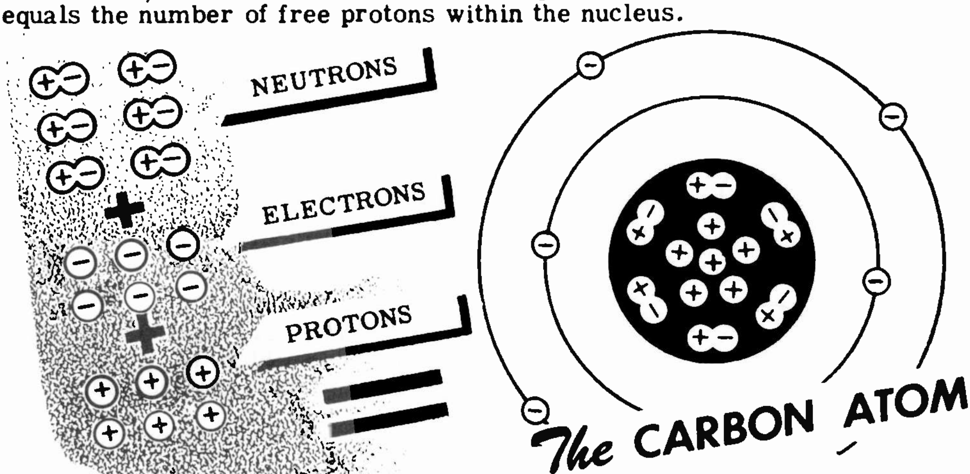
The Breakdown of the Atom

Now that you know that all materials are made up of molecules which consist of various combinations of about only 100 different types of atoms, you will want to know what all this has to do with electricity. Increase the magnification of your imaginery super microscope still further and examine one of the atoms you find in the water molecule. Pick out the smallest atom you can see—the hydrogen atom—and examine it closely.



You see that the hydrogen atom is like a sun with one planet spinning around it. The planet is known as an "electron" and the sun is known as the "nucleus." The electron has a negative charge of electricity and the nucleus has a positive charge of electricity.

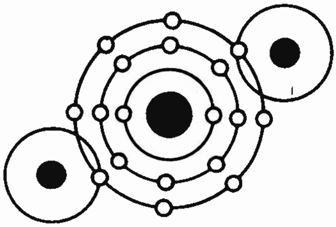
In an atom, the total number of negatively-charged electrons circling around the nucleus exactly equals the number of extra positive charges in the nucleus. The positive charges are called "protons." Besides the protons, the nucleus also contains electrically neutral particles called "neutrons," which are made up of a proton and an electron bonded together. Atoms of different elements contain different numbers of neutrons within the nucleus, but the number of electrons spinning about the nucleus always equals the number of free protons within the nucleus.



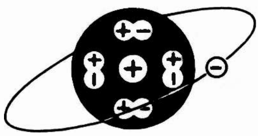
Electrons in the outer orbits of an atom are attracted to the nucleus by less force than electrons whose orbits are near the nucleus. These outer electrons are called "free" electrons and may be easily forced from their orbits, while electrons in the inner orbits are called "bound" electrons since they cannot be forced out of their orbits easily. It is the motion of the free electrons that makes up an electric current.

Review of Electricity—What It Is

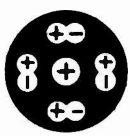
Now let's stop and review what you have found out about electricity and the electron theory. Then you will be ready to study where electricity comes from.



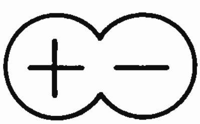
1. MOLECULE—The combination of two or more atoms.



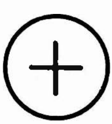
2. ATOM—The smallest physical particle into which an element can be divided.



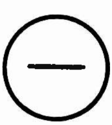
3. NUCLEUS—The heavy positively-charged part of the atom which does not move.



4. NEUTRON—The heavy neutral particle in the nucleus consisting of a proton and an electron.



5. PROTON—The heavy positively-charged particle in the nucleus.



6. ELECTRON—The very small negatively-charged particle which is practically weightless and circles the nucleus.

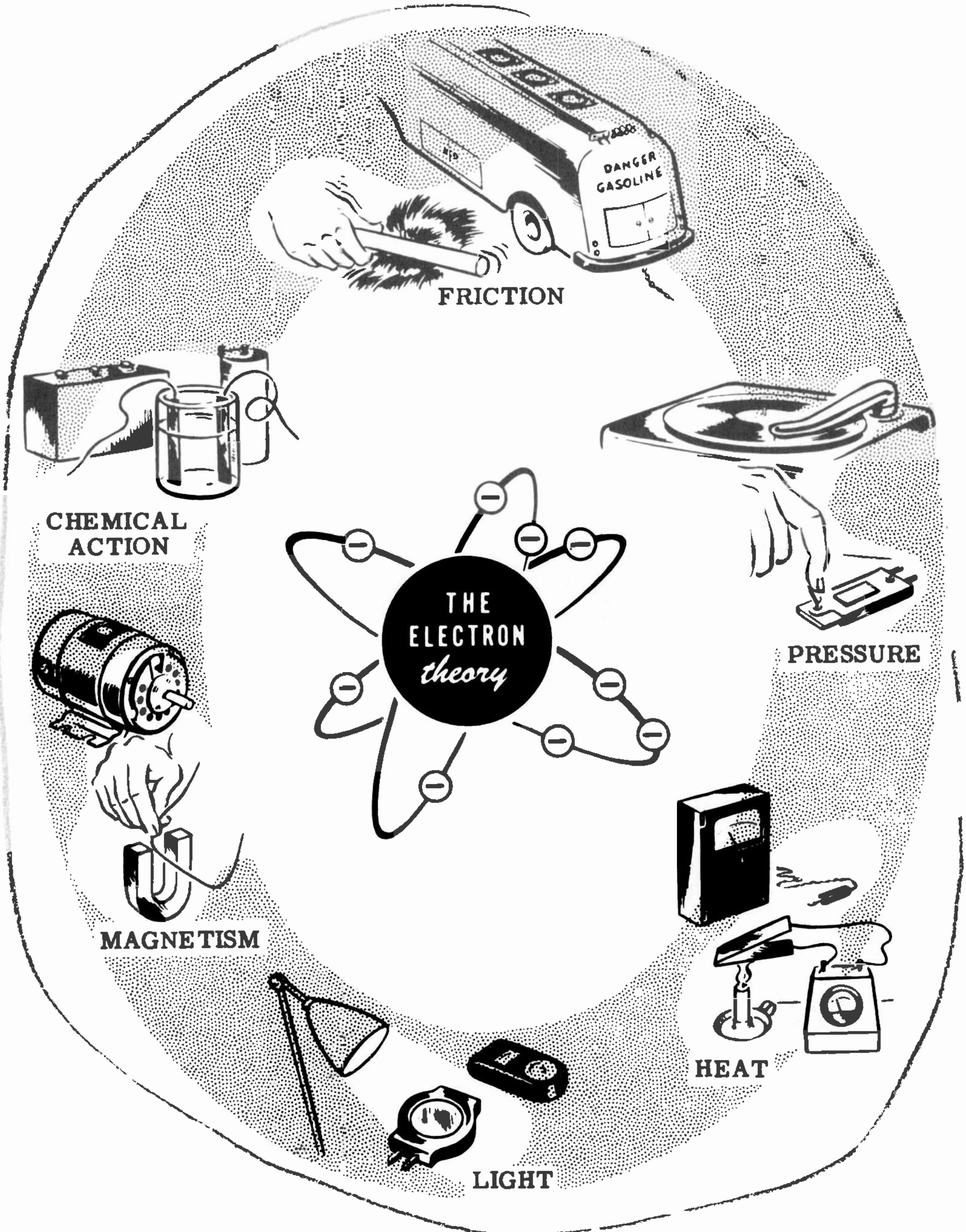
7. BOUND ELECTRONS—Electrons in the inner orbits of an atom, which cannot easily be forced out of their orbits.

8. FREE ELECTRONS—Electrons in the outer orbits of an atom, which can easily be forced out of their orbits.

9. ELECTRICITY—The effect of electrons in moving from point to point, or the effect of too many (excess) or too few (lack of) electrons in a material.

The Six Sources of Electricity

To produce electricity, some form of energy must be used to bring about the action of electrons. The six basic sources of energy which can be used are **FRICTION, PRESSURE, HEAT, LIGHT, MAGNETISM** and **CHEMICAL ACTION.** Before getting into the study of these sources, you will first find out about electric charges.



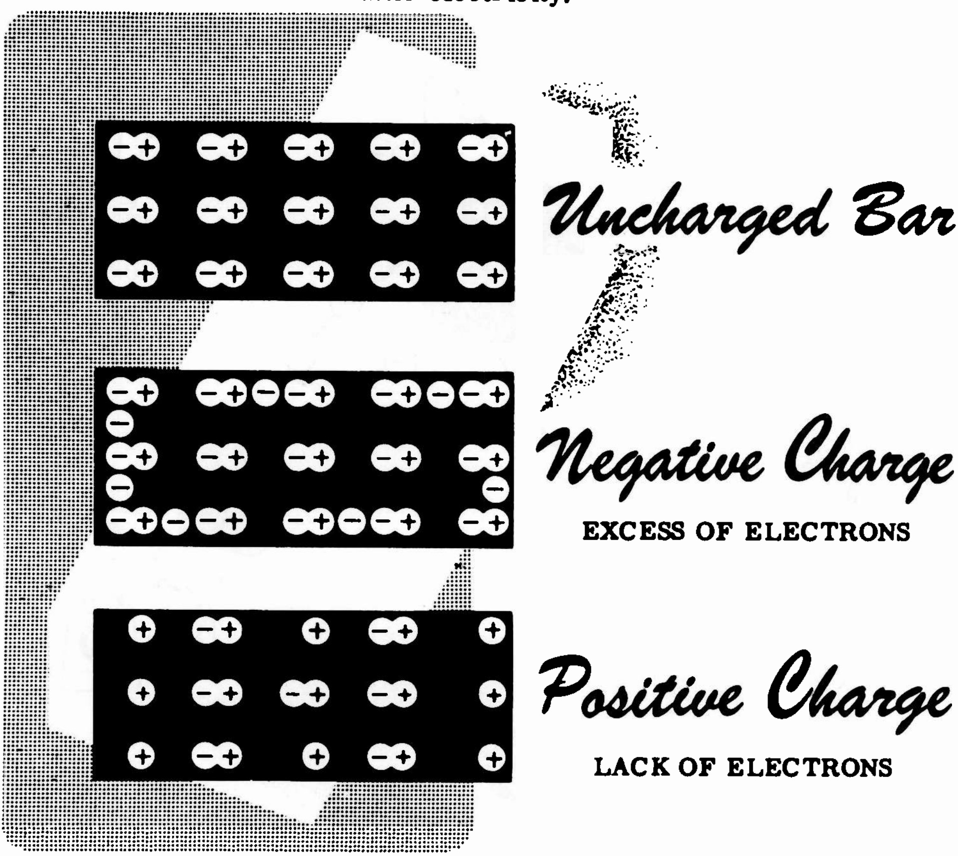
Electric Charges

You found that electrons travel around the nucleus of an atom and are held in their orbits by the attraction of the positive charge in the nucleus. If you could somehow force an electron out of its orbit, then the electron's action would become what is known as electricity.

Electrons which are forced out of their orbits in some way will leave a lack of electrons in the material which they leave and will cause an excess of electrons to exist at the point where they come to rest. This excess of electrons in one material is called a "negative" charge while the lack of electrons in the other material is called a "positive" charge. When these charges exist you have what is called "static" electricity.

To cause either a "positive" or "negative" charge, the electron must be moved while the positive charges in the nucleus do not move. Any material which has a "positive charge" will have its normal number of positive charges in the nucleus but will have electrons missing or lacking. However, a material which is negatively charged actually has an excess of electrons.

You are now ready to find out how friction can produce this excess or lack of electrons to cause static electricity.

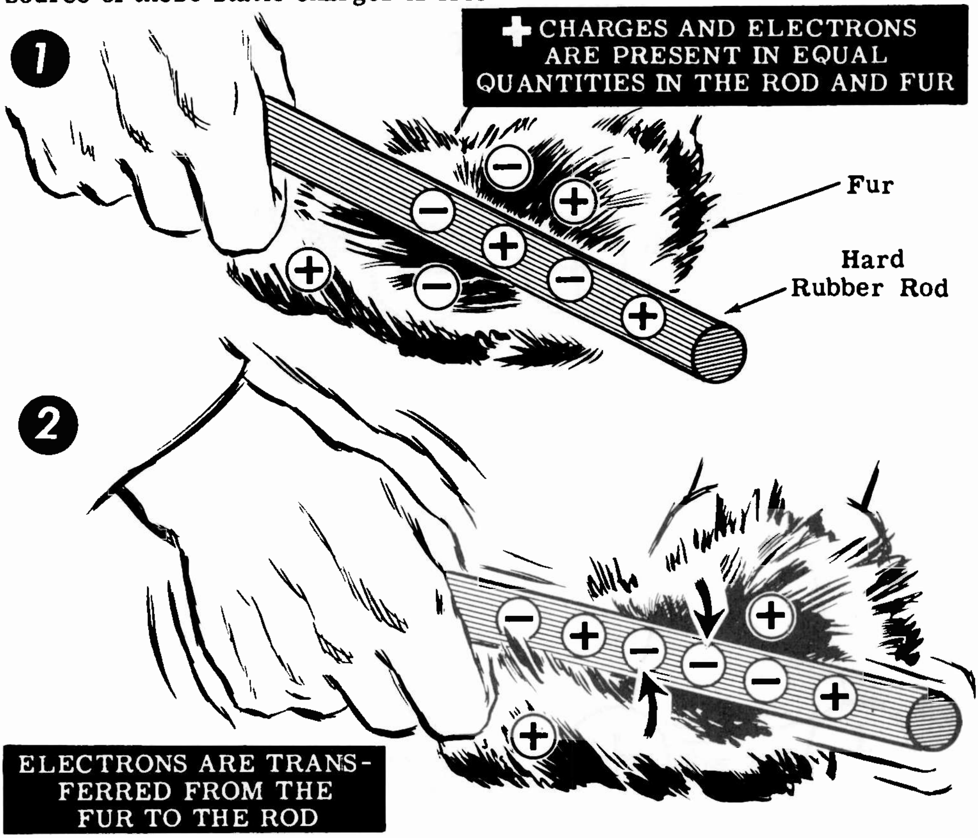


Static Charges from Friction

You have studied the electron and the meaning of positive and negative charges, so that you are now ready to find out how these charges are produced. The main source of static electricity which you will use is friction. If you should rub two different materials together, electrons may be forced out of their orbits in one material and captured in the other. The material which captures electrons would then have a negative charge and the material which loses electrons would have a positive charge.

When two materials rub together, due to friction contact, some electron orbits of the materials cross each other and one material may give up electrons to the other. If this happens, static charges are built up in the two materials, and friction has thus been a source of electricity. The charge which you might cause to exist could be either positive or negative depending on which material gives up electrons more freely.

Some materials which easily build up static electricity are glass, amber, hard rubber, waxes, flannel, silk, rayon and nylon. When hard rubber is rubbed with fur, the fur loses electrons to the rod—the rod becomes negatively charged and the fur positively charged. When glass is rubbed with silk, the glass rod loses electrons—the rod becomes positively charged and the silk negatively charged. You will find out that a static charge may transfer from one material to another without friction, but the original source of these static charges is friction.

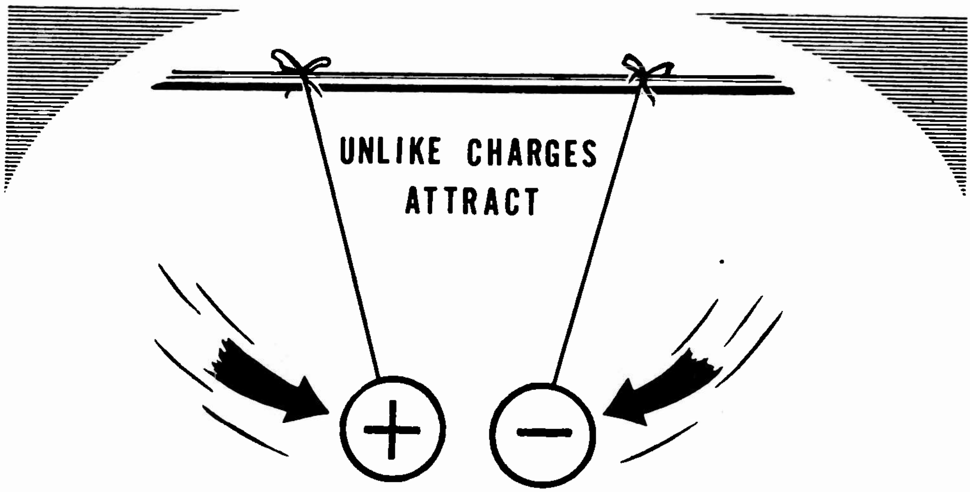


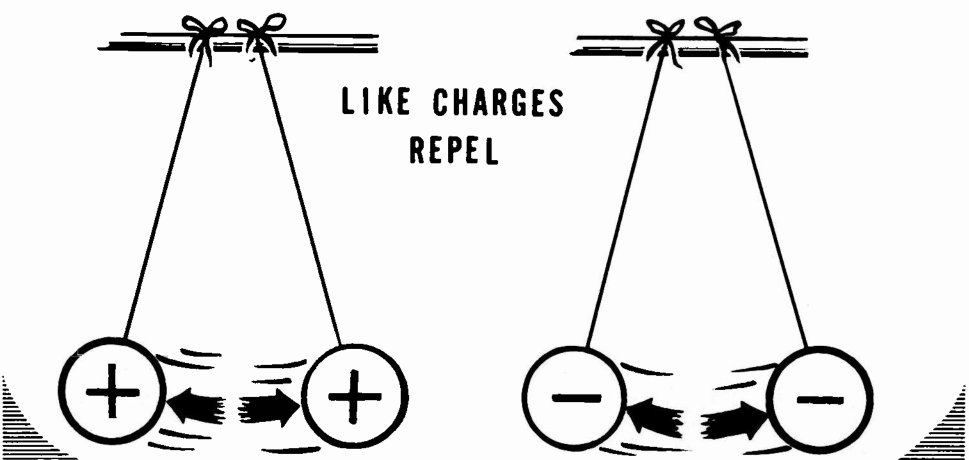
Attraction and Repulsion of Charges

When materials are charged with static electricity they behave in a manner different from normal. For instance, if you place a positively charged ball near one which is charged negatively, the balls will attract each other. If the charges are great enough and the balls are light and free to move, they will come into contact. Whether they are free to move or not, a force of attraction always exists between unlike charges.

This attraction takes place because the excess electrons of a negative charge are trying to find a place where extra electrons are needed. If you bring two materials of opposite charges together, the excess electrons of the negative charge will transfer to the material having a lack of electrons. This transfer or crossing over of electrons from a negative to a positive charge is called "discharge."

Using two balls with the same type of charge, either positive or negative, you would find that they repel each other.



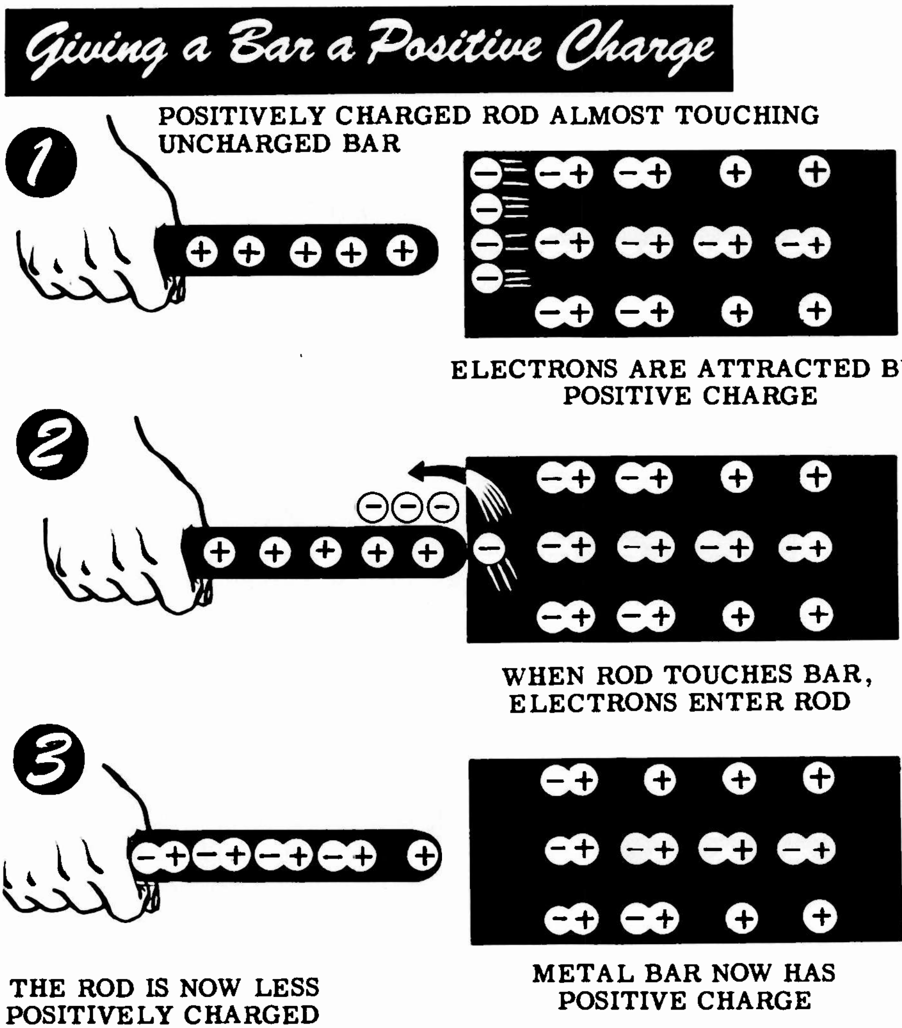


Transfer of Static Charges through Contact

While most static charges are due to friction, you will find that they may also be caused by other means. If an object has a static charge, it will influence all other nearby objects. This influence may be exerted through contact or induction.

Positive charges mean a lack of electrons and always attract electrons, while negative charges mean an excess of electrons and always repel electrons.

If you should touch a positively charged rod to an uncharged metal bar, it will attract electrons in the bar to the point of contact. Some of these electrons will leave the bar and enter the rod, causing the bar to become positively charged and decreasing the positive charge of the rod.

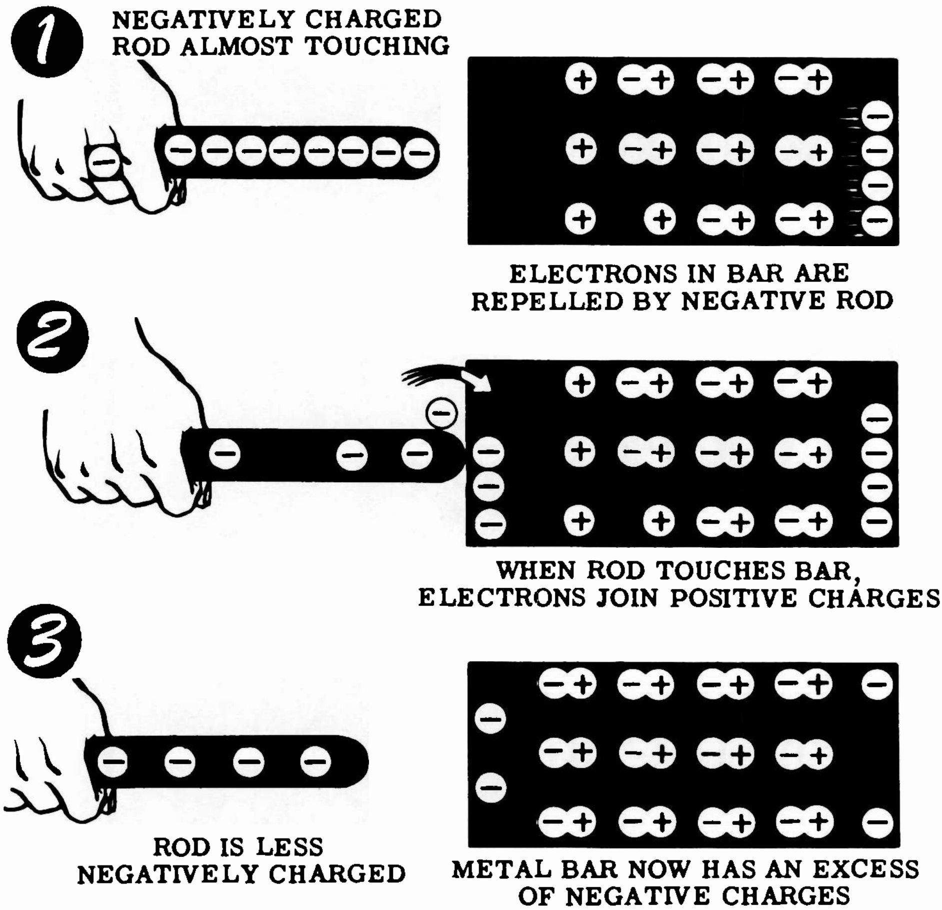


Transfer of Static Charges through Contact (continued)

By touching a negatively charged rod to the uncharged bar, you would cause the bar also to become negatively charged. As the negatively charged rod is brought near the uncharged bar, electrons in that portion of the bar nearest the rod would be repelled toward the side opposite the rod. The portion of the bar near the rod will then be charged positively and the opposite side will be charged negatively. As the rod is touched to the bar, some of the excess electrons in the negatively charged rod will flow into the bar to neutralize the positive charge in that portion of the bar but the opposite side of the bar retains its negative charge.

When the rod is lifted away from the bar, the negative charge remains in the bar and the rod is still negatively charged but has very few excess electrons. When a charged object touches an uncharged object, it loses some of its charge to the uncharged object until each has the same amount of charge.

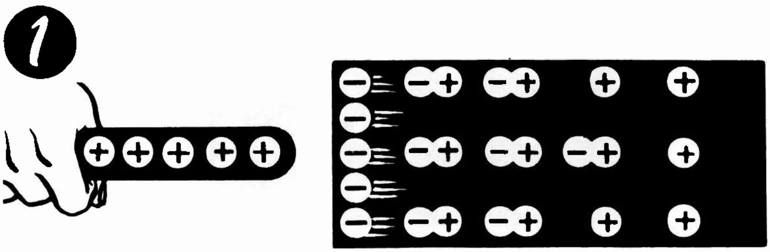
Giving a Bar a Negative Charge



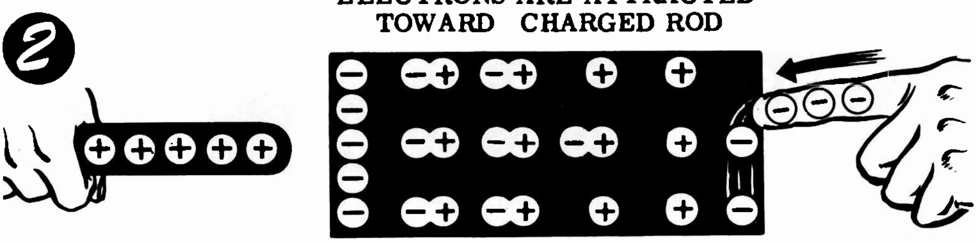
Transfer of Static Charges through Induction

You have seen what happens when you touch a metal bar with a positively charged rod. Some of the charge on the rod is transferred and the bar becomes charged. Suppose that instead of touching the bar with the rod, you only bring the positively charged rod near to the bar. In that case, electrons in the bar would be attracted to the point nearest the rod, causing a negative charge at that point. The opposite side of the bar would again lack electrons and be charged positive. Three charges would then exist, the positive charge in the rod, the negative charge in the bar at the point nearest the rod and a positive charge in the bar on the side opposite the rod. By allowing electrons from an outside source (your finger, for instance) to enter the positive end of the bar, you can give the bar a negative charge.

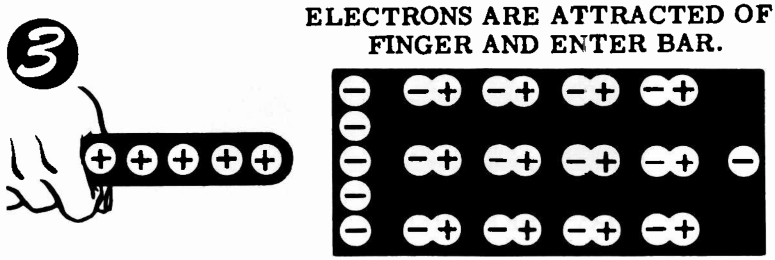
Giving a Bar a Negative Charge



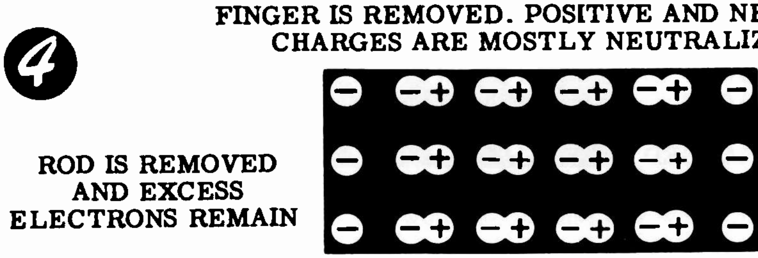
ELECTRONS ARE ATTRACTED TOWARD CHARGED ROD



ELECTRONS ARE ATTRACTED OFF FINGER AND ENTER BAR.



FINGER IS REMOVED. POSITIVE AND NEGATIVE CHARGES ARE MOSTLY NEUTRALIZED.

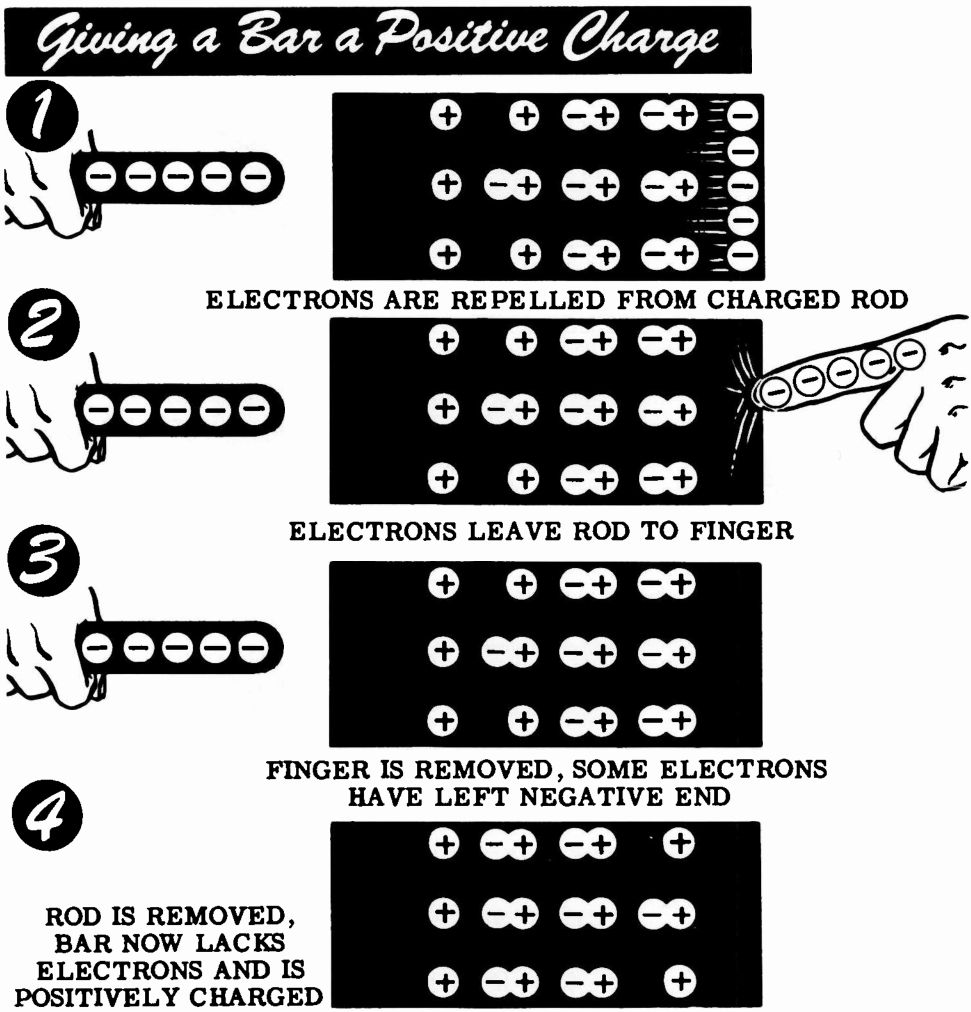


ROD IS REMOVED AND EXCESS ELECTRONS REMAIN

Transfer of Static Charges through Induction (continued)

If the rod is negatively charged when brought near to the bar, it will induce a positive charge into that end of the bar which is near the rod. Electrons in that portion of the rod will be repelled and will move to the opposite end of the bar. The original negative charge of the rod then causes two additional charges, one positive and one negative, in the bar.

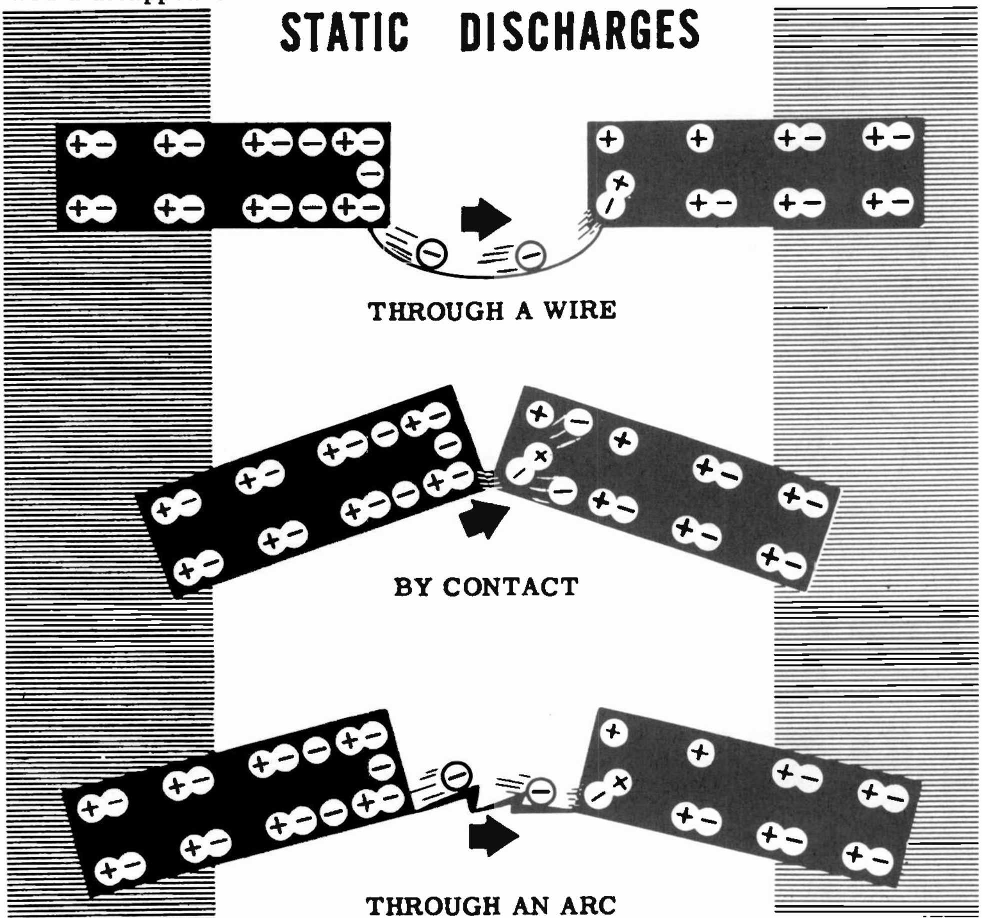
Removing the rod will leave the bar uncharged since the excess electrons in the negatively charged end will flow back to neutralize the bar. However, if before the rod is moved a path is provided for the electrons in the negatively charged portion of the bar to flow out of the bar, the entire bar will be positively charged when the rod is removed.



You have discovered that static charges can be caused by friction and contact, or induction. Now you should see how the excess or lack of electrons in the charged body may be neutralized, or discharged.

Discharge of Static Charges

Whenever two materials are charged with opposite charges and placed near one another, the excess electrons on the negatively charged material will be pulled toward the positively charged material. By connecting a wire from one material tc the other, you would provide a path for the electrons of the negative charge to cross over to the positive charge, and the charges would thereby neutralize. Instead of connecting the materials with a wire, you might touch them together (contact) and again the charges would disappear.



If you use materials with strong charges, the electrons may jump from the negative charge to the positive charge before the two materials are actually in contact. In that case, you would actually see the discharge in the form of an arc. With very strong charges, static electricity can discharge across large gaps, causing arcs many feet in length.

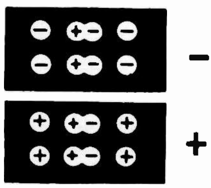
Lightning is an example of the discharge of static electricity resulting from the accumulation of a static charge in a cloud as it moves through the air. Natural static charges are built up wherever friction occurs between the air molecules, such as with moving clouds or high winds, and you will find that these charges are greatest in a very dry climate, or elsewhere when the humidity is low.

HOW FRICTION PRODUCES ELECTRICITY

Review of Friction and Static Electric Charges

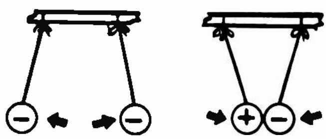
You have now found out about friction as a source of electricity, and you have seen and participated in a demonstration of how static electric charges are produced and their effect on charged and uncharged materials. You have also seen how static charges can be transferred by contact or induction, and you have learned about some of the useful applications of static electricity.

Before going on to learn about the other basic sources of electricity, you should review those facts which you have already learned.



1. NEGATIVE CHARGE — An excess of electrons.

2. POSITIVE CHARGE — A lack of electrons.

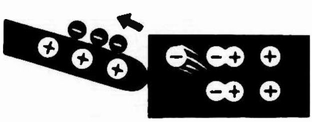


3. REPULSION OF CHARGES — Like charges repel each other.

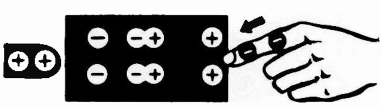
4. ATTRACTION OF CHARGES — Unlike charges attract each other.

5. STATIC ELECTRICITY — Electric charges at rest.

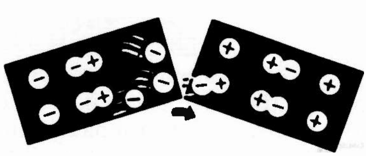
6. FRICTION CHARGE — A charge caused by rubbing one material against another.



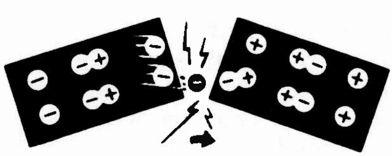
7. CONTACT CHARGE — Transfer of a charge from one material to another by direct contact.



8. INDUCTION CHARGE — Transfer of a charge from one material to another without actual contact.



9. CONTACT DISCHARGE — Electrons crossing over from a negative charge to positive through contact.



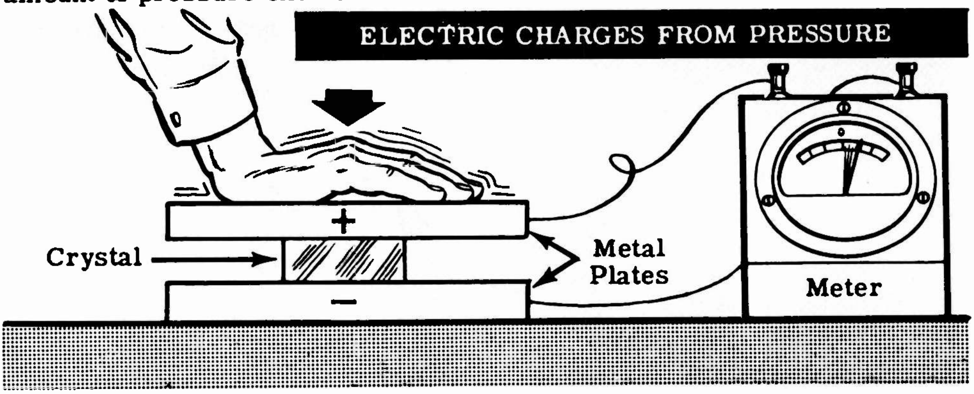
10. ARC DISCHARGE — Electrons crossing over from a negative charge to positive through an arc.

When you have completed your review of friction and static electric charges, you will go on to learn about pressure as a source of electricity.

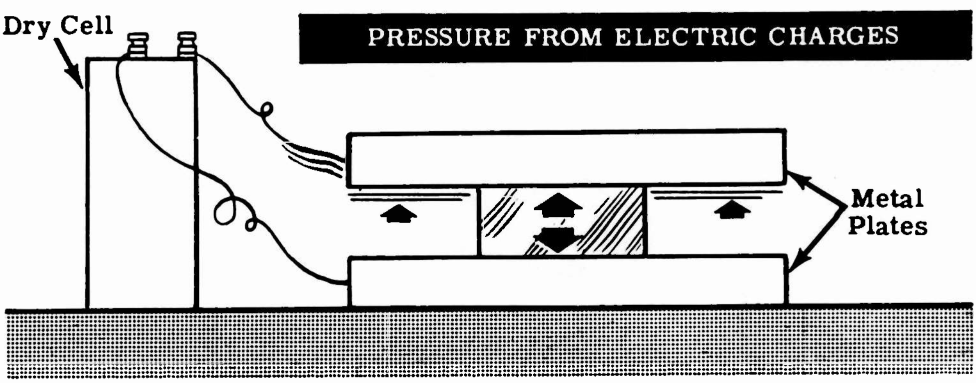
Electric Charges from Pressure

Whenever you speak into a telephone, or other type of microphone, the pressure waves of the sound energy move a diaphragm. In some cases, the diaphragm moves a coil of wire past a magnet, generating electrical energy which is transmitted through wires to a receiver. Microphones used with public address systems and radio transmitters sometimes operate on this principle. Other microphones, however, convert the pressure waves of sound directly into electricity.

Crystals of certain materials will develop electrical charges if a pressure is exerted on them. Quartz, tourmaline, and Rochelle salts are materials which illustrate the principle of pressure as a source of electricity. If a crystal made of these materials is placed between two metal plates and a pressure is exerted on the plates, an electric charge will be developed. The size of the charge produced between the plates will depend on the amount of pressure exerted.



The crystal can be used to convert electrical energy to mechanical energy by placing a charge on the plates, since the crystal will expand or contract depending on the amount and type of the charge.

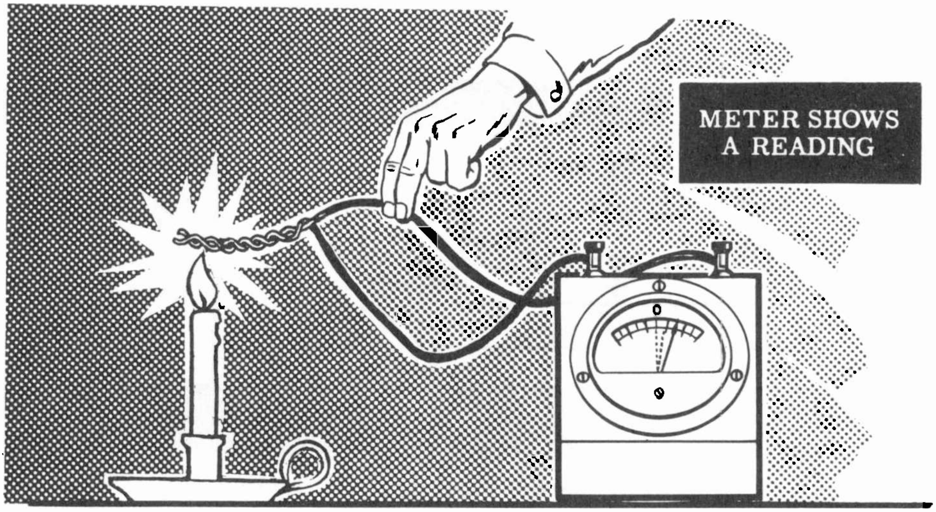


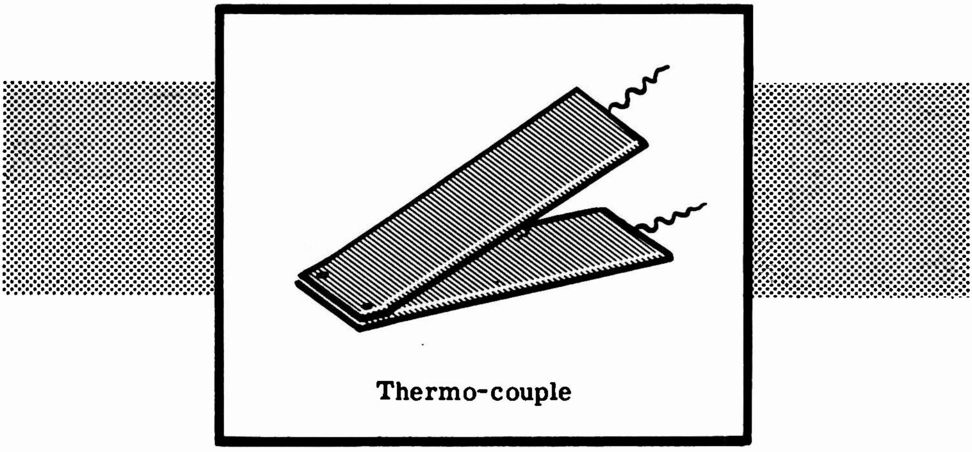
While the actual use of pressure as a source of electricity is limited to very low power applications, you will find it in many different kinds of equipment. Crystal microphones, crystal headphones, phonograph pickups and sonar equipment use crystals to generate electric charges from pressure.

Electric Charges from Heat

Another method of obtaining electricity is to convert heat into electricity directly, by heating a junction of two dissimilar metals. For example, if an iron wire and a copper wire are twisted together to form a junction, and the junction is heated, an electric charge will result. The amount of charge produced depends on the difference in temperature between the junction and the opposite ends of the two wires. A greater temperature difference results in a greater charge.

A junction of this type is called a thermo-couple and will produce electricity as long as heat is applied. While twisted wires may form a thermo-couple, more efficient thermo-couples are constructed of two pieces of dissimilar metal riveted or welded together.





Thermo-couple

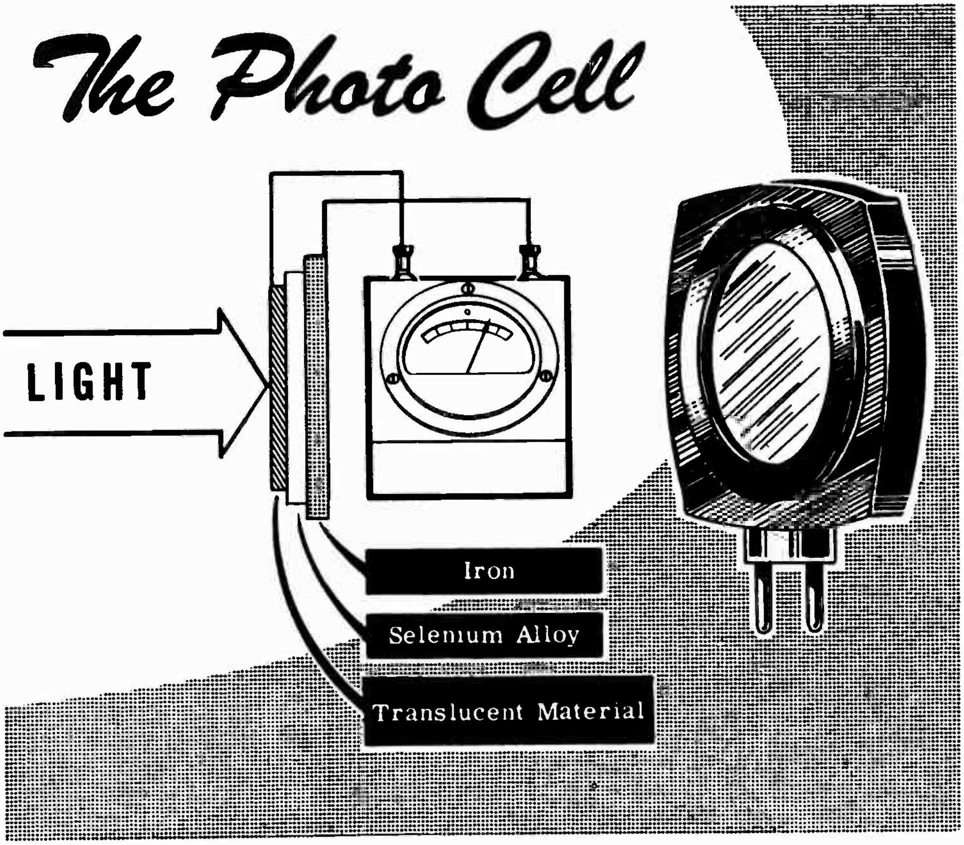
Thermo-couples do not furnish a large amount of charge and cannot be used to obtain electric power. They are normally used in connection with heat indicating devices to operate a meter directly marked in degrees of temperature.

Electric Charges from Light—Photovoltaic Effects

Electricity may be produced by using light as the source of energy converted to electricity. When light strikes certain materials, they may conduct electric charges easier, develop an electric charge, emit free electrons or convert light to heat.

The most useful of these effects is the development of an electric charge by a photo cell when light strikes the photo-sensitive material in the cell.

A photo cell is a metallic "sandwich" or disc composed of three layers of material. One outside layer is made of iron. The other outside layer is a film of translucent or semitransparent material which permits light to pass through. The center layer of material is composed of selenium alloy. The two outside layers act like electrodes. When light is focused on the selenium alloy through the translucent material an electric charge is developed between the two outside layers. If a meter is attached across these layers the amount of charge can be measured. A direct use of this type of cell is the common light meter as used in photography for determining the amount of light which is present.



Electric Charges from Light—Photo Electric Cell or Phototube

The photo electric cell, commonly called an "electric eye" or a "PE Cell," operates on the principle of the photo cell. The photo electric cell, however, depends upon a battery or some other source of electrical pressure in its operation of detecting changes in light. The photo cell has many uses, some of which are automatic headlight dimmers on automobiles, motion picture machines, automatic door openers and drinking fountains.

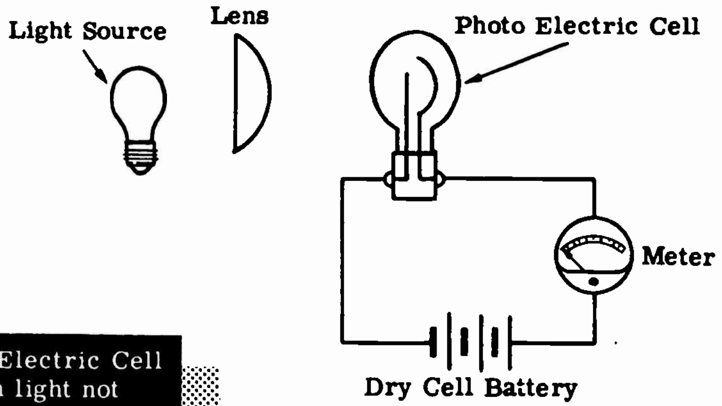


Photo Electric Cell with light not burning

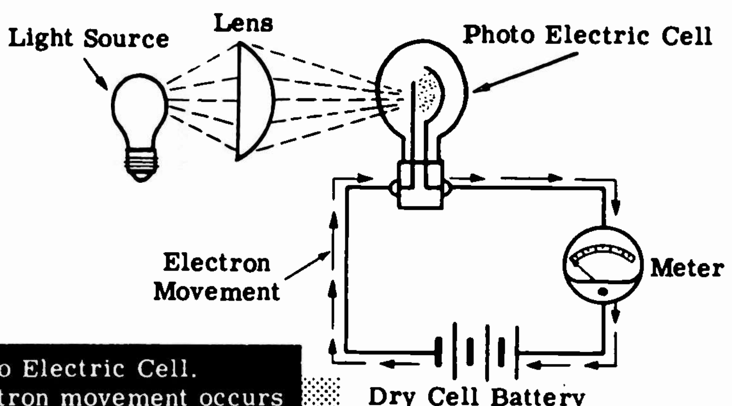


Photo Electric Cell. Electron movement occurs as light strikes the light sensitive material.

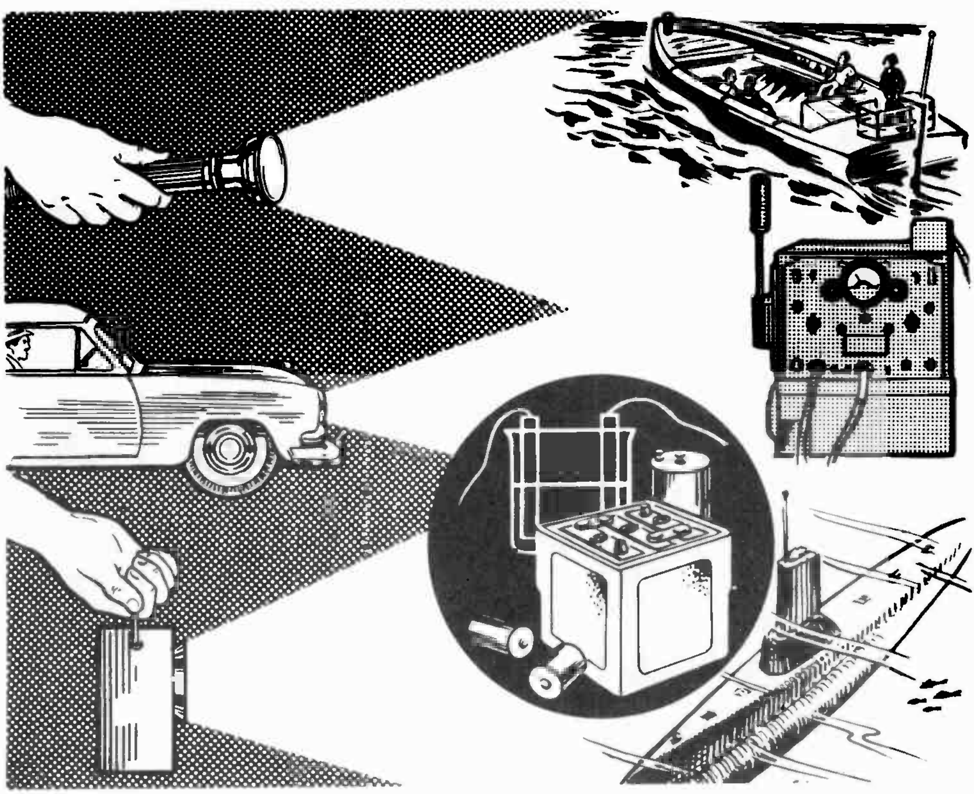
Electricity from Chemical Action

So far, you have discovered what electricity is and several sources of energy which may be used to produce it. Another source of electricity commonly used is the chemical action housed in electric cells and batteries.

Batteries are usually used for emergency and portable electric power. Whenever you use a flashlight emergency lantern or portable equipment, you will be using batteries. Batteries are the main source of power for present-day submarines. In addition, there is a wide variety of equipment which uses cells or batteries either as normal or emergency power. "Dead" batteries are a common type of equipment failure and such failures can be very serious.

Cells and batteries require more care and maintenance than most of the equipment on which you will work. Even though you may use only a few cells or batteries, if you find out how they work, where they are used and how to properly care for them, you will save time and in many cases a lot of hard work.

Now you will find out how chemical action produces electricity and the proper use and care of the cells and batteries that house this chemical action.



A Primary Cell—What It Is

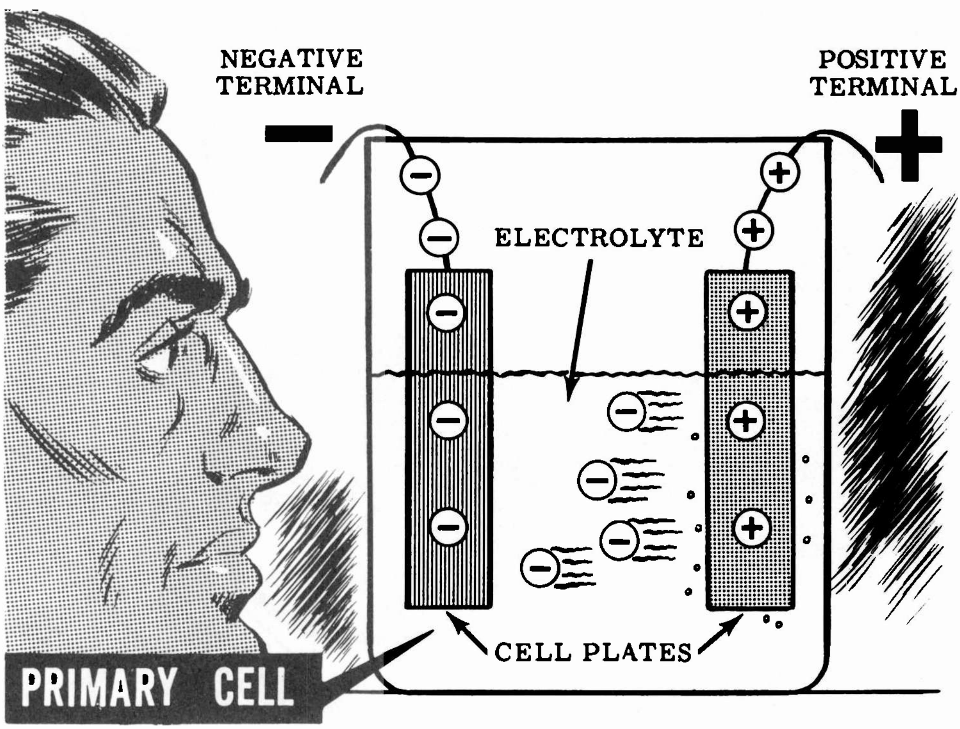
To find out how the chemical action in batteries works, you might imagine that you can see electrons and what happens to them in a primary electric cell. The basic source of electricity produced by chemical action is the electric cell and, when two or more cells are combined, they form a battery.

Now if you could see the inner workings of one of these cells, what do you suppose you would see?

First you would notice the parts of the cell and their relation to each other. You would see a case or container in which two plates of different metals, separated from each other, are immersed in the liquid which fills the container.

Watching the parts of the cell and the electrons in the cell you would see that the liquid which is called the electrolyte is pushing electrons onto one of the plates and taking them off the other plate. This action results in an excess of electrons or a negative charge on one of the plates so that a wire attached to that plate is called the negative terminal. The other plate loses electrons and becomes positively charged so that a wire attached to it is called the positive terminal.

The action of the electrolyte in carrying electrons from one plate to the other is actually a chemical reaction between the electrolyte and the two plates. This action changes chemical energy into electrical charges on the cell plates and terminals.



HOW CHEMICAL ACTION PRODUCES ELECTRICITY—PRIMARY CELLS

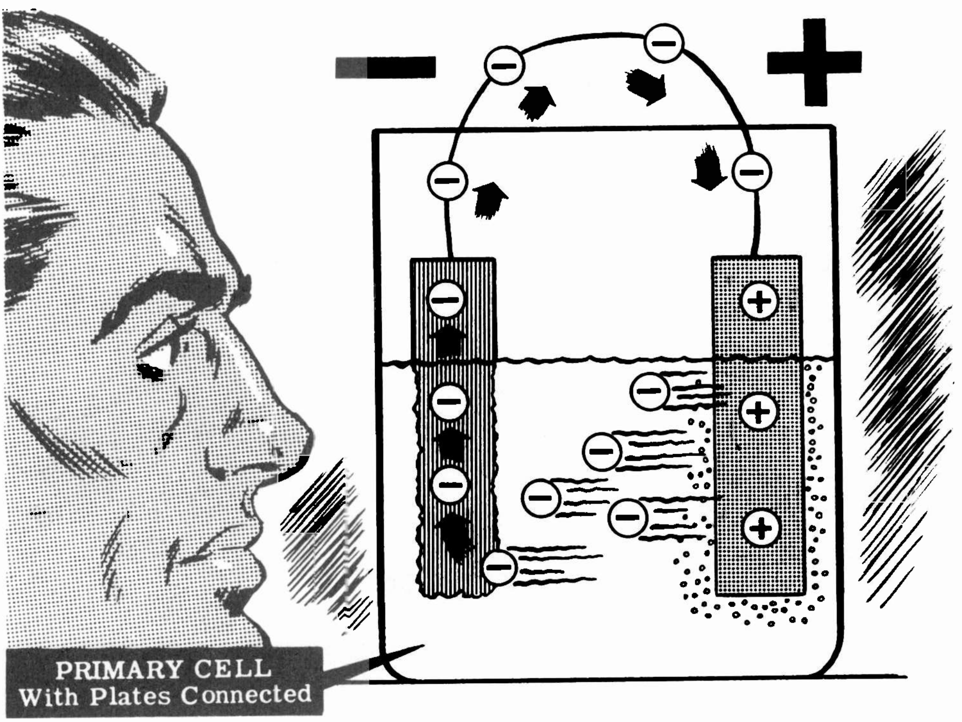
Chemical Action in a Primary Cell

With nothing connected to the cell terminals, you would see that electrons are pushed onto the negative plate until there is room for no more. The electrolyte would take from the positive plate enough electrons to make up for those it pushed onto the negative plate. Both plates would then be fully charged and no electrons would be moving between the plates.

Now suppose you connected a wire between the negative and positive terminals of the cell. You would see the electrons on the negative terminal leave the terminal and travel through the wire to the positive terminal. Since there would now be more room on the negative terminal, the electrolyte would carry more electrons across from the positive plate to the negative plate. As long as electrons leave the negative terminal and travel to the positive terminal outside the cell, the electrolyte will carry electrons from the positive plate to the negative plate inside the cell.

While the electrolyte is carrying electrons, you would see that the negative plate is being used up and you would notice bubbles of gas at the positive terminal. Eventually the negative plate would be completely dissolved in the electrolyte by the chemical action, and the cell would be "dead," or unable to furnish a charge, until the negative plate is replaced. For that reason, this type of cell is called a primary cell—meaning that once it has completely discharged, it cannot be charged again except by using new materials.

For plates in a primary cell, carbon and most metals can be used, while acids or salt compounds can be used for the electrolyte. Dry cells such as those used in flashlights and lanterns are primary cells.

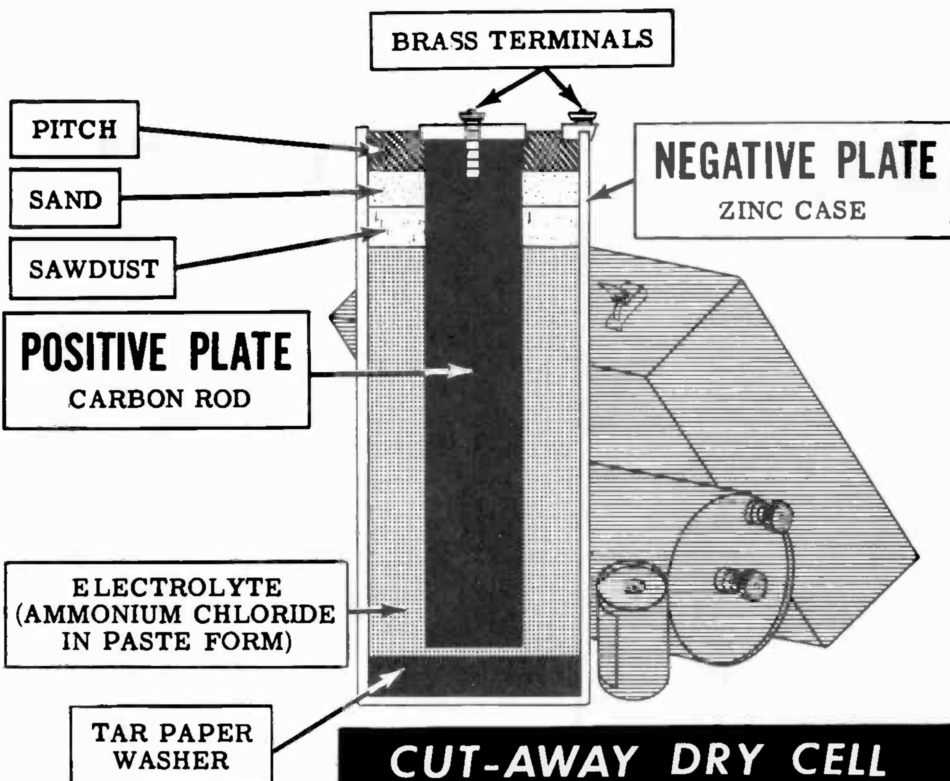


Dry Cells and Batteries

Almost any metals, acids and salts can be used in primary cells. There are many types of primary cells used in laboratories and for special applications, but the one which you have used and will be using most often is the dry cell. You will use the dry cell in many different sizes, shapes and weights—from the cell used in a pencil-size flashlight to the extra large dry cell used in emergency lanterns. Regardless of size, you will find that the material used and the operation of all dry cells is the same.

If you were to look inside a dry cell, you would find that it consists of a zinc case used as the negative plate, a carbon rod suspended in the center of the case for the positive plate, and a solution of ammonium chloride in paste form for the electrolyte. At the bottom of the zinc case you would see a tar paper washer used to keep the carbon rod from touching the zinc case. At the top, the casing would contain layers of sawdust, sand and pitch. These layers hold the carbon rod in position and prevent electrolyte leakage.

When a dry cell supplies electricity, the zinc case and the electrolyte are gradually used up. After the usable zinc and electrolyte are gone, the cell cannot supply a charge and must be replaced. Cells of this type are sealed and can be stored for a limited time without causing damage. When several such cells are connected together, they are called a dry battery. You cannot use dry cells to furnish large amounts of power so you will find them only where infrequent and emergency use is intended.



CUT-AWAY DRY CELL

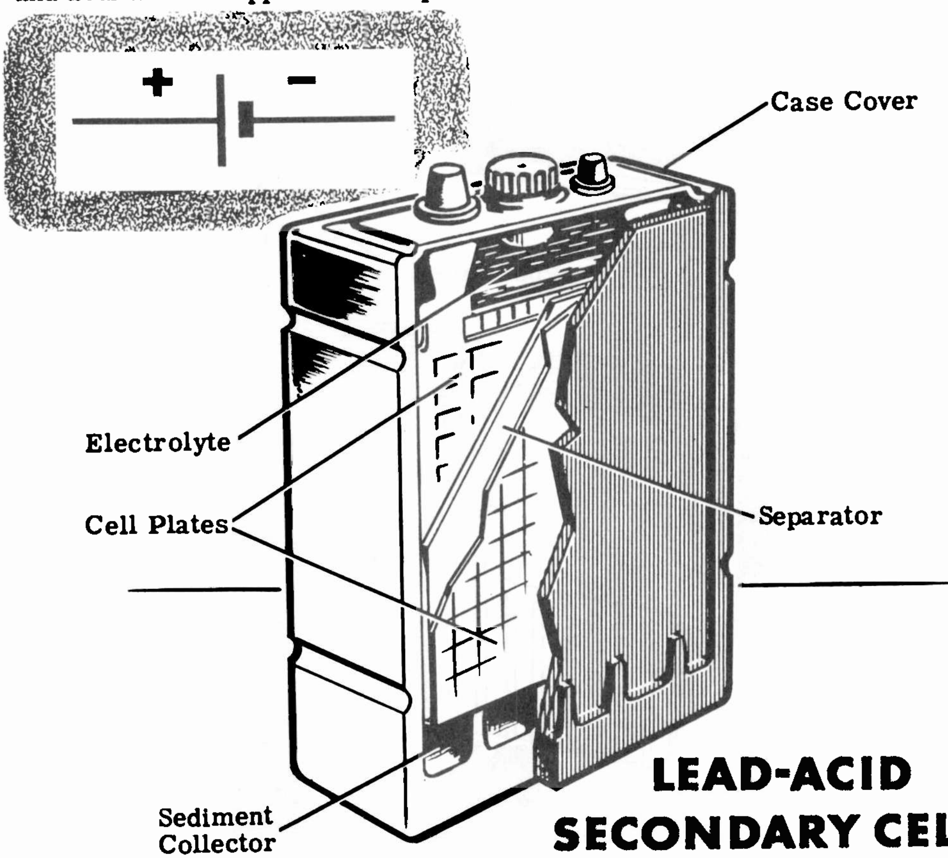
A Secondary Cell—What It Is

In studying primary cells, you learned that chemical action is commonly used as a source of electric power for emergency or portable equipment. However, it will furnish only a small amount of power and cannot be recharged.

A storage battery of secondary cells can furnish large amounts of power for a short time and can be recharged. Batteries of this type require more maintenance and care than dry cell batteries but are used widely in equipment where large amounts of electricity are needed for short periods of time.

Secondary cells used in storage batteries are of the lead-acid type. In this cell the electrolyte is sulphuric acid while the positive plate is lead peroxide and the negative plate is lead. During discharge of the cell, the acid becomes weaker and both plates change chemically to lead sulfate.

The case of a lead-acid cell is made of hard rubber or glass, which prevents corrosion and acid leaks. A space at the bottom of the cell collects the sediment formed as the cell is used. The top of the case is removable and acts as the support for the plates.



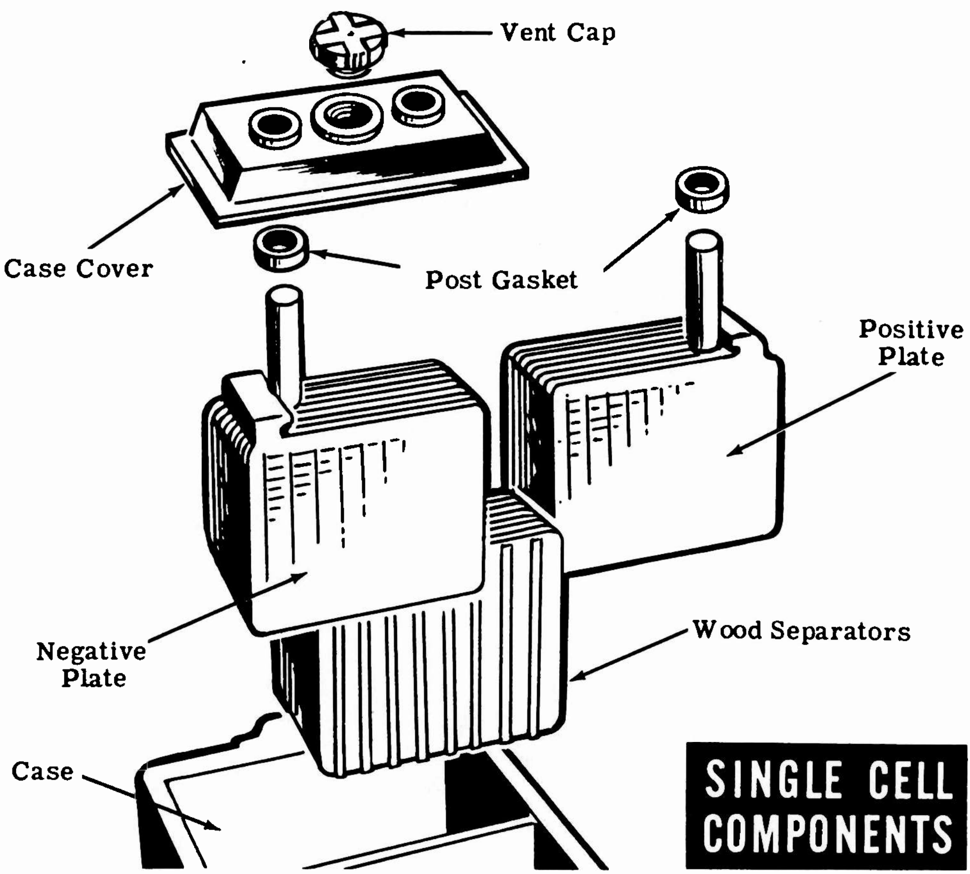
LEAD-ACID SECONDARY CELL

A Secondary Cell—What It Is (continued)

Since the active materials are not rigid enough to be mounted independently, a special grid structure of inactive metal is used to hold them. For maximum chemical action, a large plate area is desired, so each positive plate is interlaced between two negative plates. In a typical cell, you might find seven positive plates attached to a common support interlaced with eight negative plates attached to a different support. Separators, made of wood or porous glass, hold each positive and negative plate apart but let the electrolyte pass through.

The positive and negative plates are fastened to the case cover which is held in place by a special acid-resistant tar. An opening in the cover allows water to be added to the electrolyte to replace water which evaporates. The cap for this opening has a vent to allow gas to escape since the cell in operation forms gas at the positive plate.

Since these cells furnish large amounts of electricity, they require larger terminals and leads. Connections and terminals are made of lead bars since other metals would corrode rapidly due to the acid electrolyte.



SINGLE CELL COMPONENTS

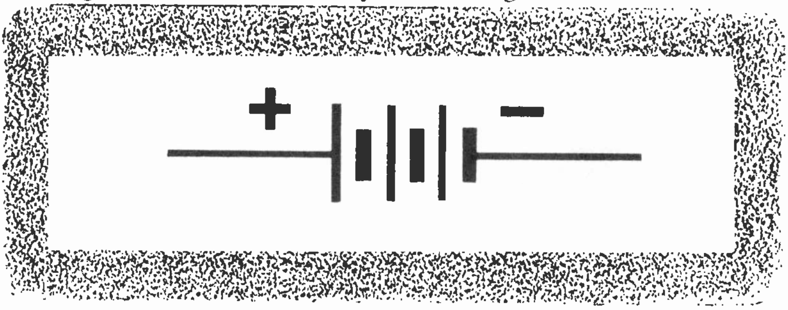
HOW CHEMICAL ACTION PRODUCES ELECTRICITY —SECONDARY CELLS

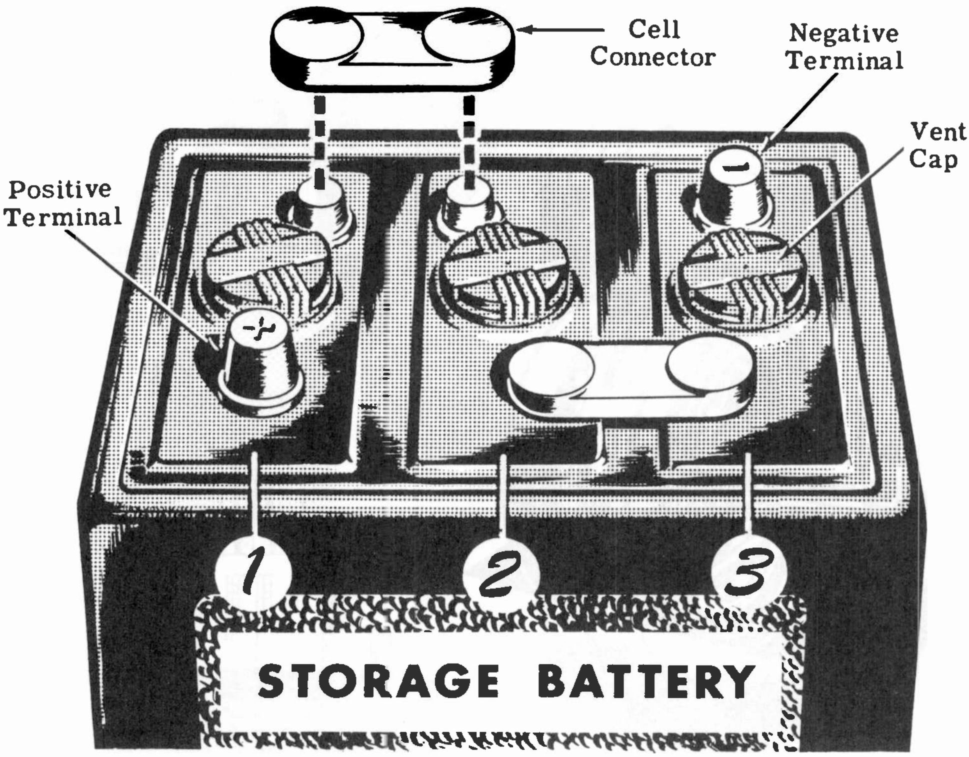
Storage Batteries

When two or more secondary cells are connected together, they form a storage battery. This battery stores electricity and can be recharged after discharge.

Most storage batteries consist of three lead-acid cells in a common case permanently connected in series. Since each lead-acid cell is rated at about two volts, connecting three cells in series produces a battery voltage of six volts.

The symbol for a secondary cell is the same as that used for a primary cell and the storage battery symbol shows three cells connected in series. Storage batteries and secondary cells are not connected in parallel since a weaker cell would cause a stronger cell to discharge, thus lowering battery strength without the battery even being used.



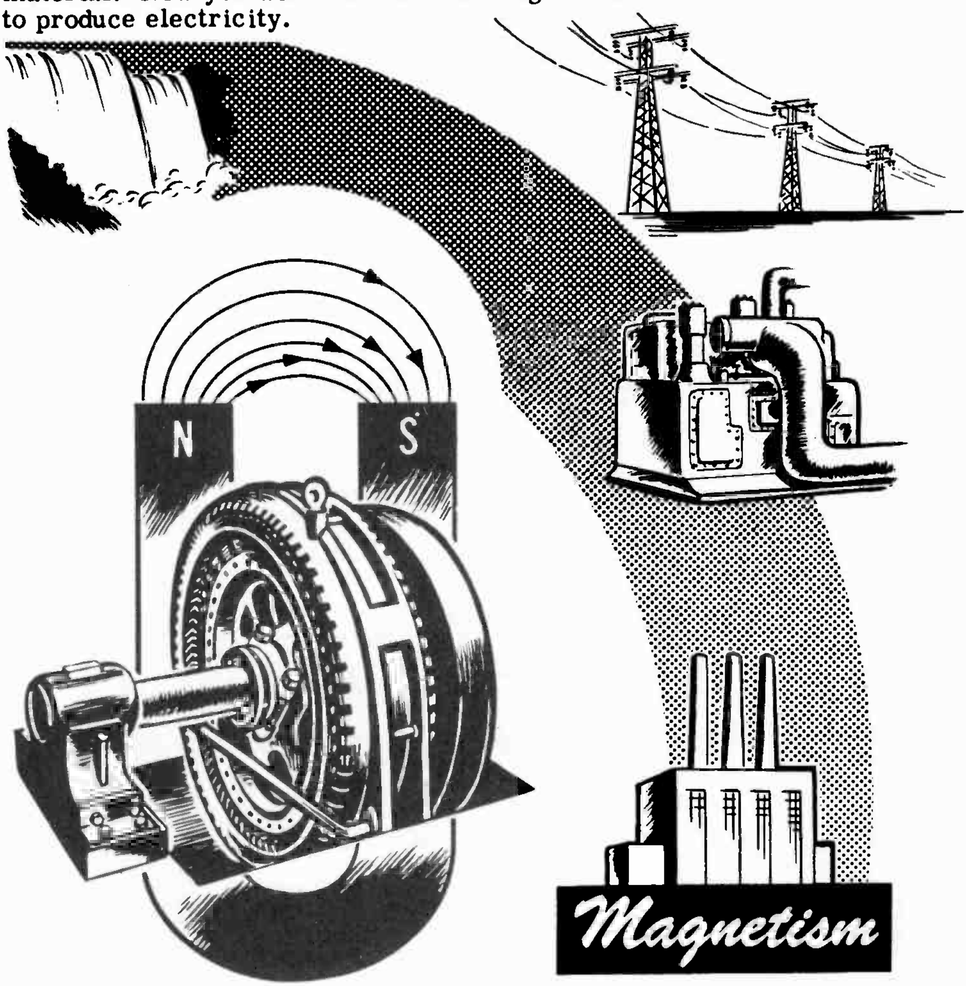


Electric Power from Magnetism

The most common method of producing electricity used for electric power is by the use of magnetism. The source of electricity must be able to maintain a large charge because the charge is being used to furnish electric power. While friction, pressure, heat and light are sources of electricity, you have found that their use is limited to special applications since they are not capable of maintaining a large enough charge for electric power.

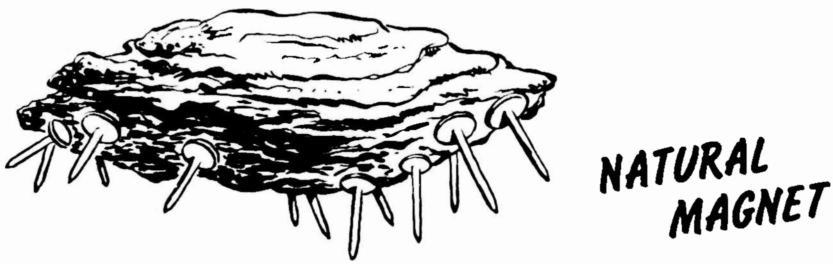
All of the electric power used, except for emergency and portable equipment, originally comes from a generator in a power plant. The generator may be driven by water power, a steam turbine or an internal combustion engine. No matter how the generator is driven, the electric power it produces is the result of the action between the wires and the magnets inside the generator.

When wires move past a magnet or a magnet moves past wires, electricity is produced in the wires because of the magnetism in the magnetic material. Now you will find out what magnetism is and how it can be used to produce electricity.



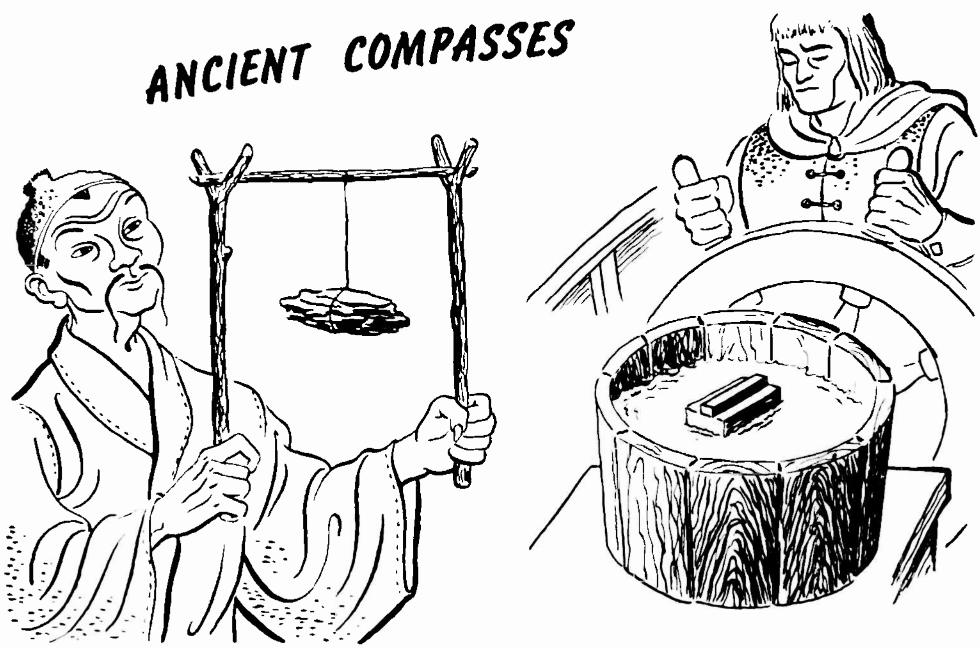
Magnetism—What It Is

In ancient times, the Greeks discovered that a certain kind of rock, which they originally found near the city of Magnesia in Asia Minor, had the power to attract and pick up bits of iron. The rock which they discovered was actually a type of iron ore called "magnetite," and its power of attraction is called "magnetism." Rocks containing ore which has this power of attraction, are called natural magnets.



Natural magnets were little used until it was discovered that a magnet mounted so that it could turn freely would always turn so that one side would point to the north. Bits of magnetite suspended on a string were called "lodestones," meaning a leading stone, and were used as crude compasses for desert travel by the Chinese more than 2,000 years ago. Crude mariner's compasses constructed of natural magnets were used by sailors in the early voyages of exploration.

The earth itself is a large natural magnet and the action of a natural magnet in turning toward the north is caused by the magnetism or force of attraction of the earth.



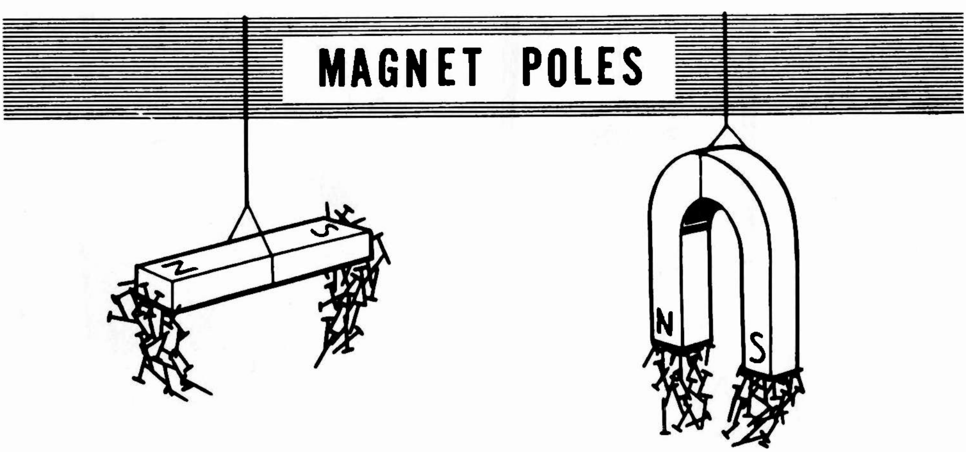
Magnetism—What It Is (continued)

In using natural magnets, it was found that a piece of iron stroked with a natural magnet became magnetized to form an artificial magnet. Artificial magnets may also be made electrically and materials other than iron may be used to form stronger magnets. Steel alloys containing nickel and cobalt make the best magnets and are usually used in strong magnets.

Iron becomes magnetized more easily than other materials but it also loses its magnetism easily so that magnets of soft iron are called temporary magnets. Magnets made of steel alloys hold their magnetism for a long period of time and are called permanent magnets.

Magnetism in a magnet is concentrated at two points, usually at the ends of the magnet. These points are called the "poles" of the magnet—one being called the "north pole," the other the "south pole." The north pole is at the end of the magnet which would point north if the magnet could swing freely, and the south pole is at the opposite end.

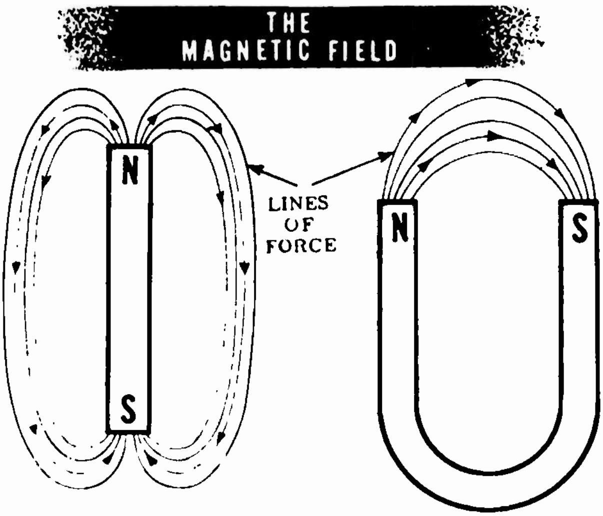
Magnets are made in various shapes, sizes and strengths. Permanent magnets are usually made of a bar of steel alloy, either straight with poles at the ends, or bent in the shape of the familiar horseshoe with poles on opposite sides of the opening.



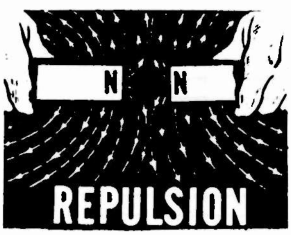
Magnetism—What It Is (continued)

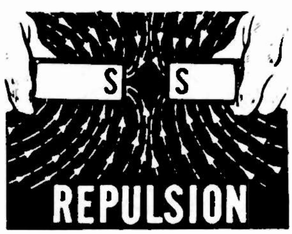
Magnetism is an invisible force and can be seen only in terms of the effect it produces. You know that the wind, for example, provides tremendous force, yet it is invisible. Similarly, magnetic force may be felt but not seen.

The magnetic field about a magnet can best be explained as invisible lines of force leaving the magnet at one point and entering it at another. These invisible lines of force are referred to as "flux lines" and the shape of the area they occupy is called the "flux pattern." The number of flux lines per square inch is called the "flux density." The points at which the flux lines leave or enter the magnet are called the "poles." The magnetic circuit is the path taken by the magnetic lines of force.



If you were to bring two magnets together with the north poles facing each other, you would feel a force of repulsion between the poles. Bringing the south poles together would also result in repulsion but, if a north pole is brought near a south pole, a force of attraction exists. In this respect, magnetic poles are very much like static charges. Like charges or poles repel each other and unlike charges or poles attract.

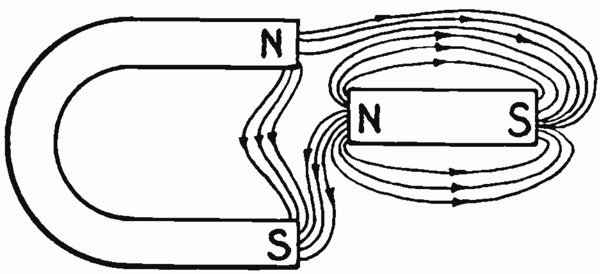




The action of the magnetic poles in attracting and repelling each other is due to the magnetic field around the magnet. As has already been explained, the invisible magnetic field is represented by lines of force which leave a magnet at the north pole and enter it at the south pole. Inside the magnet the lines travel from the south pole to the north pole so that a line of force is continuous and unbroken.

Magnetism—What It Is (continued)

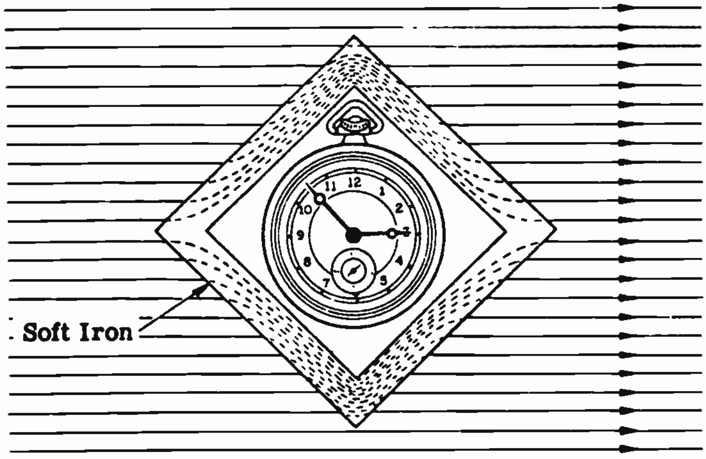
One characteristic of magnetic lines of force is such that they repel each other, never crossing or uniting. If two magnetic fields are placed near each other, as illustrated by the placement of the two magnets, below, the magnetic fields will not combine but will reform in a distorted flux pattern. (Note that the flux lines do not cross each other.)



An Example of Bypassing Flux Lines

There is no known insulator for magnetic lines. It has been found that flux lines will pass through all materials. However, they will go through some materials more easily than others. This fact makes it possible to concentrate flux lines where they are used or to bypass them around an area or instrument.

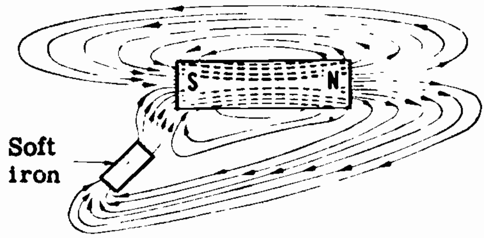
MAGNETIC SCREEN



Magnetism—What It Is (continued)

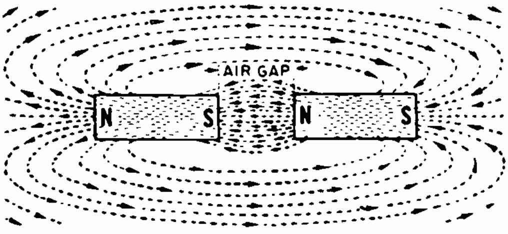
On the previous sheet you were told that magnetic lines of force will go through some materials more easily than through others. Those materials which will not pass flux lines so readily, or which seem to hinder the passage of the lines, are said to have a comparatively high "reluctance" to magnetic fields. Materials which pass, or do not hinder the "flow" of flux lines, are said to have a comparatively low reluctance to magnetic fields of force. Reluctance, with reference to a magnetic circuit, is roughly the equivalent of resistance, when an electric circuit is considered.

Magnetic lines of force take the path of least reluctance; for example, they travel more easily through iron than through the air. Since air has a greater reluctance than iron, the concentration of the magnetic field becomes greater in the iron (as compared to air) because the reluctance is decreased. In other words, the addition of iron to a magnetic circuit concentrates the magnetic field which is in use.



Effect of a soft iron bar in a magnetic field

Magnetic lines of force act like stretched rubber bands. The figure below suggests why this characteristic exists, particularly near the air gap. Note that some lines of force curve outward across the gap in moving from the north pole to the south pole. This outward curve, or stretching effect, is caused by the repulsion of each magnetic line from its neighbor. However, the lines of force tend to resist the stretching effect and therefore resemble rubber bands under tension.

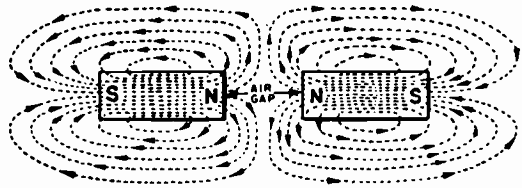


Unlike poles attract

Magnetism—What It Is (continued)

As has already been mentioned, magnetic lines of force tend to repel each other. By tracing the flux pattern of the two magnets with like poles together, in the diagram below, it can be seen why this characteristic exists.

LINES OF FORCE



The reaction between the fields of the two magnets is caused by the fact that lines of force cannot cross each other. The lines, therefore, turn aside and travel in the same direction between the pole faces of the two magnets. Since lines of force which are moving in such a manner tend to push each other apart, the magnets mutually repel each other.

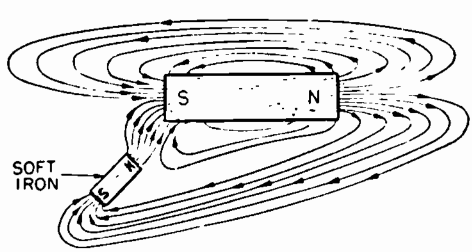
Only a certain number of magnetic lines can be crowded into a piece of material. This varies with each type of material but when the maximum number has been attained the material is said to be saturated. This phenomenon is made use of in many pieces of electrical equipment.

The property of magnetism may be induced, or introduced, in a piece of material which does not ordinarily have that characteristic. If a piece of unmagnetized soft iron is placed in the magnetic field of a permanent magnet the soft iron assumes the properties of a magnet; it becomes magnetized. This action, or process, is called magnetic induction and arises from the fact that magnetic lines of force tend to flow through a material which offers less reluctance than air to their passage.

When the lines of the magnetic field pass through the soft iron bar (see the diagram below), the molecules of the soft iron line up parallel with the lines of force, and with their north poles pointing in the direction that the lines of force are traveling through the iron. Magnetism then, is induced in the soft iron bar and in the polarity indicated.

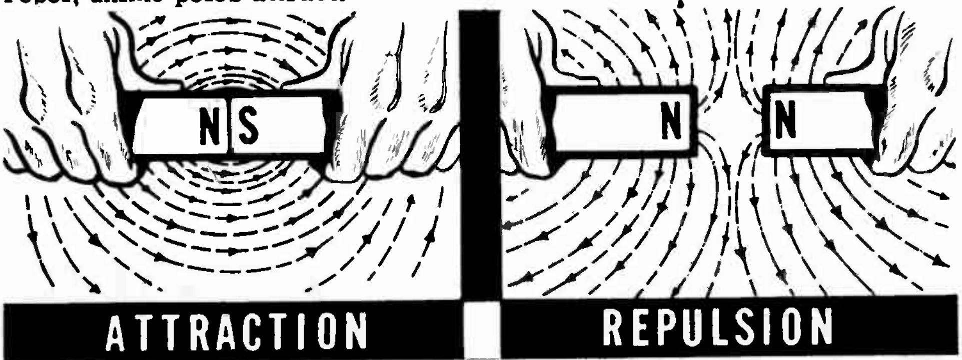
If the permanent magnet is removed, the soft iron bar will lose a good deal of its magnetic quality. The amount of magnetism which remains is called residual magnetism. The term "residual magnetism" is encountered later in this course and in the study of DC generators.

EFFECT OF A SOFT IRON BAR IN A MAGNETIC FIELD

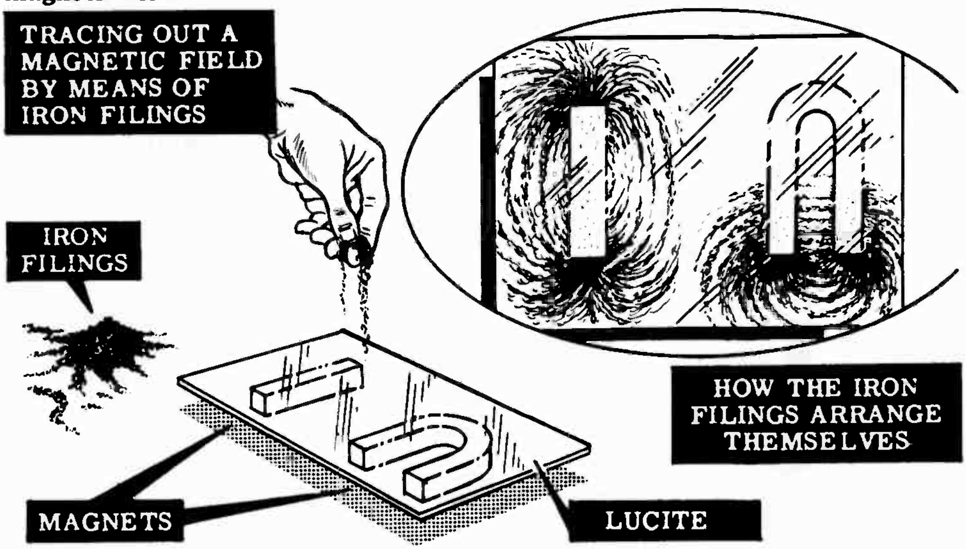


Demonstration—Magnetic Fields

To show that unlike magnetic poles attract each other, the instructor brings two bar magnets near each other with the north pole of one magnet approaching the south pole of the other. Notice that the magnets not only come together easily but attract each other strongly, showing that unlike poles attract. However, when the two magnets are brought together with similar poles opposing, it is difficult to force the magnets together, indicating that like poles repel each other. When the demonstration is repeated using horseshoe magnets, the results are the same—like poles repel, unlike poles attract.



To show how lines of force form a magnetic field around a magnet, the instructor will use a bar magnet, a horseshoe magnet and iron filings to trace out a pattern of the magnetic field. He places a sheet of lucite over the magnet and then he sprinkles iron filings on the lucite. Observe that the iron filings do not evenly cover the sheet of lucite. Instead they arrange themselves in a definite pattern, with many more filings attracted to the magnet poles than to other places on the lucite. You also see that the filings arrange themselves in a series of lines around the poles, indicating the pattern of the magnetic lines of force which make up the magnetic field.

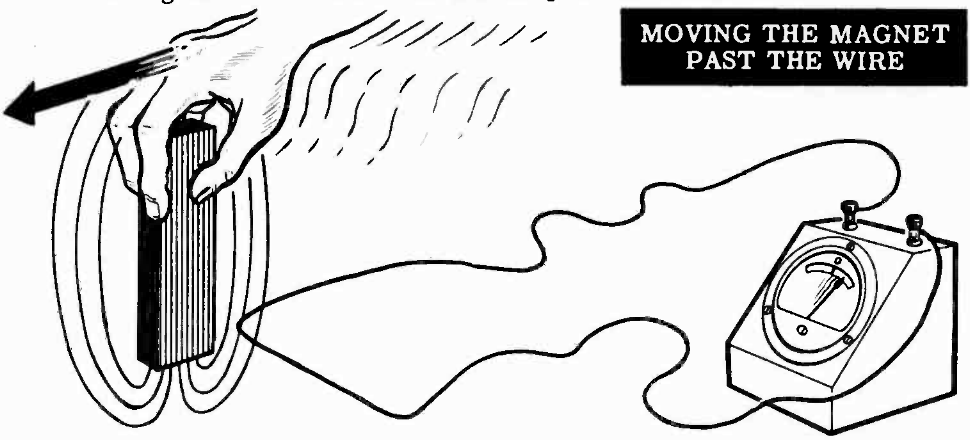


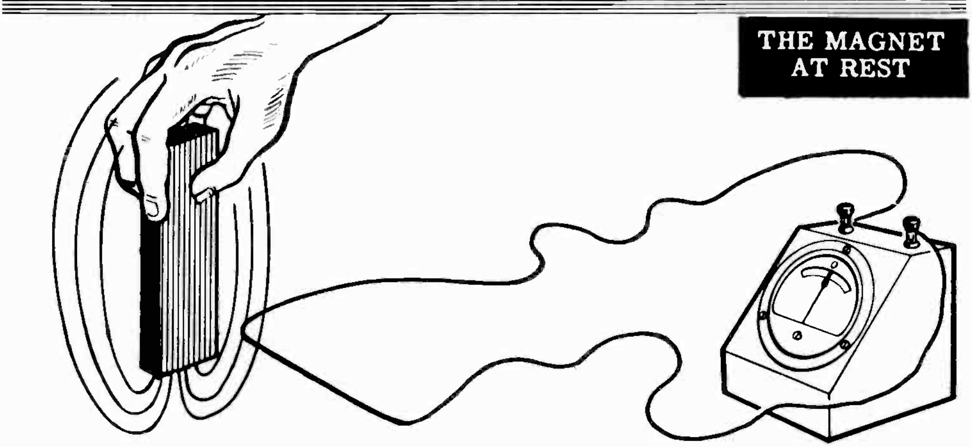
Movement of a Magnet Past a Wire

One method by which magnetism produces electricity is through the movement of a magnet past a stationary wire. If you connect a very sensitive meter across the ends of a stationary wire and then move a magnet past the wire, the meter needle will deflect. This deflection indicates that electricity is produced in the wire. Repeating the movement and observing the meter closely, you will see that the meter moves only while the magnet is passing near the wire.

Placing the magnet near the wire and holding it at rest, you will observe no deflection of the meter. Moving the magnet from this position, however, does cause the meter to deflect and shows that, alone, the magnet and wire are not able to produce electricity. In order to deflect the needle, movement of the magnet past the wire is necessary.

Movement is necessary because the magnetic field around a magnet produces an electric current in a wire only when the magnetic field is moved across the wire. When the magnet and its field are stationary, the field is not moving across the wire and will not produce a movement of electrons.





HOW MAGNETISM PRODUCES ELECTRICITY

Movement of a Wire Past a Magnet

In studying the effect of moving a magnet past a wire, you discovered that electricity was produced only while the magnet and its field were actually moving past the wire. If you move the wire past a stationary magnet, you again will notice a deflection of the meter. This deflection will occur only while the wire is moving across the magnetic field.

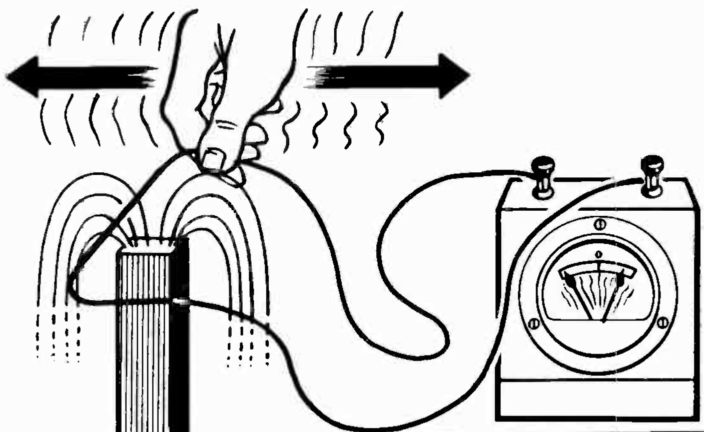
To use magnetism to produce electricity, you may either move a magnetic field across a wire or move a wire across a magnetic field.

For a continuous source of electricity, however, you need to maintain a continuous motion of either the wire or the magnetic field.

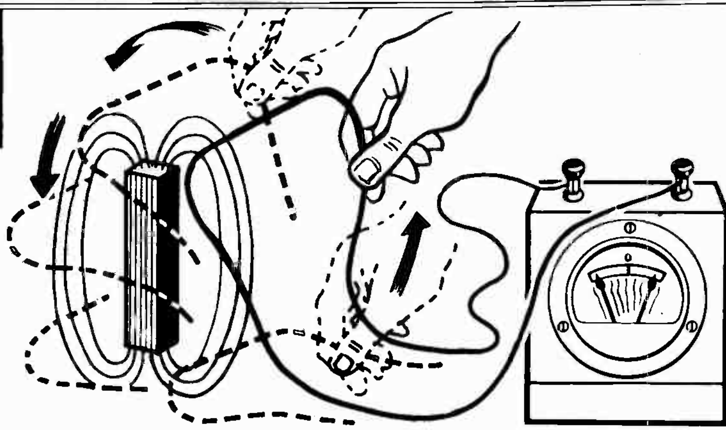
To provide continuous motion, the wire or the magnet would need to move back and forth continuously. A more practical way is to cause the wire to travel in a circle through the magnetic field.

This method of producing electricity—that of the wire traveling in a circle past the magnets—is the principle of the electric generator and is the source of most electricity used for electric power.

MOVING THE WIRE BACK AND FORTH OVER A MAGNET



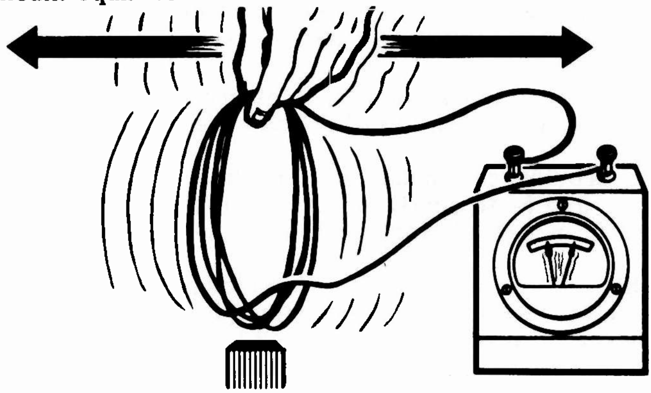
WIRE MOVING IN A CIRCLE AROUND THE MAGNET



Movement of a Wire Past a Magnet (continued)

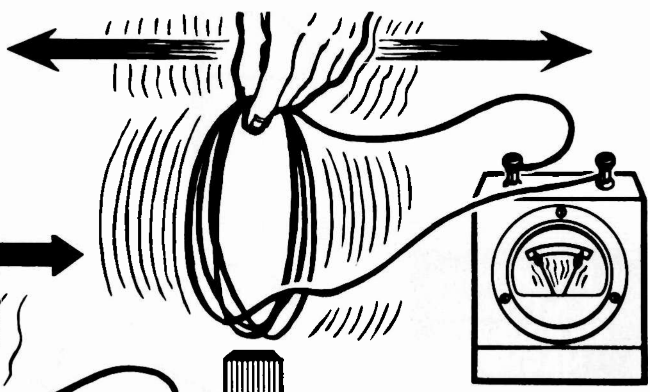
To increase the amount of electricity which can be produced by moving a wire past a magnet, you might increase the length of the wire that passes through the magnetic field, use a stronger magnet or move the wire faster. The length of the wire can be increased by winding it in several turns to form a coil. Moving the coil past the magnet will result in a much greater deflection of the meter than resulted with a single wire. Each additional coil turn will add an amount equal to that of one wire.

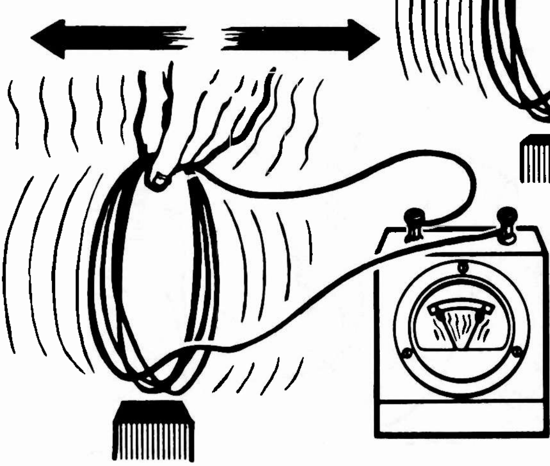
COIL OF WIRE MOVING PAST THE MAGNET



Moving a coil or a piece of wire past a weak magnet causes a weak flow of electrons. Moving the same coil or piece of wire at the same speed past a strong magnet will cause a stronger flow of electrons, as indicated by the meter deflection. Increasing the speed of the movement also results in a greater electron flow. In producing electric power, the output of an electric generator is usually controlled by changing either (1) the strength of the magnet or (2) the speed of rotation of the coil.

INCREASING SPEED OF COIL OF WIRE PAST THE MAGNET





USING A STRONGER MAGNET

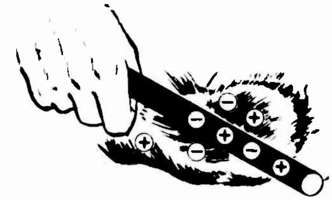
WHERE ELECTRICITY COMES FROM

Review of Electricity and How It Is Produced

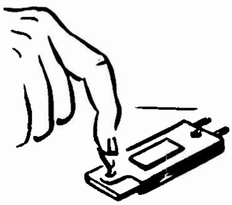
To conclude your study of how electricity is produced, suppose you review briefly what you have found out about electricity and where it comes from.

ELECTRICITY is the action of electrons which have been forced from their normal orbits around the nucleus of an atom. To force electrons out of their orbits, so they can become a source of electricity, some kind of energy is required.

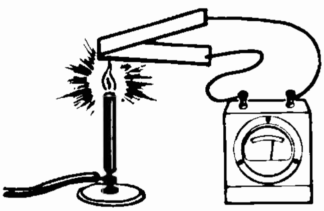
Six kinds of energy can be used:



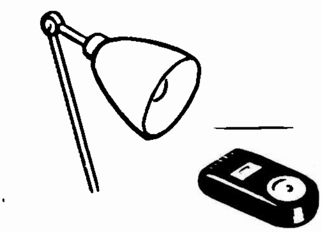
FRICTION — Electricity produced by rubbing two materials together.



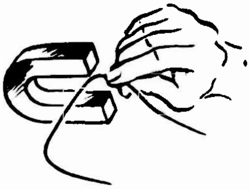
PRESSURE — Electricity produced by applying pressure to a crystal of certain materials.



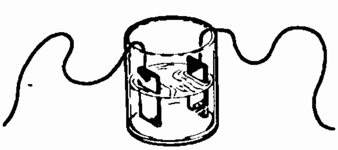
HEAT — Electricity produced by heating the junction of a thermo-couple.



LIGHT — Electricity produced by light striking photo-sensitive materials.



MAGNETISM — Electricity produced by relative movement of a magnet and a wire that results in the cutting of lines of force.



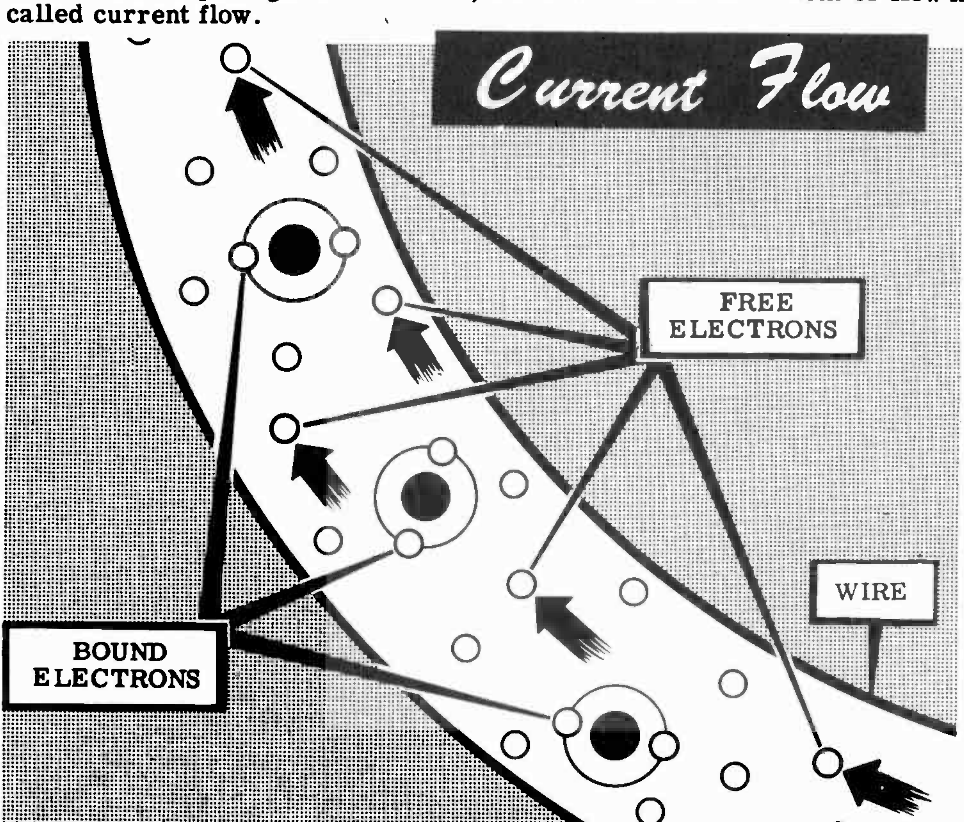
CHEMICAL ACTION — Electricity produced by chemical reaction in an electric cell.

Electrons in Motion

Electrons in the outer orbits of an atom are attracted to the nucleus by less force than electrons whose orbits are near the nucleus. These outer electrons may be easily forced from their orbits, while electrons in the inner orbits are called "bound" electrons since they cannot be forced out of their orbits.

Atoms and molecules in a material are in continuous random motion, the amount of this motion determined by the material, temperature and pressure. This random motion causes electrons in the outer rings to be forced from their orbits, becoming "free" electrons. "Free" electrons are attracted to other atoms which have lost electrons, resulting in a continuous passage of electrons from atom to atom within the material. All electrical effects make use of the "free" electrons forced out of the outer orbits. The atom itself is not affected by the loss of electrons, except that it becomes positively charged and will capture "free" electrons to replace those it has lost.

The random movement of the "free" electrons from atom to atom is normally equal in all directions so that electrons are not lost or gained by any particular part of the material. When most of the electron movement takes place in the same direction, so that one part of the material loses electrons while another part gains electrons, the net electron movement or flow is called current flow.

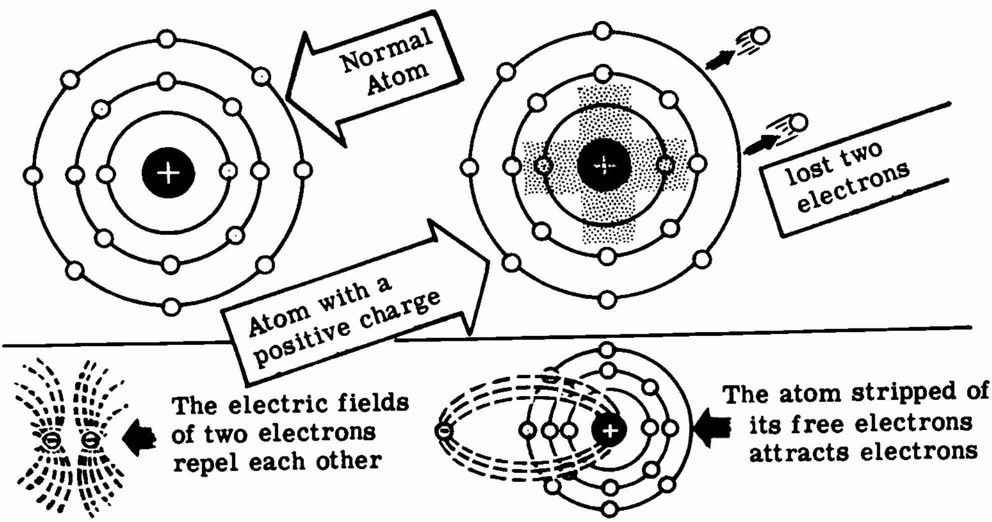


Electrons in Motion (continued)

Suppose you examine more closely what happens inside a material when an electron current begins to flow. You learned in Section II, Topic 1 that an atom is made up of a number of neutrons, protons and electrons. The protons have a positive charge, the electrons a negative charge, and the neutrons have no charge at all. The nucleus of the atom is made up of neutrons and protons and has a positive charge equal to the number of protons. Under normal conditions the number of electrons traveling around the nucleus equals the number of protons in the nucleus and the entire atom has no charge at all.

If an atom loses several of its free electrons, it then has a positive charge since there are more protons than electrons. From your work in Section II you know that like charges repel each other and unlike charges attract. About each positive or negative charge, unseen lines of force radiate in all directions and the area occupied by these lines is called an "electric field." Thus if a moving electron comes close to another electron, the second electron will be pushed away without the two electrons coming into contact.

Similarly, if an electron comes near a positive charge, the two fields reach out and attract each other even though there may be some distance between them. It is the attraction between the positive charge on the nucleus and the electrons in the outer orbit that determine the electrical characteristics of a material. If the atom of a particular material is so constructed that there is a very small attraction between the positive nucleus and the outer electrons, the outer electrons are free to leave the atom when they are under the influence of electric fields. Such a condition exists in metals; and silver, copper and aluminum have a very weak attractive force between the nucleus and the outer electrons. Substances such as glass, plastic, wood and baked clays have a very powerful bond between the nucleus and the outer electrons, and these electrons will not leave their atoms unless very strong electrical fields are applied.

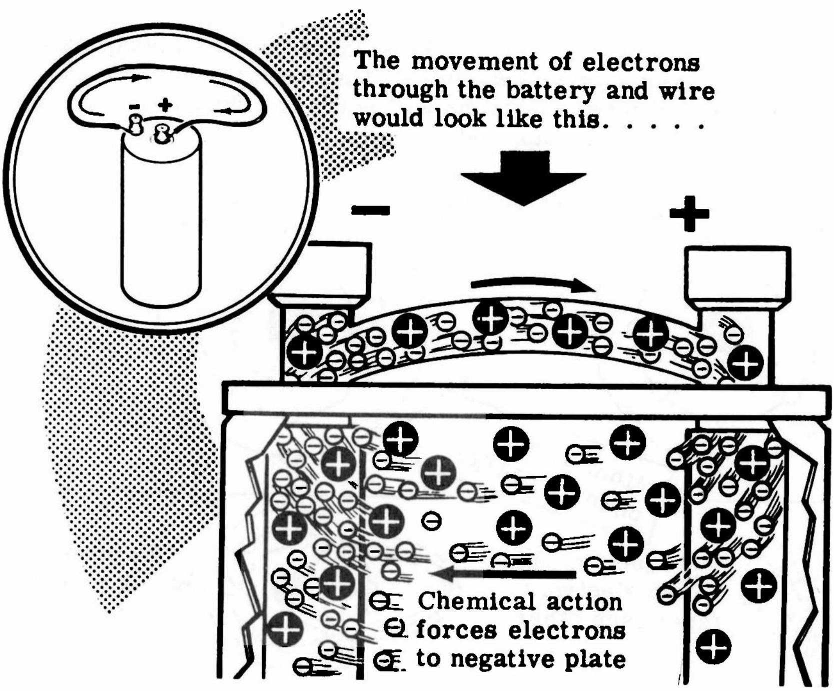


Electrons in Motion (continued)

You learned that a dry cell has the peculiar property of having an excess of electrons at its negative terminal and a shortage of electrons at its positive terminal. Suppose you examine just what happens when a metal wire is connected across the terminals of a dry cell.

The moment the wire is connected across the cell there will be an excess of electrons at the negative end and a shortage at the positive end. Remember that electrons repel each other and are attracted to places where there is a shortage of electrons. At the negative end of the cell the excess of electrons now have a place to go. The electric fields of these electrons push against the electrons in the atoms of the wire, and some of these outer electrons are pushed out of their atoms. These free electrons cannot remain where they are since their electric fields force them away from the piled up electrons at the negative terminal, so they are forced away from the negative terminal. When these newly freed electrons arrive at the next atom, they in turn force those outer electrons off their atoms and the process continues.

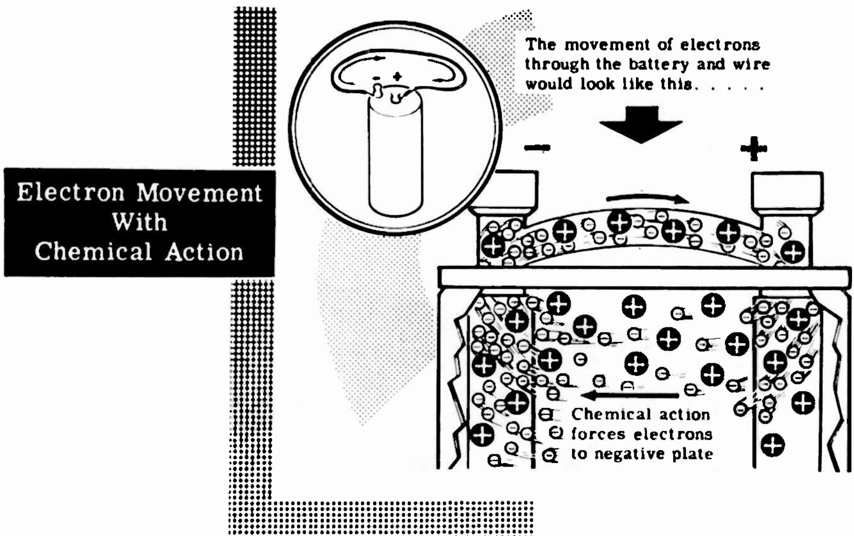
At the positive end of the wire there is a shortage of electrons, and therefore there is a strong attraction between the positive terminal and the outer electrons of the nearby atoms. These electric fields of the outer electrons are strongly pulled by the electric field of the positive terminal, and some of the electrons leave their atoms and move toward the positive end. When these electrons leave their atoms, the atoms become positively charged and electrons from the next atoms are attracted toward the positive end; and the process continues.

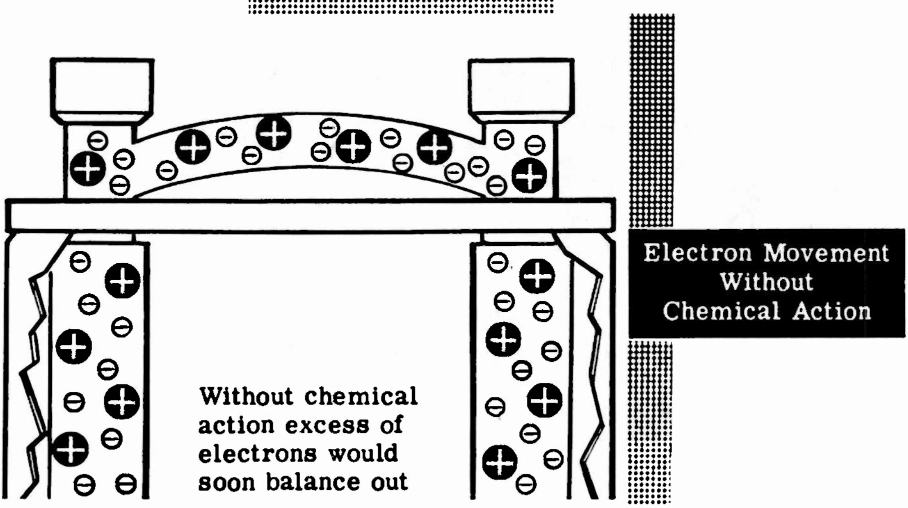


Electrons in Motion (continued)

If the excess and shortage of electrons at the two ends of the wire were fixed at a definite quantity, it would only be a very short time until all the excess electrons had traveled through the wire toward the positive end. The dry cell, however, continues to furnish excess electrons at one terminal and continues to remove electrons from the other terminal, so that the two terminals remain negative and positive for the life of the cell.

Under these conditions a constant stream of electrons begins to flow through the wire the instant the wire is connected to the cell. Electrons constantly arriving at the negative end keep applying a pushing force to the free electrons in the wire, and the constant removal of electrons from the positive end keeps applying a pulling force on the free electrons.



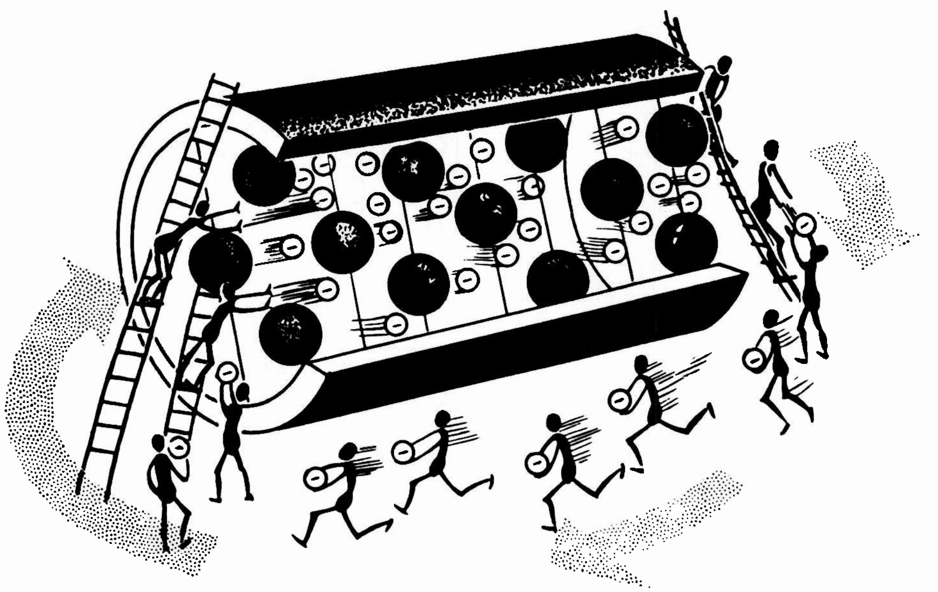


Electrons In Motion (continued)

If you have any difficulty in picturing what is happening inside the wire, suppose you examine a similar situation which makes use of more familiar components. Imagine a large piece of drain pipe in which a large number of golf balls are suspended by means of wires. Each golf ball represents an atom with its bound electrons. Now fill all of the space between the golf balls with small metal balls the size of air rifle shot (BB shot). Each small ball represents a free electron. Now imagine an army of little men removing the BB's from one end of the pipe and ramming them back into the other end. This army represents the dry cell.

Since the pipe cannot be packed any more tightly, and since it is too strong to burst, all that can happen is that there will be a constant flow of small metal balls through the pipe. The faster the little men work and the harder they push, the greater will be the flow of BB shot. The flow begins at the instant the army begins to work, and continues at the same rate until the little men are too exhausted to move any more—the dry cell is then "dead."

A very similar situation exists between the drain pipe and a wire carrying an electric current. The main difference is that in the pipe, the metal balls press directly upon each other, while in the wire, the electrons themselves do not touch but their electric fields press against each other.



= Golf ball = = atom with bound electrons

= BB shot = = free electron

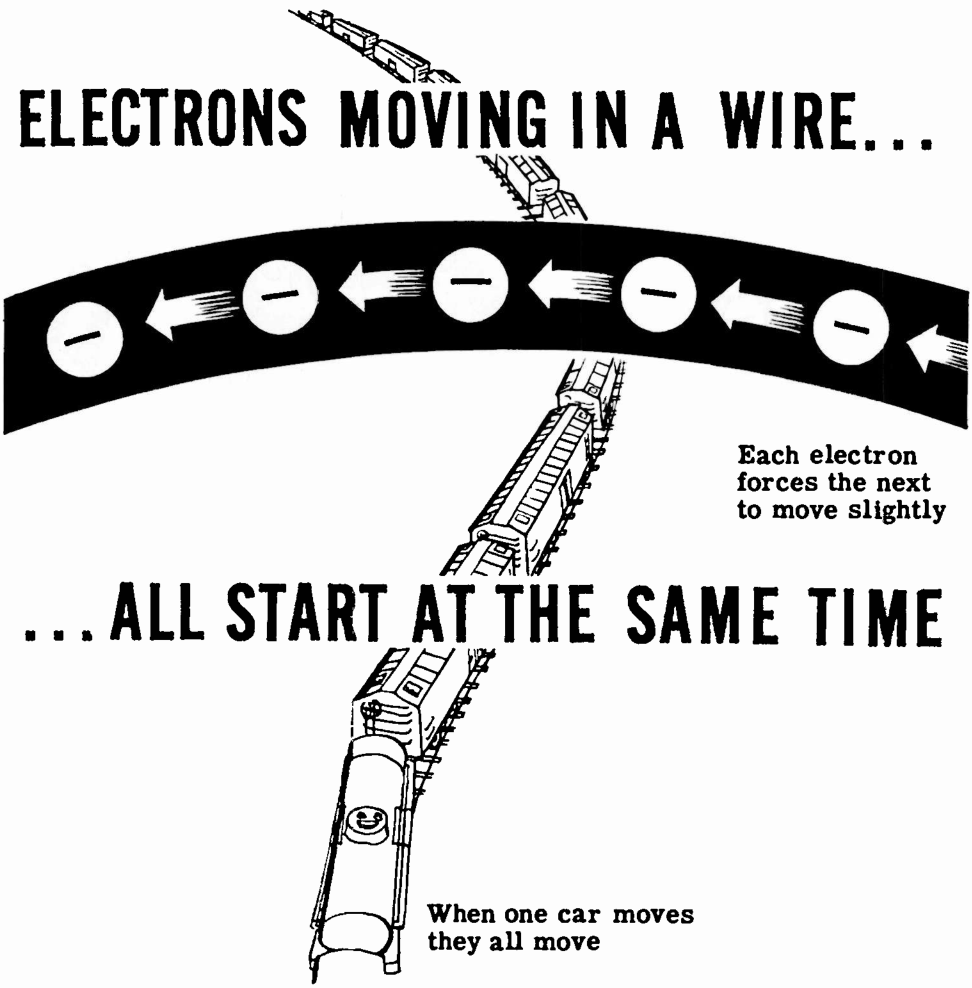
= Chemical action of dry cell

Electrons in Motion (continued)

When current flow starts in a wire, electrons start to move throughout the wire at the same time, just as the cars of a long train start and stop together.

If one car of a train moves, it causes all the cars of the train to move by the same amount, and free electrons in a wire act in the same manner. Free electrons are always present throughout the wire, and as each electron moves slightly it exerts a force on the next electron, causing it to move slightly and in turn to exert a force on the next electron. This effect continues throughout the wire.

When electrons move away from one end of a wire it becomes positively charged, causing all the free electrons in the wire to move in that direction. This movement, taking place throughout the wire simultaneously, moves electrons away from the other end of the wire and allows more electrons to enter the wire at that point.

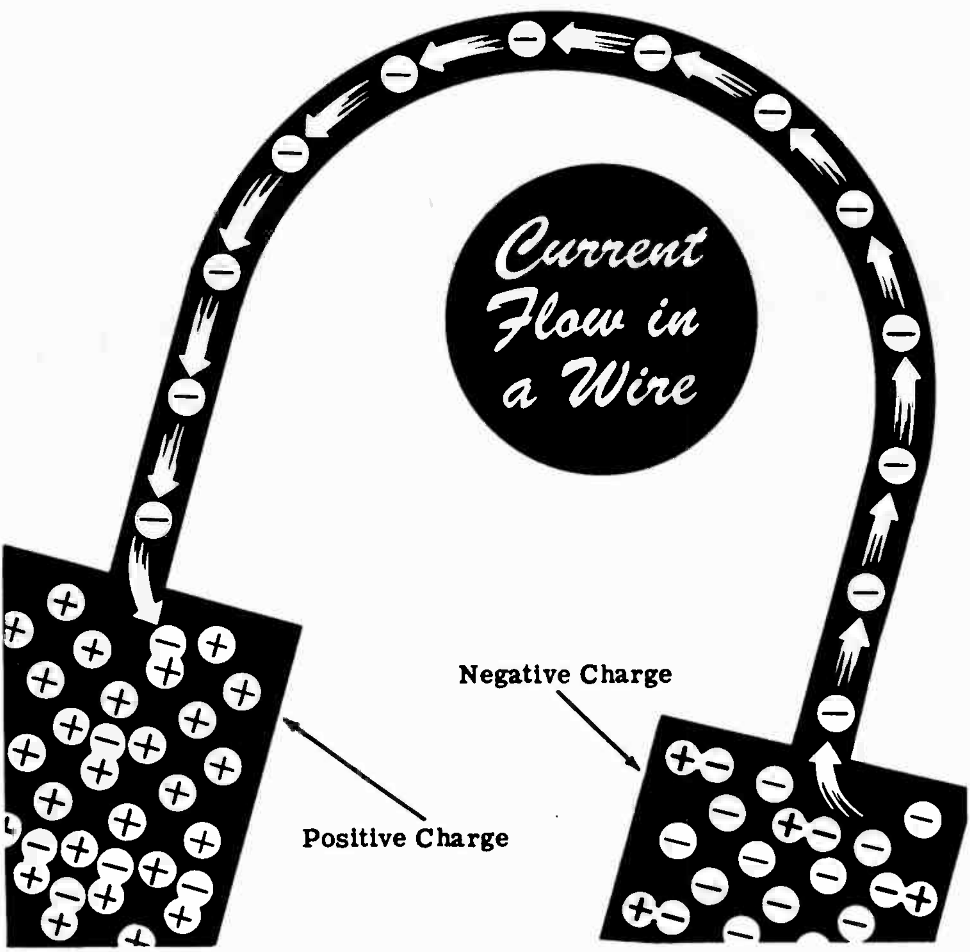


Electrons in Motion (continued)

Since electrons repel each other and are attracted by positive charges, they always tend to move from a point having an excess of electrons toward a point having a lack of electrons. Your study of the discharge of static charges showed that, when a positive charge is connected to a negative charge, the excess electrons of the negative charge move toward the positive charge.

If electrons are taken out of one end of a copper wire, a positive charge results, causing the free electrons in the wire to move toward that end. If electrons are furnished to the opposite end of the wire, causing it to be charged negatively, a continuous movement of electrons will take place from the negatively charged end of the wire toward the positively charged end. This movement of electrons is current flow and will continue as long as electrons are furnished to one end of the wire and removed at the other end.

Current flow can take place in any material where "free" electrons exist, although we are only interested in the current flow in metal wires.

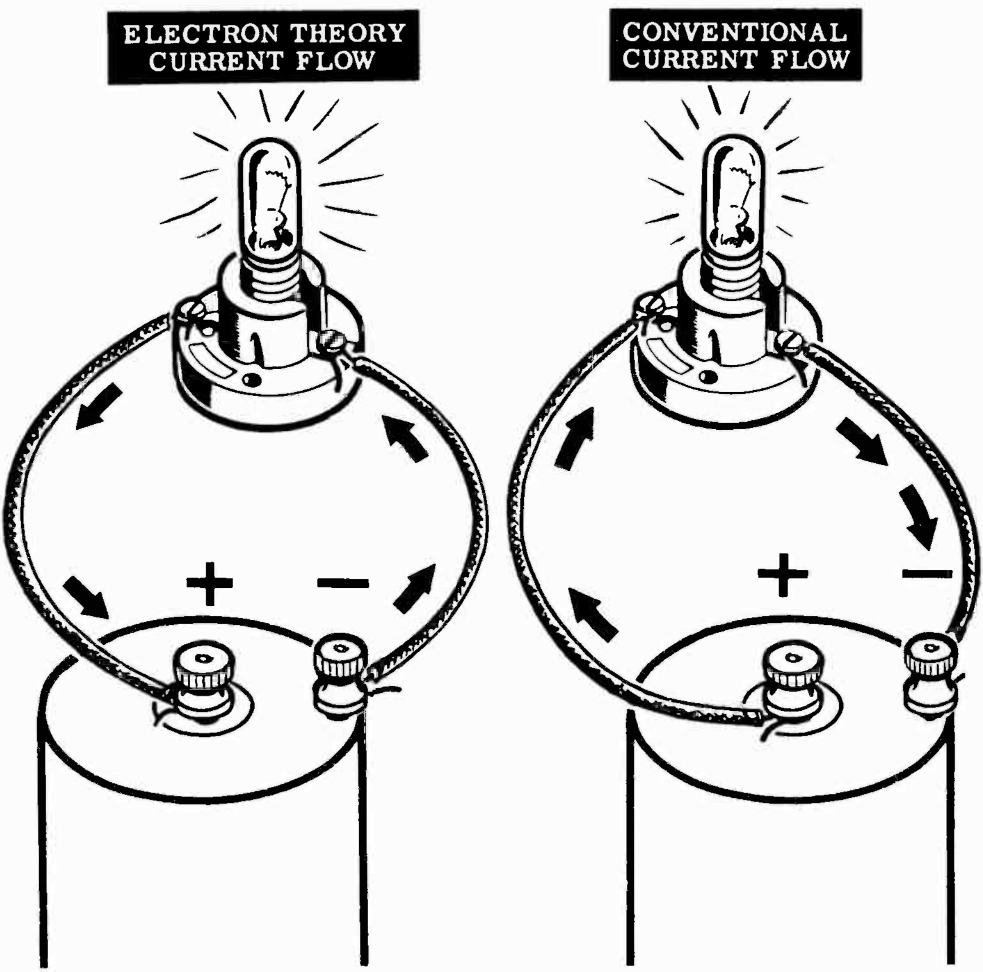


Direction of Current Flow

According to the electron theory; current flow is always from a (-) negative charge to a (+) positive charge. Thus, if a wire is connected between the terminals of a battery, current will flow from the (-) terminal to the (+) terminal.

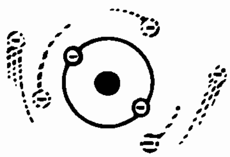
Before the electron theory of matter had been worked out, electricity was in use to operate lights, motors, etc. Electricity had been harnessed but no one knew how or why it worked. It was believed that something moved in the wire from (+) to (-). This conception of current flow is called conventional current flow. Although the electron theory of current flow (-) to (+) is the accepted theory, you will find the conventional flow (+) to (-) is sometimes used in working with certain types of electrical equipment.

For your study of electricity, current flow is concluded to be the same as the electron flow—that is, from negative to positive.

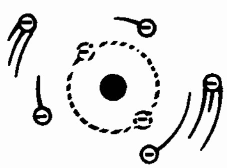


Review of Current Flow

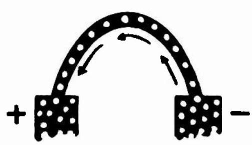
Current flow does all the work involved in the operation of electrical equipment, whether it be a simple light bulb or some complicated electronic equipment such as a radio receiver or transmitter. In order for current to flow, a continuous path must be provided between the two terminals of a source of electric charges. Now suppose you review what you have found out about current flow.



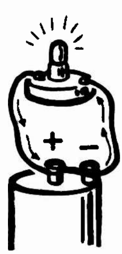
1. "BOUND" ELECTRONS — Electrons in the inner orbits of an atom which cannot easily be forced out of their orbits.



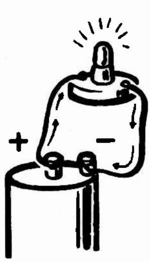
2. "FREE" ELECTRONS — Electrons in the outer orbits of an atom which can easily be forced out of their orbits.



3. CURRENT FLOW — Movement of "free" electrons in the same direction in a material.



4. ELECTRON CURRENT — Current flow from a negative charge to a positive charge.



5. CONVENTIONAL CURRENT — Current flow from a positive charge to a negative charge.

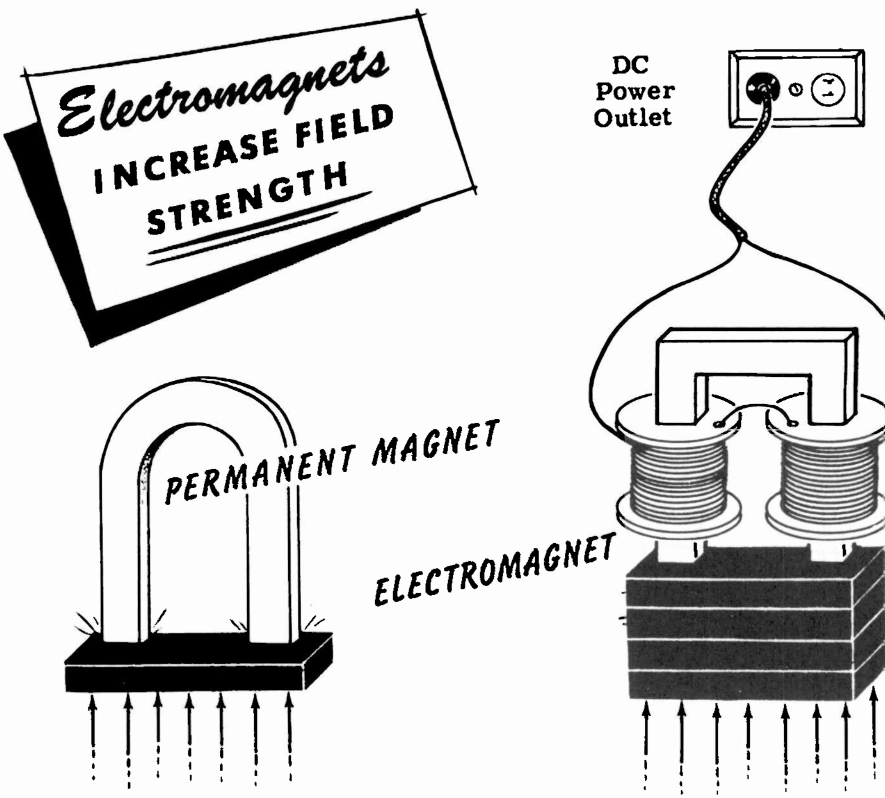
6. AMMETER — Meter used to measure amperes.

Electromagnetism

In the previous topic you learned the very important fact that an electric current can be caused to flow when you move a coil of wire so that it cuts through a magnetic field. You also learned that this is the most widespread manner in which electricity is generated for the home, for industry, and aboard ship.

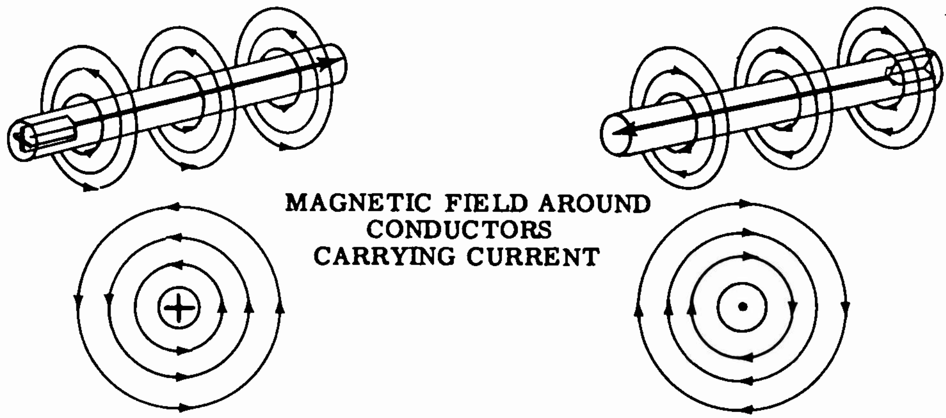
Since magnetism can be made to generate electricity, it does not seem too great a jump for the imagination to wonder if electricity can generate a magnetic field. In this topic you will see for yourself that that is exactly what can be done.

In the last topic you made use of permanent magnets to cause an electric current to flow. You saw that more current could be generated as you increased the number of turns of wire, the speed of motion of the coil and the strength of the magnetic field. It is a simple matter to accomplish the first two of these in a practical electric generator, but it is very difficult to increase the strength of a permanent magnet beyond certain limits. In order to generate large amounts of electricity a much stronger magnetic field must be used. That is accomplished, as you will see in this topic, by means of an electromagnet. Electromagnets work on the simple principle that a magnetic field can be generated by passing an electric current through a coil of wire.



Electromagnetism (continued)

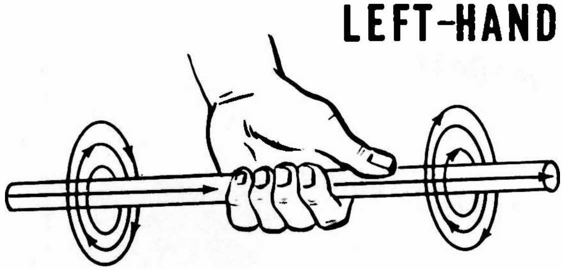
An electromagnetic field is a magnetic field caused by the current flow in a wire. Whenever electric current flows, a magnetic field exists around the conductor, and the direction of this magnetic field depends upon the direction of current flow. The illustration shows conductors carrying current in different directions. The direction of the magnetic field is counterclockwise when current flows from left to right. If the direction of current flow reverses, the direction of the magnetic field also reverses, as shown. In the cross-sectional view of the magnetic field around the conductors, the dot in the center of the circle represents the current flowing out of the paper toward you, and the cross represents the current flowing into the paper away from you.



MAGNETIC FIELD AROUND CONDUCTORS CARRYING CURRENT

A definite relationship exists between the direction of current flow in a wire and the direction of the magnetic field around the conductor. This relationship can be shown by using the left-hand rule. This rule states that if a current-carrying conductor is grasped in the left hand with the thumb pointing in the direction of the electron current flow, the fingers, when wrapped around the conductor, will point in the direction of the magnetic lines of force. The illustration shows the application of the left-hand rule to determine the direction of the magnetic field about a conductor.

LEFT-HAND RULE FOR A CONDUCTOR

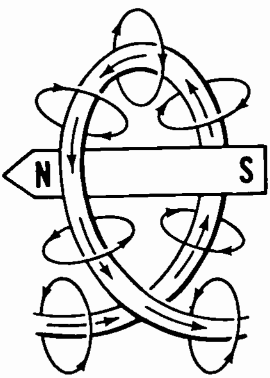


Remember that the left-hand rule is based on the electron theory of current flow (from negative to positive) and is used to determine the direction of the lines of force in an electromagnetic field.

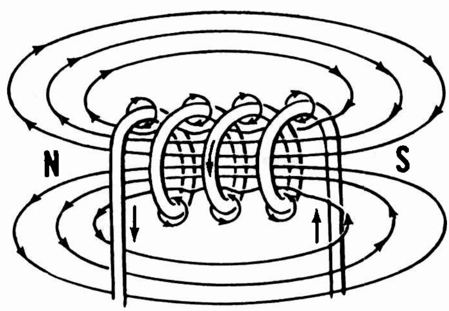
Magnetic Field of a Loop or Coil

Here is a point that you will find very important in the near future—a coil of wire carrying a current acts as a magnet. If a length of wire carrying a current is bent to form a loop, the lines of force around the conductor all leave at one side of the loop and enter at the other side. Thus the loop of wire carrying a current will act as a weak magnet having a north pole and a south pole. The north pole is on the side at which lines of force leave the loop and the south pole on the side at which they enter the loop.

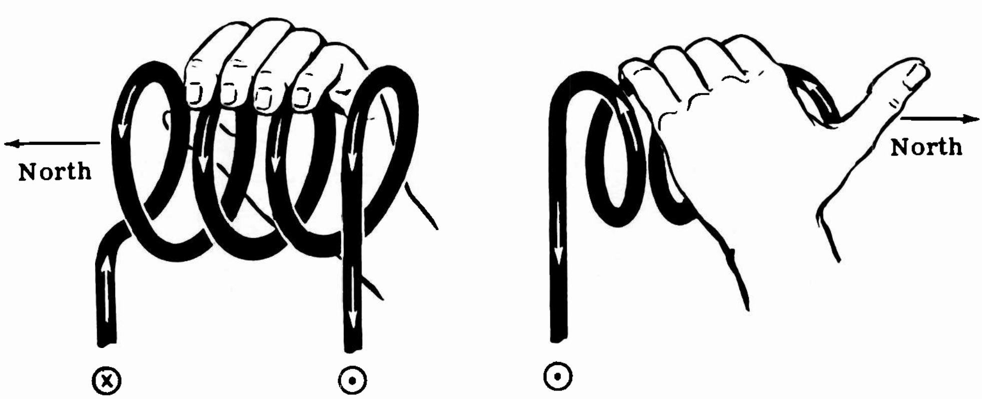
If you desire to make the magnetic field of the loop stronger, you can form the wire into a coil of many loops as shown. Now the individual fields of each loop are in series and form one strong magnetic field inside and outside the loop. In the spaces between the turns, the lines of force are in opposition and cancel each other out. The coil acts as a strong bar magnet with the north pole being the end from which the lines of force leave.



Magnetic fields around a loop and coil



A left-hand rule also exists for coils to determine the direction of the magnetic field. If the fingers of the left hand are wrapped around the coil in the direction of the current flow, the thumb will point toward the north pole end of the coil.

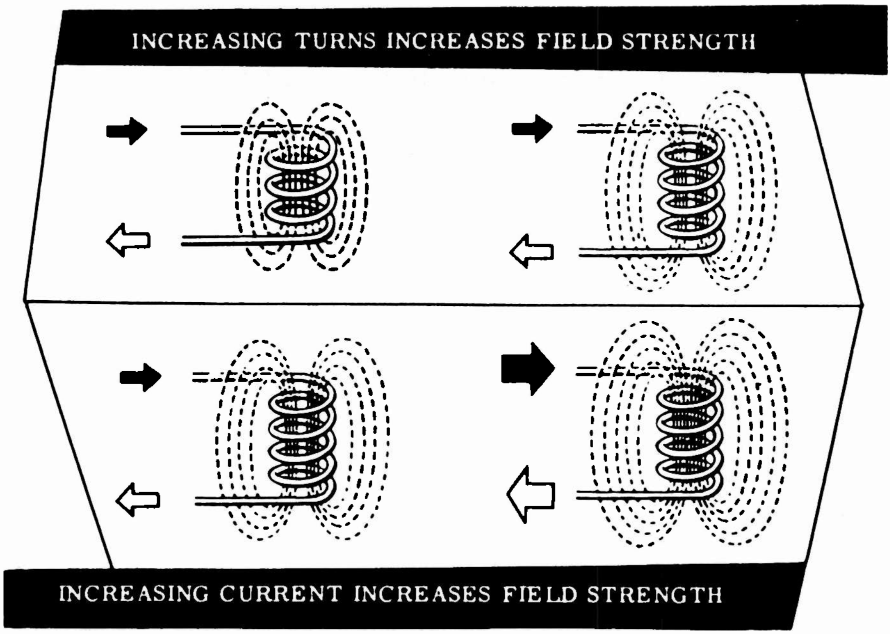


LEFT-HAND RULE FOR COILS

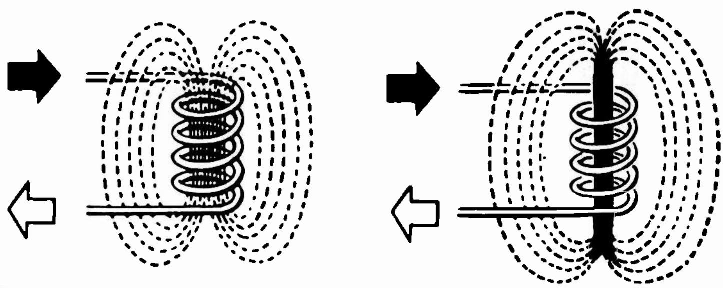
Electromagnets

Adding more turns to a current-carrying coil increases the number of lines of force, causing it to act as a stronger magnet. An increase in current also strengthens the magnetic field so that strong electromagnets have coils of many turns and carry as large a current as the wire size permits.

In comparing coils using the same core or similar cores, a unit called the ampere-turn is used. This unit is the product of the current in amperes and the number of turns of wire.



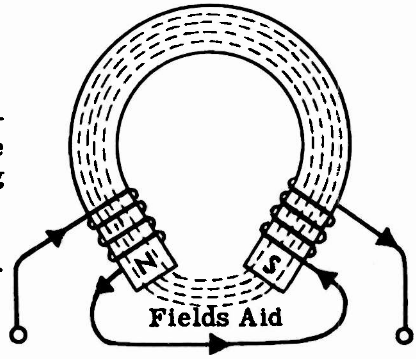
Although the field strength of an electromagnet is increased both by using a large current flow and many turns to form the coil, these factors do not concentrate the field enough for use in a practical generator. To further increase the flux density, an iron core is inserted in the coil. Because the iron core offers much less reluctance (opposition) to lines of force than air, the flux density is greatly increased.



ADDING AN IRON CORE GREATLY INCREASES FLUX DENSITY

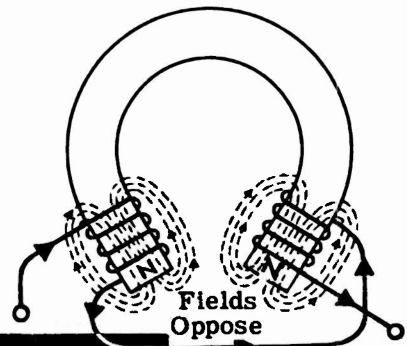
Electromagnets (continued)

If the iron core is bent to form a horseshoe and two coils are used, one on each leg of the horseshoe-shaped core as illustrated, the lines of force travel around the horseshoe and across the air gap, causing a very concentrated field to exist across the air gap. The shorter the air gap, the greater the flux density between the poles.



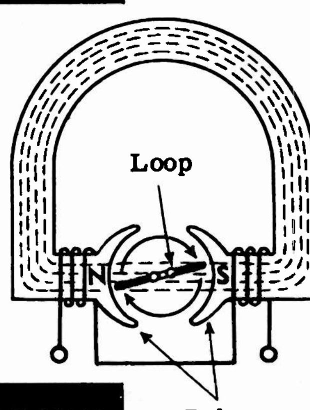
A HORSESHOE CORE ELECTROMAGNET

To cause such a field, the current flow in the series connected coils must produce two opposite magnetic poles at the ends of the core. Reversing either coil would cause the two fields to oppose each other, cancelling out the field in the air gap.



REVERSING THE FIELDS

Electric meters make use of horseshoe-type permanent magnets. Electric motors and generators also make use of a similar type of electromagnet. All of these applications require the placement of a number of loops of wire between the poles of the magnet.

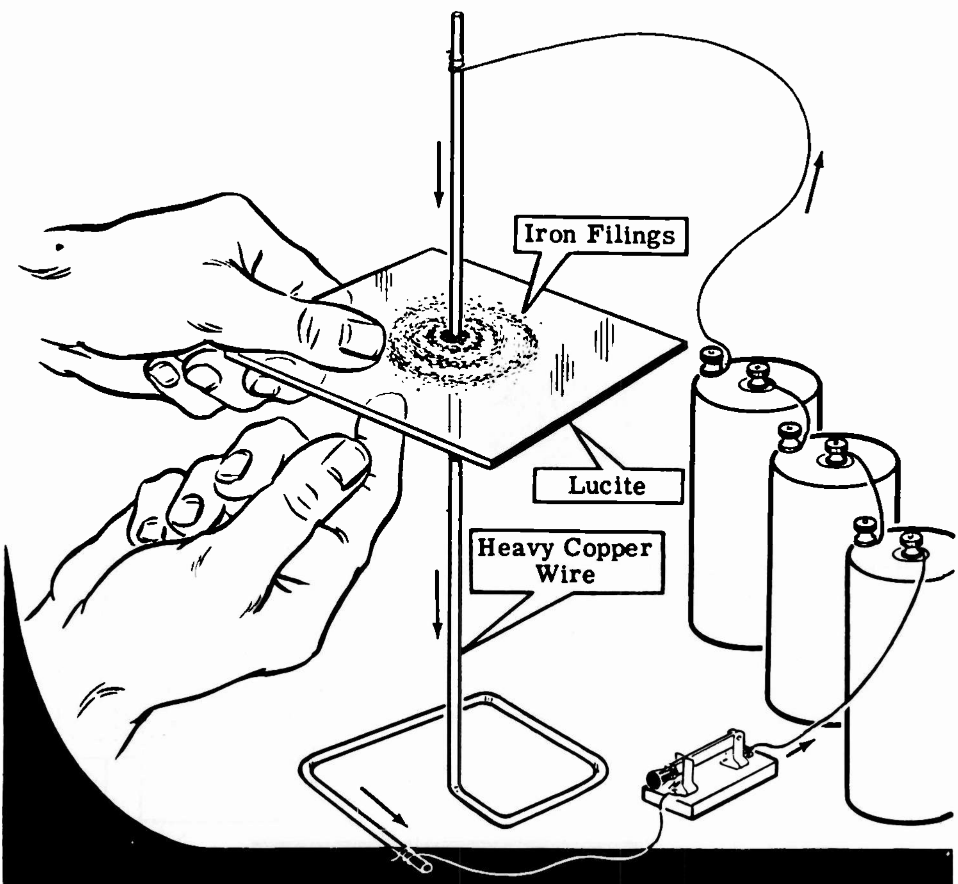


ELECTROMAGNET POLES

Demonstration—Magnetic Field Around a Conductor

To demonstrate that a magnetic field exists around a current-carrying conductor, the instructor connects a heavy copper wire in series with a switch across a dry cell battery. The copper wire is bent to support itself vertically and then inserted through a hole in the lucite sheet, which is held in a horizontal position. With the switch closed, iron filings—which have the property of aligning themselves along the lines of force in a magnetic field—are sprinkled on the lucite. The lucite is tapped lightly to make it easier for the iron filings to fall into position.

You see that the filings arrange themselves in concentric circles, showing that the magnetic lines of force form a circular pattern around the conductor. To show that the circular pattern is actually the result of the magnetic field, the instructor opens the switch and spreads the filings evenly over the cardboard, then repeats the demonstration. You see that, each time the circuit current flows, the filings arrange themselves to show the magnetic field.



IRON FILINGS INDICATE CIRCULAR PATTERN OF MAGNETIC FIELD

Demonstration—Magnetic Field around a Conductor (continued)

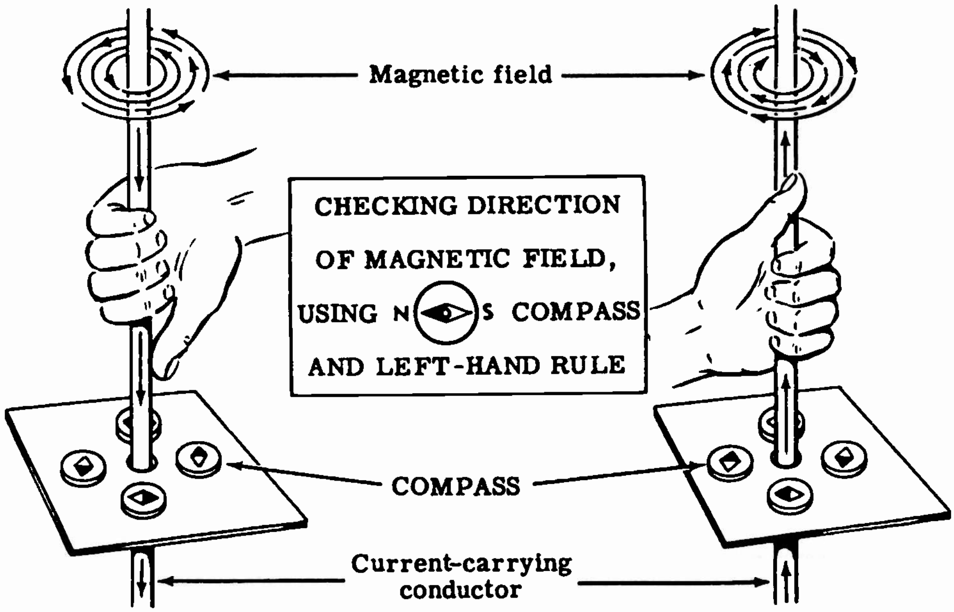
To demonstrate the direction of the magnetic field around the current-carrying conductor, a compass needle is used.

A compass needle is nothing more than a small bar magnet which will line itself up with the lines of force in a magnetic field. You know from the previous demonstration that the magnetic field is circular. Therefore, the compass needle always will be positioned at right angles to the current-carrying conductor.

The iron filings are removed from the lucite, and the compass needle is placed on the lucite about 2 inches away from the conductor. With no current flowing, the north pole end of the compass needle will point to the earth's magnetic north pole. When current flows through the conductor, the compass needle lines itself up at right angles to a radius drawn from the conductor. As the compass needle is moved around the conductor, observe that the needle always maintains itself at right angles to it. This proves that the magnetic field around the conductor is circular.

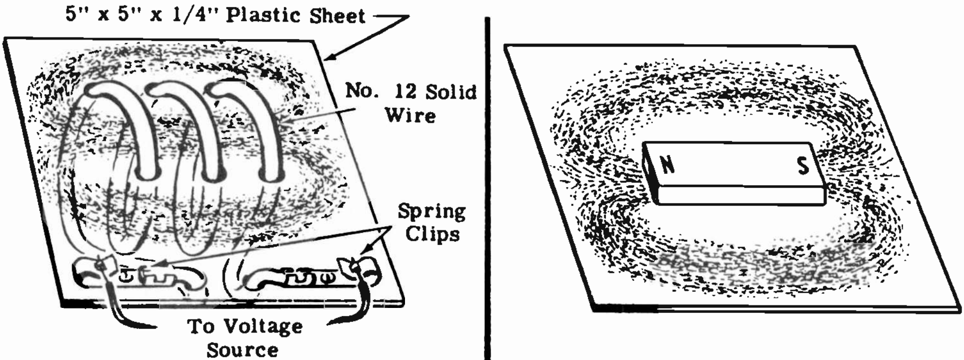
Using the left-hand rule you can check the direction of the magnetic field which was indicated by the compass needle. The direction in which the fingers go around the conductor is the same as that of the north pole of the compass needle.

If the current through the conductor is reversed, the compass needle will point in the opposite direction, indicating that the direction of the magnetic field has reversed. Application of the left-hand rule will verify this observation.



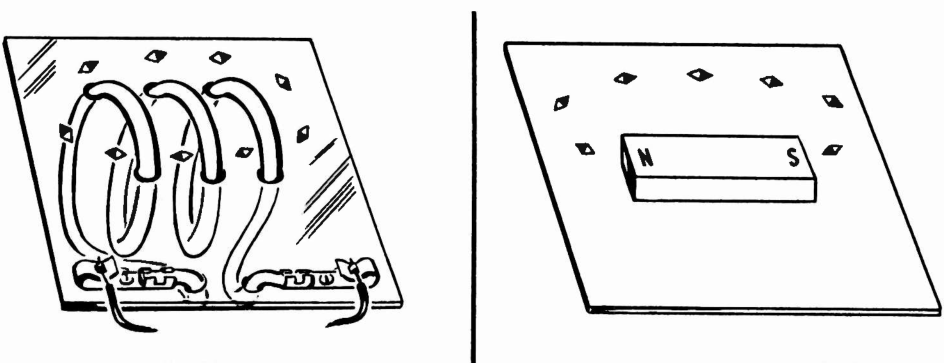
Demonstration—Magnetic Fields Around a Coil

To demonstrate the magnetic field of a coil of wire, a lucite board is used with No. 10 wire threaded through it to form a coil as shown. The rest of the circuit is the same as for the previous part of the demonstration. Iron filings are sprinkled on the lucite and current is passed through the coil. Tapping the lucite will cause the iron filings to line up parallel to the lines of force. Observe that the iron filings have formed the same pattern of a magnetic field that existed around a bar magnet.



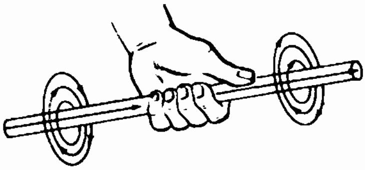
IRON FILINGS DEMONSTRATING MAGNETIC FIELD PATTERN AROUND A COIL

If the iron filings are removed, and the compass needle is placed inside the coil, the needle will line up along the axis of the coil with the north pole end of the compass pointing to the north pole end of the coil. Remember that the lines of force inside a magnet or coil flow from the south pole to the north pole. The north pole end of the coil can be verified by using the left-hand rule for coils. If the compass is placed outside the coil and moved from the north pole to the south pole, the compass needle will follow the direction of a line of force as it moves from the north pole to the south pole. When the current through the coil is reversed, the compass needle will also reverse its direction.

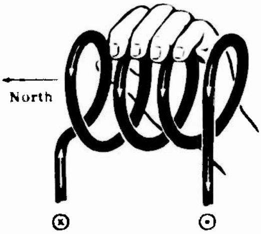


CHECKING DIRECTION OF MAGNETIC FIELD, USING COMPASS

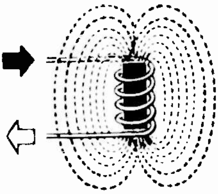
Review of Electromagnetism



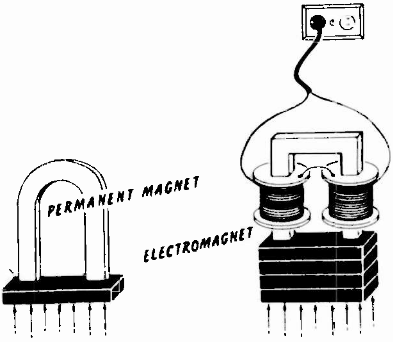
ELECTROMAGNETIC FIELD — Current flowing through a wire generates a magnetic field whose direction is determined by the direction of the current flow. The direction of the generated magnetic field is found by using the left-hand rule for a current-carrying conductor.



MAGNETIC FIELD OF A LOOP OR COIL — A loop generates a magnetic field exactly the same as a bar magnet. If many loops are added in series forming a coil, a stronger magnetic field is generated. The left-hand rule for a coil is used to determine the coil's magnetic polarity.



FIELD STRENGTH — Increasing the number of turns of a coil increases the field strength and increasing the coil current also increases the field strength. An iron core may be inserted to greatly concentrate the field (increase flux density) at the ends of the coil. The ampere-turn is the unit used in comparing the strength of magnetic fields.



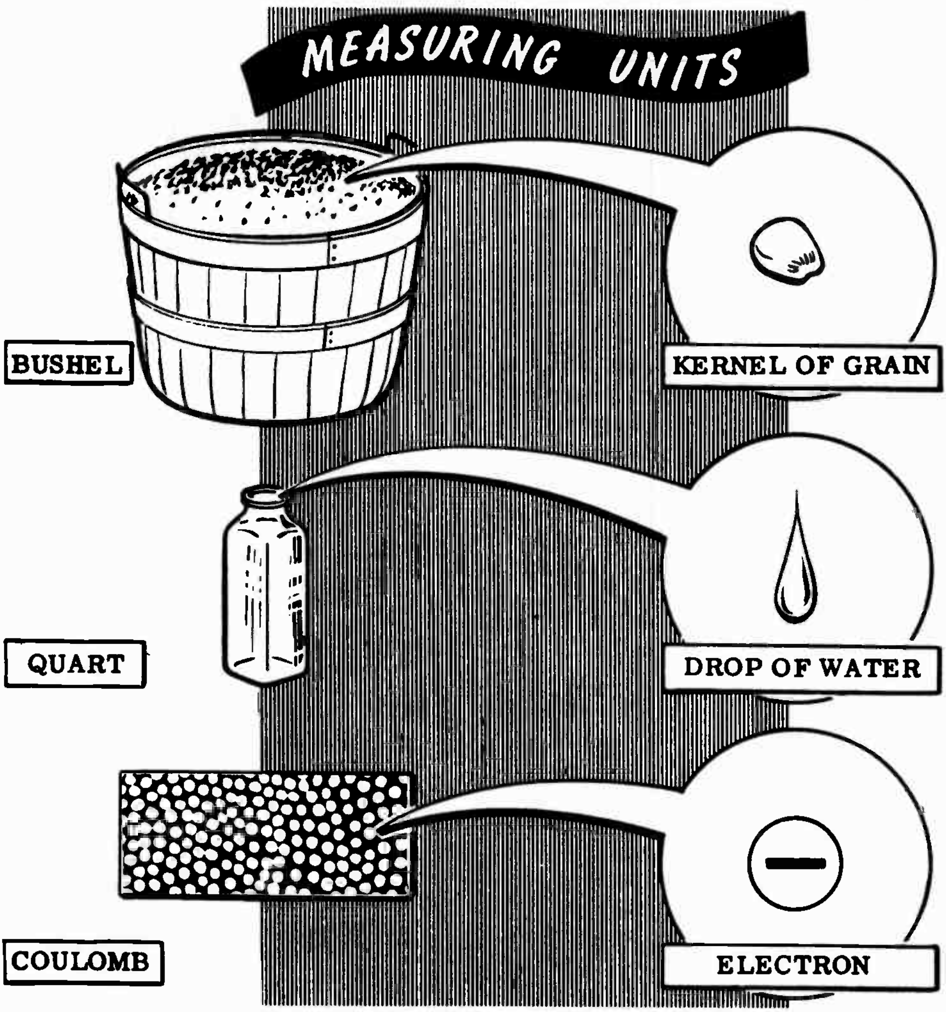
PERMANENT-MAGNET and ELECTROMAGNET FIELDS — Electromagnet fields are much stronger than the permanent magnet type, and are used in most practical electrical machinery. When electromagnets are used, the field strength can be varied by varying the amount of current flow through the field coils.

How Electric Charges Are Measured

In working with electric charges either standing still or in motion as current flow, you will need some unit for measuring the amount of electric charge. The basic unit of electrical charge is the electron but, since its charge is extremely small and the electron itself is so small that it cannot be seen, you will need to use a more practical unit of measurement.

You are familiar with the measurement of grain, for example. Each kernel of grain is much too small to be used as a practical unit of measurement; therefore the bushel, containing several million kernels, is the practical unit used. Similarly, water is not measured by counting drops of water. Instead, a unit called the quart is used. For measuring electric charges the unit used is the coulomb, which is approximately 6.28 million, million, million electrons.

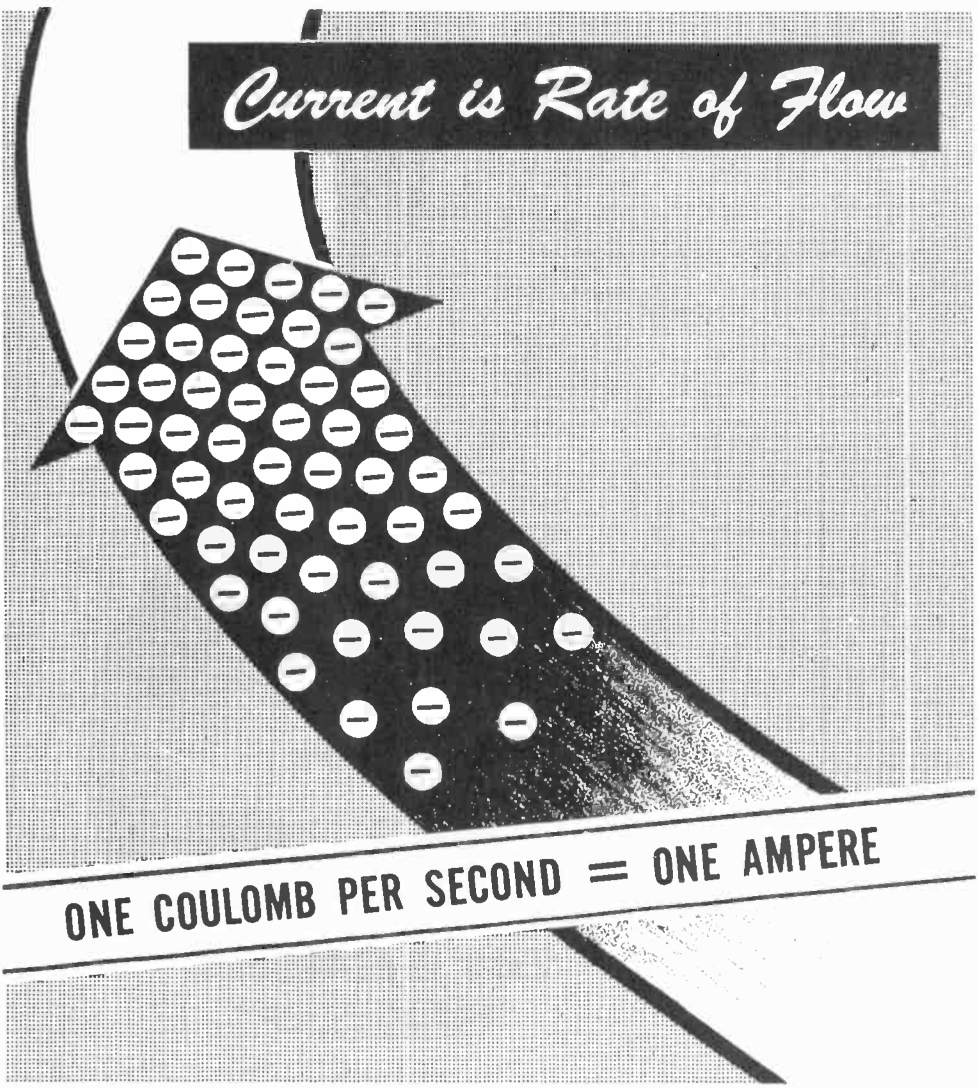
The coulomb measures the quantity of electric charge or the number of electrons regardless of whether the charge is in motion or standing still.



Units of Current Flow

Current flow is a measure of how many electrons are passing through a material in a given length of time. The coulomb is a measure of the number of electrons so that, by counting the coulombs which pass in a given amount of time, the current flow is measured. The unit of current flow is the ampere. One ampere of current is flowing when one coulomb of electrons passes through the material in one second, two amperes when two coulombs pass per second, etc.

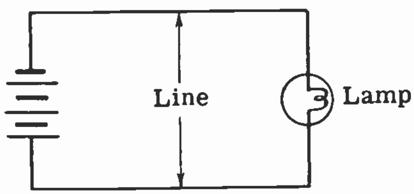
Since amperes mean coulombs per second, the ampere is a measure of rate at which electrons are moving through a material. The coulomb, which represents the number of electrons in a charge, is a measure of quantity.



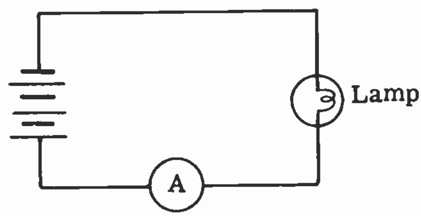
Measuring Units of Current Flow

In working with electricity, a means of measuring current flow through a material is necessary. An ammeter does this: it indicates in amperes the number of electrons passing per second.

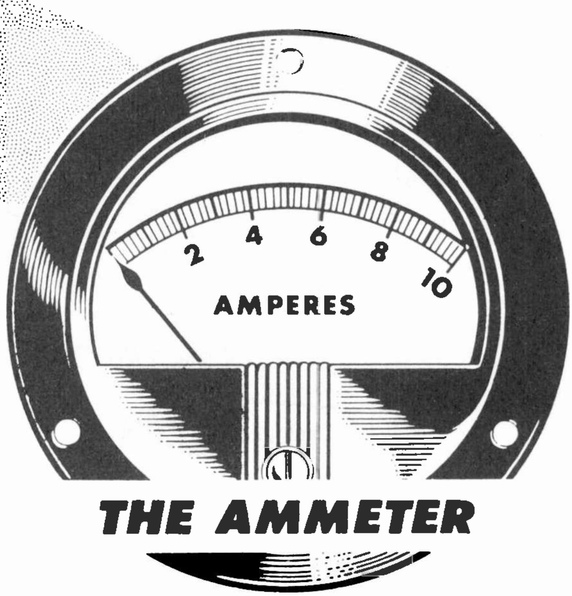
When the amount of current flowing through a circuit is to be measured, the ammeter is always connected in series with the line that delivers current to the circuit; it will be damaged if it is connected in any other way. Because an ammeter indicates the rate of electron movement just as a meter in a water system shows the rate at which gallons of water are used, it follows that in order to show correctly the amount of current being used, the ammeter must be connected into the line (by breaking or opening the line to insert it).



Without ammeter



Ammeter connected in series with line to measure lamp current.

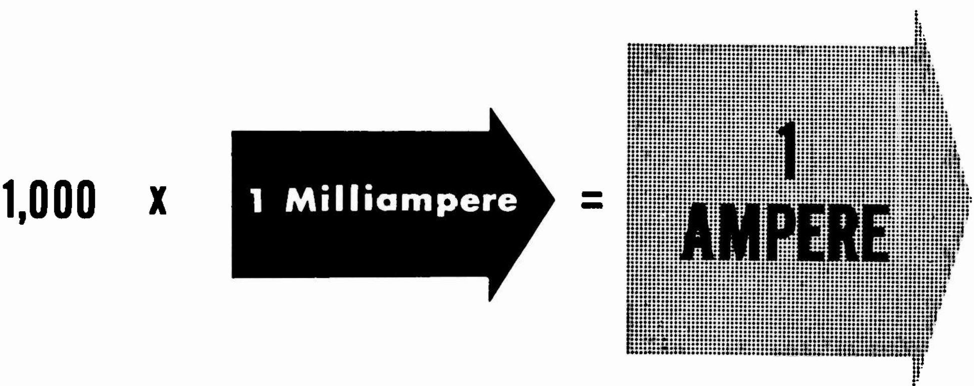


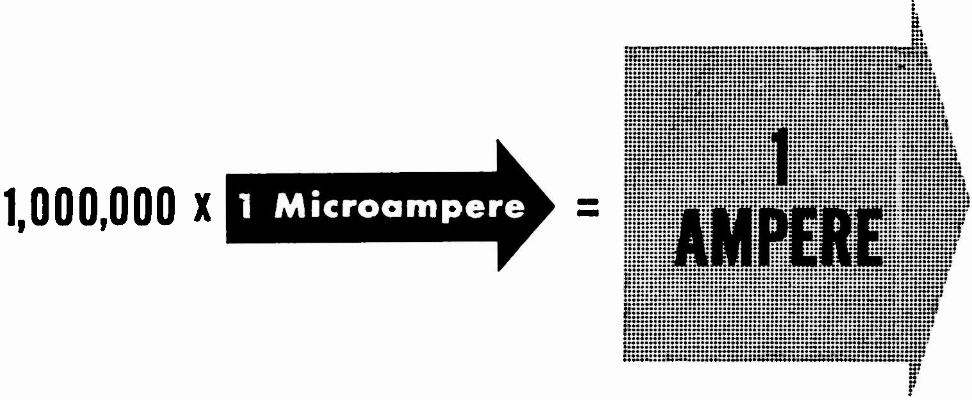
Whenever you use an ammeter, the pointer indicates on the meter scale the number of amperes of current flowing, which is also the number of coulombs passing per second.

How Small Currents Are Measured

While the ampere is the basic unit of measurement for current flow, it is not always a convenient unit to use. Current flows seldom exceed one thousand amperes but may often be as little as one one-thousandth of an ampere. For measuring currents of less than one ampere some other unit is needed. A cup of water is not measured in gallons, nor is the flow of water from a fire hydrant measured in cups. In any kind of measurement a usable unit of measurement is needed. Since current flow seldom exceeds one thousand amperes, the ampere can be used satisfactorily as the unit for currents in excess of one ampere. However, it is not convenient as the unit for currents of less than one ampere.

If the current flow is between one-thousandth of an ampere and one ampere, the unit of measure used is the milliampere (abbreviated ma.), which is equal to one-thousandth ampere. For current flow of less than one-thousandth ampere, the unit used is the microampere, which is equal to one-millionth ampere. Meters used for measuring milliamperes of current are called milliammeters, while meters used for measuring microamperes of current are called microammeters. Units of measurement are subdivided in such a way that a quantity expressed in one unit may be readily changed to another unit, either larger or smaller. For example, in volume measure one-half gallon equals two quarts, and four pints also equals two quarts. The relation between the different units of current is indicated below.





How Units of Current Are Changed

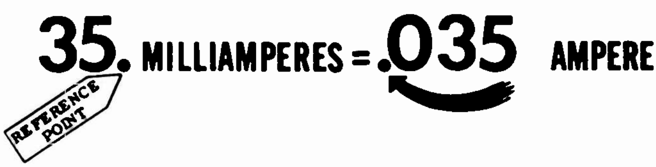
In order to work with electricity, you must be able to change from one unit of current to another. Since a milliampere(ma.) is one-thousandth of an ampere, milliamperes can be changed to amperes by moving the decimal point three places to the left. For example, 35 milliamperes is equal to 0.035 ampere . There are two steps required in order to arrive at the correct answer. First, the original position of the decimal point must be located. The decimal is then moved three places to the left, changing the unit from milliamperes to amperes. If no decimal point is given with the number, it is always understood to follow the last number in the quantity. In the example given, the reference decimal point is after the number 5, and to change from milliamperes to amperes it must be moved three places to the left. Since there are only two whole numbers to the left of the decimal point, a zero must be added to the left of the number to provide for a third place as shown.

When changing amperes to milliamperes you move the decimal point to the right instead of the left. For example, 0.125 ampere equals 125 milliamperes and 16 amperes equals 16,000 milliamperes. In these examples, the decimal point is moved three places to the right of its reference position, with three zeros added in the second example to provide the necessary decimal places.

CHANGING MILLIAMPERES TO AMPERES

35 Milliamperes = ? Ampere

Move decimal point three places to the left.



CHANGING AMPERES TO MILLIAMPERES

.125 Ampere = ? Milliamperes

Move decimal point three places to the right.

How Units of Current Are Changed (continued)

Suppose that you are working with a current of 125 microamperes and you need to express this current in amperes. If you are changing from a large unit to a small unit, the decimal point is moved to the right, while to change from a small unit to a large unit, the decimal point is moved to the left. Since a microampere is one-millionth ampere, the ampere is the larger unit. Then changing microamperes to amperes is a change from small to large units and the decimal point should be moved to the left. In order to change millionths to units, the decimal point must be moved six decimal places to the left so that 125 microamperes equals 0.000125 ampere . The reference point in 125 microamperes is after the 5, and in order to move the decimal point six places to the left you must add three zeros ahead of the number 125. When changing microamperes to milliamperes, the decimal point is moved only three places to the left, and thus 125 microamperes equals 0.125 milliampere .

If your original current is in amperes and you want to express it in microamperes, the decimal point should be moved six places to the right. For example, 3 amperes equals 3,000,000 microamperes, because the reference decimal point after the 3 is moved six places to the right with the six zeros added to provide the necessary places. To change milliamperes to microamperes the decimal point should be moved three places to the right. For example, 125 milliamperes equals 125,000 microamperes, with the three zeros added to provide the necessary decimal places.

CHANGING UNITS OF CURRENT

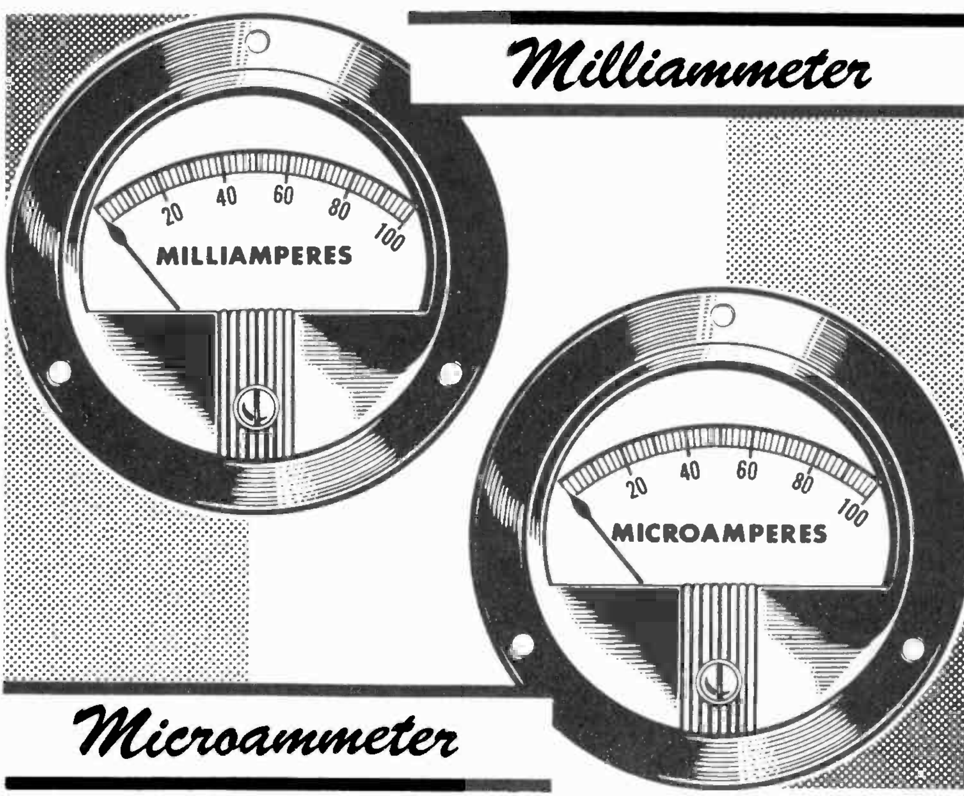
MICROAMPERES TO AMPERES	Move Decimal Point Six Places to the Left. 125. Microamperes = .000125 Ampere
MICROAMPERES TO MILLIAMPERES	Move Decimal Point Three Places to the Left. 125. Microamperes = .125 Milliampere
AMPERES TO MICROAMPERES	Move Decimal Point Six Places to the Right. 3. Amperes = 3,000,000. Microamperes
MILLIAMPERES TO MICROAMPERES	Move Decimal Point Three Places to the Right. 125. Milliamperes = 125,000. Microamperes

Milliammeters and Microammeters

An ammeter having a meter scale range of 0-1 ampere is actually a milliammeter with a range of 0-1000 milliamperes. Fractions are seldom used in electricity so that, on the 0-1 ampere range, a meter reading of 1/2 ampere is given as 0.5 ampere or 500 milliamperes. For ranges less than 1 ampere, milliammeters and microammeters are used to measure current.

If you are using currents between 1 milliampere and 1000 milliamperes, milliammeters are used to measure the amount of current. For currents of less than 1 milliampere, microammeters of the correct range are used, Very small currents of 1 microampere or less are measured on special laboratory type instruments called galvanometers. You will not normally use the galvanometer, since the currents used in electrical equipment are between 100 microamperes and 100 amperes and thus can be measured with a microammeter, milliammeter or ammeter of the correct range. Meter scale ranges for milliammeters and microammeters, like ammeters, are in multiples of 5 or 10 since these multiples are easily changed to other units.

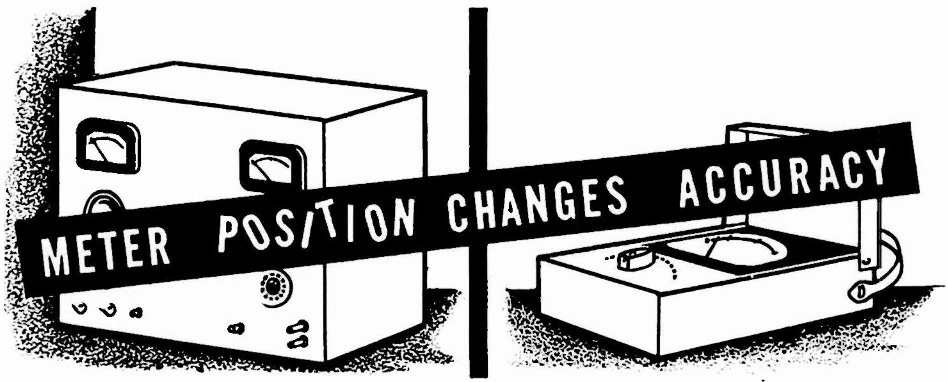
In using a meter to measure current, the maximum reading of the meter range should always be higher than the maximum current to be measured. A safe method of current measurement is to start with a meter having a range much greater than you expect to measure, in order to determine the correct meter to use.



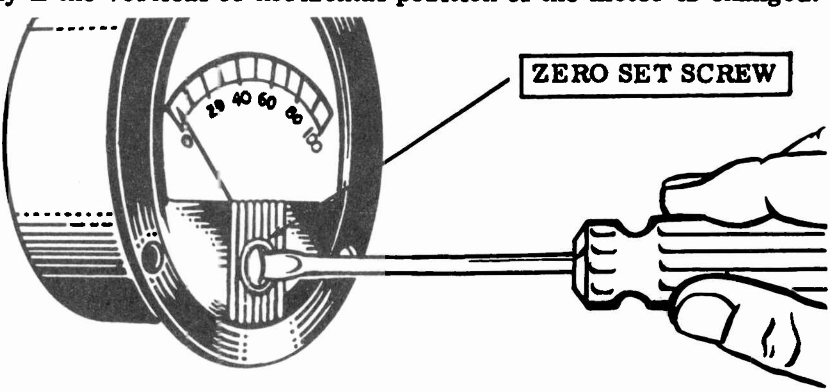
How Meter Scales Are Read

When you work with electricity it is necessary that you take accurate meter readings, to determine whether equipment is working properly, and to discover what is wrong with equipment which is not operating correctly. Many factors can cause meter readings to be inaccurate and it is necessary to keep them in mind whenever you use a meter. You will find the usable range of a meter scale does not include the extreme ends of the scale. For nearly all meters, the most accurate readings are those taken near the center of the scale. When current is measured with an ammeter, milliammeter or microammeter, the range of the meter used should be chosen to give a reading as near to mid-scale as possible.

All meters cannot be used in both horizontal and vertical positions. Due to the mechanical construction of many meters, the accuracy will vary considerably with the position of the meter. Normally, panel-mounting type meters are calibrated and adjusted for use in a vertical position. Meters used in many test sets and in some electrical equipment are made for use in a horizontal position.



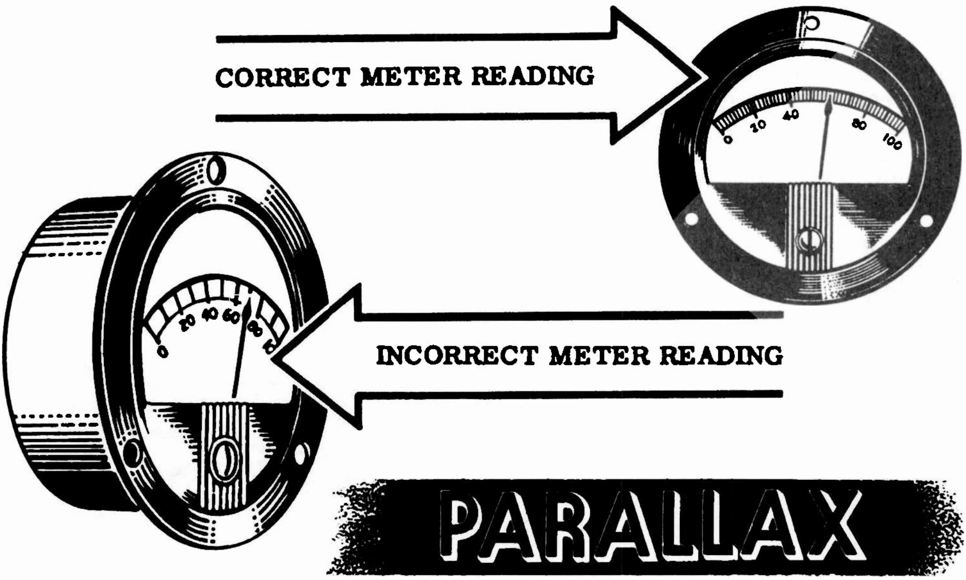
A zero set adjustment on the front of the meter is used to set the meter needle at zero on the scale when no current is flowing. This adjustment is made with a small screwdriver and should be checked when using a meter, particularly if the vertical or horizontal position of the meter is changed.



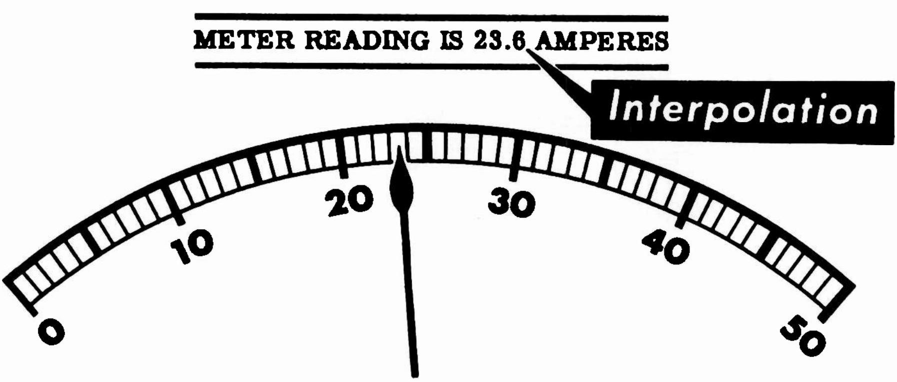
ZEROING A METER

How Meter Scales Are Read (continued)

Meter scales used to measure current are divided into equal divisions, usually with a total of between thirty and fifty divisions. The meter should always be read from a position at right angles to the meter face. Since the meter divisions are small and the meter pointer is raised above the scale, reading the pointer position from an angle will result in an inaccurate reading, often as much as an entire scale division. This type of incorrect reading is called "parallax." Most meters are slightly inaccurate due to the meter construction, and additional error from a parallax reading may result in a very inaccurate reading.



When the meter pointer reads a value of current between two divisions of the scale, usually the nearest division is used as the meter reading. However, if a more accurate reading is desired, the position of the pointer between the divisions is estimated, and the deflection between the scale divisions is added to the lower scale division. Estimating the pointer position is called "interpolation," and you will use this process in many other ways in working with electricity.



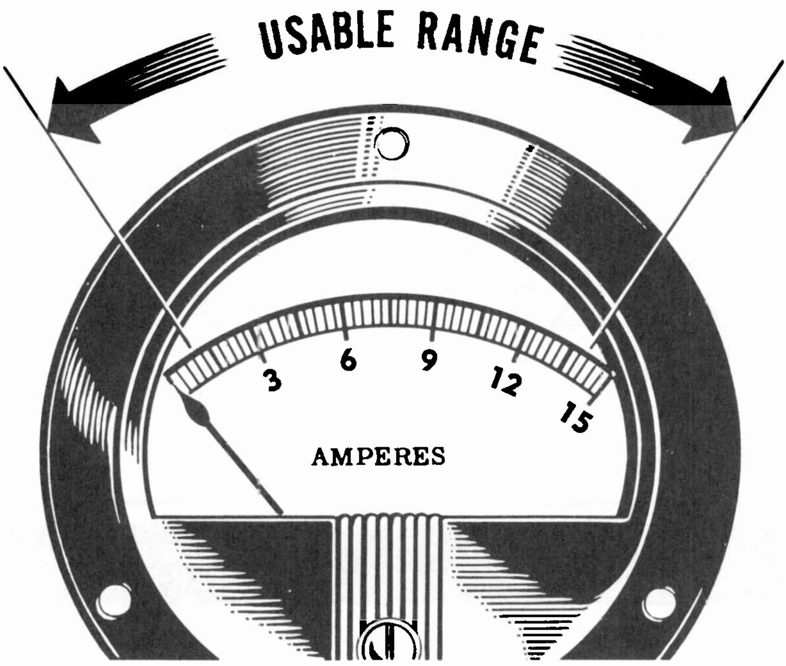
Usable Meter Range

The range of an ammeter indicates the maximum current which can be measured with the meter. Current in excess of this value will cause serious damage to the meter. If an ammeter has a range of 0-15 amp, it will measure any current flow which does not exceed 15 amperes, but a current greater than 15 amperes will damage the meter.

While the meter scale may have a range of 0-15 amperes, its useful range for purposes of measurement will be from about 1 ampere to 14 amperes. When this meter scale indicates a current of 15 amperes, the actual current may be much greater but the meter can only indicate to its maximum range. For that reason the useful maximum range of any meter is slightly less than the maximum range of the meter scale. A current of 0.1 ampere on this meter scale would be very difficult to read since it would not cause the meter needle to move far enough from zero to obtain a definite reading.

Smaller currents such as 0.001 ampere would not cause the meter needle to move and thus could not be measured at all with this meter. The useful minimum range of a meter never extends down to zero, but extends instead only to the point at which the reading can be distinguished from zero.

Ammeter ranges are usually in multiples of 5 or 10 such as 0-5 amperes, 0-50 amperes, etc. Ranges above 0-100 amperes are not common since currents in excess of 100 amperes are seldom used.

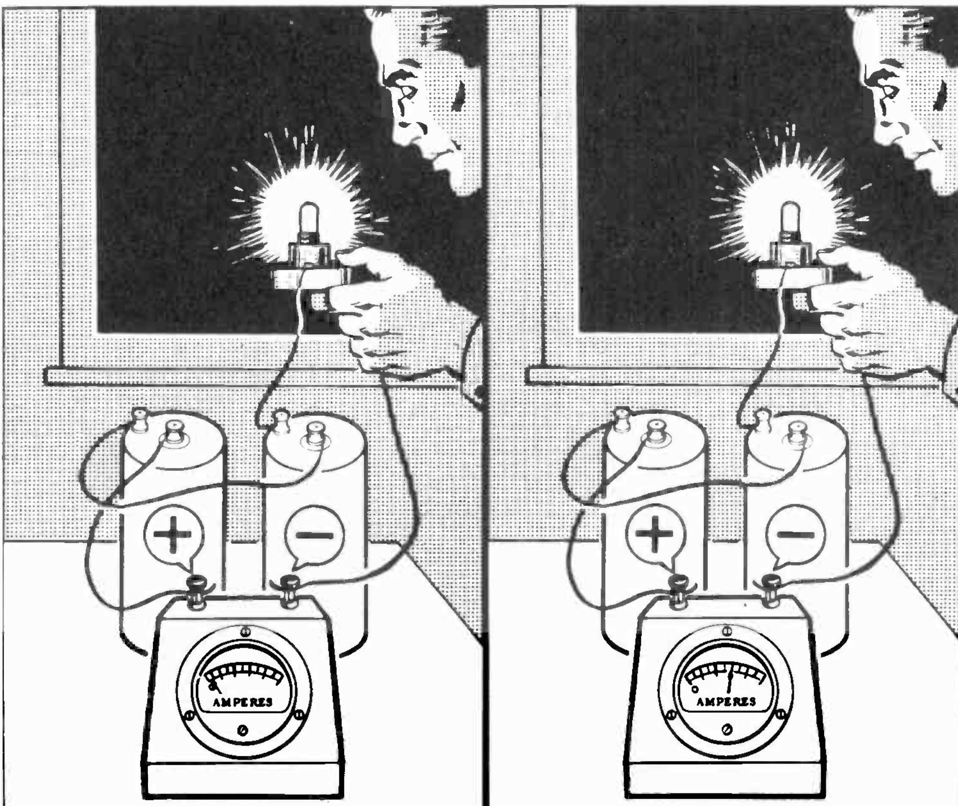


THE AMMETER

Demonstration—Ammeter Ranges

To show the importance of selecting the proper meter range for current measurement, the instructor first connects two dry cells in series to form a battery. Then the positive terminal of the 0-10 amp range ammeter is connected with a length of pushback wire to the positive terminal of the battery. Next, a lamp socket is connected between the negative terminal of the ammeter and the negative terminal of the battery.

The lamp bulb is used as a switch to control current flow. The lamp lights when it is inserted in the socket, and the meter pointer moves slightly—indicating a current flow. The meter reading indicates that the current flow is very low for the meter range used. The pointer is near the low end of the meter scale and the current cannot be read accurately.



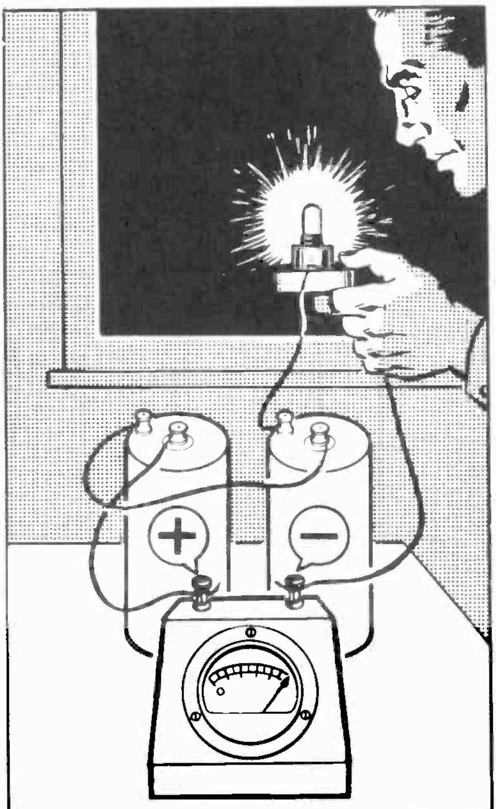
AMMETER RANGE 0-10 SLIGHT READING

AMMETER RANGE 0-1 METER READING

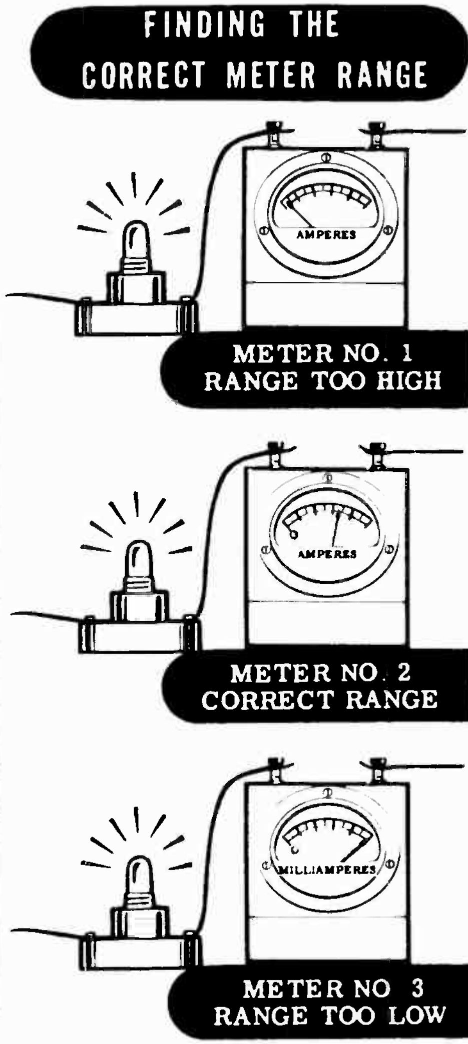
Next, the 0-1 amp range is used instead of the 0-10 amp range. Observe that when the lamp is inserted, its light indicates the current flow is the same as before. However, the meter reading now is near the midscale position of the meter scale, indicating a current flow of slightly more than one-half ampere. Since the reading is near midscale, this is the correct meter range for measuring the current.

Demonstration--Ammeter Ranges (continued)

To show the effect of using a meter having too low a range, the instructor next uses the 0-500 ma. range instead of the 0-1 amp range. Because the current flow is greater than the maximum range of the meter, the pointer deflects beyond the range of the scale and you are unable to read the amount of current flow. If this excess current flows through the meter for any length of time, it will cause serious damage to the meter. For that reason it is more important that the meter range be high enough, than that it be low enough, to obtain a good reading.



MILLIAMMETER RANGE 0-500
READING TOO HIGH

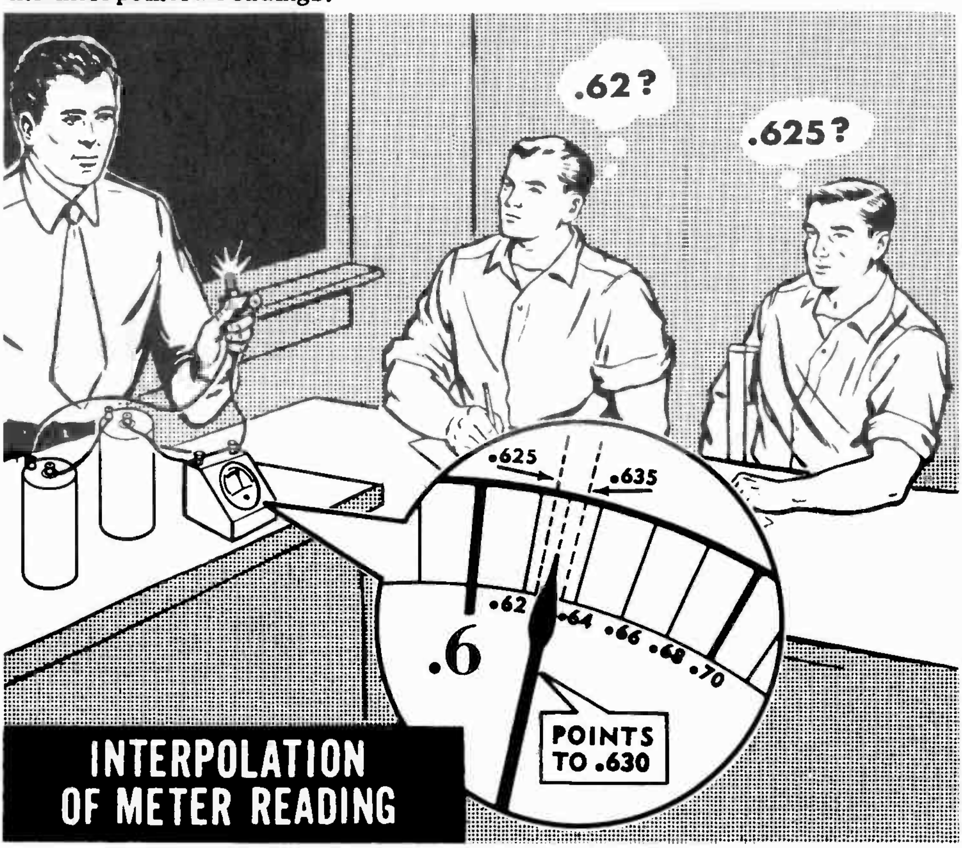


To find the correct meter range where the current expected is not known, you should always start with a meter having a high maximum range and replace it with meters having lower ranges until a meter reading is obtained near mid-scale.

Demonstration—Reading Meter Scales

You have observed that the correct ammeter range to use in measuring the current flow through the lamp is the 0-1 amp range. To show the effects of parallax on meter readings, the instructor uses a 0-1 amp range instead of the 0-500 ma. range. Now, with the lamp inserted, the meter indicates a current flow somewhat greater than one-half ampere. The instructor will ask several trainees to read the meter simultaneously from different positions and record their readings. Notice that the readings taken at wide angles differ considerably from those obtained directly in front of the meter.

Now the entire class reads the meter and interpolates the reading by estimating between scale divisions. Since the meter scale permits reading to two places directly, the interpolation is the third figure of the reading. For example, the scale divisions between .6 and .7 are .62, .64, .66 and .68. If the meter pointer is between the .62 and .64 scale divisions and is halfway between these divisions, the meter reading is .630 ampere. A reading one-fourth of the way past the .62 division is .625 ampere, three-fourths of the way past the .62 division is .635 ampere, etc. Observe that the estimated or interpolated value obtained by everyone is more accurate than the nearest scale division, but there is disagreement among the interpolated readings.

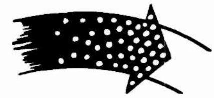


INTERPOLATION OF METER READING

Review of How Current Is Measured

To review what you have found out about how current is measured, consider some of the important facts you have studied and seen demonstrated.

1. AMPERE — Unit of rate of flow of electrons, equal to 1 coulomb per second.



2. MILLIAMPERE — A unit of current equal to one-thousandth ampere.

$$1\,\text{ma.} = \frac{1}{1000}\,\text{amp}$$

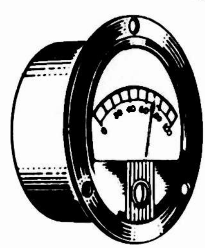
3. MICROAMPERE — A unit of current equal to one-millionth ampere.

$$1\,\mu\text{a} = \frac{1}{1{,}000{,}000}\,\text{amp}$$

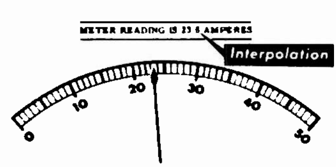
4. AMMETER — A meter used to measure currents of one ampere and greater.

5. MILLIAMMETER — A meter used to measure currents between one-thousandth ampere and one ampere.

6. MICROAMMETER — A meter used to measure currents between one-millionth ampere and one-thousandth ampere.

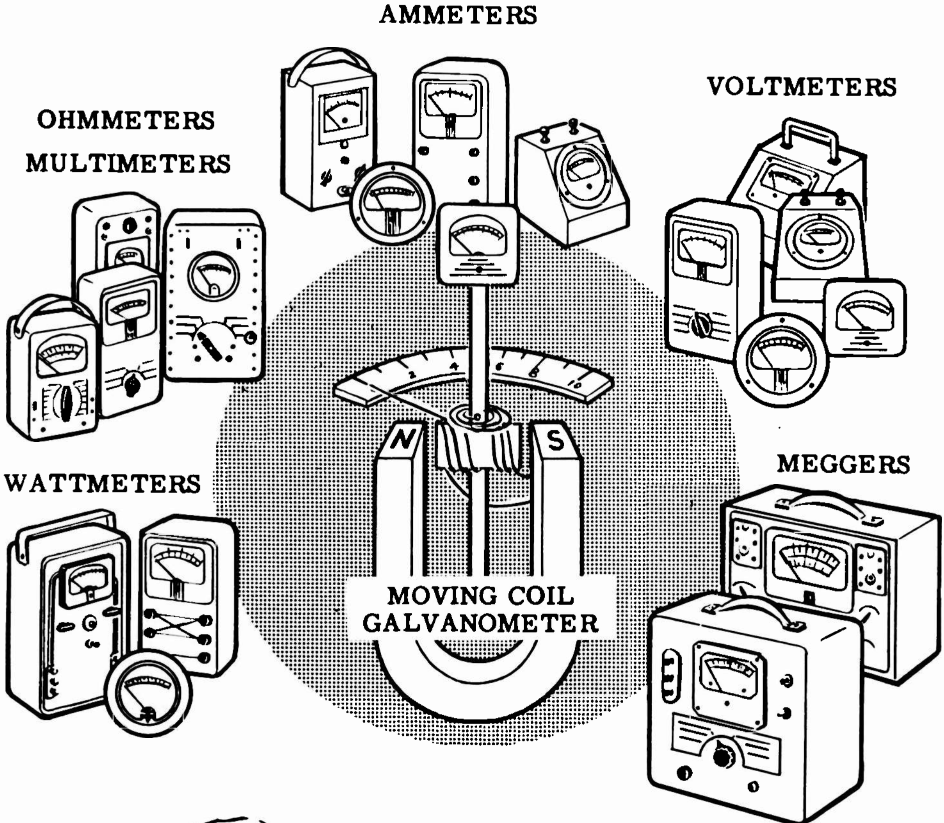


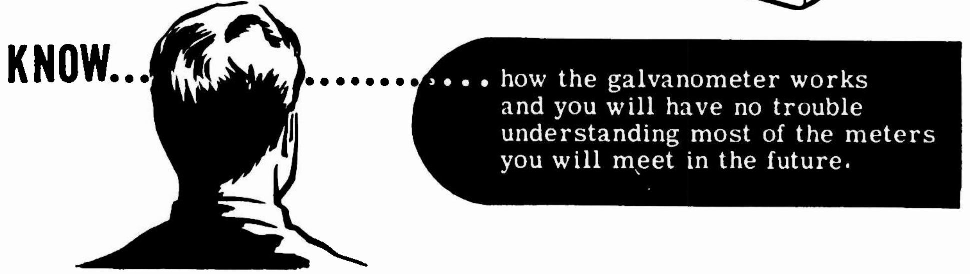
7. PARALLAX — Meter reading error due to taking a reading from an angle.



8. INTERPOLATION — Estimating the meter reading between two scale divisions.

The Basic Meter Movement



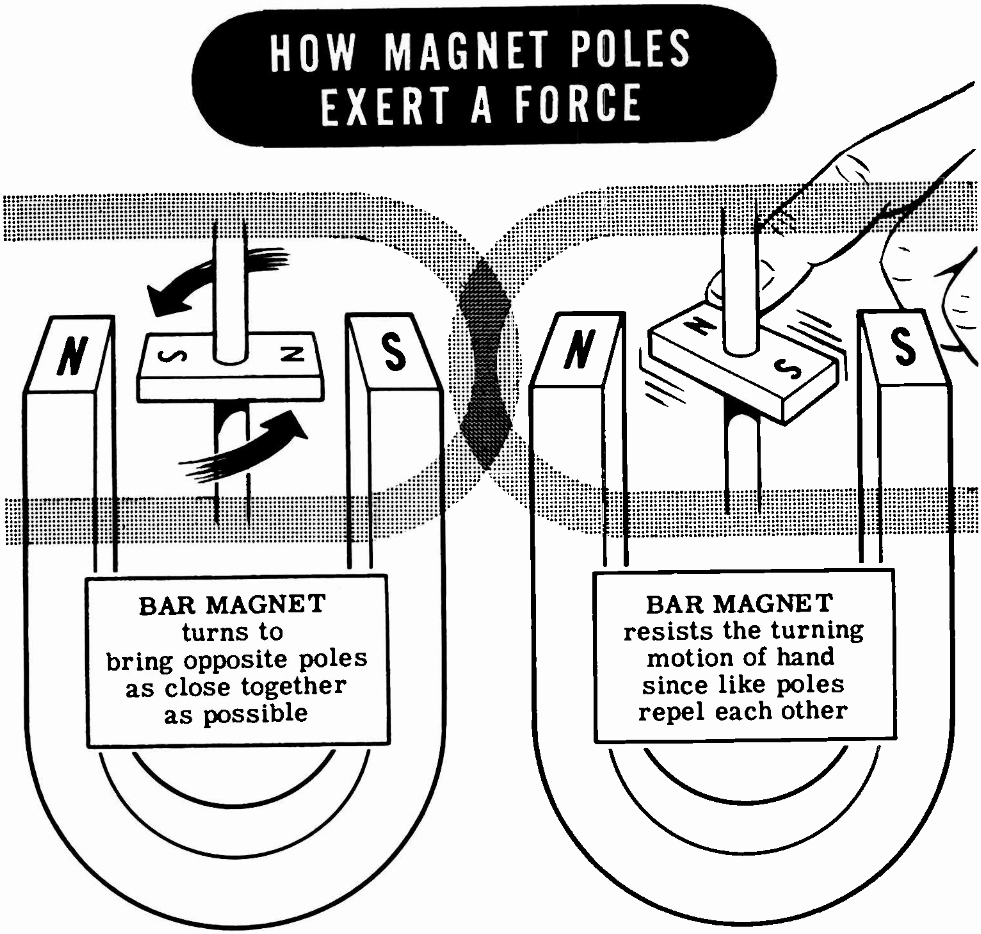


You have used meters for sometime now to show you whether or not an electric current was flowing and how much current was flowing. As you proceed further with your work in electricity, you will find yourself using meters more and more often. Meters are the right hand of anyone working in electricity or electronics, so now is the time for you to find out how they operate. All the meters you have used and nearly all the meters you will ever use are made with the same type of meter "works" or movement. This meter movement is based on the principles of an electric current-measuring device called the "moving coil galvanometer." Nearly all modern meters use the moving coil galvanometer as a basic meter movement, so once you know how it works you will have no trouble understanding all the meters you will be using in the future.

The Basic Meter Movement (continued)

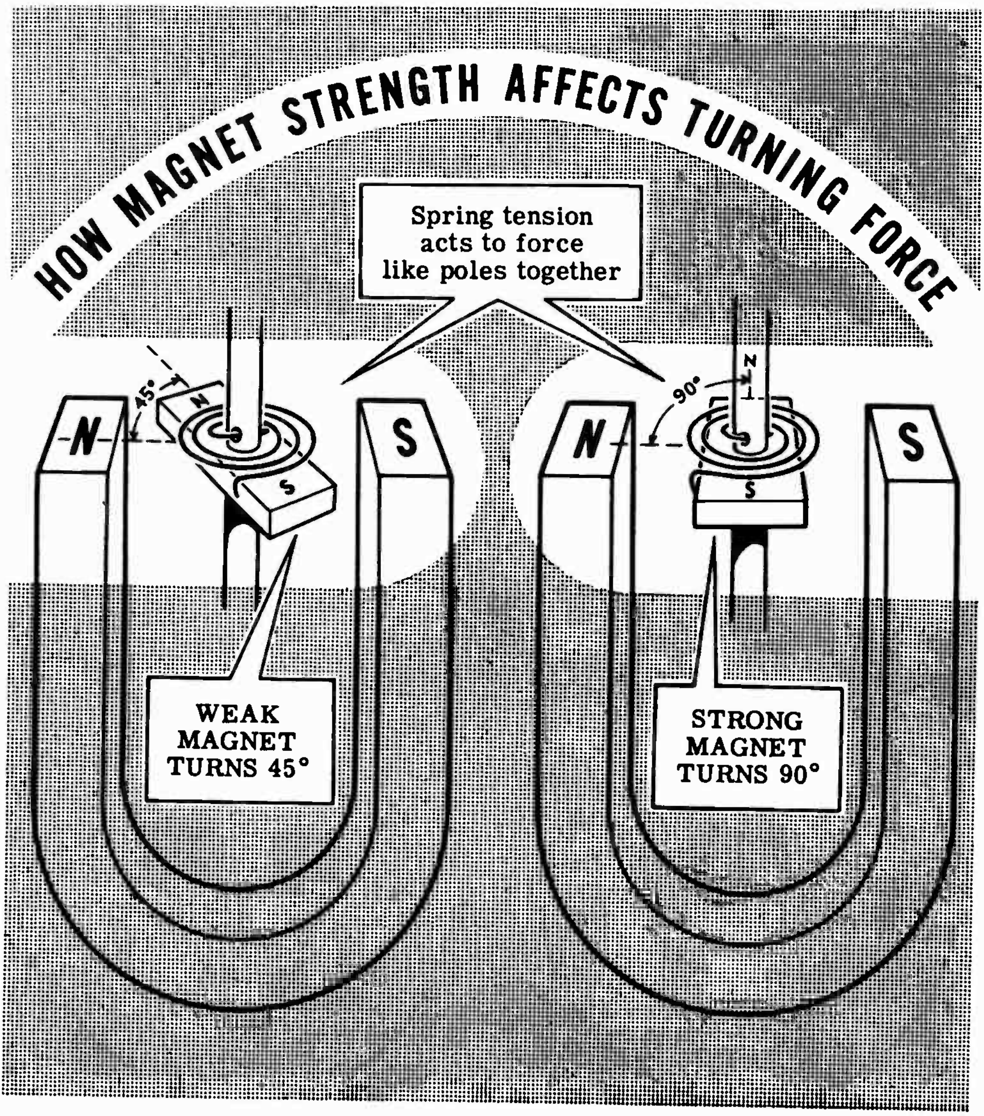
The galvanometer works on the principle of magnetic attraction and repulsion. According to this principle, which you have already learned, like poles repel each other and unlike poles attract each other. This means that two magnetic North poles will repel each other as will two magnetic South poles, while a North pole and South pole will attract one another. You can see this very well if you suspend a bar magnet on a rigidly mounted shaft, between the poles of a horseshoe magnet.

If the bar magnet is allowed to turn freely, you will find that it turns until its North pole is as close as possible to the South pole of the horseshoe magnet and its South pole is as close as possible to the North pole of the horseshoe magnet. If you turn the bar magnet to a different position, you will feel it trying to turn back to the position where the opposite poles are as near as possible to each other. The further you try to turn the bar magnet away from this position, the greater force you will feel. The greatest force will be felt when you turn the bar magnet to the position in which the like poles of each magnet are as close as possible to each other.



The Basic Meter Movement (continued)

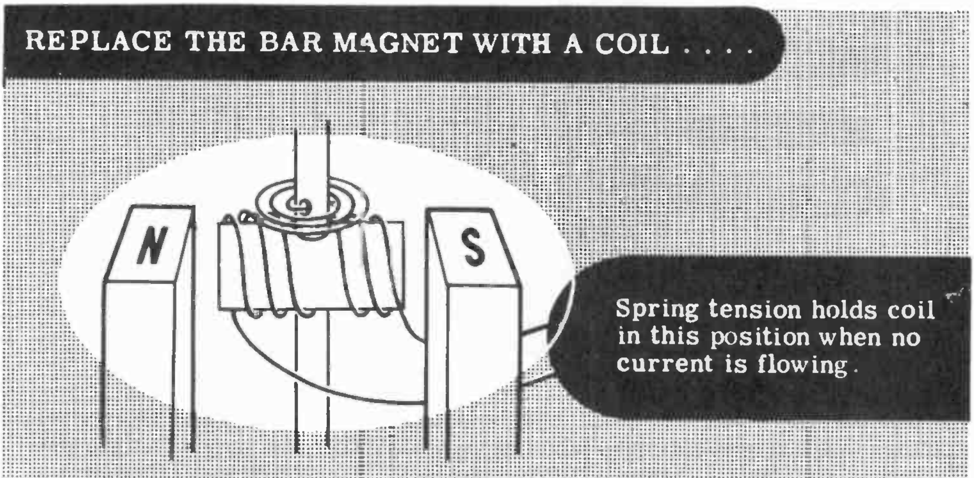
The forces of attraction and repulsion between magnetic poles become greater when stronger magnets are used. You can see this if you attach a spring to the bar magnet in such a way that the spring will have no tension when the North poles of the two magnets are as close as possible to each other. With the magnets in this position the bar magnet would normally turn freely to a position which would bring its North pole as close as possible to the South pole of the horseshoe magnet. With the spring attached it will turn only part way, to a position where its turning force is balanced by the force of the spring. If you were to replace the bar magnet with a stronger magnet, the force of repulsion between the like poles would be greater and the bar magnet would turn further against the force of the spring.

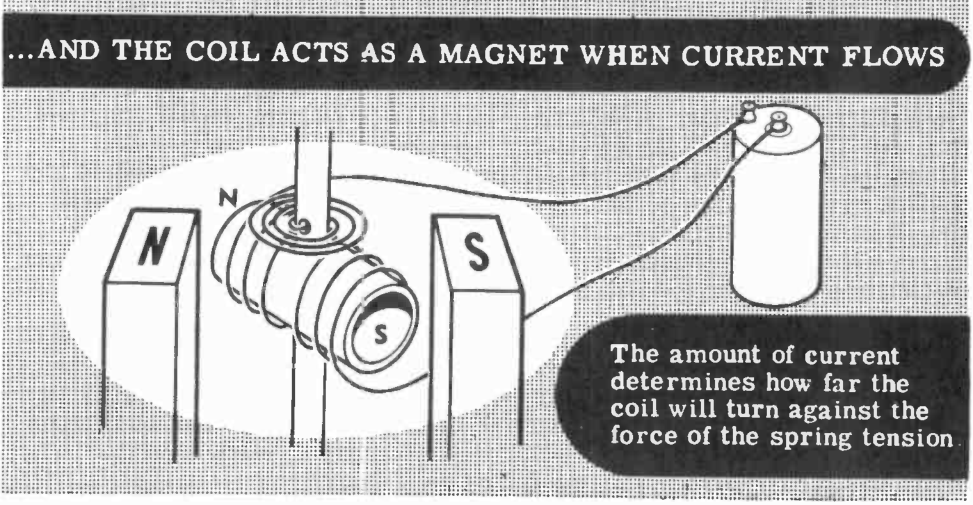


The Basic Meter Movement (continued)

If you remove the bar magnet and replace it with a coil of wire, you have a galvanometer. Whenever an electric current flows through this coil of wire, it acts like a magnet. The strength of this wire coil magnet depends on the size, shape and number of turns in the coil and the amount of electric current flowing through the coil. If the coil itself is not changed in any way, the magnetic strength of the coil will depend on the amount of current flowing through the coil. The greater the current flow in the coil, the stronger the magnetic strength of the wire coil magnet.

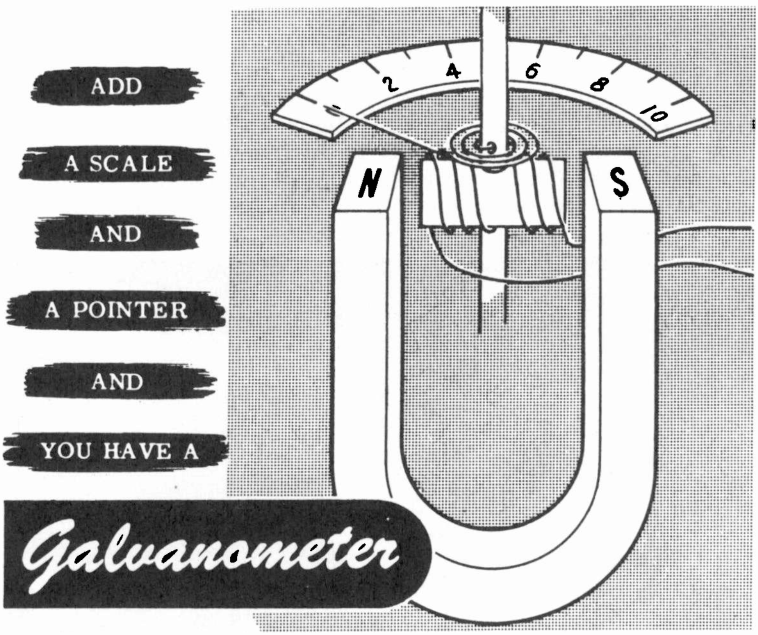
If there is no current flow in the coil, it will have no magnetic strength and the coil will turn to a position where there will be no tension on the spring. If you cause a small electric current to flow through the coil, the coil becomes a magnet and the magnetic forces—between the wire coil magnet and the horseshoe magnet—cause the coil to turn until the magnetic turning force is balanced by the force due to tension in the spring. When a larger current is made to flow through the coil, the magnet strength of the coil is increased and the wire coil turns further against the spring tension.





The Basic Meter Movement (continued)

When you want to find out how much current is flowing in a circuit, all you need to do is to connect the coil into the circuit and measure the angle through which the coil turns away from its position at rest. To measure this angle, and to calculate the amount of electric current which causes the coil to turn through this angle, is very difficult. However, by connecting a pointer to the coil and adding a scale for the pointer to travel across, you can read the amount of current directly from the scale.



Now that you have added a scale and a pointer, you have a basic DC meter, known as the D'Arsonval-type movement, which depends upon the operation of magnets and their magnetic fields. Actually, there are two magnets in this type of meter; one a stationary permanent horseshoe magnet, the other an electromagnet. The electromagnet consists of turns of wire wound on a frame, and the frame is mounted on a shaft fitted between two permanently-mounted jewel bearings. A lightweight pointer is attached to the coil, and turns with it to indicate the amount of current flow. Current passing through the coil causes it to act as a magnet with poles being attracted and repelled by those of the horseshoe magnet. The strength of the magnetic field about the coil depends upon the amount of current flow. A greater current produces a stronger field, resulting in greater forces of attraction and repulsion between the coil sides and the magnet's poles.

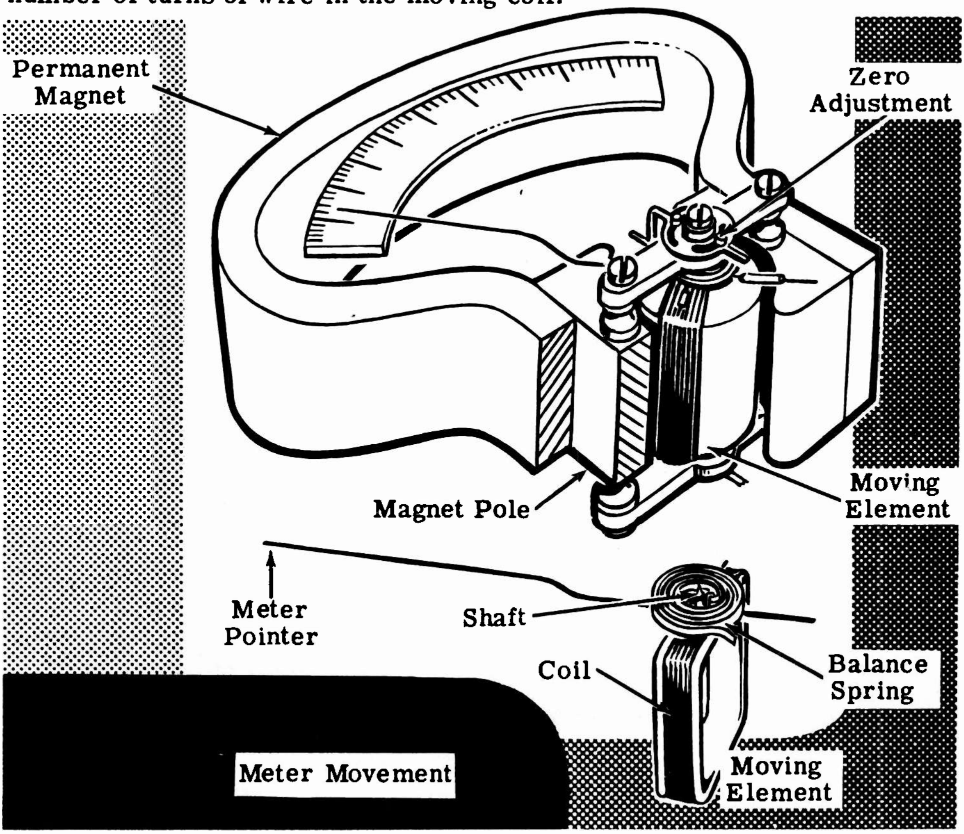
The magnetic forces of attraction and repulsion cause the coil to turn so that the unlike poles of the coil and magnet will be brought together. As the coil current increases, the coil becomes a stronger magnet and turns further because of the greater magnetic forces between the coil and magnet poles. Since the amount by which the coil turns depends upon the amount of coil current, the meter indicates the current flow directly.

Meter Movement Considerations

While galvanometers are useful in laboratory measurements of extremely small currents, they are not portable, compact or rugged enough for use in military equipment. A modern meter movement uses the principles of the galvanometer but is portable, compact, rugged and easy to read. The coil is mounted on a shaft fitted between two permanently-mounted jewel bearings. To indicate the amount of current flow a lightweight pointer is attached to the coil and turns with the coil.

Balance springs on each end of the shaft exert opposite turning forces on the coil and, by adjusting the tension of one spring, the meter pointer may be adjusted to read zero on the meter scale. Since temperature change affects both coil springs equally, the turning effect of the springs on the meter coil is canceled out. As the meter coil turns, one spring tightens to provide a retarding force, while the other spring releases its tension. In addition to providing tension, the springs are used to carry current from the meter terminals through the moving coil.

In order that the turning force will increase uniformly as the current increases, the horseshoe magnet poles are shaped to form semi-circles. This brings the coil as near as possible to the north and south poles of the permanent magnet. The amount of current required to turn the meter pointer to full-scale deflection depends upon the magnet strength and the number of turns of wire in the moving coil.

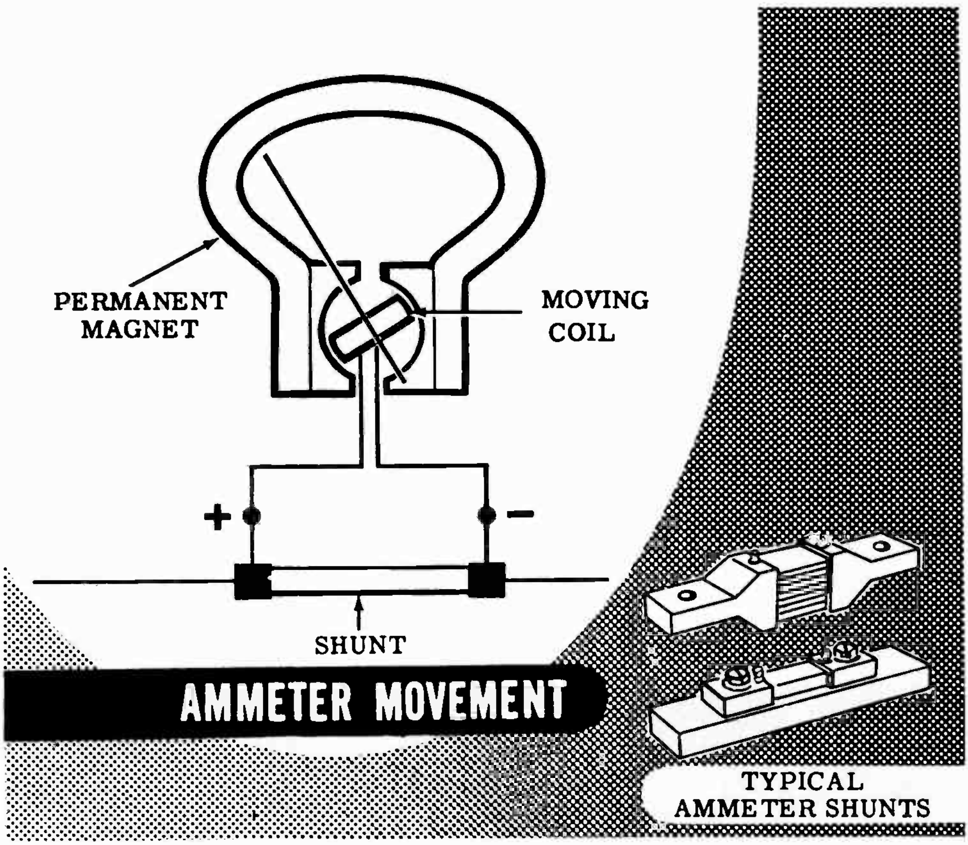


Meter Movement

How Meter Ranges Are Changed

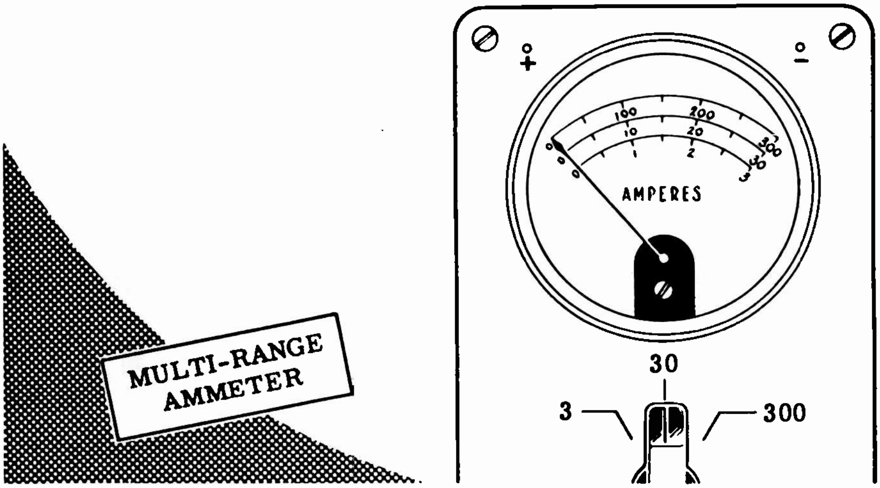
Meter ranges could be changed by using magnets of different strength or by changing the number of turns in the coil, since either of these changes would alter the amount of current needed for full-scale deflection. However, the wire used in the coil must always be large enough to carry the maximum current of the range the meter is intended for, and therefore changing the wire size would only be practical in the small current ranges, since large wire cannot be used as a moving coil. To keep the wire size and the coil small, basic meter movements are normally limited to a range of 1 milliampere or less. Also, for using a meter for more than one range, it is impractical to change the magnet or the coil each time the range is changed.

For measuring large currents a low range meter is used with a shunt, which is a heavy wire connected across the meter terminals to carry most of the current. This shunt allows only a small part of the current to actually flow through the meter coil. Usually a 0-1 milliampere meter is used, with the proper-sized shunt connected across its terminals to achieve the desired range. The 0-1 milliammeter is a basic meter movement which you will find in various types of meters you will use.



Multi-Range Ammeters

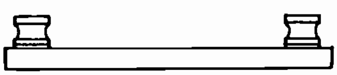
You have seen that you can change the range of an ammeter by the use of shunts. The range will vary according to the resistive value of the shunt. Some ammeters are built with a number of internal shunts, and a switching arrangement which is used to parallel different shunts across the meter movement to measure different currents. Thus a single meter movement can be used as a multi-range ammeter. A scale for each range is painted on the meter face. The diagram below shows a multi-range ammeter with a 0-3, 0-30, 0-300 ampere range. Note the three scales on the meter face.



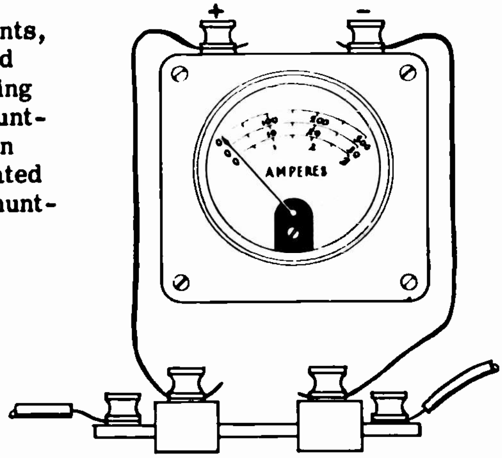
When a multi-range ammeter is used to measure an unknown current, the highest range is always used first, then the next highest range, and so on until the needle is positioned about midscale. In this way you can be assured that the current is not excessive for the meter range, and you will never have the unfortunate experience of burning out a meter movement, or of wrapping the needle around the stop-peg.

Some multimeters use external shunts, and do away with internal shunts and the switching arrangement. Changing range for such a meter involves shunting it with the appropriate shunt. In the diagram the ammeter is calibrated to read 30 amperes full-scale by shunting it with the 30-ampere shunt.

3-ampere shunt



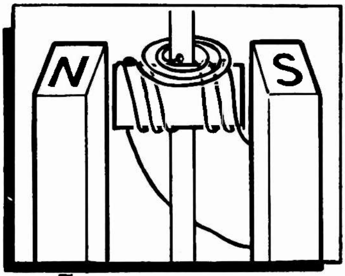
300-ampere shunt



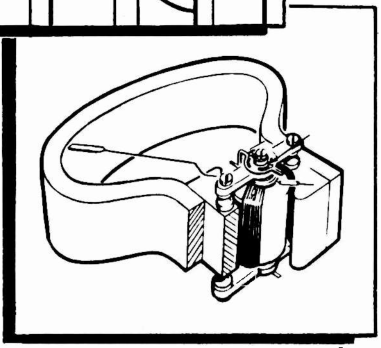
30-ampere shunt

Review of Meter Movement

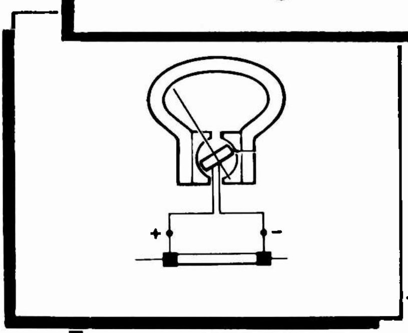
It is very possible that you may never need to repair a meter but, in order to properly use and care for meters, you need to know how a meter works. Suppose you review what you have studied.



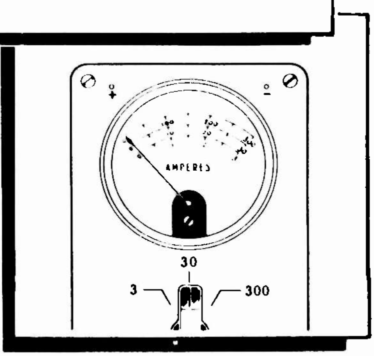
METER COIL — Moving coil which acts as a magnet when current flows in the coil.



METER MOVEMENT — Current-measuring instrument consisting of a moving coil suspended between the poles of a horseshoe magnet. Current in the coil causes the coil to turn.



BASIC AMMETER MOVEMENT — 0-1 ma. milliammeter movement with shunt wire across the meter terminals to increase the meter scale range.



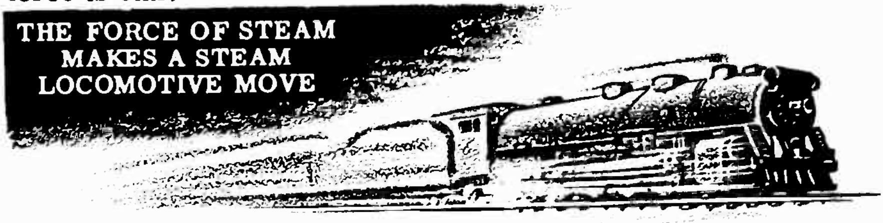
MULTI-RANGE AMMETER — A single meter movement used for measuring different current ranges. Each range requires a different shunt. The shunts may be inside the meter movement and controlled by a switching arrangement or they may be external, in which case they are connected in parallel with the meter binding posts.

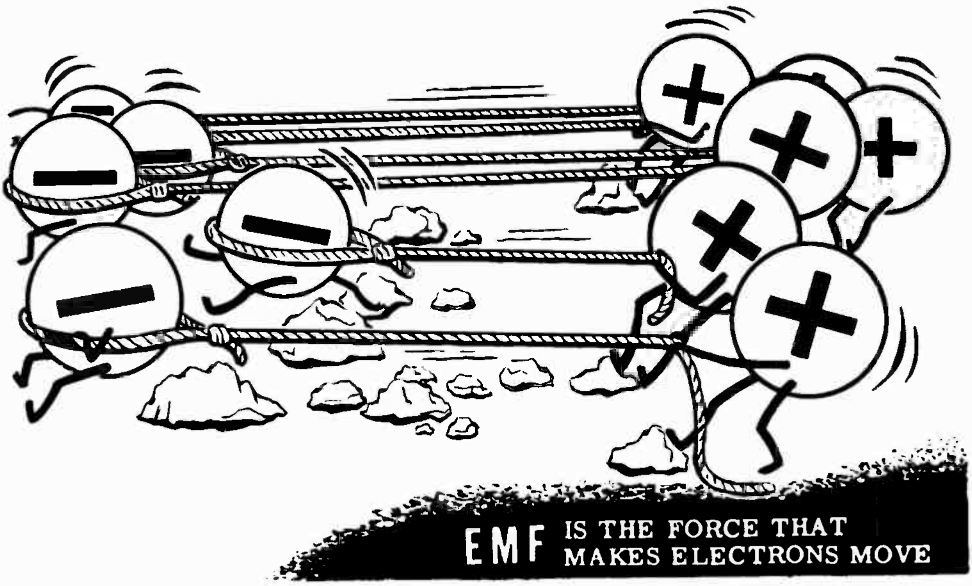
What EMF Is

Current flow takes place whenever most of the electron movement in a material is in one direction. You have found out that this movement is from a (-) charge to a (+) charge and occurs only as long as a difference in charge exists.

To create a charge, electrons must be moved, either to cause an excess or a lack of electrons at the point where the charge is to exist. A charge may be created by any of the six sources of electricity which you have studied about previously. These sources furnish the energy required to do the work of moving electrons to form a charge. Regardless of the kind of energy used to create a charge, it is changed to electrical energy once the charge is created; and the amount of electrical energy existing in the charge is exactly equal to the amount of the source energy required to create this charge.

When the current flows, the electrical energy of the charges is utilized to move electrons from less positive to more positive charges. This electrical energy is called electromotive force (emf) and is the moving force which causes current flow. Electrons may be moved to cause a charge by using energy from any of the six sources of electricity; but, when electrons move from one charge to another as current flow, the moving force is emf.



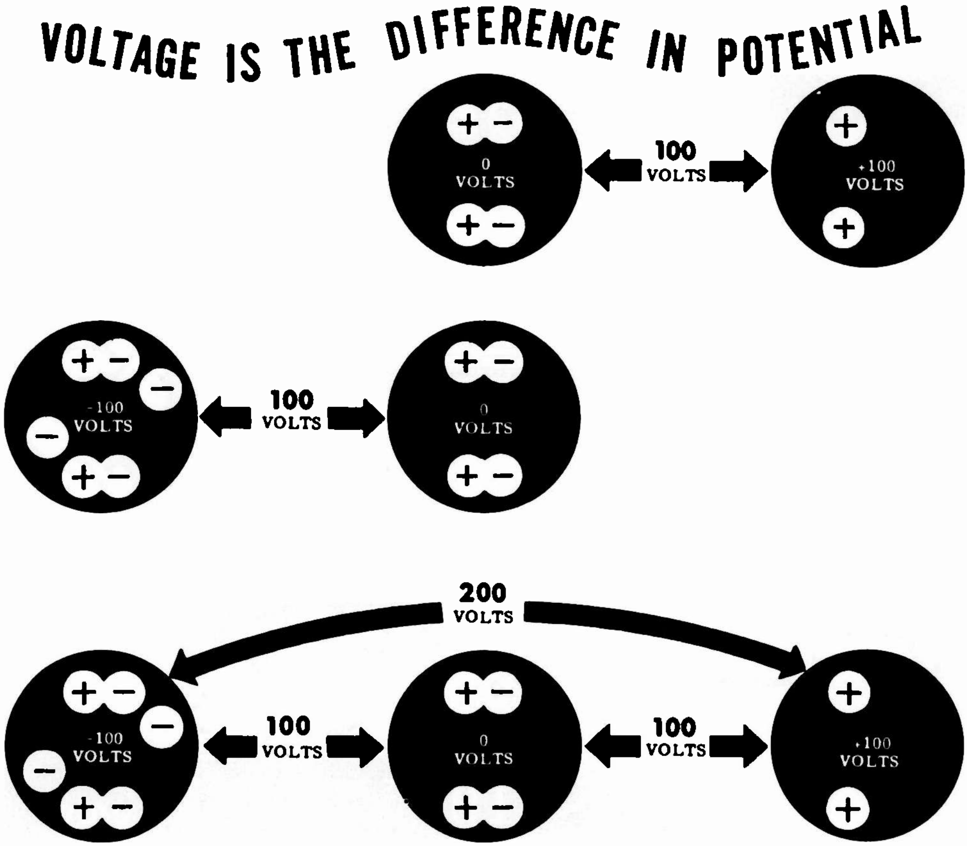


What EMF Is (continued)

An electric charge, whether positive or negative, represents a reserve of energy. This reserve energy is potential energy as long as it is not being used. The potential energy of a charge is equal to the amount of work done to create the charge, and the unit used to measure this work is the volt. The electromotive force of a charge is equal to the potential of the charge and is expressed in volts.

When two unequal charges exist, the electromotive force between the charges is equal to the difference in potential of the two charges. Since the potential of each charge is expressed in volts the difference in potential is also expressed in volts. The difference in potential between two charges is the electromotive force acting between the charges—commonly called voltage.

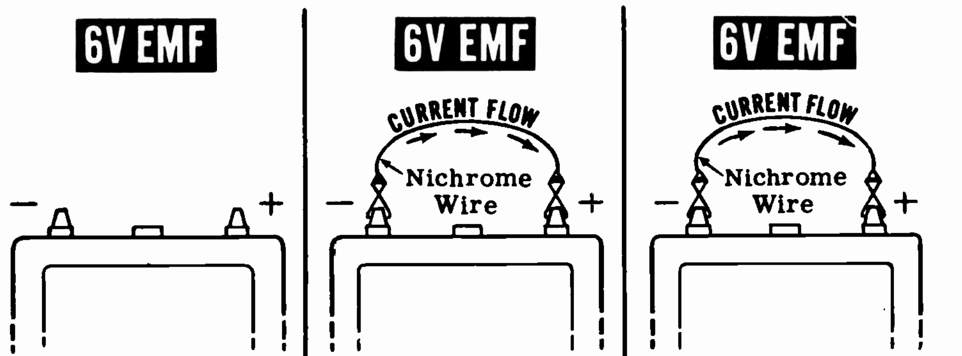
Voltage or a difference in potential exists between any two charges which are not exactly equal. Even an uncharged body has a potential difference with respect to a charged body; it is positive with respect to a negative charge and negative with respect to a positive charge. Voltage exists, for example, between two unequal positive charges or between two unequal negative charges. Thus voltage is purely relative and is not used to express the actual amount of charge, but rather to compare one charge to another and indicate the electromotive force between the two charges being compared.



How EMF Is Maintained

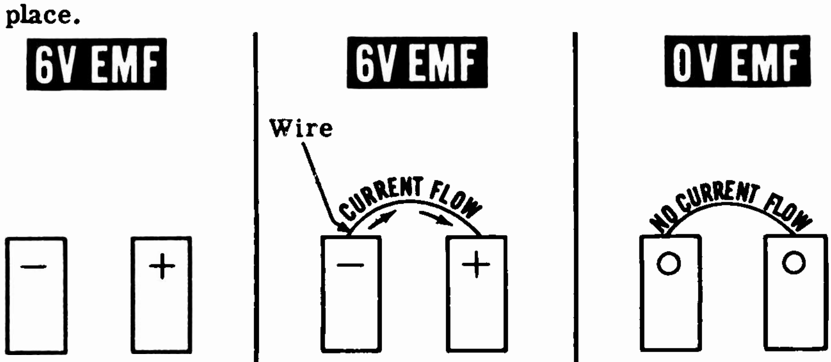
Of the six sources of electricity, you will usually use only magnetism and chemical action. Electric charges obtained from friction, pressure, heat and light are only used in special applications and are never used as a source of electric power.

In order to cause continuous current flow, electric charges must be maintained so that the difference of potential remains the same at all times. At the terminals of a battery, opposite charges exist caused by the chemical action within the battery, and as current flows from the (-) terminal to the (+) terminal the chemical action maintains the charges at their original value. A generator acts in the same manner, with the action of a wire moving through a magnetic field maintaining a constant charge on each of the generator terminals. The voltage between the generator or battery terminals remains constant and the charges on the terminals never become equal to each other as long as the chemical action continues in the battery and as long as the generator wire continues to move through the magnetic field.



Battery | Battery discharging | EMF maintained

If the charges were not maintained at the terminals, as in the case of two charged bars shown below, current flow from the (-) terminal to the (+) terminal would cause the two charges to become equal as the excess electrons of the (-) charge moved to the (+) charge. The voltage between the terminals then would fall to zero volts and current flow would no longer take place.

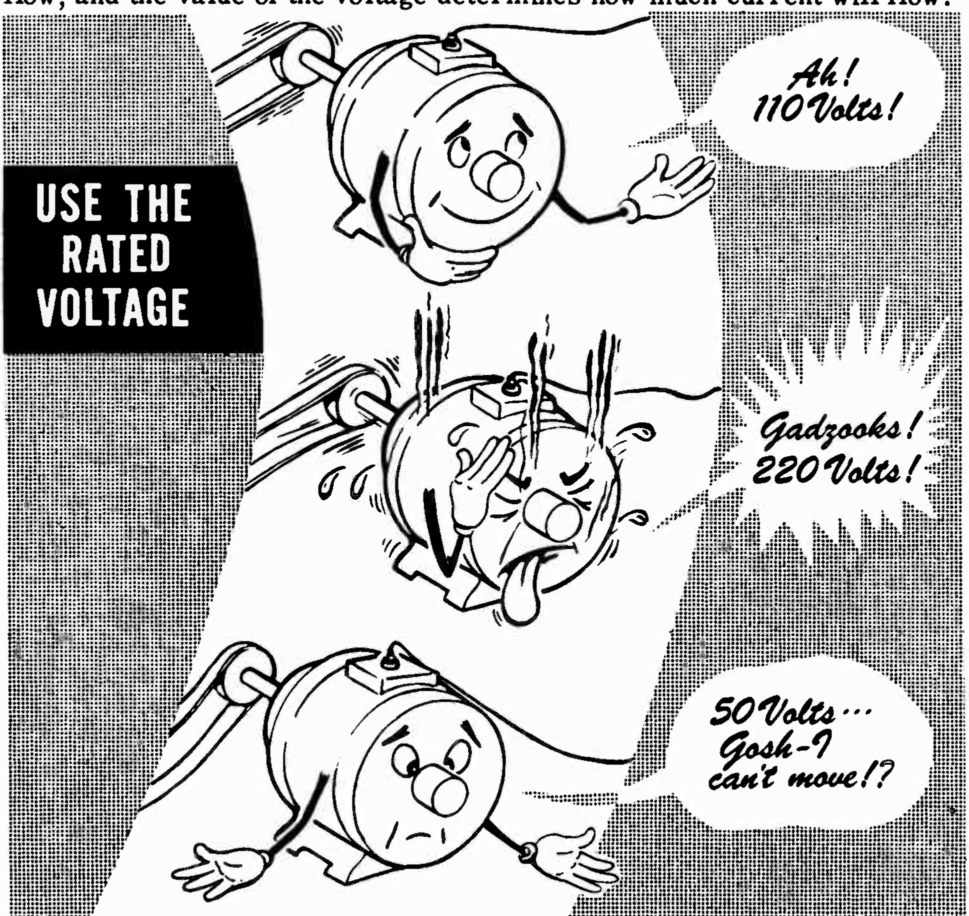


Charged bars | Bars discharging | EMF not maintained

Voltage and Current Flow

Whenever two points of unequal charge are connected, a current flows from the more negative to the more positive charge. The greater the emf or voltage between the charges, the greater the amount of current flow. Electrical equipment is designed to operate with a certain amount of current flow, and when this amount is exceeded the equipment may be damaged. You have seen all kinds of equipment such as electric lamps, motors, radios, etc. with the voltage rating indicated. The voltage will differ on certain types of equipment, but it is usually 110 volts. This rating on a lamp, for example, means that 110 volts will cause the correct current flow. Using a higher voltage will result in a greater current flow and "burn out" the lamp, while a lower voltage will not cause enough current flow.

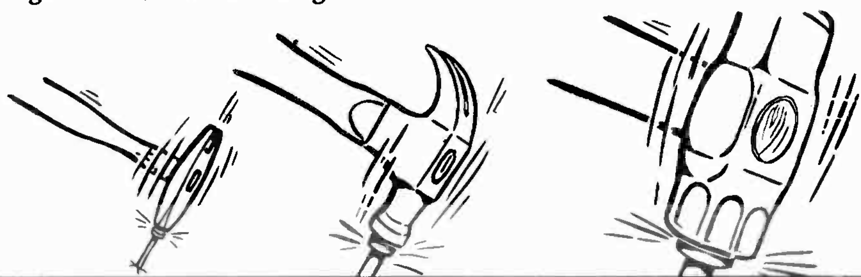
If a motor is designed to operate on 110 volts and you connect it to a 220-volt electric power line, the motor will be "burned out" due to excessive current flow; but the same motor placed across a 50-volt line will not operate properly because not enough current will flow. While current flow makes equipment work, it takes emf or voltage to cause the current to flow, and the value of the voltage determines how much current will flow.



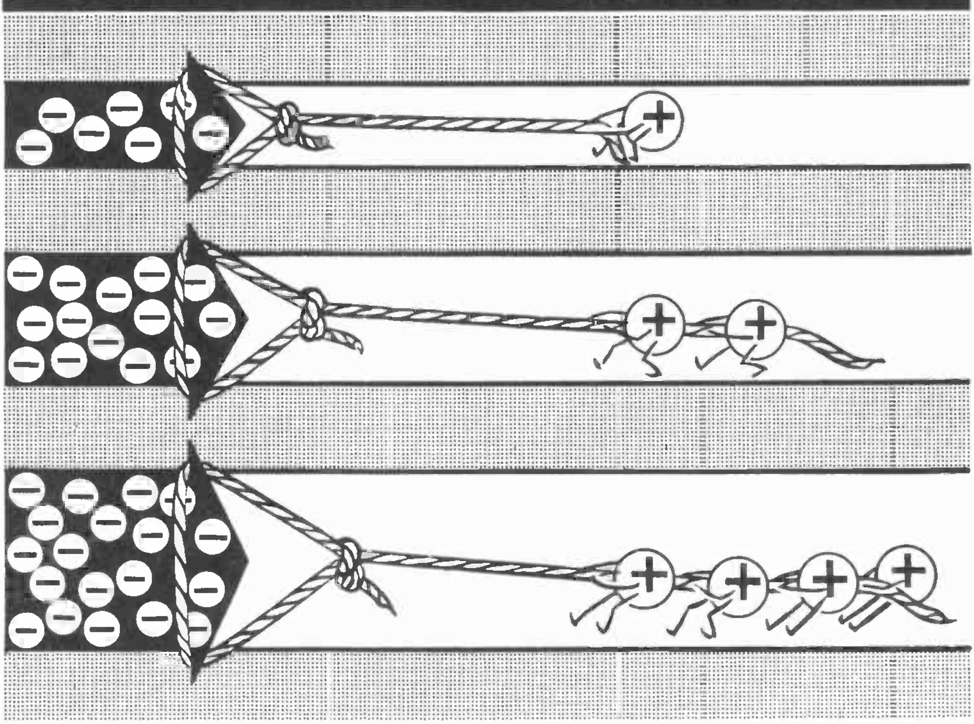
Voltage and Current Flow (continued)

Electromotive force—voltage—is used like any other type of force. To drive a nail you might use any number of different size hammers but only one size would furnish exactly the right amount of force for a particular nail. You would not use a sledge hammer to drive a tack nor a tack hammer to drive a large spike. Choosing the correct size hammer to drive a nail is just as important as finding the correct size nail to use for a given job.

Similarly, electrical devices and equipment operate best when the correct current flows, but for a given device or equipment you must choose the correct amount of voltage to cause just the right amount of current flow. Too large a voltage will cause too much current flow, while too small a voltage will not cause enough current flow.



A LARGE NAIL REQUIRES A LARGE HAMMER ....
.... MORE CURRENT FLOW REQUIRES MORE VOLTAGE

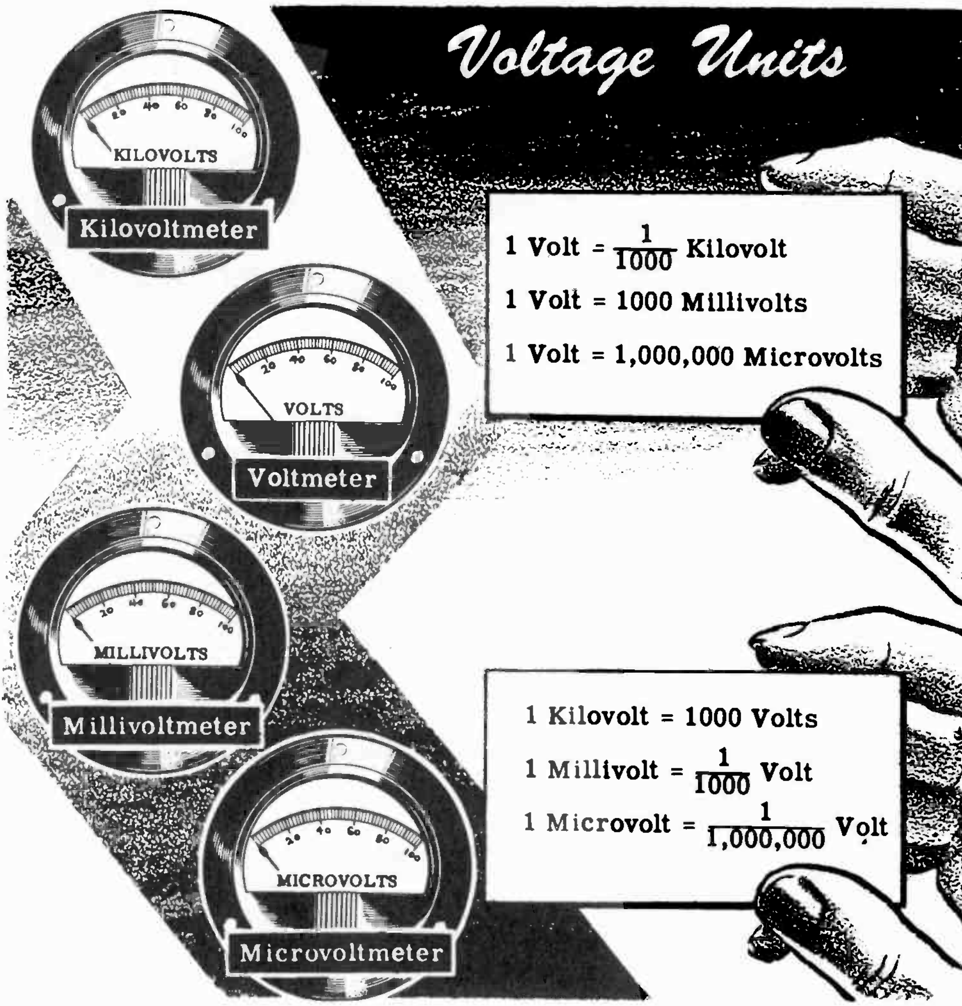


HOW VOLTAGE IS MEASURED

Units of Voltage

The electromotive force between two unequal charges is usually expressed in volts but, when the difference in potential is only a fraction of a volt or is more than a thousand volts, other units are used. For voltages of less than one volt, millivolts and microvolts are used, just as milliamperes and microamperes are used to express currents less than one ampere. While current seldom exceeds one thousand amperes, voltage often exceeds one thousand volts, so that the kilovolt—equal to one thousand volts—is used as the unit of measurement. When the potential difference between two charges is between one-thousandth of a volt and one volt, the unit of measure is the millivolt; when it is between one-millionth volt and one-thousandth volt, the unit is the microvolt.

Meters for measuring voltage have scale ranges in microvolts, millivolts, volts and kilovolts, depending on the units of voltage to be measured. Ordinarily you will work with voltages between 1 and 500 volts and use the volt as a unit. Voltages of less than 1 volt and more than 500 volts are not used except in special applications of electrical equipment.



Changing Units of Voltage

Units of voltage measurement are changed in the same way that units of current are changed. In order to change millivolts to volts, the decimal point is moved three places to the left, and to change volts to millivolts the decimal point is moved three places to the right. Similarly, in changing microvolts to volts, the decimal point is moved six places to the left, and in changing volts to microvolts the decimal point is moved six places to the right. These examples show that, in changing units, the same rules of moving the decimal point apply to both voltage and current.

Kilo (meaning one thousand) is not used to express current, but since it is used to express voltage, you need to know how to change kilovolts to volts and the reverse. To change kilovolts to volts the decimal point is moved three places to the right, and to change volts to kilovolts it is moved three places to the left. For example, 5 kilovolts equals 5,000 volts, since the decimal point is after the 5. Three zeros are added to provide the necessary places. Also, 450 volts equals 0.45 kilovolt as the decimal point is moved three places to the left.

CHANGING VOLTAGE UNITS

VOLTS TO KILOVOLTS

Move the decimal point
3 places to the left.

450 volts = .45 kilovolt

KILOVOLTS TO VOLTS

Move the decimal point
3 places to the right.

5 kilovolts = 5000 volts

VOLTS TO MILLIVOLTS

Move the decimal point
3 places to the right.

15 volts = 15000 millivolts

MILLIVOLTS TO VOLTS

Move the decimal point
3 places to the left.

500 millivolts =.5 volt

VOLTS TO MICROVOLTS

Move the decimal point
6 places to the right.

15 volts = 15,000,000 microvolts

MICROVOLTS TO VOLTS

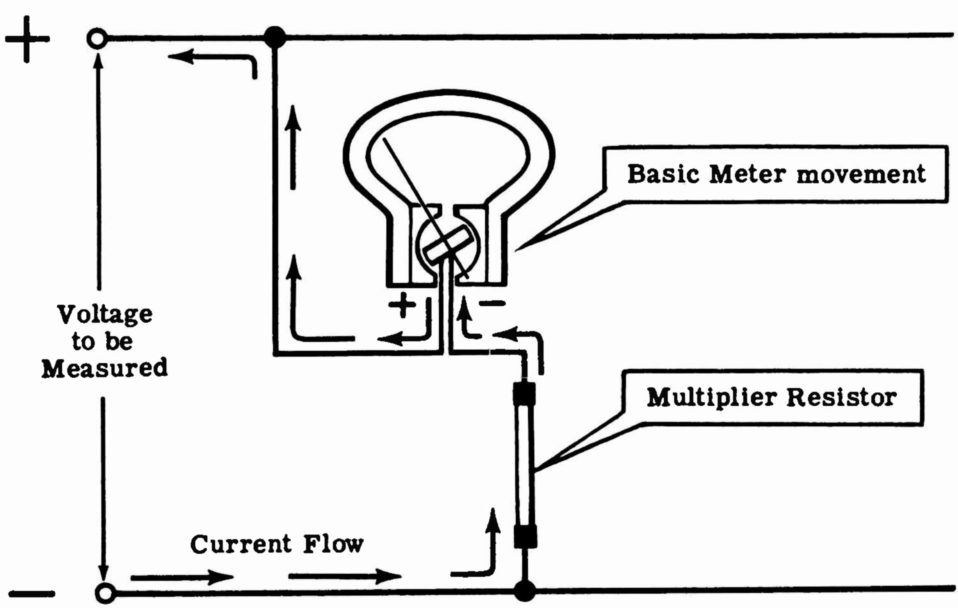
Move the decimal point
6 places to the left.

3505 microvolts =.003505 volt

How a Voltmeter Works

An ammeter measures the rate at which charges are moving through a material. Since the rate of current flow varies with the voltage difference between charges, a greater current flow through a given material indicates a greater voltage across the given material. Voltage is measured by a voltmeter, which measures the current flow through a given material, called a multiplier resistor, connected in series with it. A little later you will find out more about resistors and resistance. For a given multiplier, the meter will indicate a large current if the voltage is high, or a small current if the voltage is low. The meter scale can then be marked in volts.

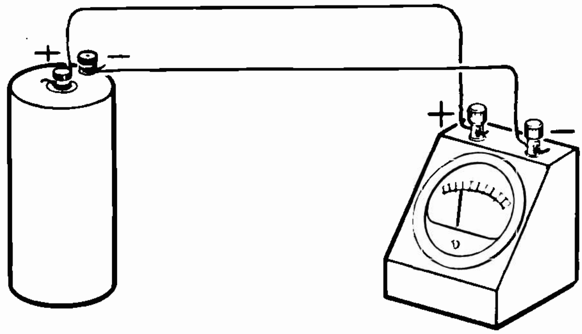
The multiplier resistor determines the scale range of a voltmeter. Since the multiplier is built into most of the voltmeters you will use, you can measure voltage by making very simple connections. Whenever the (+) meter terminal is connected to the (+) terminal of the voltage source and the (-) meter terminal to the (-) terminal of the voltage source, with nothing else connected in series, the meter reads voltage directly. When using a voltmeter it is important to observe the correct meter polarity and to use a meter with a maximum scale range greater than the maximum voltage you expect to read.



VOLTMETER

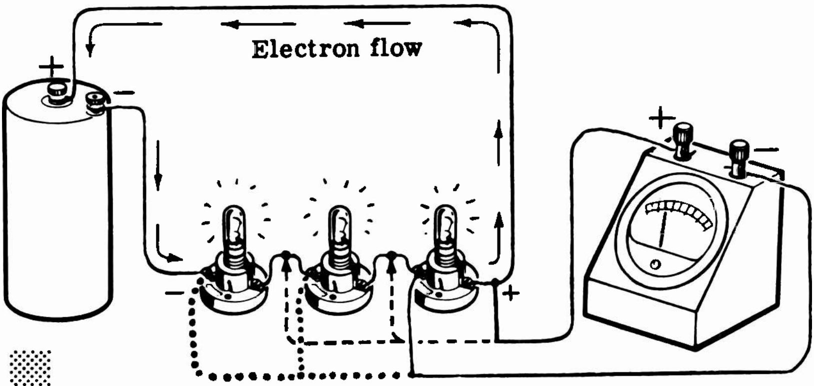
How a Voltmeter is Used

A voltmeter is used to measure electrical pressure anywhere in a circuit. If it is to measure a source of voltage such as a battery, the negative side of the voltmeter is always connected to the negative side of the battery, and the positive side of the voltmeter is always connected to the positive side of the battery. If these connections are reversed, the meter needle will move to the left of the zero mark, and a reading cannot be obtained.



CONNECT A VOLTMETER PLUS TO PLUS - MINUS TO MINUS

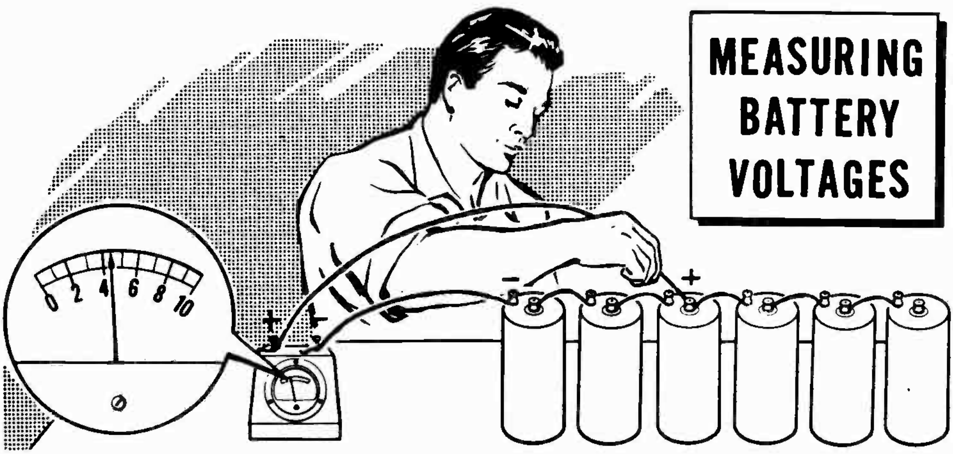
When the voltmeter is to measure the voltage drop across a load, the negative lead is connected to the side of load into which the electrons enter (the - side), and the positive lead is connected to the side of the load from which the electrons emerge (the + side).



HOW TO CONNECT A VOLTMETER ACROSS A LOAD

Demonstration—Voltage and Current Flow

In order to show the effect of voltage on current flow, the instructor connects six dry cells in series to form a 9-volt battery, connecting (+) to (-) between the cells. Using an 0-10 volt voltmeter, he connects the (-) meter terminal to the (-) battery terminal. He then touches the (+) meter terminal to each cell (+) terminal in turn. Observe that the cell voltages add and that, using the battery (-) terminal and the various cell (+) terminals, voltages of 1.5, 3, 4.5, 6, 7.5 and 9 volts are obtainable.

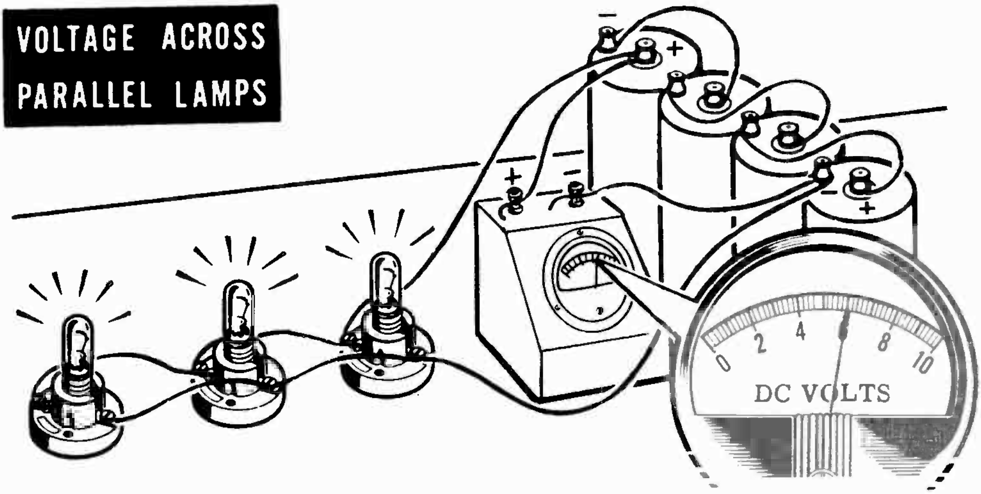


Next, two pushback wire leads are connected to the terminals of a lamp socket and the voltmeter is connected across the socket terminals. The socket lead from the (-) meter terminal is connected to the (-) battery terminal, and a 6-volt lamp is inserted in the socket. As the instructor touches the socket lead which connects to the (+) meter terminal to each of the battery (+) terminals in turn, notice that as the voltage indicated by the voltmeter reading rises the lamp light is brighter—indicating that more current is flowing. You see that the lamp, which is rated for 6 volts, lights with excessive brightness on 7.5 and 9 volts, indicating that the voltage is beyond the lamp rating. You also see that for voltages of less than 6 volts the lamp is dim—indicating that the voltage is too low for proper operation.

Demonstration—Voltage and Current Flow (continued)

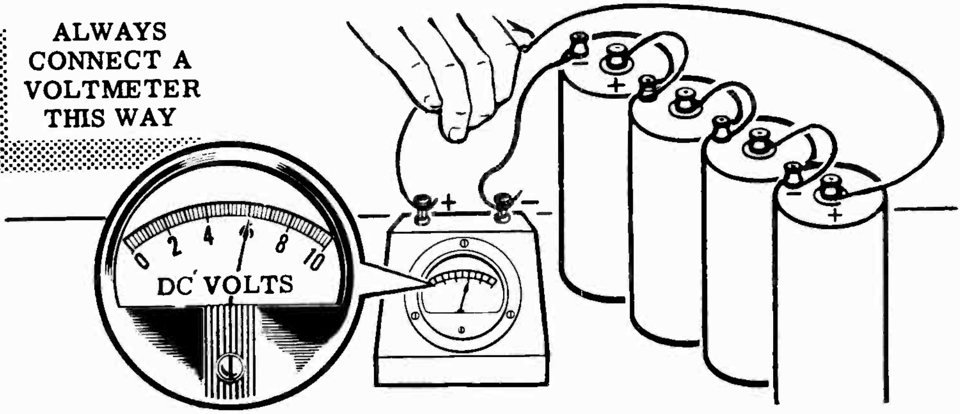
Two cells are now removed from the battery to form a 6-volt battery. The instructor connects the voltmeter across this battery, making certain to observe the correct meter polarity, and you see that it reads 6 volts. Now three lamp sockets are connected in parallel; this parallel combination is connected across the 6-volt battery, and lamps are inserted into the sockets. As each lamp is inserted notice that each lamp lights with the same brilliance as that of the first lamp, which indicates an increase in current flow between the battery terminals, but that the voltmeter indicates very little change in the charges at the battery terminals.

VOLTAGE ACROSS PARALLEL LAMPS



The instructor stresses the importance of correct connection of the voltmeter. A voltmeter should always be connected so that its positive lead goes to the plus side and its negative lead goes to the minus side of the voltage points under measurement. If the leads are incorrectly placed the needle will read down scale so that an accurate reading cannot be obtained, and it will also be impossible to determine whether or not the voltmeter range you are using is high enough to include the voltages under measurement. The meter may be damaged, too, even during the comparatively short time it takes to reverse the meter leads.

ALWAYS CONNECT A VOLTMETER THIS WAY



Multi-range Voltmeters

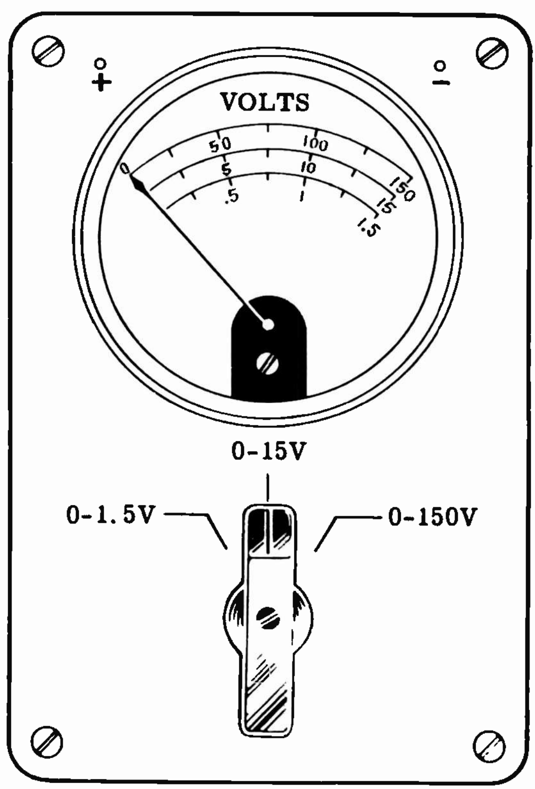
The range of any voltmeter can be increased by the addition of a multiplier to the voltmeter circuit, in series with the basic meter movement. The multiplier causes reduction of the deflection of the pointer on the meter, and by using multipliers of known values, the deflection can be reduced as much as desired.

Multi-range voltmeters, like multi-range ammeters, are instruments which you will use frequently. They are physically very similar to ammeters, and their multipliers are usually located inside the meter, with suitable switches or sets of terminals on the outside for selecting range. Proper range is selected by starting with the highest range and working downward, until the needle reads about midscale.

Because they are lightweight, portable, and can be set up for different voltage ranges by the flick of a switch, multi-range voltmeters are extremely useful.

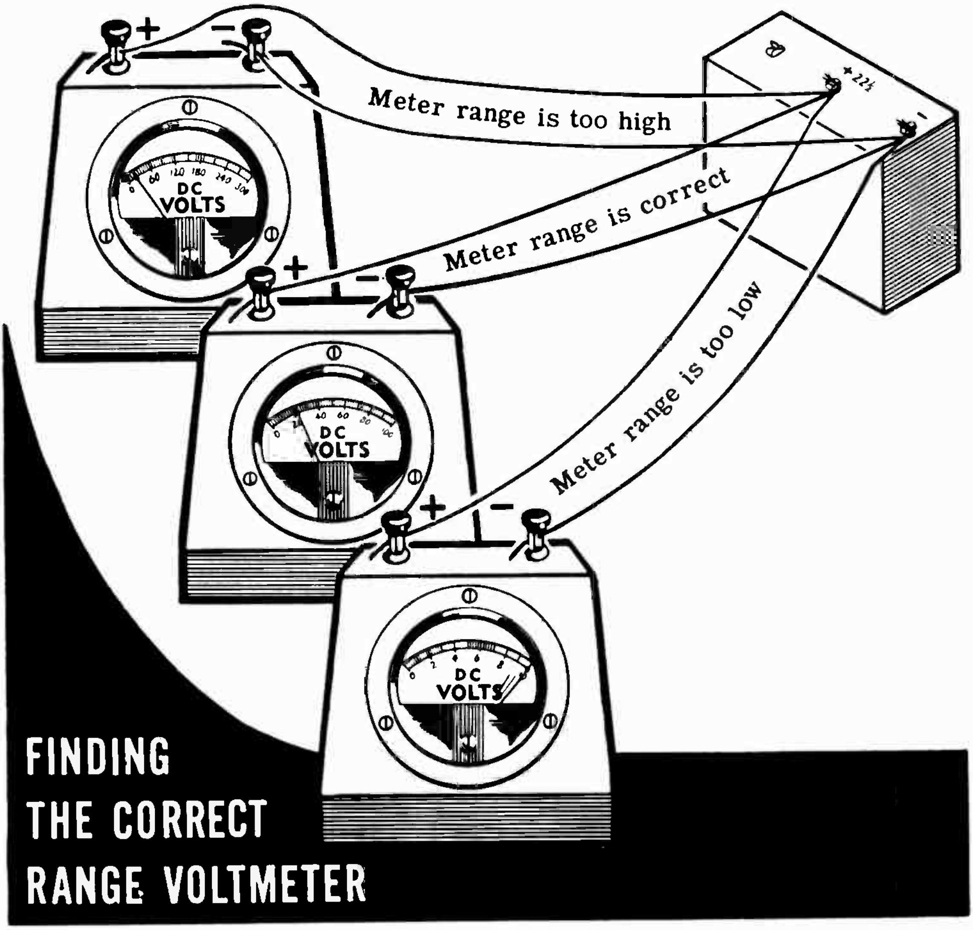
The simplified drawing below shows a three-range, multi-range voltmeter.

TYPICAL 3-RANGE MULTI-RANGE VOLTMETER



Demonstration—Voltmeter Ranges

To demonstrate the proper method to use in selecting the correct voltmeter range to measure a DC voltage, the instructor connects separate wire leads to the (-) battery terminal and to the (+) 22.5-volt battery terminal. Across these leads, he connects each of the voltmeters in turn. As you see, the deflection on the 0-300 volt range is too small to read properly, and the deflection on the 0-10 volt range is beyond the maximum range of the meter, while on the 0-100 volt range the deflection is in the usable range of the meter, being slightly more than 1/5 of full-scale deflection.

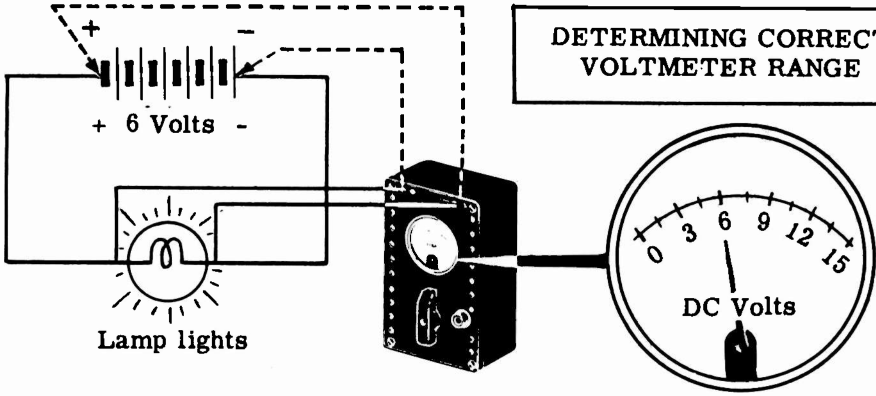


To further illustrate the importance of choosing the correct meter range, the procedure is repeated for various voltages obtained by connecting dry cell batteries in series. Notice that, whether the voltage used is 3 volts or 135 volts, the instructor always uses the highest meter range first and reduces the range until the proper range is selected.

Next, a high range voltmeter is used on a low voltage to check the polarity of the voltage. You see that the instructor does not use a low range meter for this check, nor does he maintain the meter connection any longer than is necessary to determine whether the pointer turns in the right direction.

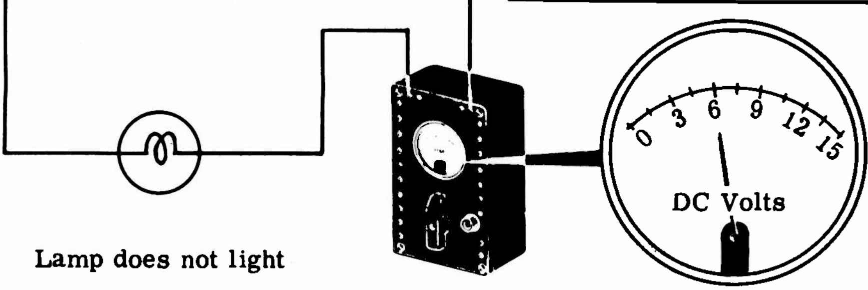
Demonstration—Range Selection and Correct Voltmeter Connection

To show how to select the correct range on a multirange voltmeter, the instructor constructs a six-volt dry-cell battery by connecting four dry cells in series and connecting a lamp socket across the battery terminals. He inserts a lamp and, using the multirange voltmeter 0-1.5, 15, 150 with the selector on the meter set on the 0-150 scale, measures the voltage across the lamp socket terminals and then across the battery terminals. Then he sets the selector on the meter on the 0-15 scale and repeats the performance. He finds that the 0-15 is the correct scale and that the lamp voltage equals the battery voltage.



DETERMINING CORRECT VOLTMETER RANGE

Using the same circuit, he connects the voltmeter (its selector is set on the 0-15 scale) in series with the circuit by breaking one of the connections to the lamp; the voltmeter reads the full battery voltage. Next he removes the lamp from its socket and the voltmeter reading drops to zero. He notes that a voltmeter connected as an ammeter reads voltage but does not allow enough current to flow to light the lamp, because only a very small current can flow through the large resistance of the multiplier built into the 0-15 voltmeter range.



VOLTMETER CONNECTED AS AMMETER

HOW VOLTAGE IS MEASURED

Review of Voltage Units and Measurement

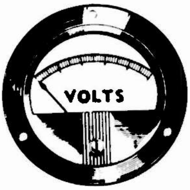
Now suppose you look again at what you have studied and seen concerning the units of voltage and how voltage is measured.

VOLTAGE UNITS

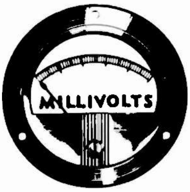
1 kilovolt = 1000 volts	1 volt = $\frac{1}{1000}$ kilovolt
1 millivolt = $\frac{1}{1000}$ volt	1 volt = 1000 millivolts
1 microvolt = $\frac{1}{1,000,000}$ volt	1 volt = 1,000,000 microvolts

CHANGING VOLTAGE UNITS

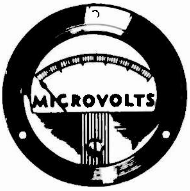
To Change	Move the Decimal Point
Kilovolts to Volts	Three places to the RIGHT
Volts to Kilovolts	Three places to the LEFT
Volts to Millivolts	Three places to the RIGHT
Millivolts to Volts	Three places to the LEFT
Volts to Microvolts	Six places to the RIGHT
Microvolts to Volts	Six places to the LEFT
Millivolts to Microvolts	Three places to the RIGHT
Microvolts to Millivolts	Three places to the LEFT



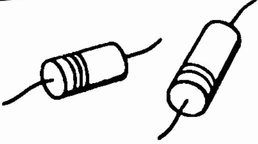
VOLTMETER — Basic meter movement with a series-connected multiplier, calibrated to measure voltage.



MILLIVOLTMETER — Voltmeter calibrated to measure voltages of more than 1 millivolt and less than 1 volt.



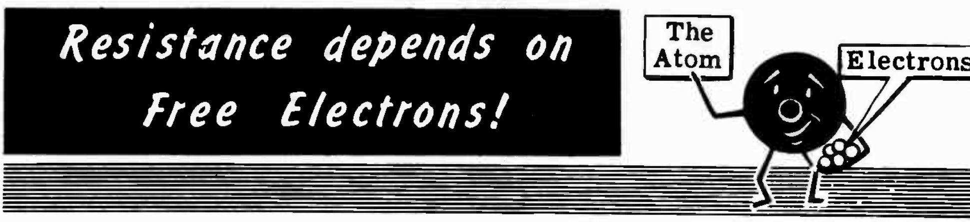
MICROVOLTMETER — Voltmeter calibrated to measure voltages of more than 1 microvolt and less than 1 millivolt.

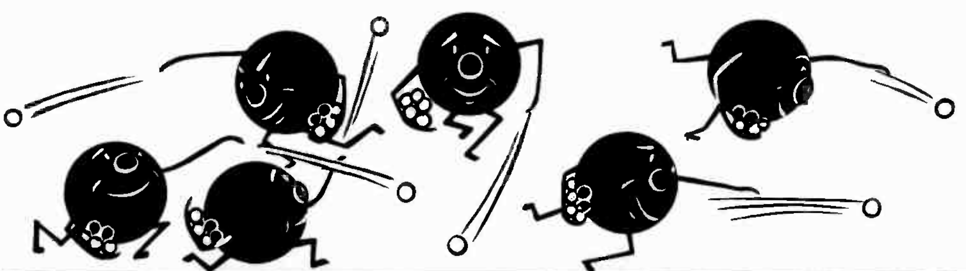


MULTIPLIERS — Materials used in series with a basic meter movement to determine the voltage range of a voltmeter.

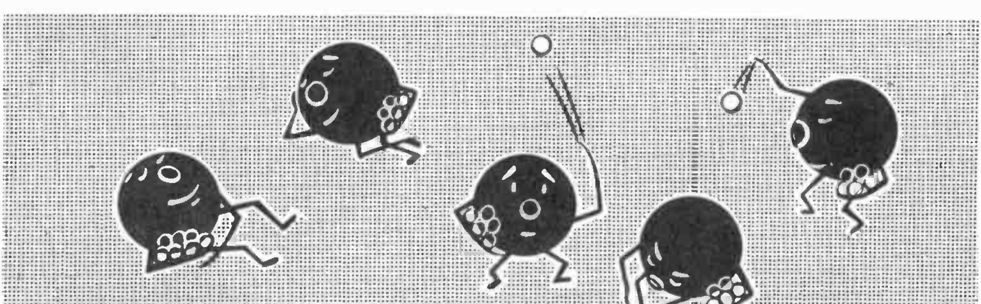
What Resistance Is

The opposition to current flow is not the same for all materials. Current flow itself is the movement of "free" electrons through a material, and the number of "free" electrons in a material determines its opposition to current flow. Atoms of some materials give up their outer electrons easily and such materials offer little opposition to current flow, while other materials hold onto their outer electrons and such materials offer considerable opposition to current flow. Every material has some opposition to current flow, whether large or small, and this opposition is called resistance.





Materials having little resistance give up many Free electrons.



Materials having much resistance give up few Free electrons.

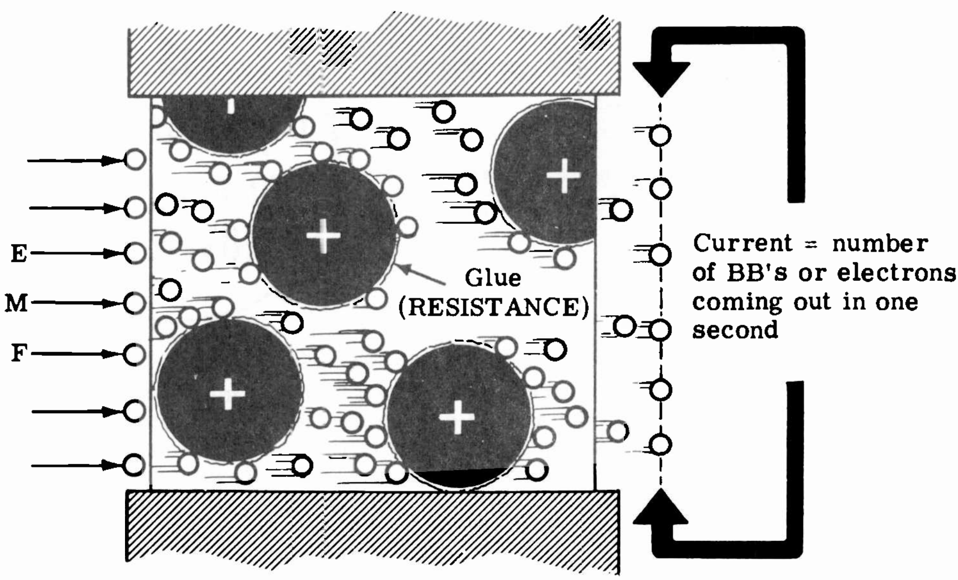
What Resistance Is (continued)

In order to picture resistance in a situation involving more familiar components, picture again the drain pipe that you read about earlier in this section. As you remember, the drain pipe contained a large number of golf balls firmly held in place by wires and each of these represented an atom with its bound electrons. The space in between the golf balls was filled with small metal balls the size of air rifle shot. Each of these metal balls represented a free electron. When the metal balls were removed from one end and rammed into the other end, a flow of these balls was begun in the pipe.

To get the concept of resistance, imagine that each golf ball is covered with a special type of glue. This glue will not come off the golf ball but it will cause the steel balls to stick to it. The strength of the glue varies with the type of material being represented. If the material is copper the glue is very weak and the free electrons will not be held strongly. However, if the material is glass, the glue is very strong and will hold onto the free electrons and not let them go. A push (voltage) that would cause billions of metal balls to come out of the open end each second when a weak glue is used, would cause only two or three of the metal balls to come out when a powerful glue is used.

The resistance of a material may be compared to the strength of the glue just described. When the push (voltage) is kept the same, there will be a smaller and smaller flow of metal balls (or electrons) as the strength of the glue (or resistance) is increased.

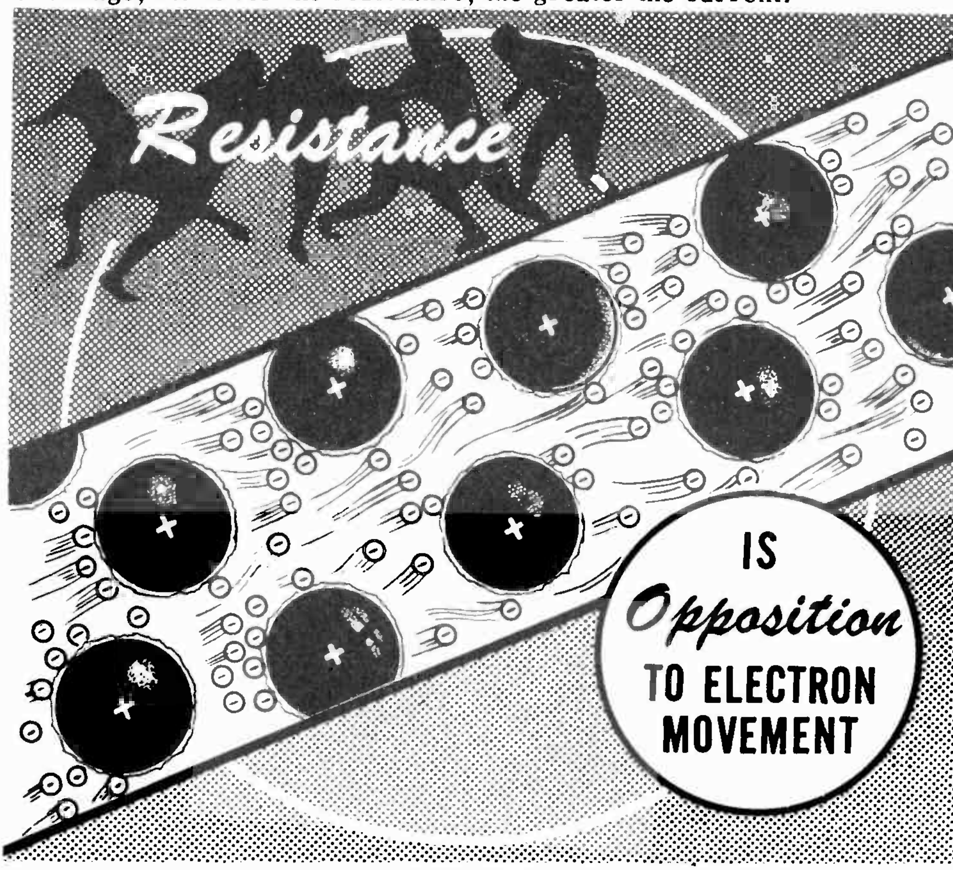
An atom does not have any glue on it, but the electric fields of the positive charges in the nucleus hold the electric fields of the outer electrons in very much the same manner. This force of attraction may be large or small depending upon the structure of the atom (type of material).



What Resistance Is (continued)

You know that an electric current is the movement of "free" electrons in a material and that an electric current does not begin flowing all by itself, because it needs a source of electrical force to move the "free electrons" through the material. You have also found out that an electric current will not continue to flow if the source of electrical energy is removed. You can see from all this that there is something in a material that resists the flow of electric current—something that holds on to the "free" electrons and will not release them until sufficient force is applied. This opposition to electrical current flow is called resistance. This resistance corresponds to the strength of the "glue" described on the previous sheet.

With a constant amount of electrical force (voltage), the more opposition you have to current flow (resistance), the smaller will be the number of electrons flowing through the material (current). Using the same source of voltage, the lower the resistance, the greater the current.

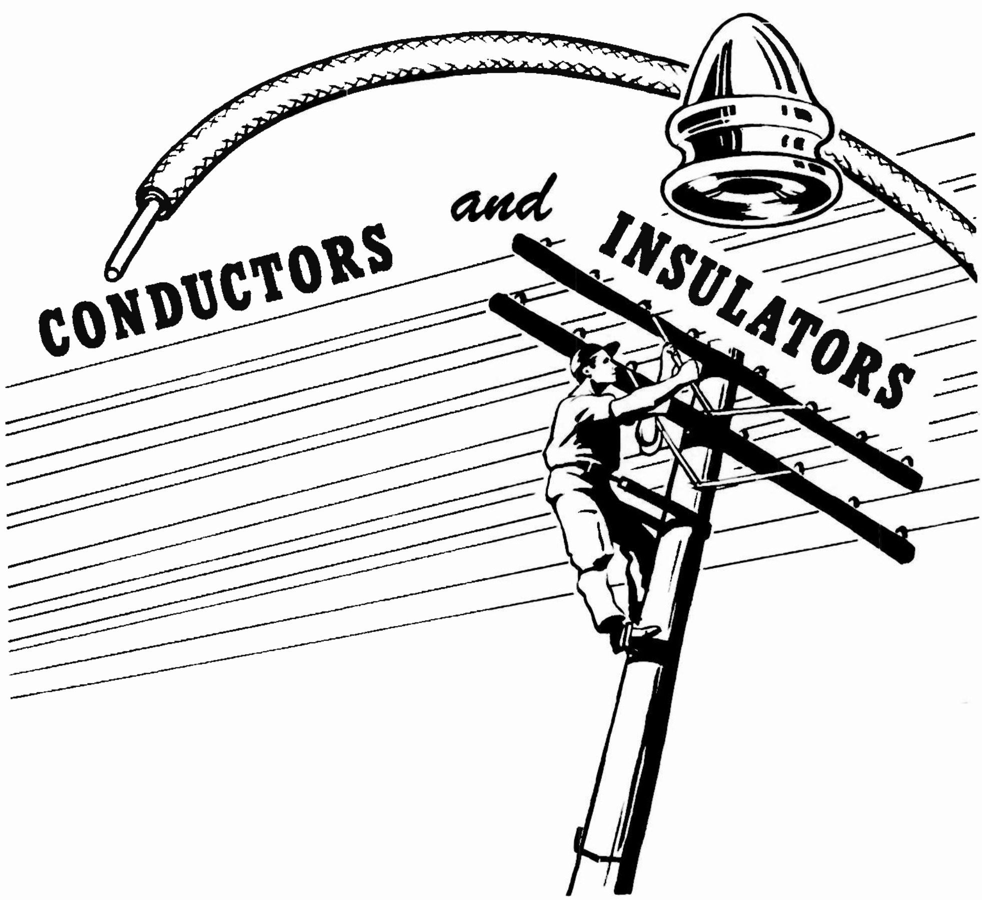


Thus if you have a fixed source of voltage, you can increase the current by decreasing the resistance, and you can decrease the current by increasing the resistance. By increasing or decreasing the amount of resistance—opposition to electron movement—in a circuit, you can adjust the amount of current flow to meet the operating needs of a piece of electrical equipment.

Conductors and Insulators

You may have heard it said that a conductor is a poor insulator and that an insulator is a poor conductor. While this statement does not tell exactly what a conductor or an insulator is, it is nevertheless a true statement. Conductors are materials which offer very little opposition to the flow of current and therefore are used to carry or conduct electricity. Insulators are materials which offer much opposition to the flow of current and therefore are used to block or insulate against the flow of current. Both conductors and insulators conduct current but in vastly different amounts, the current flow in an insulator being so small it is usually considered to equal zero.

Materials which are good conductors have a plentiful supply of free electrons while insulating materials do not, since they will not easily give up the electrons in the outer orbits of their atoms. Metals are the best conductors,with copper, aluminum and iron wire being used commonly to conduct current. Carbon and ordinary water are non-metallic materials sometimes used as conductors, while such materials as glass, paper, rubber, ceramics and certain plastics are commonly used as insulators.



Factors Controlling Resistance—Material

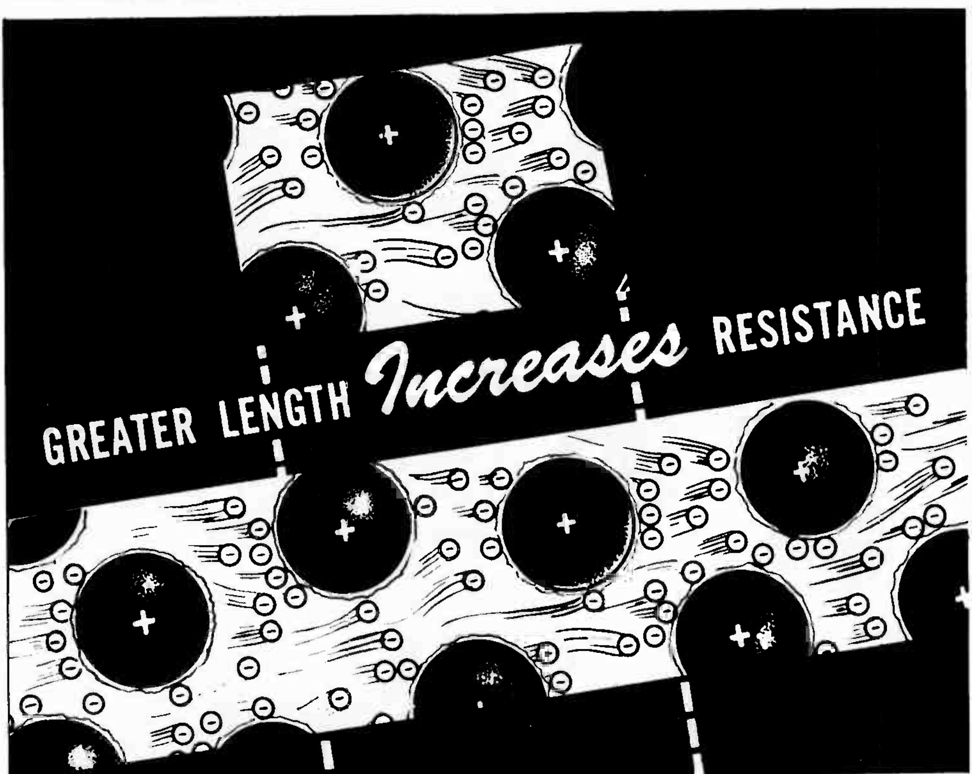
Even the very best conductors have some resistance which limits the flow of electric current through them. The resistance of any object, such as a wire conductor for example, depends upon four factors—the material of which it is made, its length, its cross-sectional area and its temperature. Suppose you examine each of these factors controlling resistance and see how each one affects the total resistance of an object.

You already know that the material of which an object is made affects its resistance. The ease with which different materials give up their outer electrons is a very important factor in determining the resistance of an object. If you had four wires identical in length and cross-sectional area but made of different materials—silver, copper, aluminum and iron—you would find that each had a different resistance. A dry cell connected across each of them would cause a different current to flow. Silver is the best conductor of electricity—with copper, aluminum and iron having more resistance in that order. All materials conduct an electric current to some extent, and all materials can be assigned a value of "resistivity" which indicates just how well that material will conduct an electric current.

Factors Controlling Resistance—Length

The next factor greatly affecting the resistance of a conductor is its length. The longer the length, the greater the resistance; and the shorter the length, the lower the resistance. You know that a material such as iron resists the flow of electric current, simply because of the manner in which each atom holds on to its outer electrons. It is easy to see that the more iron you put in the path of an electric current, the less will be the current flow.

Suppose you were to connect an iron wire four inches long and 1/100 inch thick in series with an ammeter. As soon as you connect this across a dry cell, a certain amount of current will flow. The amount of current that flows depends upon the voltage of the dry cell and the number of times the electron gets "stuck" or "attracted" by the atoms in its path between the terminals of the voltage source. If you were to double the length of the iron wire, making it eight inches long, there would be twice as much iron in the path of the electric current and the electron would be held by twice as many atoms in its path between the terminals of the voltage source. By doubling the length of the electric current path between the terminals of the dry cell, you have put twice as many attractions in the way, and you have doubled the resistance.



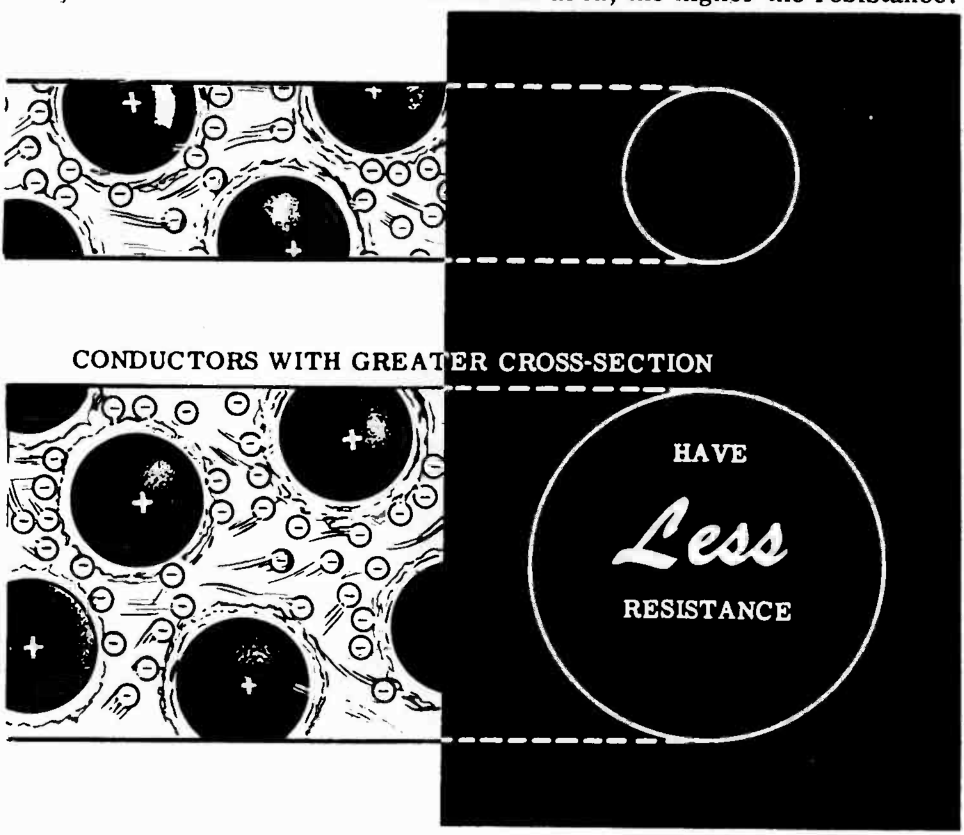
The longer the length of a conductor, the greater resistance it will offer to electric current flow. The shorter the length of a given type of conductor, the less resistance it will offer to the flow of an electric current.

Factors Controlling Resistance—Cross-Sectional Area

Another factor affecting the resistance of a conductor is its cross-sectional area. To understand what cross-sectional area means, suppose you 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, the lower is the resistance of the wire; and the smaller this area, the higher is the resistance of the wire.

To see how this works suppose that you were to connect an iron wire four inches long and 1/100 inch thick in series with an ammeter. As soon as you connect this across a dry cell, a certain amount of current will flow. The amount of current that flows depends upon the voltage of the dry cell and the path of iron wire put in the way of the current flow between the terminals of the voltage source. You can see that the electric current has a pretty narrow wire (1/100 inch thick) to travel through. If you were to remove the iron wire and replace it with another wire which has the same length but twice the cross-sectional area, the current flow would double. This happens because you now have a "wider path" for the electric current to flow through—twice as many free electrons are available to make up the current which has the same length of path to flow through.

The larger the cross-sectional area of a conductor, the lower the resistance; and the smaller the cross-sectional area, the higher the resistance.



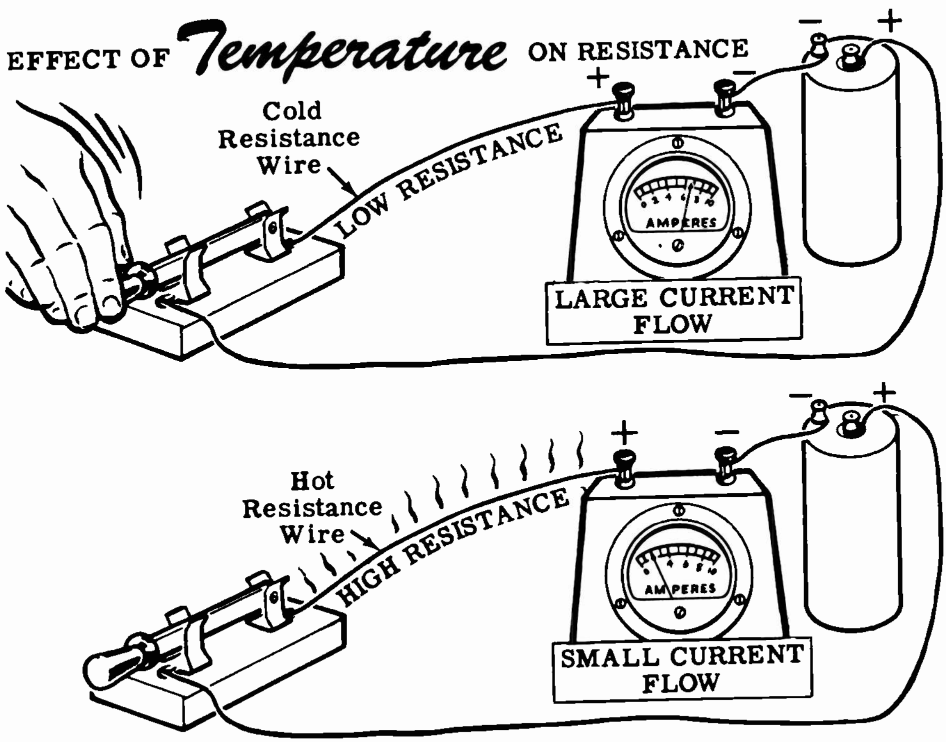
Factors Controlling Resistance—Temperature

The final factor affecting the resistance of a conductor is its temperature. For most materials the hotter the material, the more resistance it offers to the flow of an electric current; and the colder the material, the less resistance it offers to the flow of an electric current. This effect comes about because a change in the temperature of a material changes the ease with which that material releases its outer electrons.

You can see this effect by connecting a length of resistance wire, a switch and a dry cell in series. When you close the switch a certain amount of electric current will flow through the wire. In a short time the wire will begin to heat up. As the wire begins to heat, its atoms hold more tightly onto the outer electrons and the resistance goes up. You can see the resistance go up by watching the meter; as the wire gets hotter and hotter, the resistance to the electric current rises and the meter reading will fall lower and lower. When the wire has reached its maximum heat, its resistance will stop increasing and the meter reading will remain at a steady value.

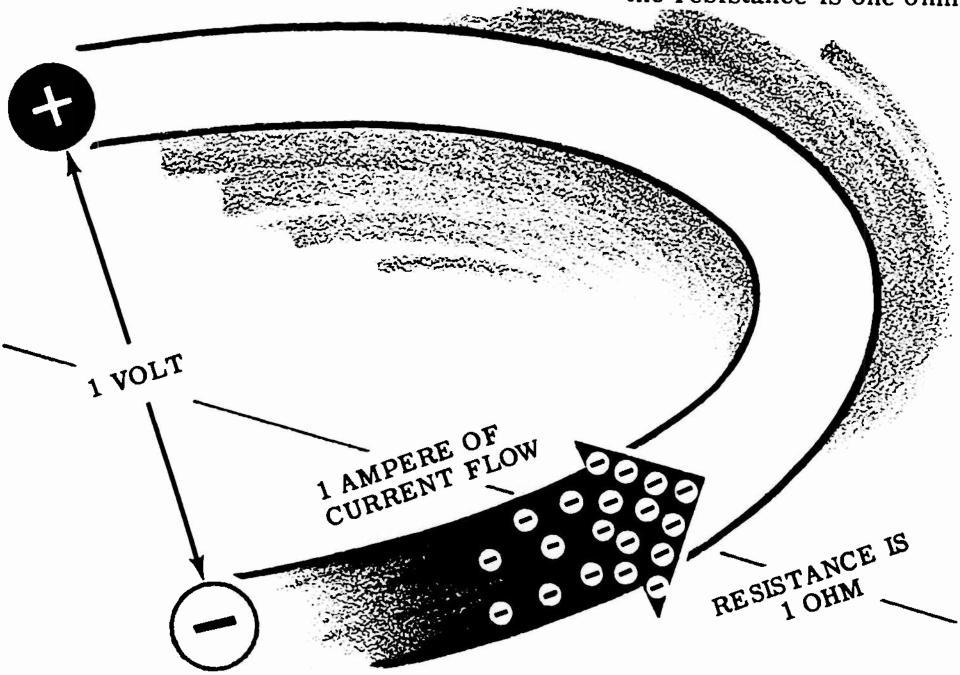
Some materials such as carbon and electrolytic solutions lower their resistance to an electric current as the temperature increases, and the electric current increases as the temperature increases. The effect of temperature upon resistance varies with the type of material—in materials such as copper and aluminum, it is very slight. The effect of temperature on resistance is the least important of the four factors controlling resistance—material, length, cross-sectional area and temperature.

EFFECT OF *Temperature* ON RESISTANCE



Units of Resistance

When one volt causes one ampere of current flow,
the resistance is one ohm.



To measure current the ampere is used as a unit of measure and to measure voltage the volt is used. These units are necessary in order to compare different currents and different voltages. In the same manner, a unit of measure is needed to compare the resistance of different conductors. The basic unit of resistance is the ohm, equal to that resistance which will allow exactly one ampere of current to flow when one volt of emf is applied across the resistance.

Suppose you connect a copper wire across a voltage source of 1 volt and adjust the length of the wire until the current flow through the wire is exactly one ampere. The resistance of the length of copper wire then is exactly 1 ohm. If you were to use wire of any other materials—iron, silver, etc.—you would find that the wire length and size would not be the same as that for copper. However, in each case you could find a length of the wire which would allow exactly 1 ampere of current to flow when connected across a 1-volt voltage source,and each of these lengths would have a resistance of 1 ohm. The resistances of other lengths and sizes of wire are compared to these 1-ohm lengths, and their resistances are expressed in ohms.

Like other parts of a circuit, a symbol is used to indicate resistance.

Units of Resistance (continued)

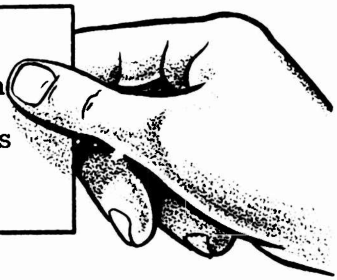
Most of the time you will use resistance values which can be expressed in ohms but for certain special applications you may use small values of less than one ohm or values greater than one million ohms. Fractional values of resistance are expressed in microhms and very large values are expressed in megohms. One microhm equals one-millionth ohm, while one megohm is equal to a million ohms.

Units of resistance are changed in the same manner as units of current or voltage. To change microhms to ohms the decimal point is moved six places to the left, and to change ohms to microhms the decimal point is moved six places to the right. To change megohms to ohms the decimal point is moved six places to the right, and to change ohms to megohms it is moved six places to the left.

For resistances between one thousand and one million ohms the unit used is the kilohm (K) which is always abbreviated in use. Ten kilohms is written 10K and equals 10,000 ohms. To change kilohms to ohms the decimal point is moved three places to the right, and to change ohms to kilohms the decimal point is moved three places to the left.

1 Microhm = $\frac{1}{1,000,000}$ ohm

1 Megohm = 1,000,000 ohms



CHANGING RESISTANCE UNITS

MICROHMS TO OHMS
Move the decimal point 6 places to the left

35000 microhms = .035 ohm

OHMS TO MICROHMS
Move the decimal point 6 places to the right

3.6 ohms = 3,600,000 microhms

KILOHMS TO OHMS
Move the decimal point 3 places to the right

6 kilohms = 6000 ohms

OHMS TO KILOHMS
Move the decimal point 3 places to the left

6530 ohms = 6.530 kilohms

MEGOHMS TO OHMS
Move the decimal point 6 places to the right

2.7 megohms = 2,700,000 ohms

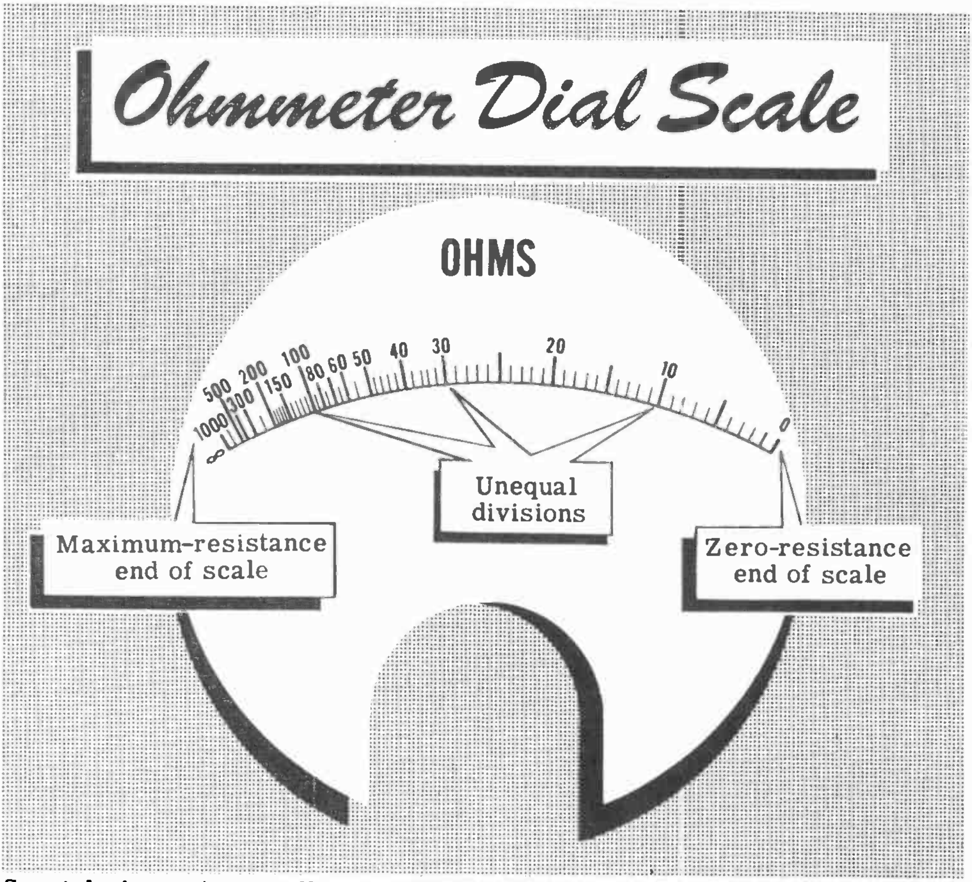
OHMS TO MEGOHMS
Move the decimal point 6 places to the left

650,000 ohms = .65 megohm

How Resistance Is Measured

Voltmeters and ammeters are meters you are familiar with and have used to measure voltage and current. Meters used to measure resistance are called ohmmeters. These meters differ from ammeters and voltmeters particularly in that the scale divisions are not equally spaced, and the meter requires a built-in battery for proper operation. When using the ohmmeter, no voltage should be present across the resistance being measured except that of the ohmmeter battery; otherwise, the ohmmeter will be damaged.

Ohmmeter ranges usually vary from 0-1000 ohms to 0-10 megohms. The accuracy of the meter readings decreases at the maximum end of each scale, particularly for the megohm ranges, because the scale divisions become so closely spaced that an accurate reading cannot be obtained. Unlike other meters, the zero end of the ohmmeter scale is at full-scale deflection of the meter pointer.



Special ohmmeters called "meggers" are required to measure values of resistance over 10 megohms, since the built-in voltage required is very high for ranges above 10 megohms. Some meggers use high voltage batteries and others use a special type of hand generator to obtain the necessary voltage. While ohmmeters are used to measure the resistance of conductors, the most important use of meggers is to measure and test insulation resistance.

Resistors—Construction and Properties

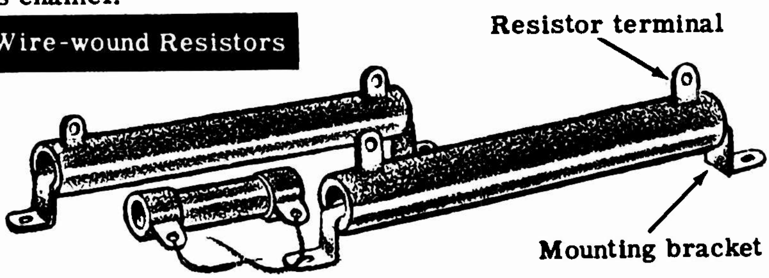
There is a certain amount of resistance in all of the electrical equipment which you use. However, sometimes this resistance is not enough to control the flow of current to the extent desired. When additional control is required—for example, when starting a motor—resistance is purposely added to that of the equipment. Devices which are used to introduce additional resistance are called resistors.

You will use a wide variety of resistors, some of which have a fixed value and others which are variable. All resistors are made either of special resistance wire, of graphite (carbon) composition, or of metal film. Wire-wound resistors are usually used to control large currents while carbon resistors control currents which are relatively small.

Vitreous enameled wire-wound resistors are constructed by winding resistance wire on a porcelain base, attaching the wire ends to metal terminals, and coating the wire and base with powdered glass and baked enamel to protect the wire and conduct heat away from it.

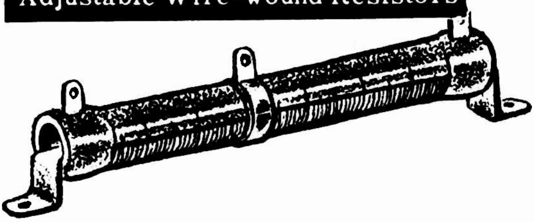
Fixed wire-wound resistors are also used which have coating other than vitreous enamel.

Fixed Wire-wound Resistors

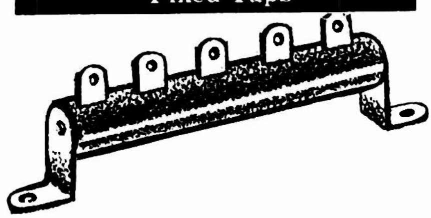


Wire-wound resistors may have fixed taps which can be used to change the resistance value in steps, or sliders which can be adjusted to change the resistance to any fraction of the total resistance.

Adjustable Wire-wound Resistors

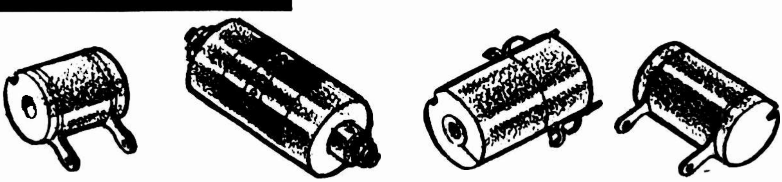


Wire-wound Resistor With Fixed Taps



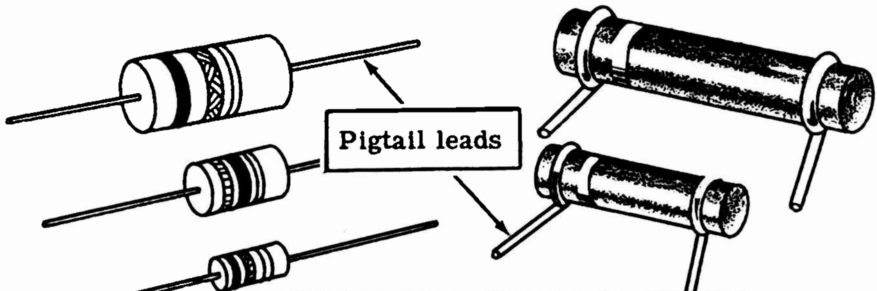
Precision wound resistors of Manganin wire are used where the resistance value must be very accurate such as in test instruments.

Precision Wire-wound Resistors



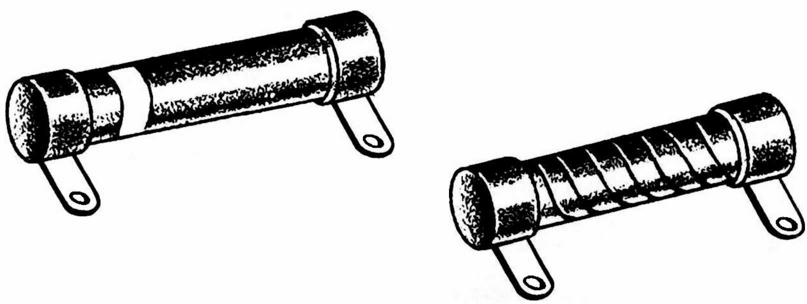
Resistors—Construction and Properties (continued)

Carbon resistors are constructed of a rod of compressed graphite and binding material, with wire leads attached to each end of the rod. The rod is then either painted or covered by an insulating coating of ceramic. Leads used for this type of resistor are called pigtail leads.



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

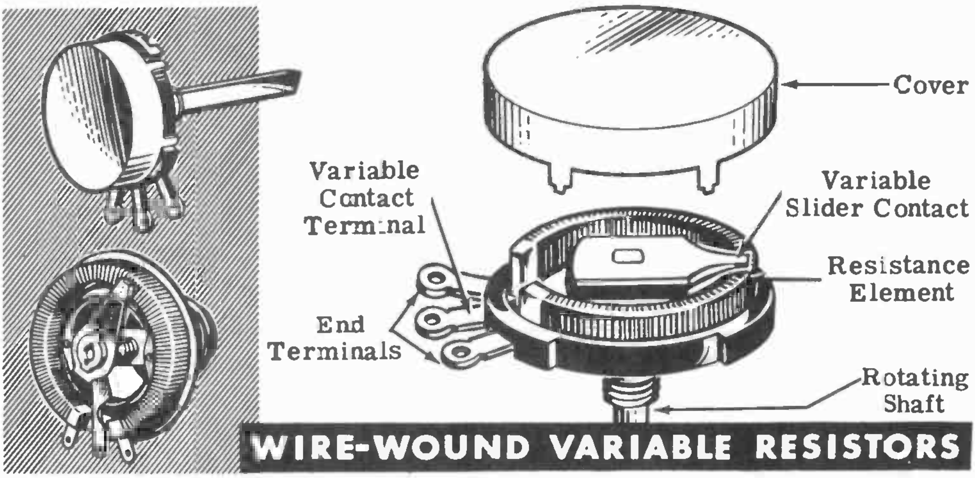
Metal film resistors are constructed in the same manner as spiral-coated carbon resistors except that the film is metallic instead of carbon.

METAL FILM RESISTORS

Resistors—Construction and Properties (continued)

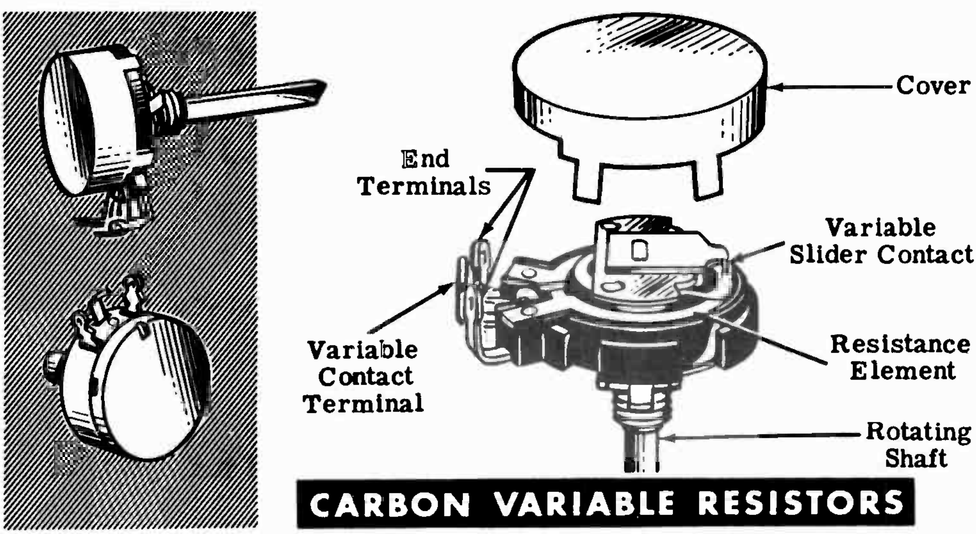
You will not always use resistors of fixed value, since very often you will need to change resistance while the equipment is in operation. To do this you will use both carbon and wire-wound variable resistors, depending on the amount of current to be controlled—wire-wound for large currents and carbon for small currents.

Wire-wound variable resistors are constructed by winding resistance wire on a porcelain or bakelite circular form, with a contact arm which can be adjusted to any position on the circular form by means of a rotating shaft. A lead connected to this movable contact can then be used, with one or both of the end leads, to vary the resistance used.



WIRE-WOUND VARIABLE RESISTORS

For controlling small currents, carbon variable resistors are constructed by depositing a carbon compound on a fiber disk. A contact on a movable arm acts to vary the resistance as the arm shaft is turned.



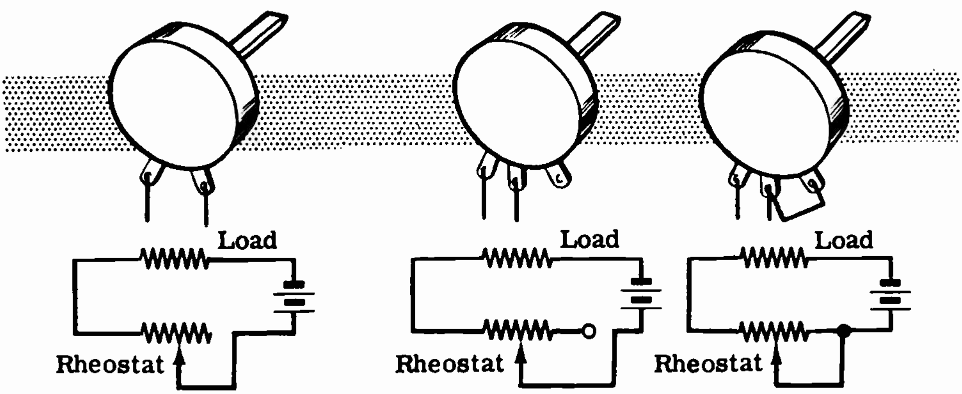
CARBON VARIABLE RESISTORS

Resistors—Construction and Properties (continued)

Variable resistors of either type—wire-wound or carbon—may usually be used in two ways, as a rheostat or as a potentiometer. Some variable resistors have only two terminals and these can only be used as rheostats. A three-terminal variable resistor connected as a rheostat has only two leads connected to the electrical circuit and is used to vary the resistance between these two leads. If the variable contact terminal and one end terminal are connected together directly and act as only one lead in the circuit, the variable resistor acts as a rheostat.

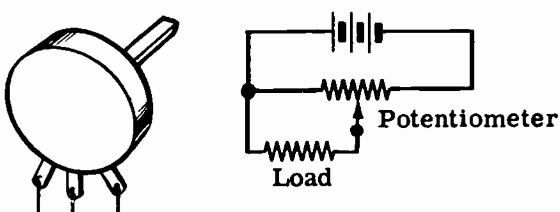
TWO-TERMINAL VARIABLE RESISTORS

THREE-TERMINAL VARIABLE RESISTORS



Rheostat Connections

If the three terminals of a variable resistor each connect to different parts of the circuit, it is connected as a potentiometer. With this kind of connection the resistance between the end terminals is always the same, and the variable arm provides a contact which can be moved to any position between the end terminals. A potentiometer does not vary the total resistance between the end terminals but, instead, varies the amount of resistance between each end and the center contact with both resistances changing as the variable contact is moved—one increasing as the other decreases.



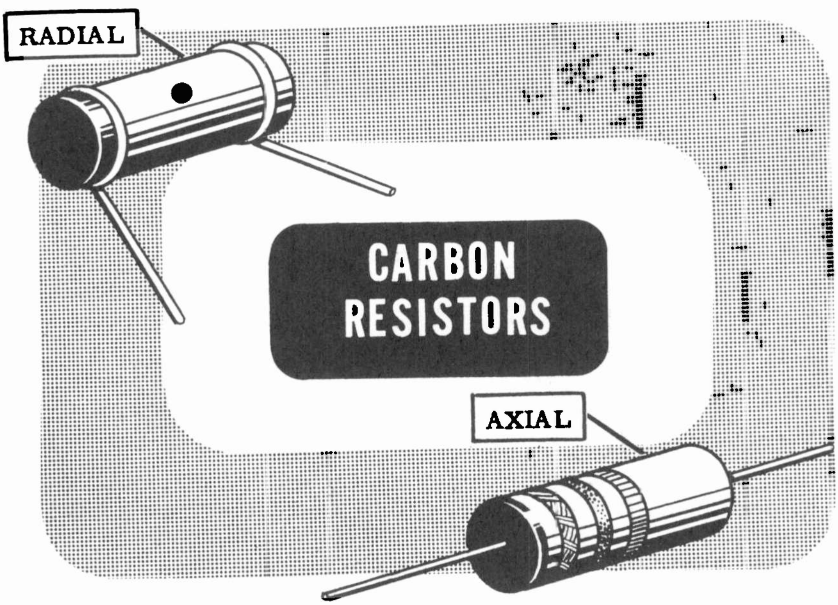
Potentiometer Connections

Resistor Color 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 of a resistor by its marking. Most wire-wound resistors have the resistance value printed in ohms on the body of the resistor. If they are not marked in this manner, you must use an ohmmeter. Many carbon resistors also have their values printed on them, but carbon resistors are often mounted so that you cannot read the printed marking. Also, heat often discolors the resistor body, making it impossible to read a printed marking, and in addition, some carbon resistors are so small that a printed marking could not be read. To make the value of carbon resistors easy to read, a color 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 color code, but the colors are painted in a different manner on each type.

Radial lead resistors are constructed with the wire leads wound around the ends of the carbon rod which makes up the body of the resistor. The leads come off at right angles and the entire resistor body—including the leads wound around the body—is painted but not insulated, since the paint is not a good insulator. Because of this poor insulation, this type of resistor must be mounted where it will not come into contact with other parts of a circuit. Radial lead resistors are rarely found in modern equipment although they were widely used in the past.

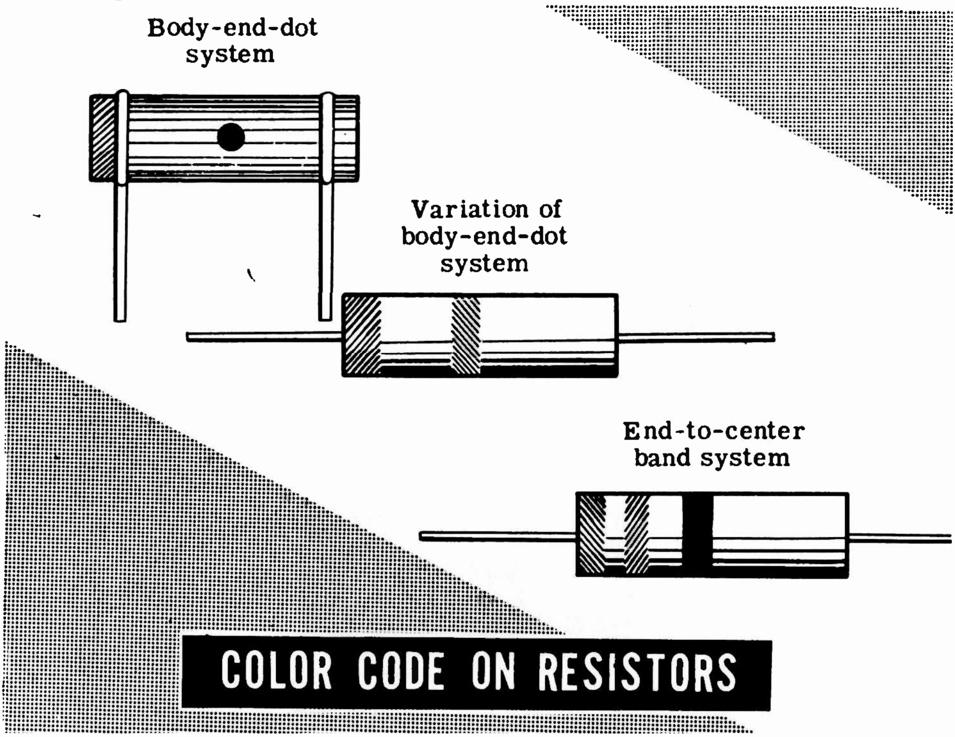


Axial lead resistors are made with the leads molded into the ends of the carbon rod of the resistor body. The leads extend straight out from the ends and in line with the body of the resistor. The carbon rod is completely coated with a ceramic material which is a good insulator.

Resistor Color Code (continued)

As mentioned on the previous sheet, the radial lead type and the axial lead type resistors both use the same color code, but the colors are painted on in a different manner for each of the two types. Radial resistors are coded with the body-end-dot system—as are a few axial type resistors. Most axial resistors are coded by the end-to-center band system of marking.

In each color code system of marking, three colors are used to indicate the resistance value in ohms, and a fourth color is sometimes used to indicate the tolerance of the resistor. By reading the colors in the correct order and by substituting numbers from the color code, you can immediately tell all you need to know about a resistor. As you practice using the color code shown on the next sheet, you will soon get to know the numerical value of each color and you will be able to tell the value of a resistor at a glance.



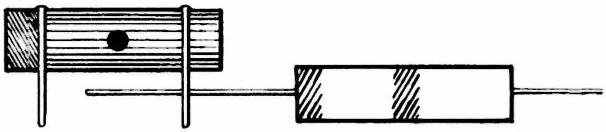
Before you go on to the color code, you should find out something about resistor tolerance. It is very difficult to manufacture a resistor to the exact value required. For many uses the actual resistance in ohms can be 20 percent higher or lower than the value marked on the resistor without causing any difficulty. Many times the actual resistance required need be no closer than 10 percent higher or lower than the marked value. This percentage variation between the marked value and the actual value of a resistor is known as the "tolerance" of a resistor. A resistor coded for a 5-percent tolerance will be no more than 5 percent higher or lower than the value indicated by the color code.

Resistor Color Code (continued)

This is how you use the color code—

Color	Number	Tolerance	Color	Number	Tolerance
Black	0	-	Violet	7	7%
Brown	1	1%	Gray	8	8%
Red	2	2%	White	9	9%
Orange	3	3%	Gold	-	5%
Yellow	4	4%	Silver	-	10%
Green	5	5%	No Color	-	20%
Blue	6	6%			

Body-End-Dot Marking

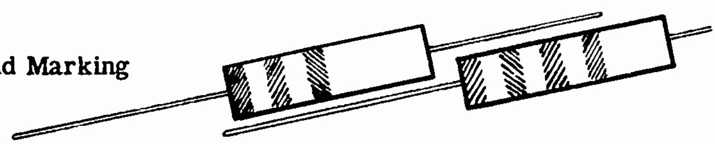


Resistors using this system of marking are coded by having the body of the resistor a solid color, one end of another color and a dot of a third color near the middle of the resistor. For example, you may have a resistor with a green body, red end and orange dot. The body color indicates the first digit, the end color the second digit and the dot the number of zeros to be added to the digits. The value of the resistor then is 52,000 ohms, obtained as follows—

Body	End	Dot
1st digit	2nd digit	Number of zeros
Green	Red	Orange
5	2	000

52,000 ohms

End-to-Center Band Marking



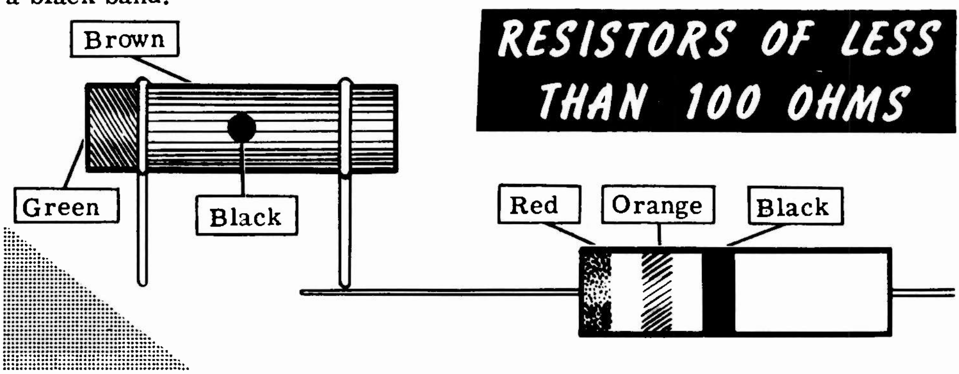
Axial resistors are usually marked with bands of color at one end of the resistor. The body color is not used to indicate the resistor value and may be any color that is not identical to any of the color bands. For example, you may have a resistor with a brown body, having three bands of color (red, green and yellow) at one end. The color bands are read from the end toward the center and the resistor value is 250,000 ohms, obtained as follows—

1st Band	2nd Band	3rd Band
1st digit	2nd digit	Number of zeros
Red	Green	Yellow
2	5	0000

250,000 ohms

Resistor Color Code (continued)

Whenever the center dot or the third band are black the resistor value is less than 100 ohms, since black means that no zeros are to be added to the digits. Suppose you have two resistors—one with a brown body, green end and black dot, the other with a red band, an orange band and a black band.



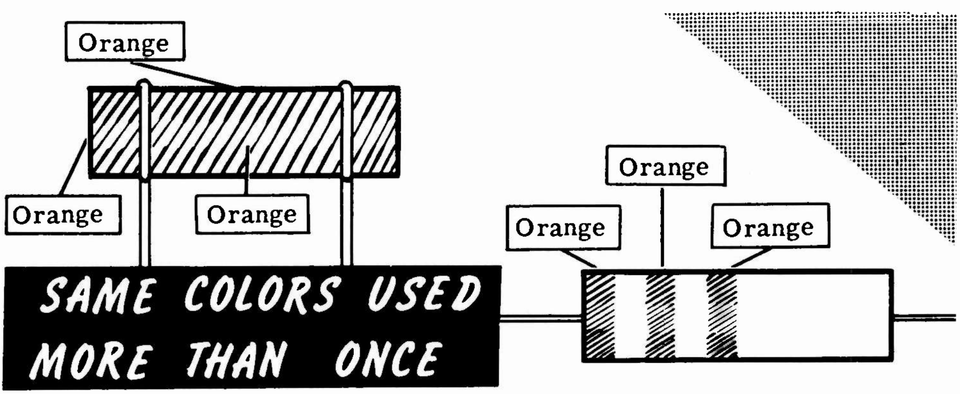
You read these resistor values and find that they are 15 ohms and 23 ohms, obtained as follows—

Body	End	Dot	1st Band	2nd Band	3rd Band
Brown	Green	Black	Red	Orange	Black
1	5	-	2	3	-

15 ohms

23 ohms

If the same color is used more than once, the body, end and dot may all be the same color or any two may be the same; but the color code is used in exactly the same way as before. For example, a 33,000-ohm resistor will be entirely orange if the body-end-dot marking is used, or will have three orange bands if the end-to-center marking is used.



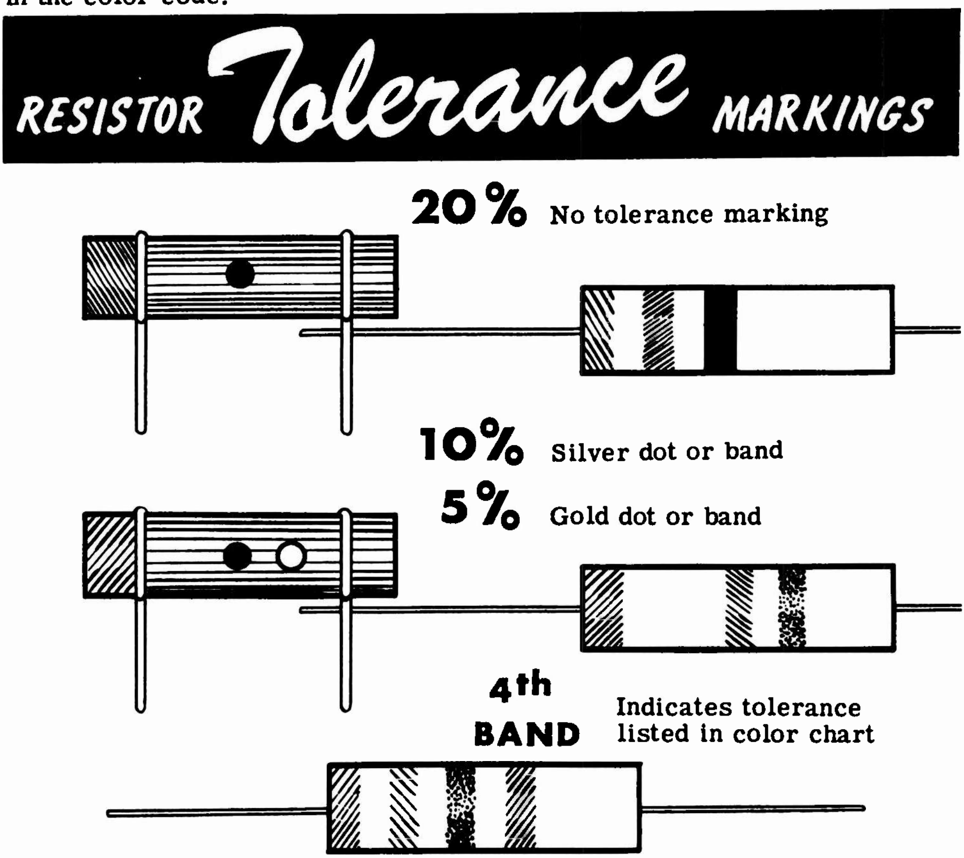
Body	End	Dot	1st Band	2nd Band	3rd Band
Orange	Orange	Orange	Orange	Orange	Orange
3	3	000	3	3	000

33,000 ohms

33,000 ohms

Resistor Color Code (continued)

If only three colors are used, the tolerance (accuracy) of the coded value is 20 percent; but, if a fourth color is used, it indicates that the tolerance is less than 20 percent as indicated by the color code. A silver dot any place on the resistor indicates a tolerance of 10 percent while a gold dot indicates a tolerance of 5 percent. A fourth band on axial resistors is used to indicate tolerance and, if it is a color other than silver or gold, the tolerance in percentage corresponds to the number assigned that color in the color code.

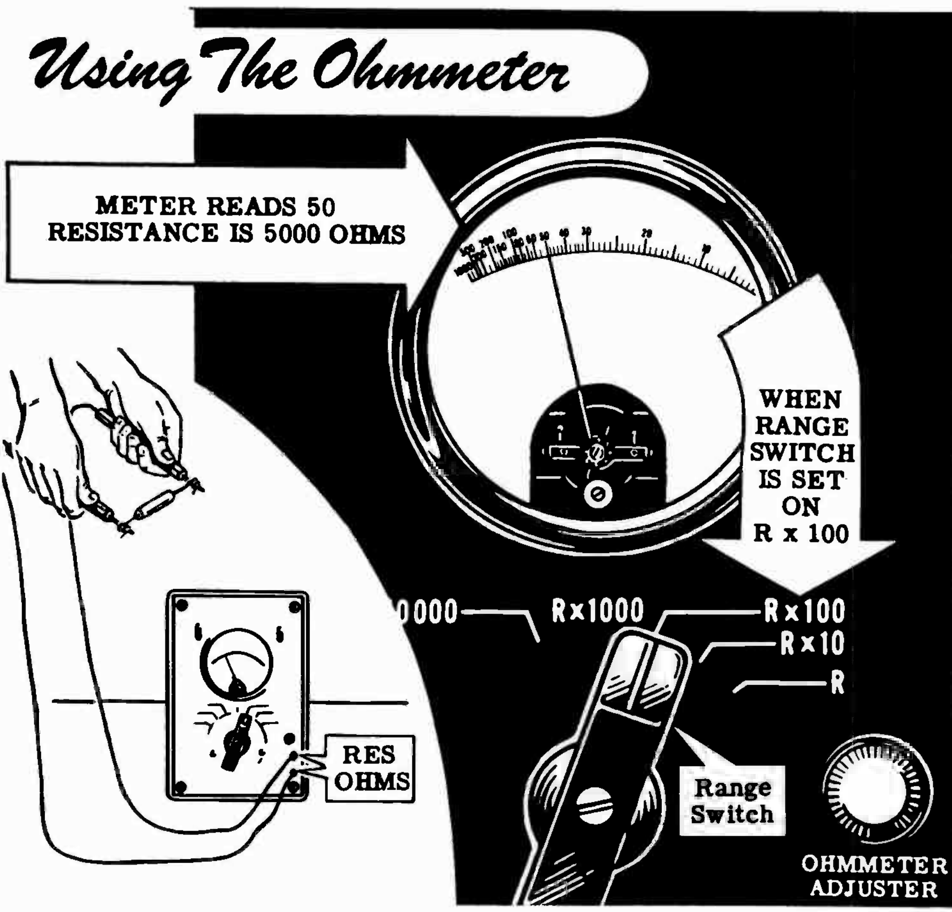


Carbon resistors are made in values which have only two significant figures followed by zeros. Resistors are available between 1 and 99 ohms differing in value by only 1 ohm—for example, 55 and 56 ohms; but between 100 and 1,000 ohms the difference is 10 ohms—for example, 550 and 560 ohms. Similarly between 1,000 and 10,000 the nearest values differ by 100 ohms, and between 100,000 and 1,000,000 the nearest values differ by 10,000 ohms. If you need a value which is not obtainable—for example, 5,650 ohms—two resistors in series are used. To obtain 5,650 ohms you can use several combinations: 5,600 and 50 ohms, 5,000 and 650 ohms, 5,200 and 450 ohms, etc. However, for most of your work in electricity the closest value obtainable is used since accuracy beyond two digits is not normally required.

Demonstration—the Ohmmeter

To demonstrate the correct use of the ohmmeter for measuring resistance the instructor next shows how to operate and use the multirange ohmmeter for measuring resistance. During this demonstration you see that the instructor uses only the ohmmeter ranges—R, R x 10, R x 100 and R x 1000—turning the RANGE SELECTOR SWITCH to one of these ranges before inserting the test leads.

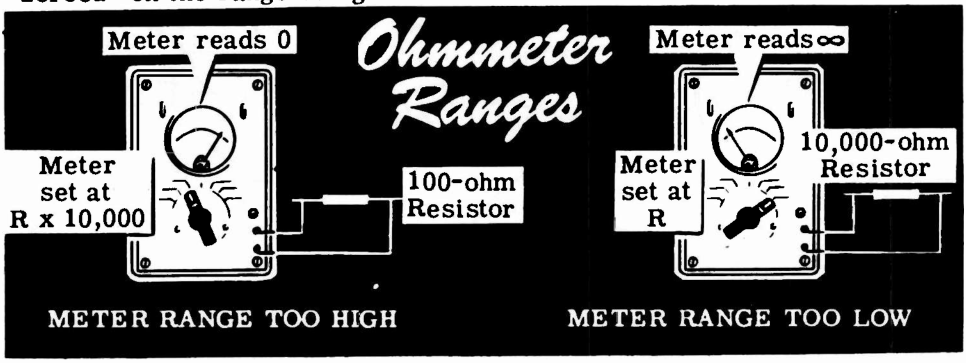
With the test leads inserted in the meter jacks marked RES OHMS, the instructor touches the test prods together to find out if the meter deflects to approximately full scale. The range selector switch is set at the desired range and the OHMMETER ADJUSTER control is adjusted to obtain exactly full-scale deflection—zero ohms on the meter scale. To measure a resistor, the instructor "zeros" the meter after selecting the correct range and then touches the test prods to the two leads of the resistor. The meter will then indicate a resistance reading. If the range used is R the resistance is read directly on the top scale of the meter, but should one of the other ranges be used the scale reading is multiplied by the multiplier for that range. For example, if the meter is set to the range R x 100 and the meter scale reading is 50, the resistance is 5,000 ohms.



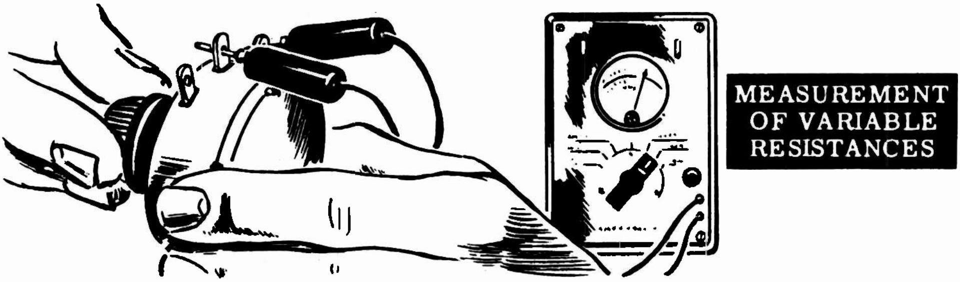
Demonstration—the Ohmmeter (continued)

As several resistors are measured, observe that each time the meter range is changed it must be "zeroed" again, as the zero adjustment is slightly different for each range. While the instructor measures those resistors which you have previously checked with the color code, compare the measured values to those you obtained at that time. Allowing for the tolerance rating of the resistors, the values should be about the same, but in most cases the meter reading is more accurate.

While the instructor measures the various resistors, you can see the importance of choosing the correct meter range. Low values of resistance read 0 ohms on the higher ohmmeter ranges, and high values of resistance read the maximum scale reading on the lower ohmmeter ranges. For example, a 100-ohm resistor measured on the R x 10,000 scale reads 0 ohms, and a 10,000-ohm resistor measured on the R scale reads infinite ohms. In order to find the correct ohmmeter range to use, the best procedure, as illustrated by the instructor, is to place the test prods on the resistor leads and turn the ohmmeter range switch through all the ranges until a range is found which gives a reading near mid-scale. Remember though, before an accurate reading can be made, the ohmmeter must be "zeroed" on the range being used.



Next the instructor connects one meter test prod to the center terminal of a variable resistor and the other test prod to one of the outside terminals of the variable resistor. To show how resistance can be varied he turns the shaft, and you see that the resistance between these terminals changes as the shaft turns. With the meter leads connected across the outside terminals of the variable resistor, the shaft is again turned and you see that the resistance between these terminals is not varied.

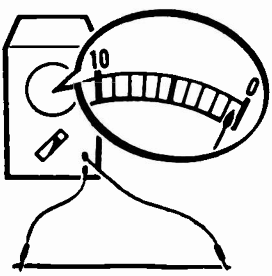


Demonstration—Resistance Factors

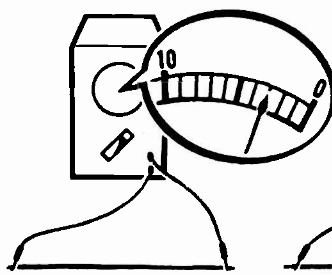
You have seen the different resistors measured, and perhaps you have wondered how resistors of identical size and shape can have such a range of resistance values. In carbon resistors the carbon rod is made of finely ground graphite (carbon) mixed with a filler material, and by varying the amount of carbon used in the mixture the resistance is varied over a wide range. For wire resistors the resistance is changed by using a different size or length of wire and by using wires of different materials, but using the same size porcelain or bakelite forms.

To show the effect of the type material on the resistance of a conductor the instructor takes two equal lengths of wire—one of copper pushback wire and the other of nichrome—and measures their resistance. Notice that the copper wire has less than 1 ohm of resistance while the nichrome wire has more than 1 ohm of resistance.

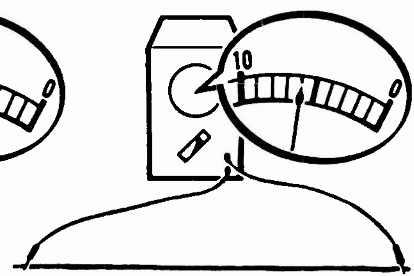
Using nichrome wire, the instructor next demonstrates the effect of length and cross-section on resistance. To show the effect of conductor length on resistance, two lengths of wire are used, one being twice as long as the other. Using the ohmmeter, the resistance of each wire is measured, and you see that the longer wire has twice the resistance of the other.



Copper wire

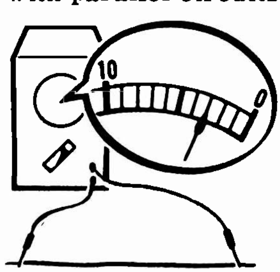


Nichrome wire

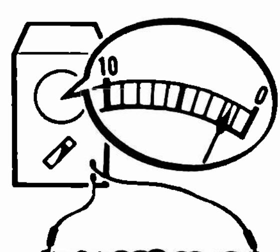


Double-length Nichrome wire

The longer wire is then bent double and twisted to form one length equal to the length of the short wire, but having twice the cross-section. Now when the resistances are measured you see that the length of doubled wire has the lower resistance because of its greater cross-section. Wires having greater cross-section not only have lower resistance but also can carry more current, since more paths are available for current flow. You will find out more about the effects of increased cross-section later, when you work with parallel circuits.



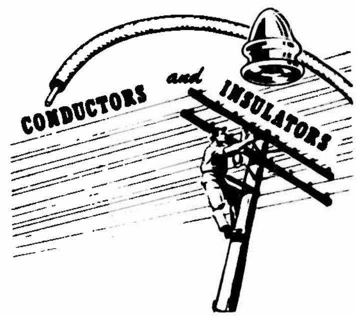
Single cross-section
Nichrome wire



Double cross-section
Nichrome wire

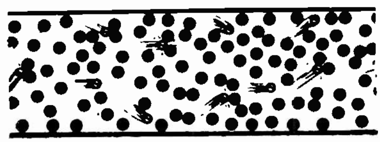
Review of Resistance

Now you are ready to perform an experiment on resistors, but first briefly review what you have read and seen concerning resistance and how it is measured.

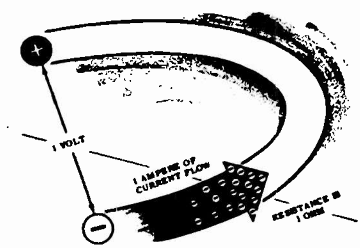


CONDUCTOR — A material which gives up "free" electrons easily and offers little opposition to current flow.

INSULATOR — A material which does not give up "free" electrons easily and offers great opposition to current flow.



RESISTANCE — Opposition offered by a material to the flow of current.



OHM — Basic unit of resistance measure equal to that resistance which allows 1 ampere of current to flow when an emf of 1 volt is applied across the resistance.

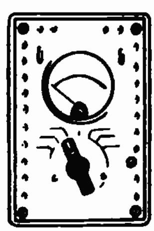
MEGOHM -- One megohm equals one million ohms.

$$1\,\text{Meg}\Omega = 1{,}000{,}000\ \Omega$$

MICROHM — One microhm equals one-millionth ohm.

$$1\,\mu\Omega = \frac{1}{1{,}000{,}000}\,\Omega$$

OHMMETER -- Meter used to measure resistance directly.

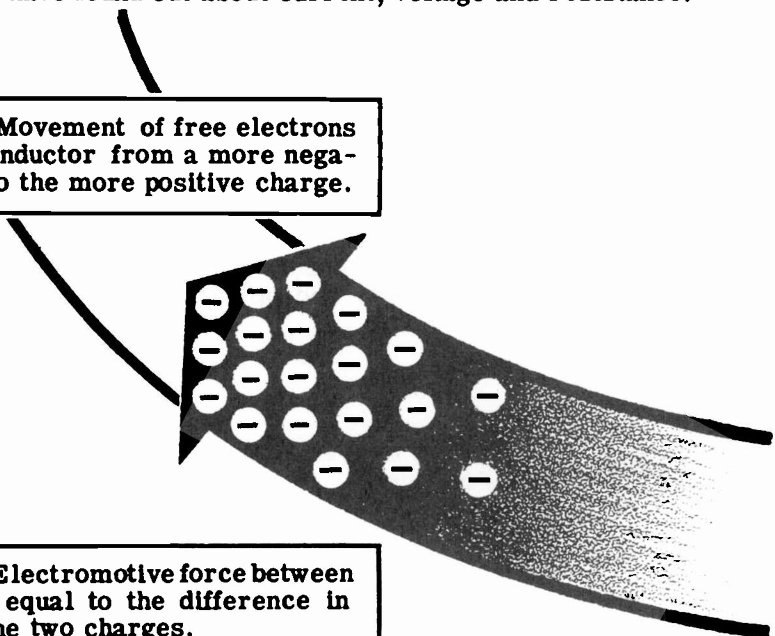


RESISTOR -- Device having resistance used to control current flow.

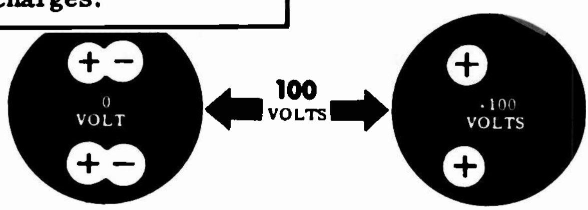
Review of Current, Voltage and Resistance

As a conclusion to your study of electricity in action you should consider again what you have found out about current, voltage and resistance.

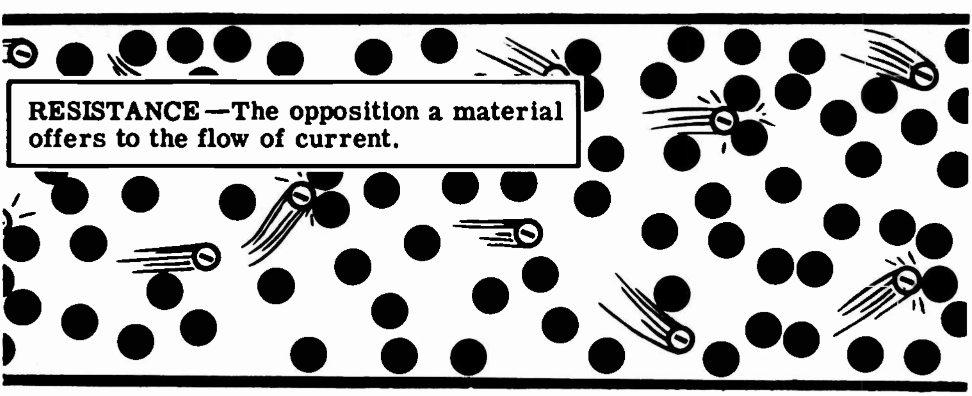
CURRENT—Movement of free electrons through a conductor from a more negative charge to the more positive charge.



VOLTAGE—Electromotive force between two charges, equal to the difference in potential of the two charges.



RESISTANCE—The opposition a material offers to the flow of current.



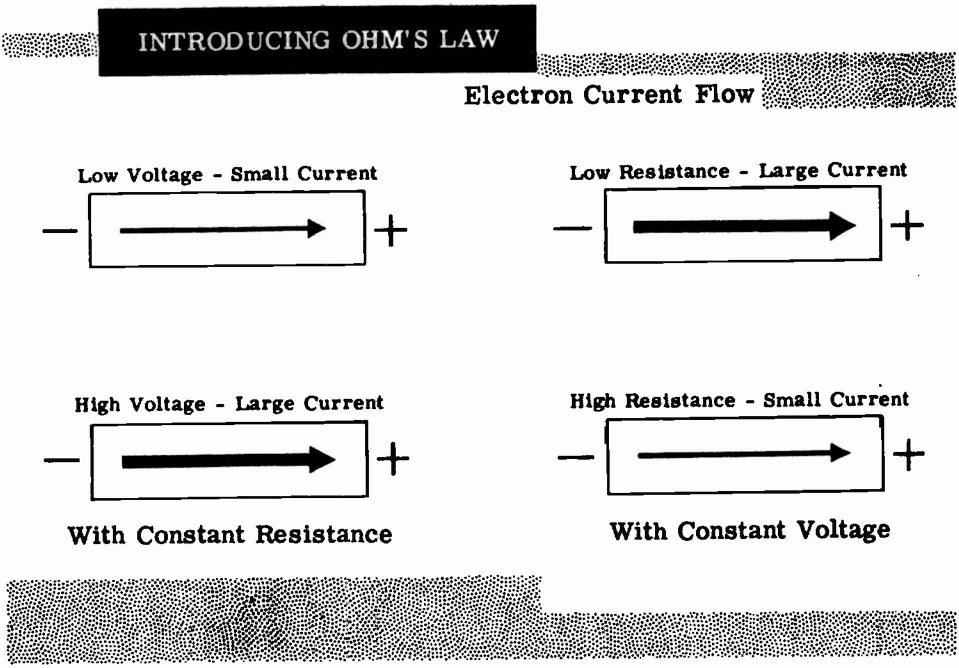
Particularly you should recall the relationships between current, voltage and resistance. Current flow is caused by the voltage between two points and is limited by the resistance between the points. In continuing your study you will next find out about electric circuits and how they use current, voltage and resistance.

The Relationship Between Voltage, Current and Resistance

Voltage, as you know, is the amount of electromotive force (emf) that is applied across a load (resistance) in order to make an electron current flow through the resistance. It should be easy for you to see that the greater the voltage you apply across a resistance the greater will be the number of electrons that flow through in a second. Similarly, the lower the voltage you apply, the smaller will be the electron current.

Resistance, as you know, is the effect that impedes the flow of electrons. If you increase the resistance of the load across which a constant voltage is applied, less electron current will flow. Similarly, the lower you make the resistance, the greater will be the electron flow.

This relationship between voltage, resistance and current as described in the two previous paragraphs was studied by the German mathematician George Simon Ohm. His description, now known as Ohm's law, says that current varies directly with the voltage and inversely with the resistance. The mathematical analysis of this law is of no concern to you at present, but you will learn about it when you get into Volume 2



INDEX TO VOL. 1

(Note: A cumulative index covering all five volumes in this series will be found at the end of Volume 5.)

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