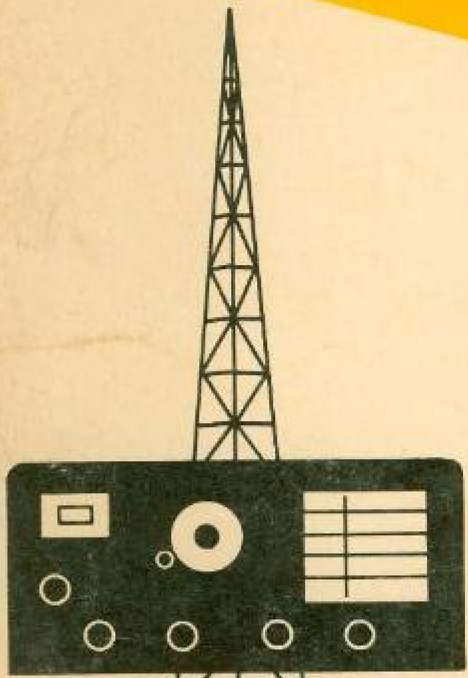
basic radio

by M. TEPPER



RIDER

basic radio

by **MARVIN TEPPER**

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FUNDAMENTALS OF RADIO TELEMETRY

VOL. 1

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PREFACE

The purpose of this book is to fill a need for a text stating in plain, everyday language, what many people consider a complex technical subject. A technical subject need not be complex. Careful filling in of the background with essential information, and then leading step by step to the final explanation, provides a logical method of explaining the most difficult subject.

It would be impossible to cover in a single book or series of books, the immense scope implied in the word *electronics*. However, an understanding of radio circuits serves as a foundation for advanced study in all fields of electronics, such as television, radar, computers, etc. For teaching radio, the all-important basic tool of electronics, most available textbooks are woefully inadequate. One type contains information so brief as to acquaint rather than instruct. Another type is based on the premise that teaching a student to design a circuit is the best method of having him understand that circuit's operation.

Basic Radio represents the neglected middle ground. It is a course in radio communications, as distinct from a general course in electronics. The text deals with the circuitry and techniques used for the transmission and reception of intelligence via radio energy. Assuming no prior knowledge of electricity or electronics, the six volumes of this course "begin at the beginning" and carry the reader in logical steps through a study of electricity and electronics as required for a clear understanding of radio receivers and transmitters. Illustrations are used on every page to reinforce the highlights of that page. All examples given are based on actual or typical circuitry to make the course as practical and realistic as possible. Most important, the text provides a solid foundation upon which the reader can build his further, more advanced knowledge of electronics.

The sequence of *Basic Radio* first establishes a knowledge of d-c electricity. Upon this is built an understanding of the slightly more involved a-c electricity. Equipped with this information the reader is ready to study the operation of electron tubes and electron tube circuits, including power supplies, amplifiers, oscillators, etc. Having covered the components of electronic circuitry in Volumes 1 through 3, we assemble these components in Volume 4, and develop the complete radio receiver, AM and FM. In Volume 5 we recognize the development of the transistor, and devote the entire volume to the theory and circuitry of transistor receivers and semiconductors. The last volume of the course, Volume 6, covers the long-neglected subject of transmitters, antennas, and transmission lines.

No prior knowledge of algebra, electricity, or any associated subject is required for the understanding of this series; it is self-contained. Embracing a vast amount of information, it cannot be read like a novel, skimming through for the high points. Each page contains a carefully selected thought or group of thoughts. Readers should take advantage of this, and study each individual page as a separate subject.

Whenever someone is presented with an award he gives thanks and acknowledgement to those "without whose help . . . " etc. It is no different here. The most patient, and long-suffering was my wife Celia, who typed, and typed, and typed. To her, the editorial staff of John F. Rider, and others in the "background", my heartfelt thanks and gratitude for their assistance and understanding patience.

MARVIN TEPPER

Malden, Mass.
September 1961

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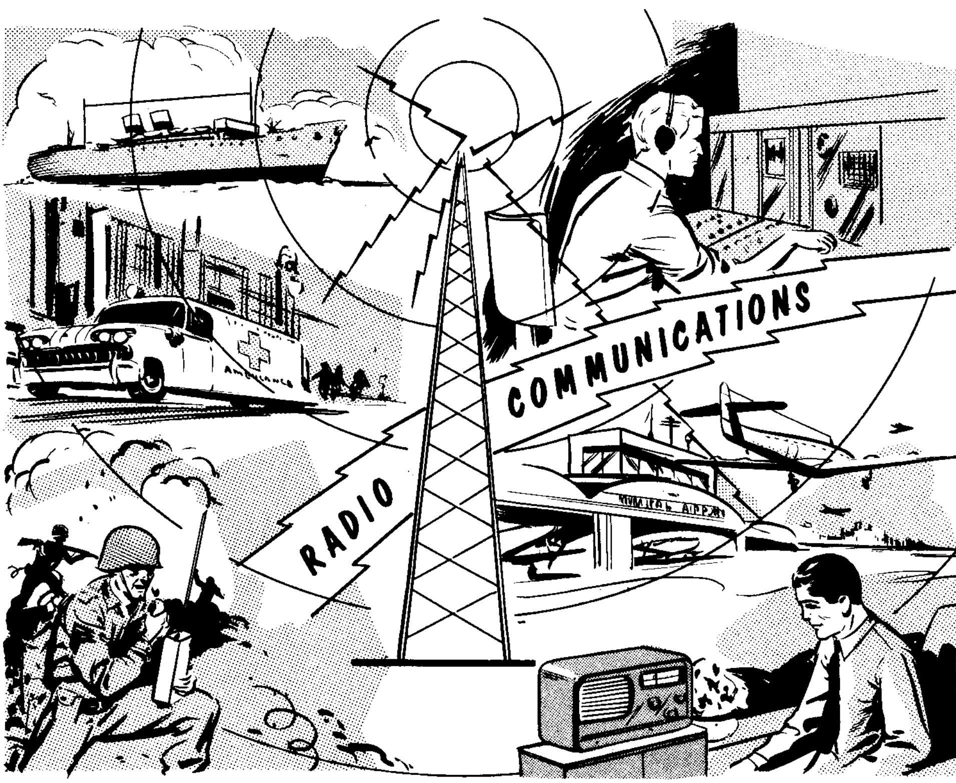
VOL. I — BASIC RADIO

Introduction to Radio

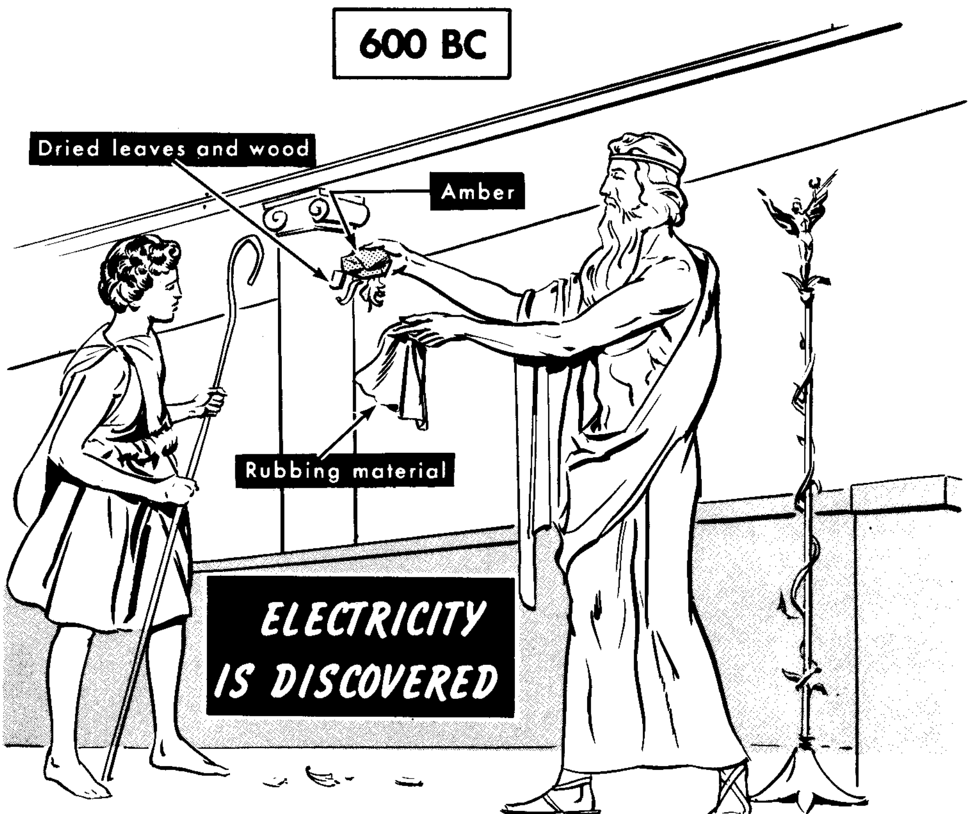
Radio is the name applied to the most successful and most frequently used facility for communicating with all parts of the world. Radio communication is speedy and reliable. An important news event -- a political incident, the death of a famous person, any significant occurrence anywhere in the world -- can be made known instantly everywhere else in the world through the medium of radio. The speed of the radio wave is approximately 186,000 miles per second, rapid enough to circle the globe at the equator slightly more than seven times per second. But the dissemination of news, culture and entertainment by radio broadcasting is but one of the many functions of radio. Police radio, marine radio, and aviation radio are equally important because they function to safeguard human life on land, on and beneath the sea, and in the air.



Without the benefits of radio, conquest of space would be impossible. The transmission of vital information from satellites to earth is one application of radio in this effort. Television is basically a radio system. The ability to detect an unseen hostile target and to locate its position and distance from a point of observation is another application of radio: it is called Radar -- RAdio Detection And Ranging. An understanding of the workings of radio is also the basis for understanding the widespread applications of electronics. And it all begins with a study of electricity.

The Early History of Electricity

Knowledge concerning electricity started with the Greeks. It is said that at about 600 BC, the Greek philosopher Thales of Miletus discovered that a certain substance (now known as amber), when rubbed with certain materials, displayed a peculiar force. It would attract tiny bits of dried leaves and wood to itself. Thales had no explanation for the action, but he gave the name electron to the substance. The word "electron" is in use today but its meaning is far different now, as you will learn.

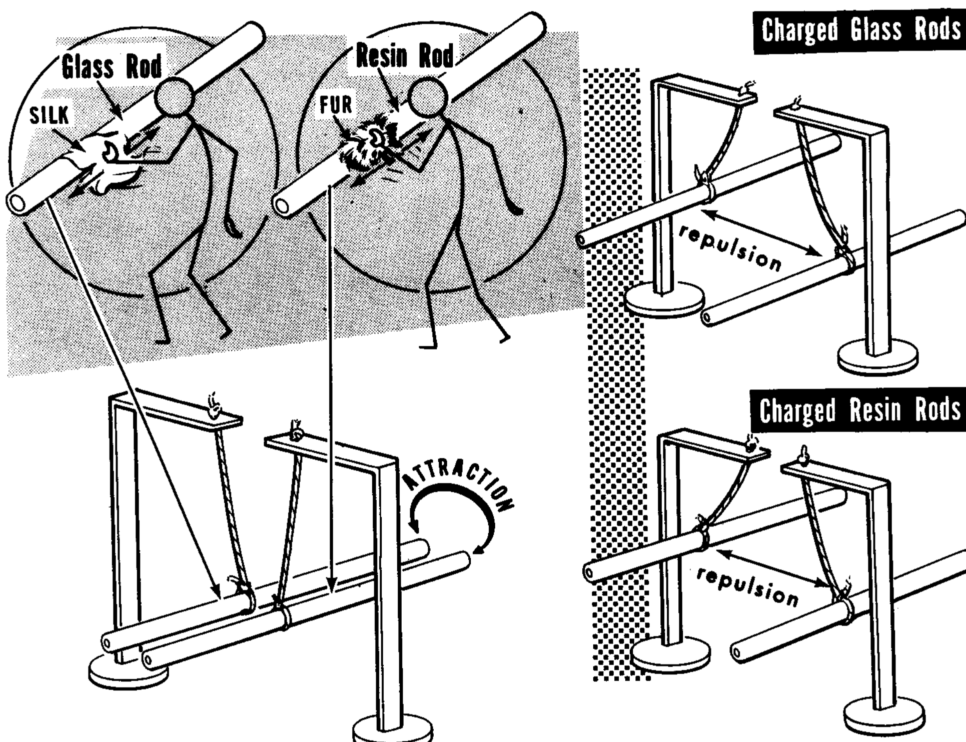


The behavior of amber remained a mystery for about a thousand years. But as time passed, more and more substances which behaved like amber were discovered. About the year 1600, an English scientist named William Gilbert compiled a list of so-called electriks, or substances that could be electrified or "charged with electricity", by rubbing (friction). When electrified, they could attract tiny objects such as bits of paper and threads of cloth. Then, in the early 18th century, experimenters with electriks discovered that many materials, when rubbed with other materials such as fur or wool, not only would attract tiny objects, but would attract or repel each other. The action was not understood and it was declared to be the display of electrical force due to a mysterious something known as electricity.

A Famous Experiment in Electricity

One of the far-reaching experiments performed in the field of electricity was the rubbing of a glass rod with a piece of silk, and the rubbing of a resin rod with a piece of fur, after which the two electrically charged or, simply, charged rods were suspended near each other and allowed to demonstrate their electrical effects on each other.

The charged resin rod and the charged glass rod attracted each other! The charged resin rod repelled another resin rod that had been similarly rubbed with the fur! The charged glass rod repelled another glass rod that had been rubbed with the silk!

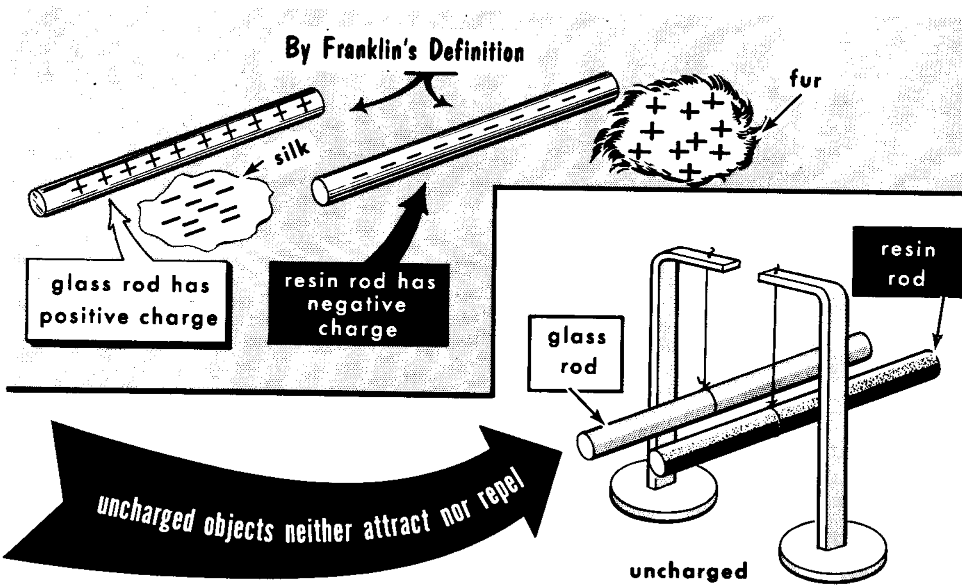


EARLY OBSERVATIONS MADE IN RUBBING GLASS AND RESIN RODS

It was also found that the action of rubbing the resin rod with the fur also had charged the fur. But the kind of charge was such that the fur and the resin rod were attracted to each other, whereas the charged glass rod and the fur repelled one another. The silk used for rubbing also displayed electrical effects. It too had acquired a charge when it was used to rub the glass rod, and its charge was such that it was attracted to the glass rod as well as by the fur, but it was repelled by the electrified resin rod.

A Famous Experiment In Electricity (contd.)

Many ideas were advanced as explanations for the actions observed. Charles Dufay, a French chemist, suggested that the different behavior of the charged rods was due to the presence of two kinds of electricity -- resinous in the resin rod, and vitreous in the glass. Benjamin Franklin, one of America's founders, recommended a change in the names identifying the two kinds of electricity. He suggested the name positive (symbolized by the plus sign +) for the kind of charge on the glass, and negative (symbolized by the minus sign -) for the kind of charge on the resin rod. These names were accepted and have been in use ever since.



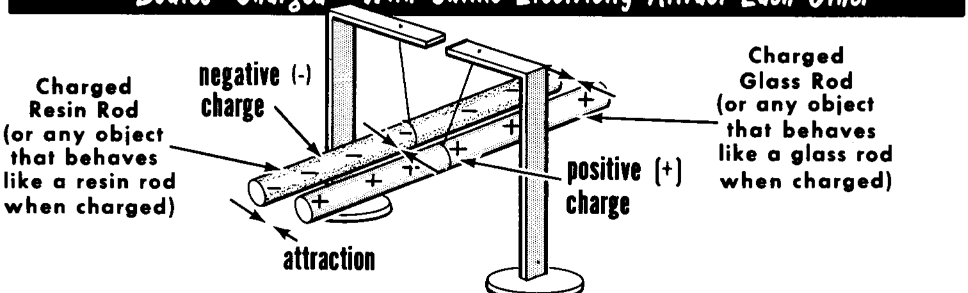
Franklin also suggested the idea that everything in its normal state, that is all objects which are not electrified, are made of equal amounts of positive and negative electricity. Such uncharged objects do not display electrical effects (attraction or repulsion) because the effects of one kind of electricity are offset by the effects of the other kind of electricity. He visualized the so-called electrified or charged condition of an object as being the presence of more of one kind of electricity than of the other kind. The part of the electrified resin rod which was rubbed was charged with negative electricity because it contained more negative electricity than positive electricity. The amount of negative charge was equal to the excess of negative electricity over positive electricity. In a practical sense, negative charge was produced in the resin rod by rubbing. The glass rod, on the other hand, was charged with positive electricity in the area where it was rubbed because it contained more positive electricity than negative electricity. The amount of positive charge was equal to the excess of positive electricity over negative electricity. Again, in a practical sense, positive charge was produced in the glass rod by rubbing.

A Famous Experiment in Electricity (contd.)

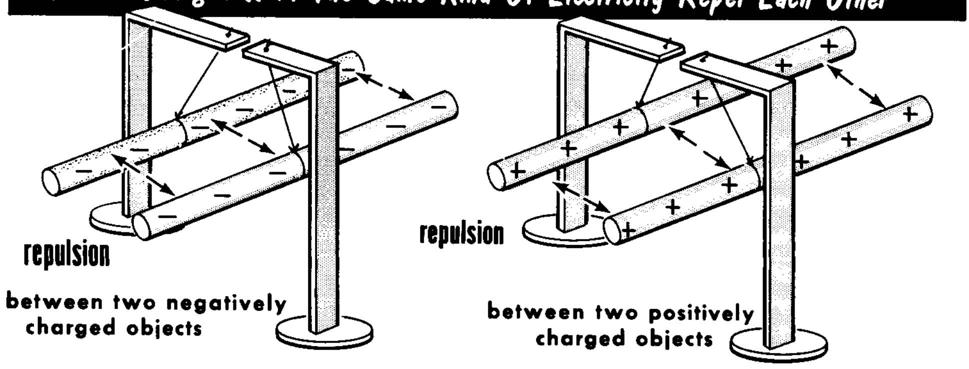
Franklin advanced several more fundamental ideas. He said that any object (body) which, when charged, behaved like the electrified resin rod, had a "negative charge." In other words, the glass rod was attracted to the resin rod and also the silk; therefore, the resin rod and the silk were charged with the same kind of electricity -- negative. By the same reasoning, any charged object (body) which behaved like the charged glass rod was charged with positive electricity. The resin rod was attracted to the glass rod and also to the fur; therefore, the glass rod and the fur were charged with the same kind of electricity -- positive.

It was observed that bodies which carried unlike charges -- the resin rod and the glass rod, the silk and the fur, the resin rod and the fur, the glass rod and the silk -- were attracted to each other. On the other hand, when the fur and the glass rod, or the resin rod and the silk (all of which carried the same kind of charge) were allowed to act on each other, it was noted that they repelled each other. From these findings came certain fundamental conclusions: namely, that bodies charged with unlike electricity attract each other, whereas bodies charged with the same kind of electricity repel each other. These experiments and observations did not explain what electricity was; they simply dealt with observable behavior of the assumed two kinds of electricity. Interestingly enough, these conclusions were correct and have become fundamental laws of electricity.

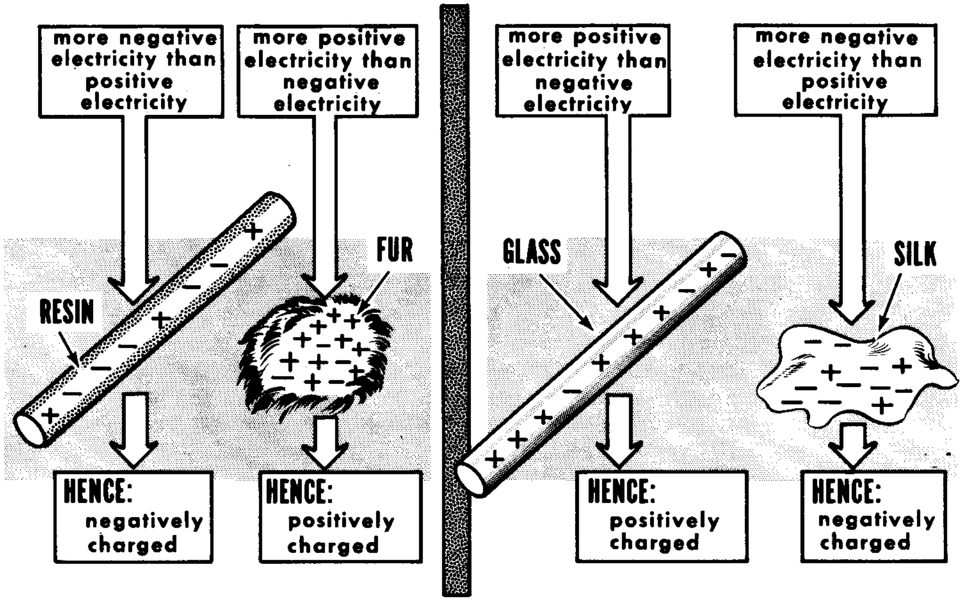
Bodies Charged With Unlike Electricity Attract Each Other



Bodies Charged With The Same Kind Of Electricity Repel Each Other



Electrical Charging By Rubbing



Early Explanation Of Negatively and Positively Charged Objects

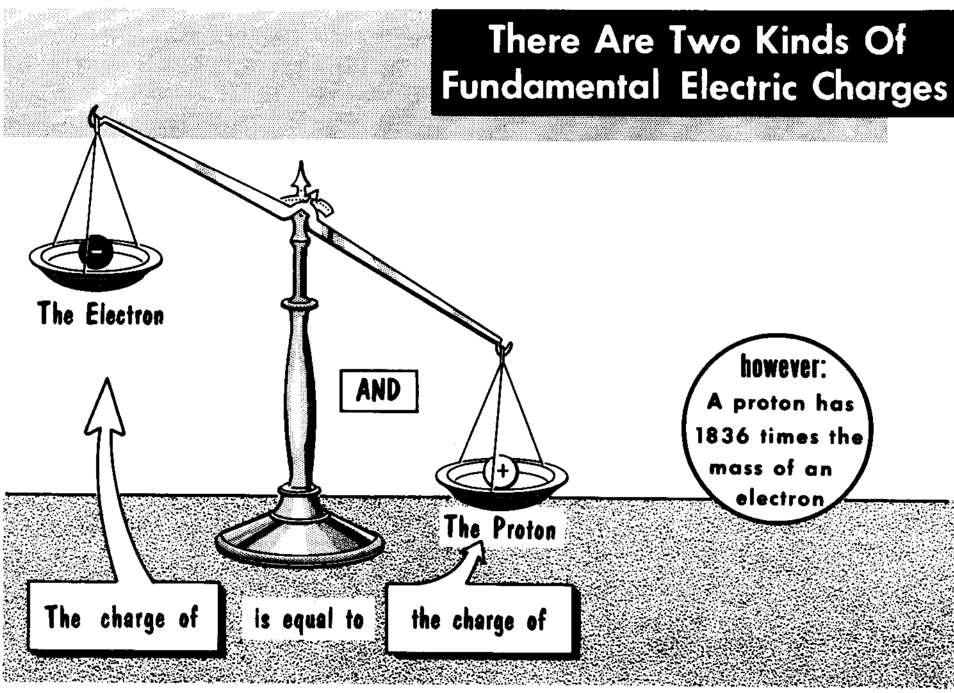
Franklin explained "charging by rubbing" in the following way. When the resin rod was rubbed with the fur, the surface friction caused some of the positive electricity in the resin to go to the fur. Now the rubbed part of the resin rod had more negative electricity than it had positive electricity; hence, it was negatively charged. On the other hand, the part of the fur used for rubbing now contained more positive electricity than negative electricity; therefore, it was positively charged. In the case of the glass rod rubbed with the silk, the silk gave up positive electricity which went to the glass, giving the rubbed portion of the glass rod a preponderance of positive electricity; therefore, a positive charge. Having given up positive electricity, the part of the silk used for rubbing was left with more negative electricity than positive electricity; hence, it was negatively charged.

It so happens that Franklin was not correct in his identification of which kind of electricity went where. Science has since learned that it was negative electricity which was displaced; from the fur to the resin rod, and from the glass to the silk. But the identities of the final charge created on the electrified resin rod and on the electrified glass rod as established then are in use today. Equally important, as you shall learn later on, is that several other concepts advanced at that time are in use today; namely that everything is made of two kinds of electricity and that one kind of electricity can be separated from the other kind. But before we can discuss the modern versions of these happenings, we must develop the atomic concept of matter and the electronic concept of electricity.

The Modern Concept of Electricity

Although our concepts of electricity differ substantially from the ideas of Franklin's time, the pattern of modern thinking, strangely enough, follows the explanation of electrical behavior as expressed then.

There are two kinds of electricity. Still using Franklin's terms, we speak of them as positive and negative. Whereas in Franklin's day electricity was visualized as a fluid, today we believe that electricity exists as minute, virtually weightless spherical specks or particles -- the positive electricity particles being called protons, and the negative electricity particles being called electrons. We don't know if the proton is, or just carries, a certain amount of positive electricity, or if the electron is, or just carries, a certain amount of negative electricity. Either concept is acceptable because it leads to the same thing.



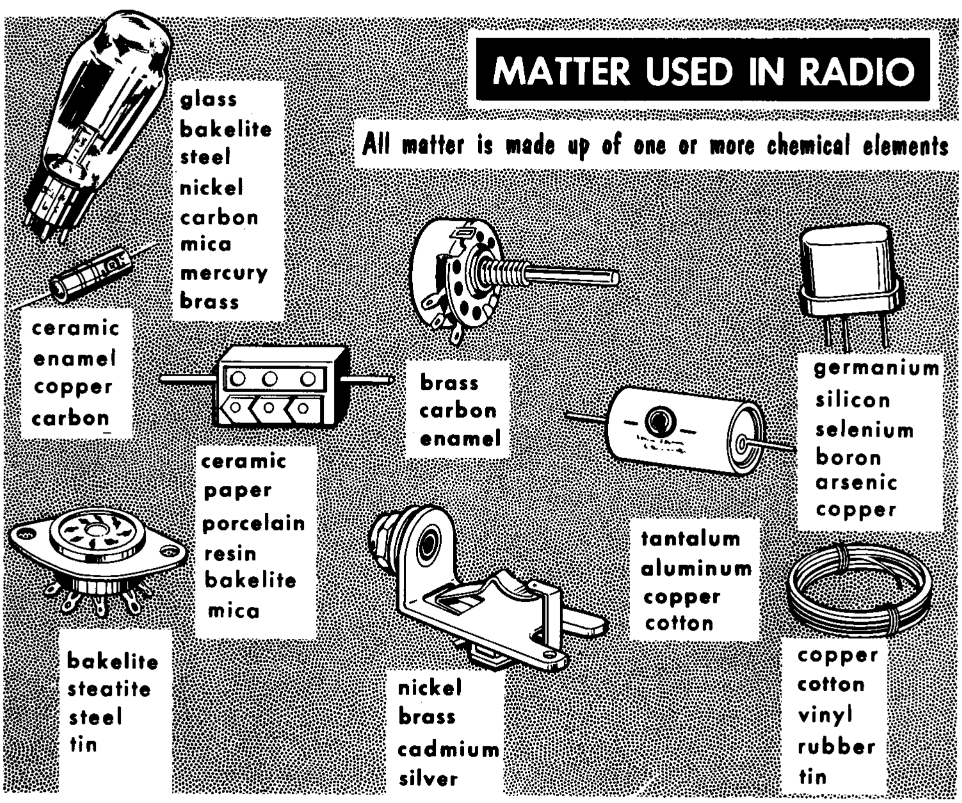
Man has never seen a proton or an electron because the particles are too tiny for even the greatest known magnification to make them visible. But this has not prevented the development of certain ideas about them. For instance, it has been established that the amount of positive electricity associated with a proton is exactly equal to the amount of negative electricity associated with an electron. Each is the smallest amount of electricity of its kind known. Therefore, the proton is the fundamental charge of positive electricity, and the electron is the fundamental charge of negative electricity. Each is an impractically small amount, but finite just the same. Operating electrical systems involve the motion of fantastic quantities of electrons, as you shall learn.

Matter and Chemical Elements

How do the specks of electricity -- protons and electrons -- fit into the scheme of things? The answer is that they are the main ingredients of everything.

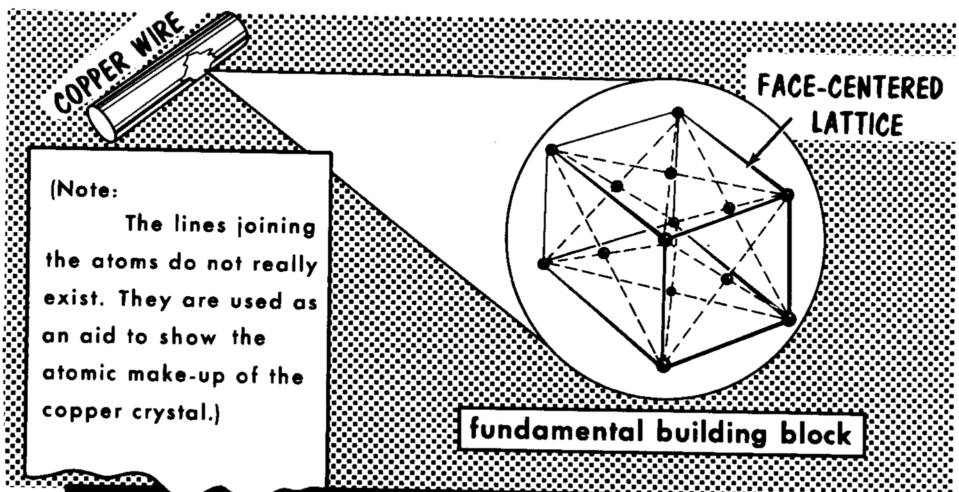
Everything in the world you can see or touch, and even the many things invisible to the naked eye but known to exist, make up the matter of the universe. Matter exists in solid, liquid, or gaseous states. Blood, skin, bone, steel, water, glass, rubber, powder, gold, smoke, copper, tobacco, and air are just some of the many examples of matter. Chemically speaking, all matter is made of one or more of the 102 "pure" substances identified as chemical elements. The word "pure" as applied to a chemical element is that it consists of only one substance. By definition, a chemical element is a substance which cannot be subdivided into two or more different substances by any known chemical means, nor can it be produced by the chemical combination of two or more different substances.

We are interested in chemical elements because so many of them are used as the ingredients that make up the various components that comprise electrical circuits and equipment. In some instances, elements such as copper, aluminum, and carbon are used directly; at other times, compounds (combinations of different elements) are used in the construction of electrical and electronic components.



The Atom

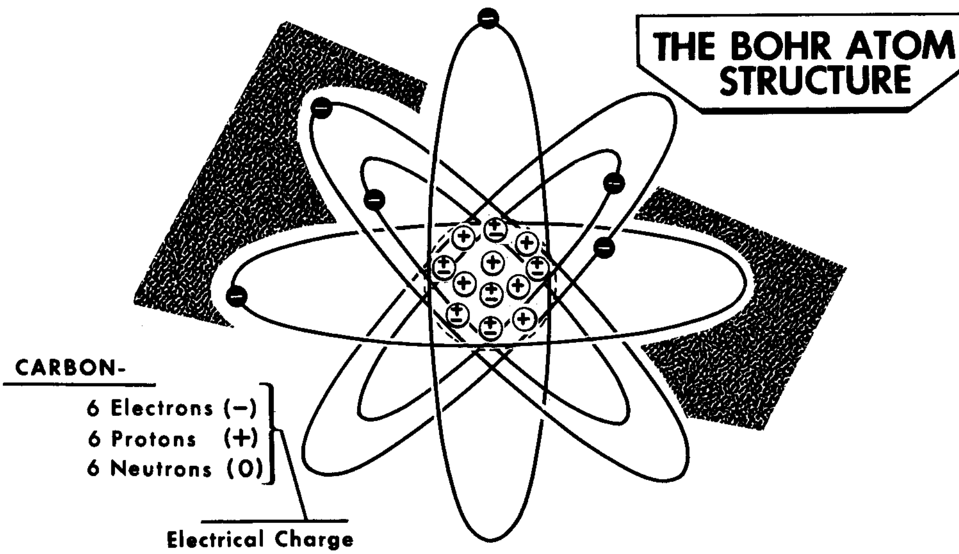
If a small quantity of a chemical element, solid, liquid or gas, could be reduced in amount by a continuous series of subdivisions, the fundamental building block of the element eventually would be reached. This is the atom. Science knows no way of performing such a subdivision, and consequently no one has ever seen an atom. But even though we lack this ability, we accept the idea that nature has built everything out of atoms. Atoms form the chemical elements, and chemical elements singly, or in combination make up everything else; therefore, in the fundamental sense, everything is made of atoms.



THE COPPER CRYSTAL -- THE TINIEST PIECE OF COPPER THAT BEHAVES LIKE COPPER. IT CONSISTS OF 14 ATOMS IN A FIXED FORMATION.

The smallest possible amount of some gaseous elements which display the properties of the gases is a molecule, made up of two atoms that are in an electrical bond. Oxygen is one of these, Hydrogen and Chlorine are others. Then there are gaseous elements for which the smallest quantity of the substance is a single atom. Helium, Argon and Neon are examples. In the case of the elemental metals, a different situation prevails. The smallest amount of the element is a single atom, as for instance copper, silver, gold, iron, lead, tin and others, but the smallest amount of the metal which displays the physical properties of the metal -- expansion, contraction, malleability -- is a crystal. (Sometimes, the crystal of a metal is called a giant molecule). A crystal of a metal is an organization of atoms of the element arranged in a particular formation. For instance, the tiniest amount of pure copper which will behave like the metal is 14 atoms of copper arranged in a geometric pattern called a face-centered lattice. A length of copper wire would be made of a tremendous amount of these crystals. Other elemental metals have their atoms arranged in different formations. Remembering the geometric pattern of the crystal of copper is not vital to understanding the workings of electricity.

Every Atom Is Made of Electricity



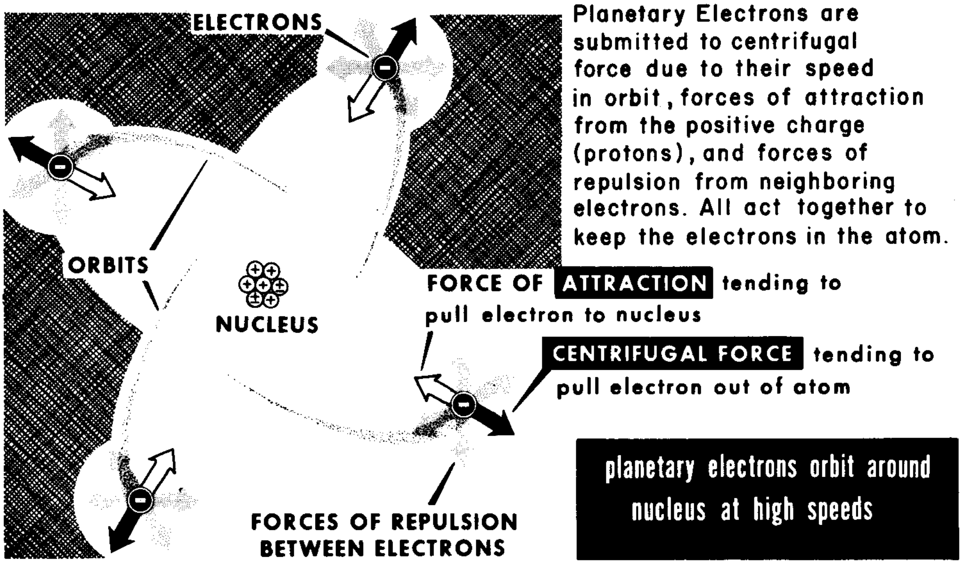
A SUBMICROSCOPIC SOLAR SYSTEM

Every atom (regardless of kind) is an organized structure whose main parts are comprised of particles of positive electricity (protons) and particles of negative electricity (electrons). When we say that one atom is different from another (each being representative of a different kind of chemical element), we mean simply that the two atoms are made of different amounts of positive electricity, with each having as much negative electricity as positive electricity.

A popular concept of the atom was advanced by Niels Bohr, a Danish physicist. He visualized the atom as having a stationary center (or nucleus) in which was concentrated all the positive electricity of the atom (all the protons). Also present in the nucleus of all but the Hydrogen atom was still another kind of particle called a neutron. Each kind of atom contained a different number of neutrons, but since the neutron contributes nothing of electrical character to the atom, we need not discuss it any further. Revolving around the nucleus with very high velocity and at different distances from it are the specks of negative electricity -- planetary electrons -- which balance the positive electricity content of the atom. In any one kind of atom, there are associated with it as many planetary electrons as there are protons in the nucleus, or as much negative electricity as positive electricity. As a convenience in identifying the different kinds of atoms, each kind is associated with a number and with one or two letters. The numerical reference states the number of protons in the atom (hence, the number of planetary electrons too), while the letter symbol identifies the chemical element. As typical examples, the Hydrogen atom (H) is #1; the Carbon atom (C) is #6; the Copper atom (Cu) is #29; the Silver atom (Ag) is #47, and so on.

Electrical Forces In The Atom

What keeps the circling electrons from flying out of the atom under the influence of the centrifugal force that each planetary electron feels? The general concept is that the electrons are held in their orbits against the pull of centrifugal force by the electrical force of attraction between the protons in the nucleus and the orbiting electrons. The electrical force is manifested as a mechanical force; it pulls the electrons inwards towards the nucleus while the centrifugal force is pulling the electrons outward away from the center. The two forces are in exact balance; therefore, the electrons do not leave the atom nor do they "fall" into the nucleus. Each fundamental particle of electricity is inseparably endowed with the property of attracting an oppositely charged particle to itself, and repelling every similarly charged particle. The protons in the nucleus also feel a pull towards the electrons, but the much greater mass of the individual proton keeps it put where it is.



Planetary Electrons are submitted to centrifugal force due to their speed in orbit, forces of attraction from the positive charge (protons), and forces of repulsion from neighboring electrons. All act together to keep the electrons in the atom.

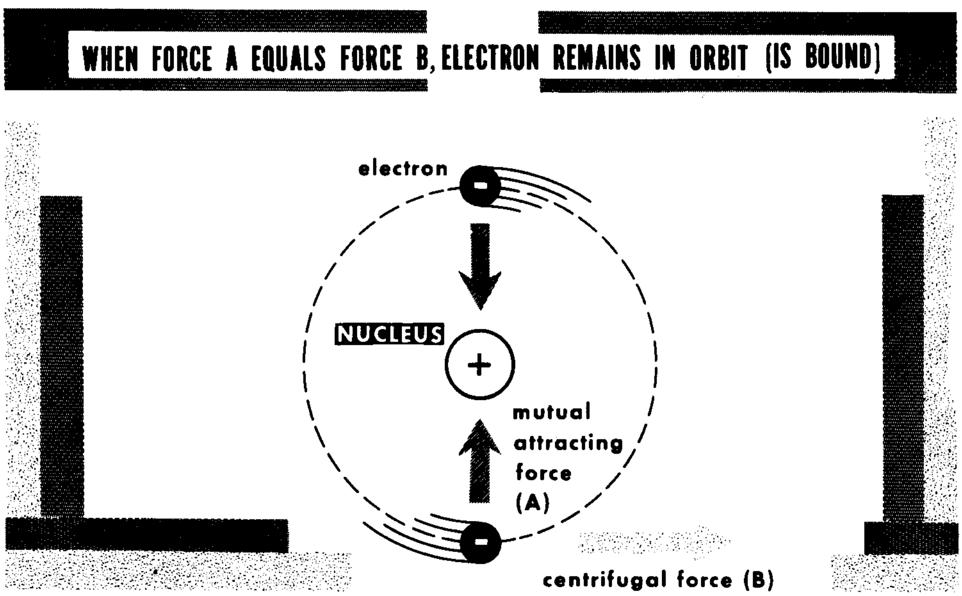
A force of repulsion exists between each orbiting electron and acts in all directions, thus keeping the planetary electrons in their positions in the orbits. A similar force of repulsion exists between individual protons which are separated, but when they are as densely packed as they are in the nucleus, there is a "something" which accounts for their not flying apart.

The electrical forces in the atom are fundamental and tremendous. Were this not so, the universe would fly apart. As long as the atom is in electrical equilibrium, that is, equal numbers of protons and electrons, the electrical and mechanical force condition is confined strictly to the inside of the atom. Neither the protons nor the electrons inside an electrically-neutral atom (equal numbers of protons and electrons) have any effect on other electrons and protons outside of the atom. This subject will receive more attention later, as we develop several related ideas.

Bound Electrons

The electrical forces referred to on the preceding page exist inside every atom but the behavior of these forces is not exactly the same in the different kinds of atoms. For our purposes, we need not consider the different kinds of atoms on an individual variety basis; it is sufficient if we deal with two main categories--nonmetals and metals. We shall consider each separately.

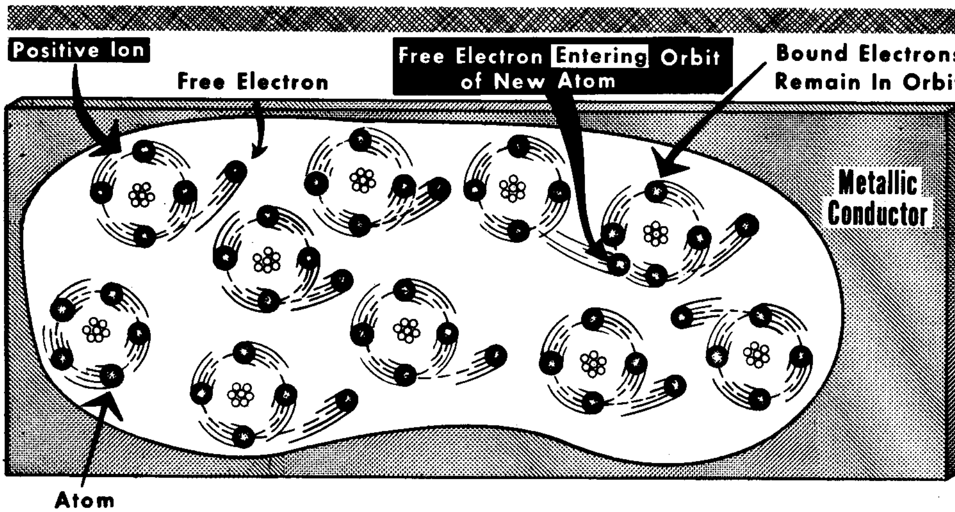
Under all normal conditions, the force of attraction between the protons in the nucleus and the planetary electrons in the atoms of nonmetals is sufficiently strong to keep all the electrons tightly "locked" inside the atomic structure. The electrons revolving in orbits close to the nucleus, as well as those revolving at the farthermost distances from the center of the atom, are "bound" to the atom. An occasional atom may let go of one of its outermost electrons, but by and large, we assume that the nonmetallic materials are made mainly of atoms which are in electrical balance (always have equal numbers of protons and electrons). They are electrically-neutral atoms.



This situation is not an unchangeable one Given a different set of conditions (which we might call "abnormal") such as the application of a sufficiently strong external force--one strong enough to overcome the binding forces between the protons and outermost electrons inside the atomic structure--it is possible to upset the electrical balance. It is possible to literally "tear" one or more electrons out of the atom, or even temporarily "add" an electron to the atom. Strangely enough, such external forces can be developed rather easily. Rubbing the resin rod with the fur and the glass rod with the silk are examples of "abnormal" conditions--that is, the application of such external force. The surface atoms of the fur and the glass rod released electrons, whereas the surface atoms of the resin rod and the silk temporarily accepted them.

Free Electrons In Metals

We have explained how the electrons in the atoms of nonmetals are bound to the atom. On the other hand, it is an accepted theory that the protons in the nucleus of the atom of a metal hold onto all but one of the normal complement of planetary electrons.



FREE ELECTRONS MOVE IN RANDOM MOTION THROUGHOUT METALLIC CONDUCTOR

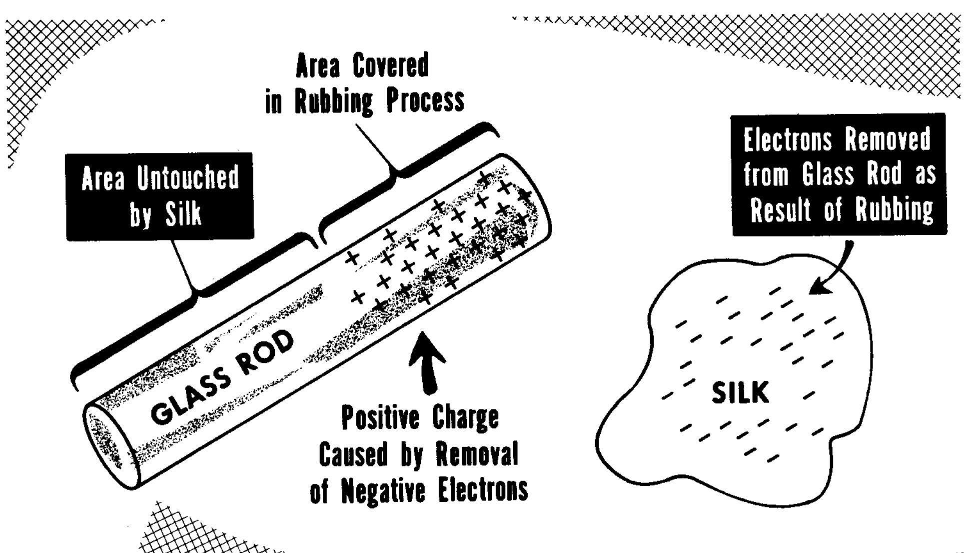
The situation is explained in the following way. The electron (or electrons) that orbits at the farthest distance from the nucleus in the atom of metals is believed to follow an elliptical path. (An ellipse is a geometrical figure which has the shape of a hoop that has been flattened slightly). The other orbits are assumed to be circular. As a case in point, let us assume an atom of copper. The outermost orbit is occupied by a single electron, this orbit being elliptical. At one point in the path of travel, the electron is very close to the nucleus; at another point, the electron is far removed from the nucleus. When the electron is farthest from the nucleus, it is released because the force of attraction between it and the cluster of protons is not sufficiently strong to keep the electron in its orbit. It is believed that this action occurs in the atoms of all metals, although not exactly to the same extent in each kind.

The liberated electrons are called "free electrons". They wander among the atoms of the metal throughout all parts of the metal in a random manner (presumably uniformly distributed throughout the metal), as many moving in one direction as in another. Every atom which has lost an electron now has a preponderance of positive charge, that amounting to one proton. These atoms are called "positive ions". However, for every positive ion in the metal there is a free electron so that the balance between positive and negative electricity is maintained and the metal as a whole remains electrically neutral.

The Modern Concept of Charging

The modern concept of "charging with electricity" or simply, "charging" is nothing more than disturbing either the equality of the electron and proton content in an object, or the uniform distributions of the negative and positive electricity content.

The four examples of nonmetallic substances used in the Franklin experiment became charged because electrons were torn from the surface atoms of one material (the fur and the glass rod) and transferred to the surface atoms of the other material (the resin rod and the silk) during the rubbing process. The emphasis on the surface atoms is made for a reason. The atoms of all solid substances are to all intents and purposes fixed in their locations. When electrons are transferred from the surface atoms of one nonmetallic object to surface atoms of another nonmetallic object, the negative charge is transferred from one particular place to another. Whatever charge is given up or acquired by rubbing, the action occurs over the area where the friction took place. The charged condition is therefore localized to certain places on the surface. This point is stressed because the action is somewhat different in objects made of metals.

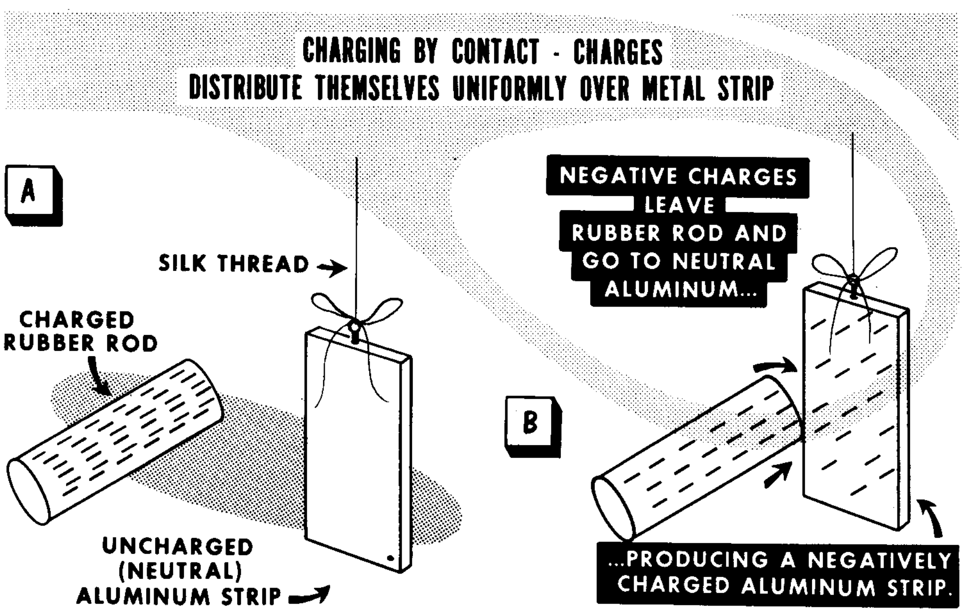


CHARGE ACQUIRED BY RUBBING OCCURS ONLY OVER AREA WHERE FRICTION TOOK PLACE

Charging By Contact

The frictional method of charging (rubbing) is applicable to nonmetals and metals alike, but not too successfully to the latter. A preferred method of charging metallic objects is by contact. We are concerned with the charging of metal objects because metals are used in radio equipment.

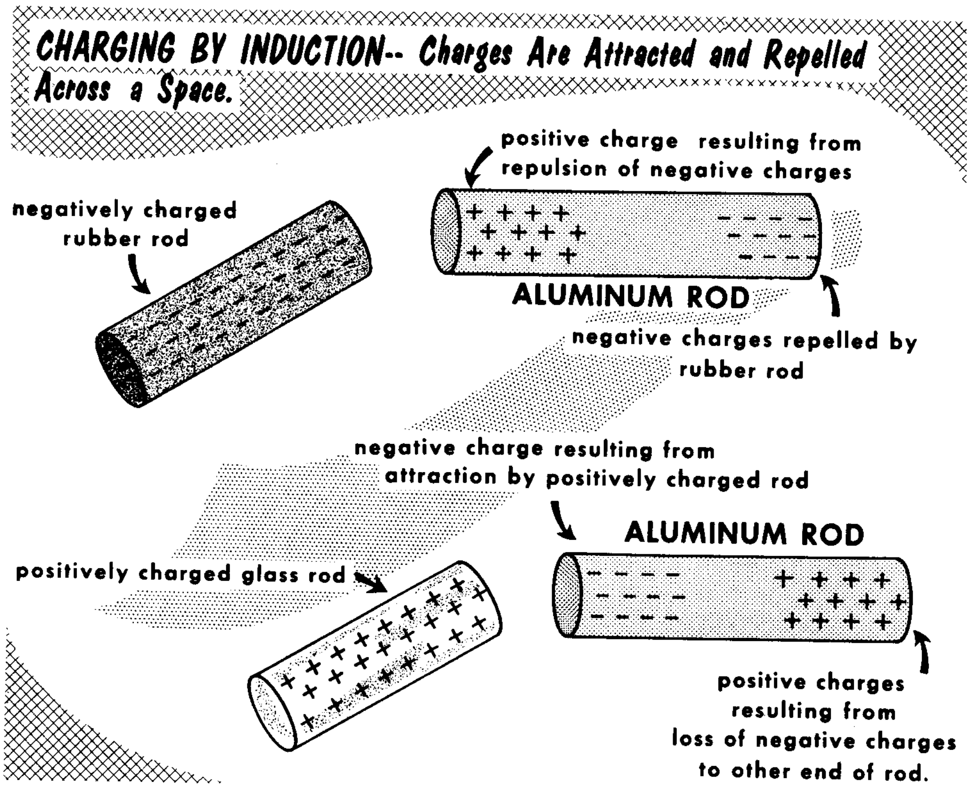
Let us assume we have a hard rubber rod which has been given a negative charge by some means. (Hard rubber behaves like resin). We also have a small strip of aluminum which is electrically neutral. The strip is suspended by a silk thread. We now make momentary contact between the charged rubber rod and the metal strip. Some of the electrons leave the rubber and go to the aluminum. Having given up some of its electrons, the rubber now has less negative charge; but now, the metal strip also has a negative charge. The total of the acquired electrons, plus the free electrons, plus the bound electrons in the atom of the metal exceeds the total of the protons in the metal. Thus, the total negative electricity content exceeds the total positive electricity content; hence, the net negative charge. However, unlike the behavior of the nonmetallic object, the electrons passed on to the aluminum distribute themselves uniformly over the entire surface of the strip, after which (to all intents and purposes) they are at rest.



In other words, the acquired negative charge is not localized to the point of contact with the rubber. It exists everywhere on the aluminum surface. If a positively-charged glass rod had been used as the charging body in place of the negatively-charged rubber rod, some of the free electrons moving along the surface of the aluminum would have gone to the glass, leaving a preponderance of positively-charged atoms (positive ions) in the metal. The metal strip then would have been charged positively.

Charging By Induction

There is still another method of charging an object. It is called charging by induction. We shall apply it to metallic objects rather than nonmetallic because the practical applications of the phenomenon involve metallic components.



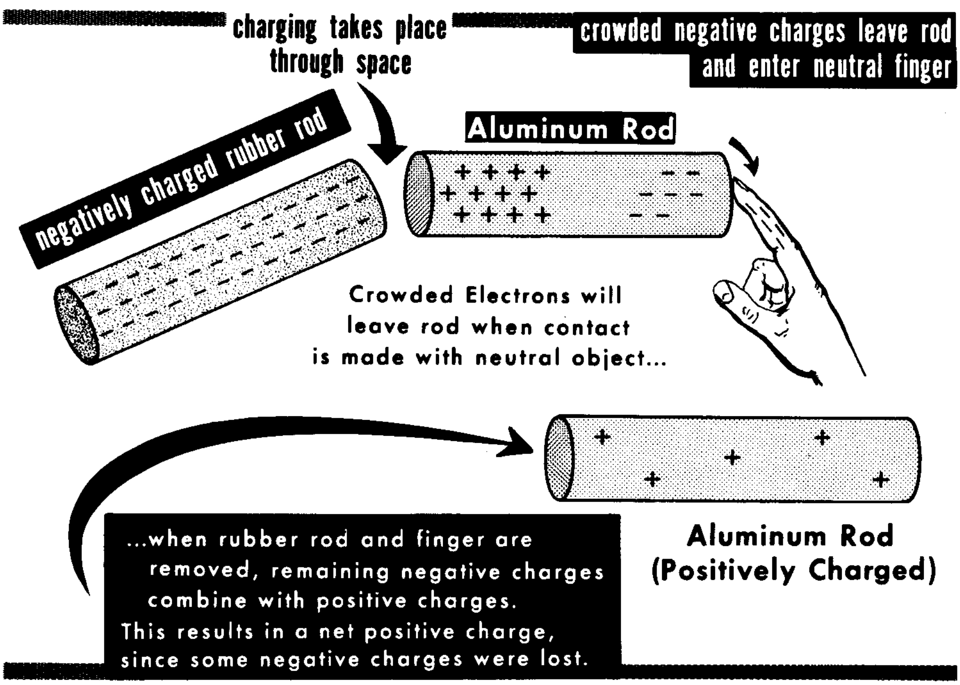
Imagine an uncharged aluminum rod suspended by a silk thread. (Any other metal could by used). Also a negatively-charged rubber rod. The negatively-charged rubber rod exerts an influence on the free electrons within the aluminum rod, acting across the space separating the two rods. Complying with the law that like charges repel, the rubber rod drives the free electrons wandering in the aluminum rod away from the end nearest the rubber rod. Now there is a decrease in the number of free electrons at that end of the aluminum rod which is nearest the charged rubber rod and a crowding of free electrons at the other end of the metal rod. This condition exists as long as the charged rubber rod is held near the metal rod.

If, instead of using a negatively-charged rod as the charging body, we used a positively-charged glass rod, the free electrons in the metal rod would be attracted towards the end which is nearest the glass rod, causing a crowding at this end and a shortage at the other end.

Charging By Induction (cont'd.)

Let us continue the experiment with the metal bar being acted upon by the negatively-charged rubber rod. As shown in the illustration, some of the free electrons are crowded at the end away from the rubber, having been repelled from the end near the rubber rod by the energy associated with the negatively-charged rubber.

Now we momentarily touch the end of the metal rod farthest from the rubber. The human body is not the best-known path for electricity, but it is good enough for this purpose. The crowded electrons tending to repel each other readily leave the metal and go to the finger. Then, we remove the charged rubber rod from the vicinity of the metal rod. The free electrons inside the metal redistribute themselves uniformly throughout the metal, but now, there are more atoms shy electrons than there are free electrons in the metal. The metal rod contains more positive electricity than negative electricity; hence, it has acquired a positive charge. It is to be noted that a negatively-charged charging body induces a positive charge in the original electrical neutral body. In other words, the charge induced is the opposite of the inducing charge.

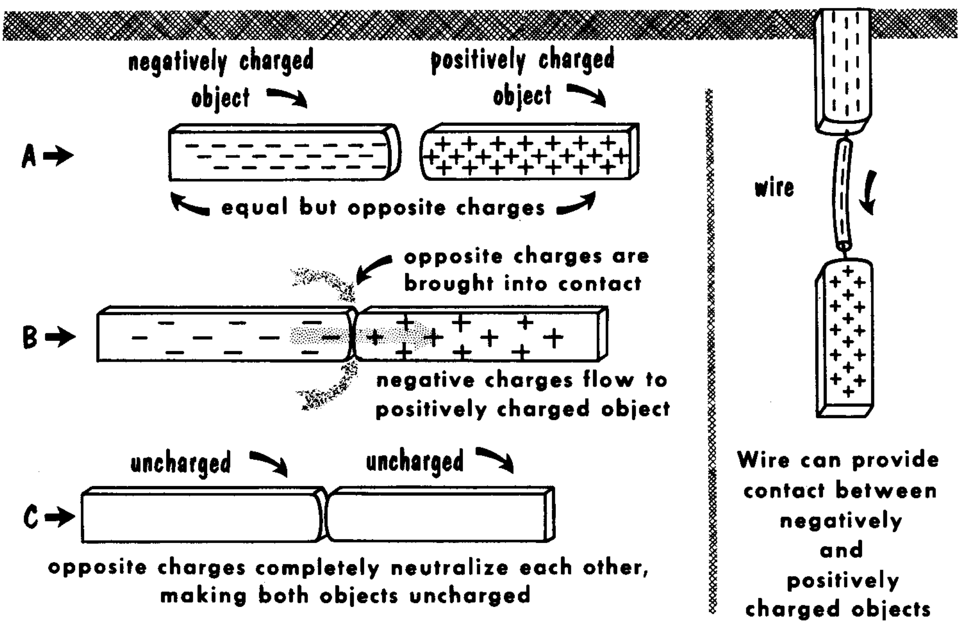


If the charging body had been a positively-charged glass rod, the metal would have had a shortage of free electrons at the end farthest from the glass rod. The positively-charged atoms at this end would pull electrons from the finger that touched the metal. Removing the charged glass rod from the vicinity of the metal would then leave the metal with more free electrons than positively-charged atoms -- or a net negative charge.

Discharging A Charged Object

You have learned that the electron and the proton are associated with electrical energy. If we think in terms of theory only, we say that a negative and positive charge are subject to a force which attracts each to the other; similar charges tend to repel each other. If we take the practical viewpoint, we realize that it is the electron, the very much lighter of the two fundamental charges of electricity, which performs the motion. (Each proton has about 1837 times the mass of an electron). Moreover, the positive electricity is locked inside the atom; it does not move under the influence of forces that act between charges. If we give a free electron the opportunity to move from one place to another under the influence of a nearby positive charge, it will do so, but the positive charge will not move.

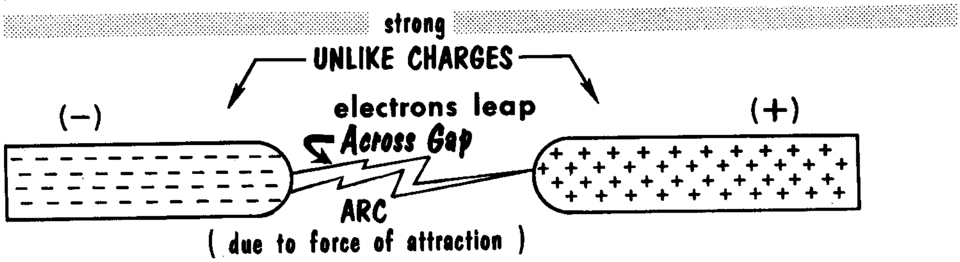
If we arrange for a negatively-charged object and a positively-charged one to make physical contact, the point of contact becomes the path over which the excess electrons on the negatively-charged object move to the positively-charged atoms on the positively-charged object. If both objects have equal amounts of unlike charge, all the electrons corresponding to the negative charge will flow to the positively-charged body, where they will neutralize the positive charge and create an electrically-balanced (neutral) condition in both objects. We have, in fact, discharged both charged objects by physical contact. Another kind of physical path could be a piece of wire which touches both objects at the same time. The flow of electrons through the wire is another story in itself.



CHARGED OBJECTS CAN BE DISCHARGED BY CONTACT

Discharging A Charged Object (cont'd)

Objects bearing unlike charges can be discharged without using a physical path between them. Assume two objects, one with a very strong negative charge, the other with an equally strong positive charge. If the two charged objects are brought sufficiently close to each other but not touching, the excess electrons on the negative object will, under the influence of the force of attraction between unlike charges, leap across the gap to the positively-charged object. The movement of electrons through air produces a visible flash of light accompanied by an audible crackling sound. The visible phenomenon is called an arc. The greater the accumulation of the unlike charge on the two objects, the wider the separation that can be bridged by the arc. Lightning is an example of arc discharge between dissimilarly-charged clouds, or between a charged cloud and earth.

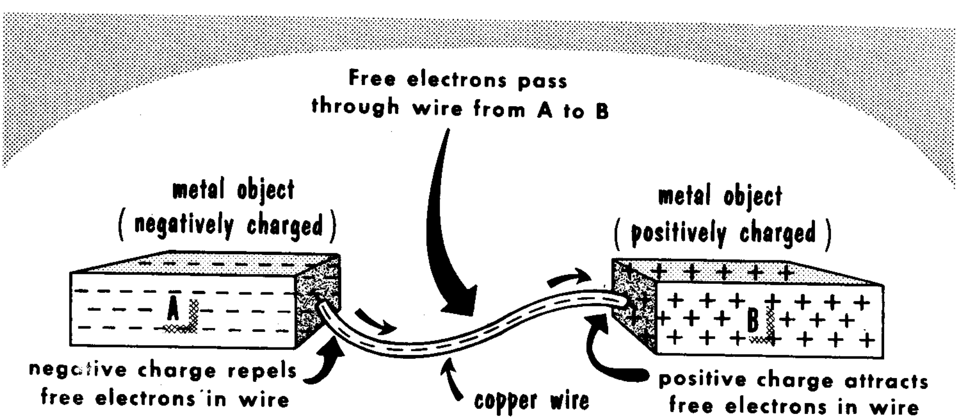


If all the surplus electrons on the negatively-charged object move over to the positively-charged object, both objects become electrically neutral. That is, the charged objects are discharged; the negatively-charged object because it has lost its surplus electrons, and the positively-charged object because it has acquired enough free electrons to neutralize the excess positively-charged atoms (positive ions) of the metal. It is conceivable that not all of the surplus electrons will move to the positively-charged object during the arc, in which case both objects will remain in a charged state, with each now bearing less charge than before the occurance of the arc.

Discharging Through a Wire

It is easy to visualize the action of discharging two charged objects by direct contact. The excess electrons on the negative object stream to the positive ions on the positive object. But how does the discharge action take place through a wire which joins two oppositely-charged metal objects? The answer is important to the study of electricity.

Let us assume the following conditions: The negatively-charged object (A) bears great numbers of excess free electrons along its surface. The positively-charged object (B) has an equivalent shortage of free electrons along its surface. Finally, a piece of copper wire is connected between the pieces of metal. When the copper wire joins A and B, the excess free electrons on A have free electrons which they can repel (the free electrons in the wire). Hence, the wire is a path into which the excess free electrons on A can move. Simultaneously, the excess positive ions on B now have free electrons (in the wire) on which they can exert a force of attraction. Thus, the free electrons in the wire feel a force of repulsion at one end and a force of attraction at the other. Actually, the electrons throughout the wire are subject to these forces. The net result is that the excess free electrons on A enter the wire at the same time the excess positive ions on B are pulling free electrons out of the wire. Of course, as excess electrons leave A, the amount of negative charge diminishes, and as they go to B the amount of positive charge diminishes.

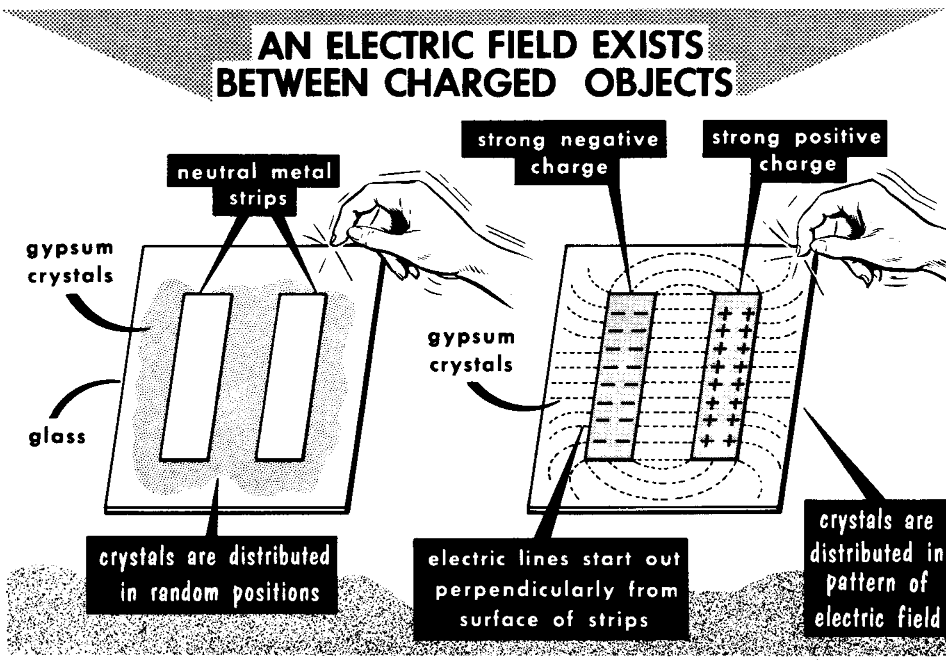


DISCHARGING CHARGED OBJECTS THROUGH WIRE
-- as many electrons leave wire and enter B as enter the wire at A

When all the excess electrons have left A and entered B, both strips are fully discharged and no further movement takes place between the two metal objects through the wire. Note that the movement of electrons through the wire is in a single direction -- from negative to positive -- and it happens without any change in the number of free electrons that are present in the wire at any one time, because as many leave the wire as enter it.

Demonstrating the Electric Field Concept

You have learned that the motion between charges or charged objects (attraction or repulsion) is caused by the presence of an electric force. We also said that the charging process was the equivalent of storing electrical energy. But where is the force which moves charged objects? And where does the storage of electrical energy take place? Strangely enough, both are found in the same place -- in the space between the charged objects. This is explained by the concept of the electric field of force, also known simply as the electric field. The space between and all around charged objects is filled with electrical energy--the energy of the electric field that is associated with the charge on the objects. This energy can do work.

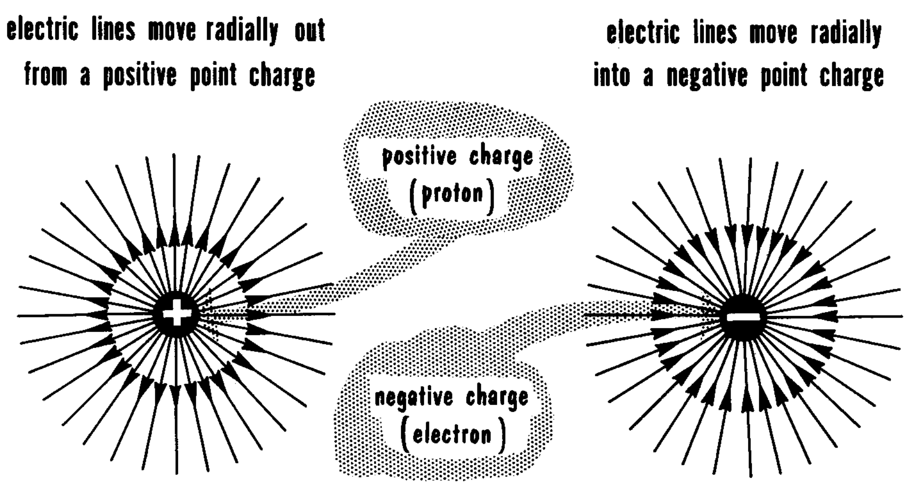


It can be demonstrated in the following way. Assume two electrically-neutral parallel-positioned metal strips cemented onto a pane of glass. Now we drop crystals of gypsum (or very tiny bristles of hair) onto the plate, and tap the glass slightly. The gypsum (or tiny pieces of hair) occupy random positions. That is, nothing happens. Now, remove the crystals (or hair) and give one metal plate an exceptionally strong negative charge and the other plate an equally strong positive charge. Then drop the crystals onto the plate and tap the glass. A distinct line pattern will be seen between the metal strips and around them. Something has happened! The unlike charge given to the two plates has created an electric field between and around the metal strips. The electrical energy that constitutes the field acted on the crystals (or the hair) and made them line themselves up in a special way. The field exerted mechanical force. If the two charged strips could move, they would move towards each other.

Electric Lines of Force

The electric field between the two charged metal strips shown on the preceding page has a distinct line pattern. One gathers the impression that the gypsum crystals acted on by the energy in the electric field aligned themselves along "lines" of energy. It is explained in the following way.

THE ELECTRIC FIELD AROUND POSITIVE AND NEGATIVE POINT CHARGES



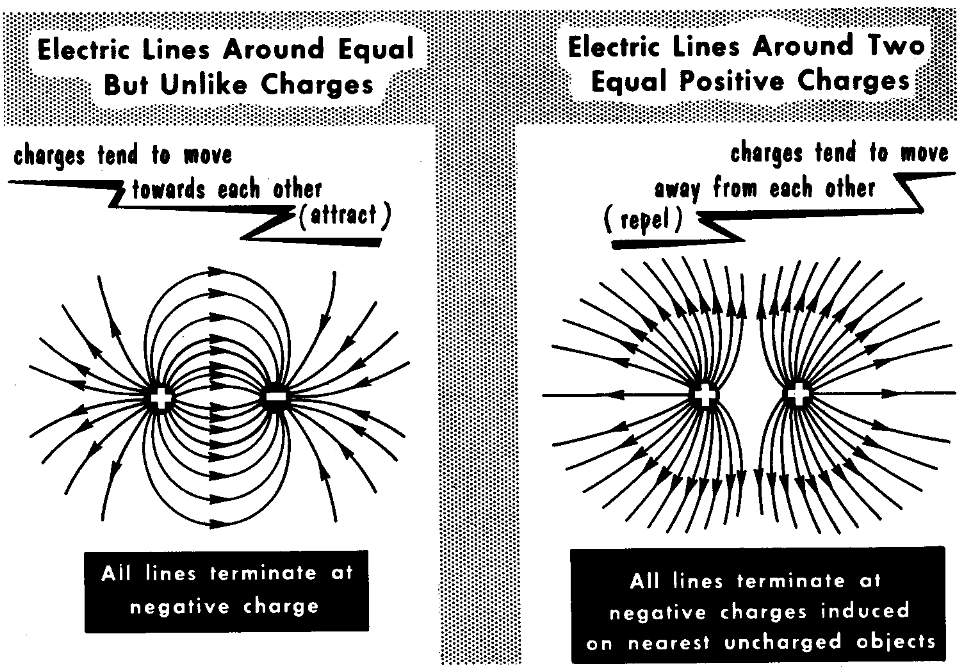
Every electron and proton has an electric field of its own. The energy of the fundamental charge is in this field. The electric field occupies the space all around the charge. Michael Faraday, an Irish scientist, pictured this field in a certain way. He visualized the field as being made up of "pencils of energy" which can conveniently be illustrated by innumerable straight lines which radiate outward in all directions from the center of the charge. He called these lines electric lines of force, or simply, lines of force.

Faraday said that a line of force behaved in certain ways. It had a direction of action; it exerted force in the direction in which it pointed, as indicated by an arrowhead drawn on the line. The direction was, and is (by arbitrary convention) that in which it would make an imaginary positive test charge move. So it pointed away from the proton and toward the electron. Another accepted form of behavior of lines of force is that those lines which advance in the same direction repel one another. A third form of behavior which he conceived was that lines of force which joined unlike charges behaved like stretched rubber bands that always wanted to contract. So, when we say that unlike charges attract, it is the action of the lines of force in the electric field between the charges that pulls them together. When we say that like charges repel, it is the force of repulsion between the lines of force going in the same direction that move facing charges apart.

Lines of Force (cont'd.)

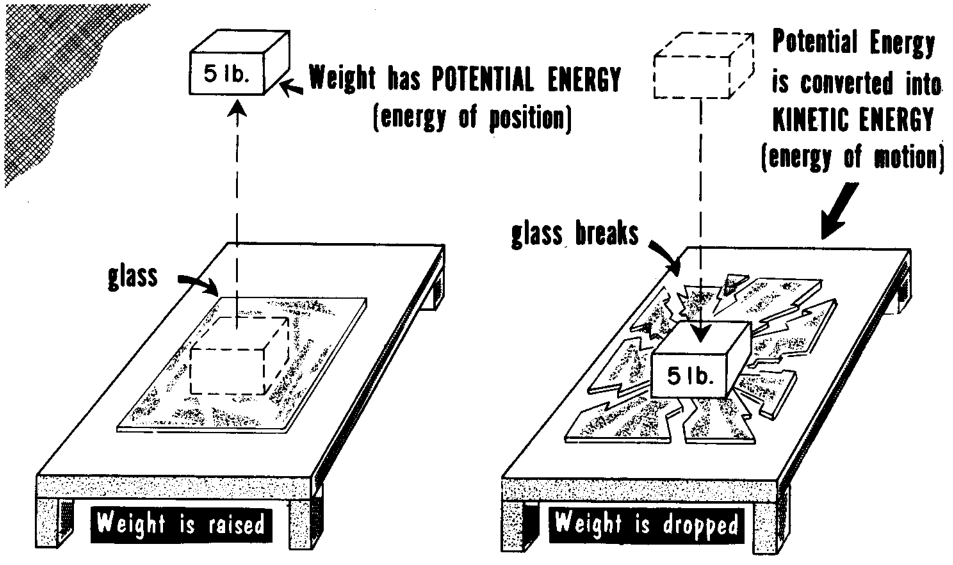
The lines of force concept is a ready means for explaining the apparent absence of electrical effects around electrically-neutral objects, and the electric field around charged objects. Interestingly, an electric field exists around the electrons and protons even in an uncharged object, but the fields have equal intensity and are opposite in direction of action at all points equidistant from the charge. One charge offsets the effects of the other everywhere; therefore, there is no detectable electric field surrounding the object. On this basis, an electrically-neutral atom is considered as having no external electric field. When the process of charging causes an accumulation of electrons on one object and positive ions on the other, each charged object has its own electric field, but two fields acting on each other produce a single net electric field between them.

In the case of the positive ions, each ion contains more protons than electrons; hence, it has a net electric field, that of the surplus protons. The energy of this field is detectable beyond the limits of the ion. The same condition is true in the case of the negative ion, except that now the electric field is that due to the excess electrons.



As to the line formation of the electric field between the parallel metal strips, it follows the reasoning of the lines of force concept. Actually, there are innumerable lines of force between the strips. The lines of force are substantially parallel between the strips, because the mutual force of attraction between them straightens them.

Potential and Kinetic Energy



MECHANICAL DEMONSTRATION OF POTENTIAL AND KINETIC ENERGY

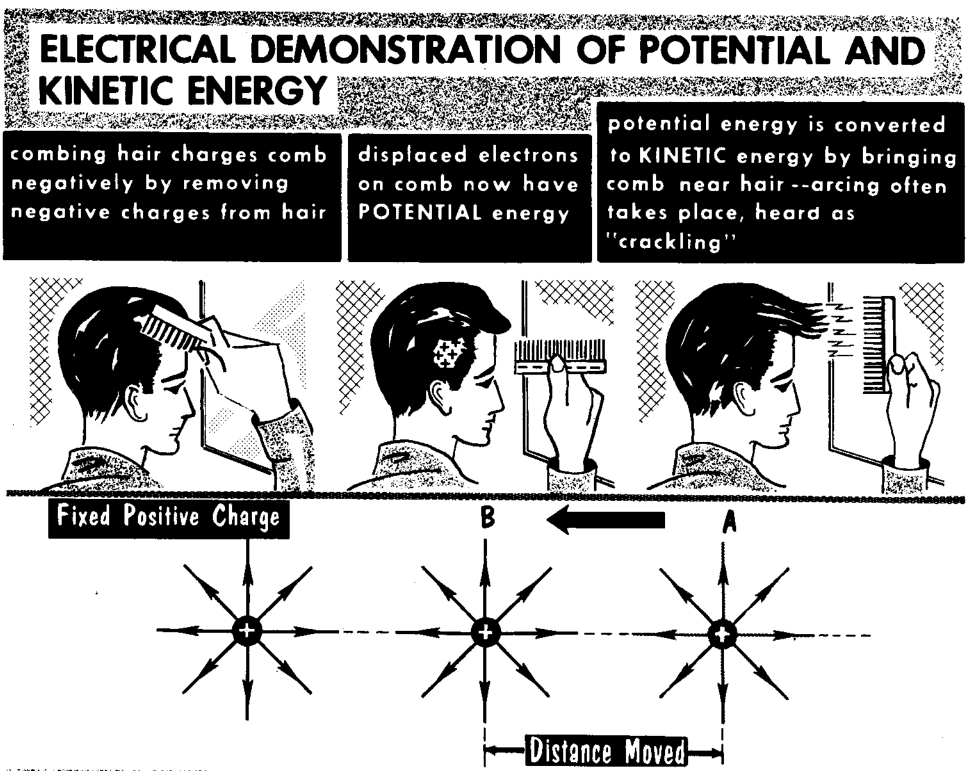
In the study of practical electricity, we are concerned mainly with the movement of free electrons and the conditions which govern their movement. In this connection, the subject of electricity has a language all its own wherein certain words identify particular conditions. One of these words is "potential". Potential is an abridgment of "potential energy", the energy associated with position. To illustrate this, consider the following. Assume a 5-pound weight resting on a pane of glass which in turn is resting on a table. Now you raise the weight above the glass to a height of say, 6 feet. Then you let it fall. The glass shatters. Where did the weight acquire the energy to break the glass? The answer is simple, even though you may not have thought much about it.

The energy to break the glass was acquired by the weight from your effort in lifting it against the gravitational pull of the earth. This pull accounts for everything falling to the ground, and if it were possible to do so, falling towards the center of the earth. You did work on the weight; that is, you gave energy to the weight when you raised it above the glass. You gave the weight potential energy--the energy of position. The higher you raise the weight above the table, the more work is done on it and the greater is the amount of potential energy stored in the weight. When you allowed the weight to fall, the potential energy was converted to kinetic energy--the energy of motion. When the weight struck the glass, the kinetic energy was changed into heat energy, sound energy, and mechanical energy, all of which are related to the actual physical breaking of the glass and the sound which accompanies the action.

Potential (cont'd.)

Let us now assume that we remove free electrons from an object by any one of the charging processes described, and pass these electrons on to another object. Whatever the method used, the displacement of the electrons requires the application of energy to make them move against either the force of attraction of the positive ions remaining after the electrons have been taken away, or against the force of repulsion from other free electrons which are on the surface to which the electrons are being transferred. The displaced electrons now have acquired potential energy. The greater the displacement, the greater is the amount of work that must be done, and the greater the potential energy acquired by the displaced electrons.

Now, if we arrange for the displaced electrons to go back to where they were, the potential energy is converted to kinetic energy (the energy of motion) and the moving charges can do work. The higher the potential of the charge at any point, the more work can be done when the potential energy is converted into kinetic energy. We save time by referring to the point or place where the charge or charges exist as being at a certain "potential" relative to some reference point, rather than describing it in terms of potential energy.

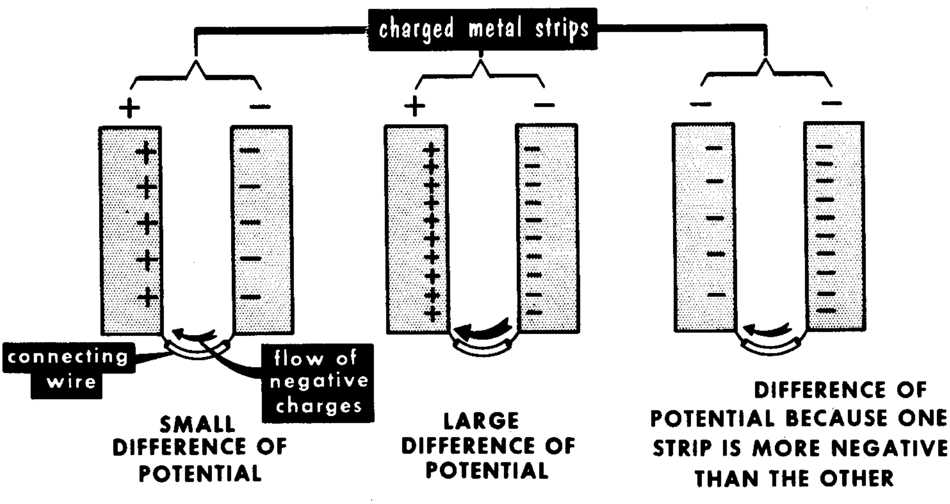


Positive charge at point B has potential equal to Work Done in moving it from point A to point B in opposition to repulsive force of fixed positive charge.

Difference of Potential

Another phrase encountered very often in electricity is "difference of potential" It, too, is related to the movement of free electrons. Difference of potential expresses a situation which determines the tendency of free electrons to move from one place to another. When we accumulate an excess of free electrons on an object and create a shortage of free electrons on another, we create a difference of potential between these two charged objects. You can consider the objects as charged metal strips, if you desire. Given a path between these two objects, free electrons would move from the "negative" strip to the "positive" strip. The greater the excess of free electrons on one strip and the more the shortage of free electrons on the other, the greater is the difference of potential between the two strips and the stronger would be the tendency of the free electrons on the negatively-charged strip to go to the positively-charged strip.

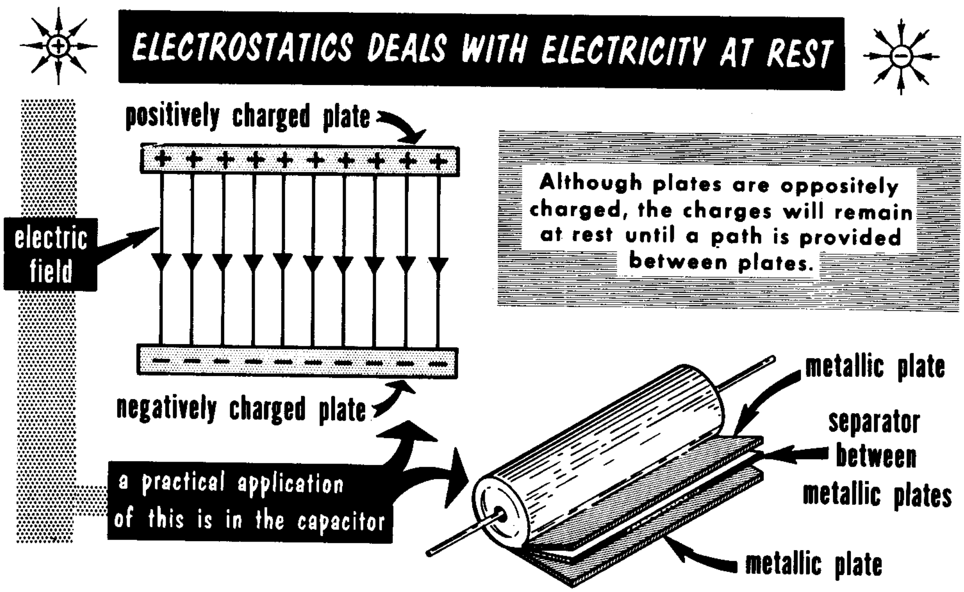
CHARGES TEND TO MOVE BETWEEN TWO POINTS THAT ARE AT DIFFERENT POTENTIALS



It is important however, to understand that a <u>difference of potential</u> exists between any two points or places where unequal amounts of free electrons exist. Conceivably, two metal strips (or any other objects) may be charged negatively, one <u>less</u> than the other. A difference of potential exists between these charged objects. Thus, there would be a tendency for electrons to move from the more negatively-charged object to the less negatively-charged object until both objects were at the same potential, after which there would be no further tendency of the electrons to move between the two charged objects. In other words, and this is a very important condition, movement of free electrons through the wire that connected the two metal strips described several pages back occurred while a difference of potential existed between them.

Static Electricity and Electrostatics

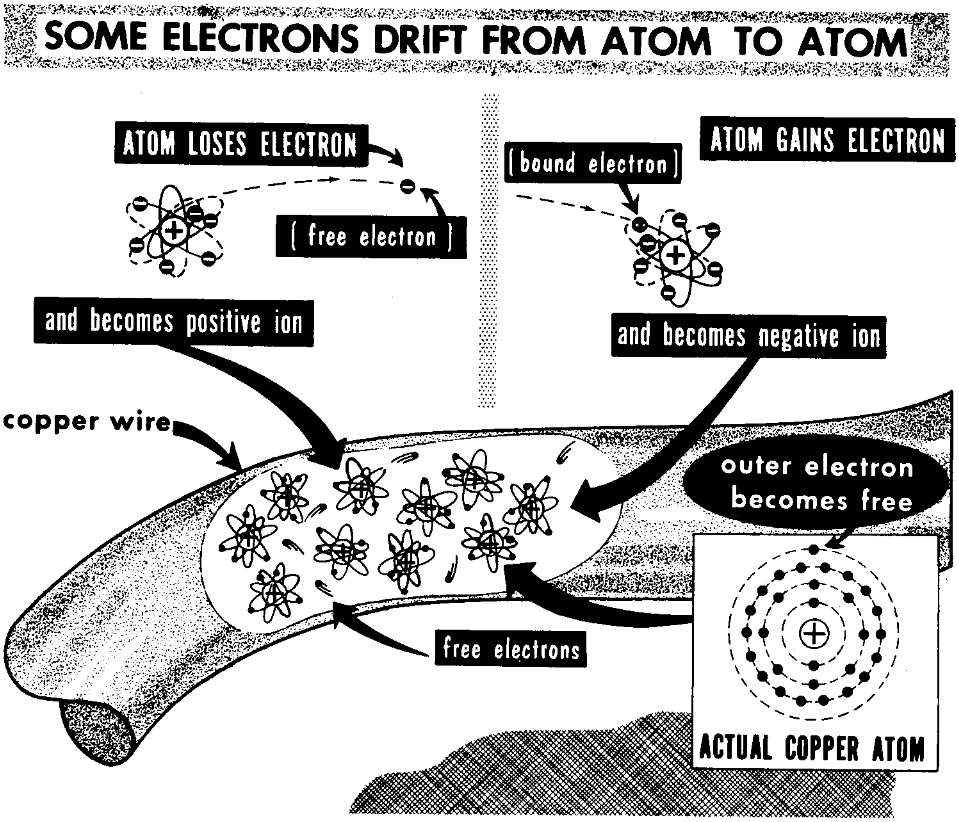
One area of the study of electricity is called electrostatics. We have discussed charging and discharging. Whether the method of charge was by friction, contact, or induction, electrons were displaced from one object to another, after which the electrons came to rest at a new location, creating a charged state. The name given to electricity at rest is static electricity, and the broad subject of charging and discharging (the behavior of static electricity) is called electrostatics. The study of electric fields between charged objects falls under the heading of electrostatics.



We must not confuse the electrically-neutral condition of an object with the meaning of electricity at rest. Electrical phenomena is not usually associated with an electrically-neutral object except to recognize that it can be charged But when it is electrically neutral, it has no electrical effects because for all intents and purposes it has no electrical field. In addition, it is important to understand that while a metallic object contains a tremendous number of free electrons in motion, when this object is charged by acquiring electrons, these surplus electrons are (to all intents and purposes) at rest along the surface of the metal.

There are practical reasons for having emphasized the phenomena of charging and discharging. Charging an object is the equivalent of storing electrical energy on the object; discharging an object is the equivalent of releasing the electrical energy. The practical device which does this in radio equipment, and about which you will learn more later, is called a capacitor (also known as a condenser). The purpose of a capacitor is to store electrical energy and to release it when it is needed. As we will learn, electrical charges also play an important role in the operation of tubes and transistors.

Free Electrons and Electric Current

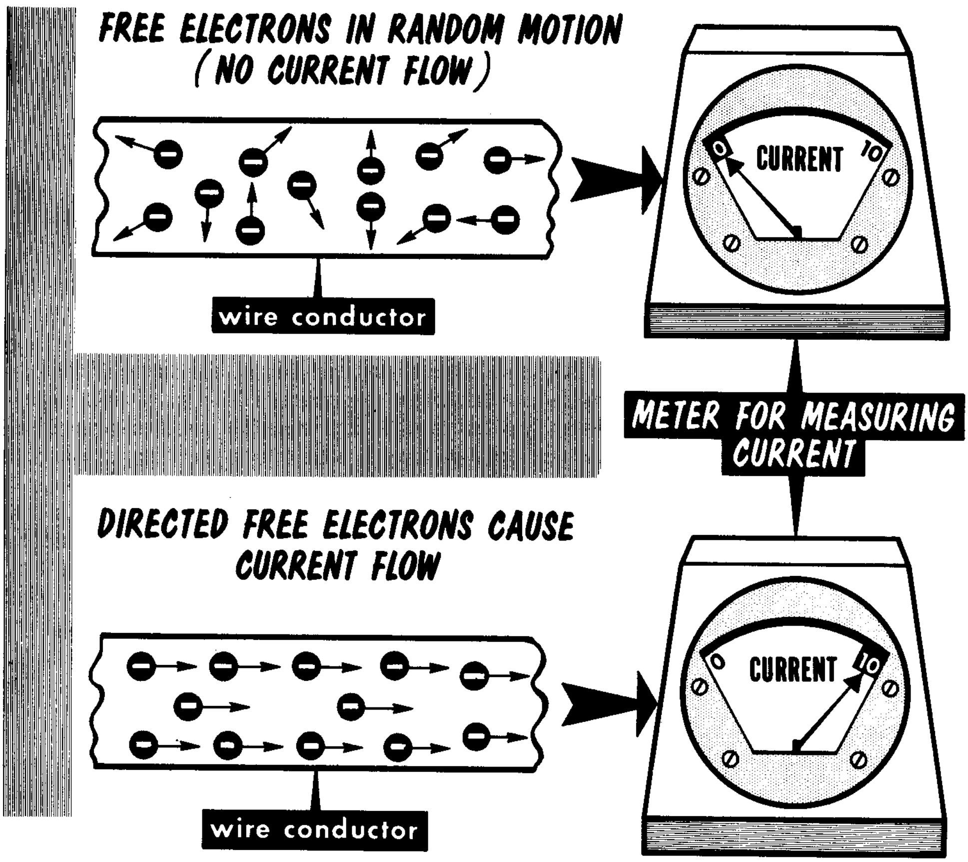


The study of the atom was intended to serve several purposes. First, to lay the foundation for the explanation of electrical charge and discharge. This we have done. Second, to be the basis for the explanation of electric current. This we shall do now.

Let us take an imaginary glimpse inside a piece of copper wire. What we see would not be too much different in any other kind of metal. The atoms shy electrons (more correctly known as positive ions) perform a to-and-fro motion over a very limited distance each side of a "fixed" position. Although describing a vibratory motion, we can, for all purposes, consider the ions as being fixed in location in the wire. In between, a host of free electrons drift slowly in all directions--as many moving in one direction as in the opposite direction. While performing this motion, the free electrons attach themselves momentarily to the ions, and even to atoms which have acquired the balancing electron--only to be freed again a moment later. The free electrons collide with each other, as well as with atoms. This is an important phenomenon, as you shall soon learn. Obviously, metal contains wandering negative electricity (wandering electrons) but it is not usable electricity as it is. We must change electron movement from random to controlled. Then it is electric current.

Free Electrons And Electric Current (cont'd.)

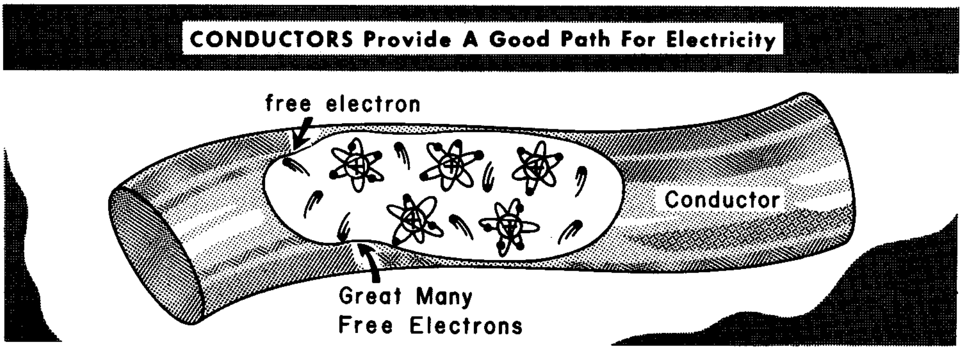
A few pages back, we described the motion of free electrons through a wire connected to two metal strips charged with unlike electricity. The direction of electron flow was from the negative to the positive strip. Such movement was a controlled motion--it had a definite direction--a singular direction throughout the wire. Although the flow of electrons did not last for long, it did constitute electric current while it lasted. We define electric current as free electrons performing a controlled motion.



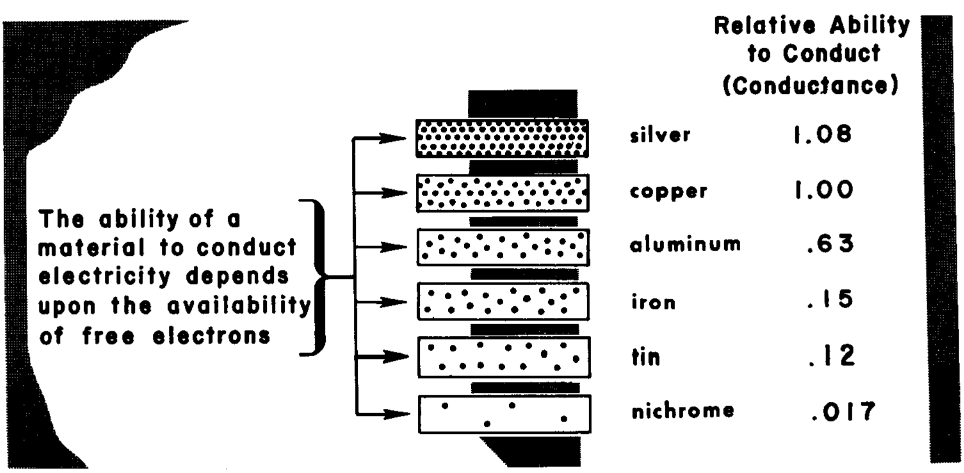
Let's consider electric current in a different way. When free electrons are drifting at random in a wire, as much charge (electricity) moves in one direction as in the opposite direction. There is, therefore, no continuous delivery of electricity from one point to another in a constant direction through the wire. But when the random motion of the electrons is changed to controlled motion, electricity is delivered continuously in a constant direction through the wire. Such delivery of charge is electric current. As you will learn later, two important considerations of electric current are the direction of flow, and the quantity of electricity that is transported in a period of time--the period being 1 second.

Conductors

Based on the atomic concept of matter and the electrical makeup of the atom, all things are made of electricity. Yet, all materials are not equally good as paths for electricity (electric current). Conductors is the name assigned to a broad category of materials through which a practical amount of electric current can flow under normal conditions. Most conductors are metallic.



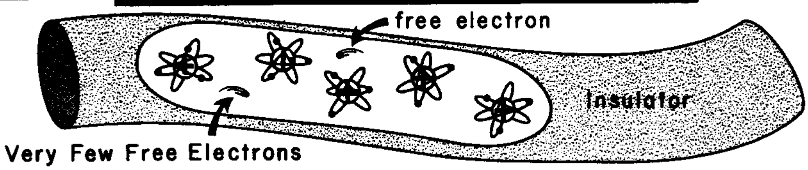
The usefulness of metal to conduct electric current stems from the abundance of free electrons in the material, the free electrons being electricity that is available to be moved through the metal when the material is part of a complete electrical system. However, not all metals are equally good conductors. The availability of free electrons for a given length and cross section is not the same in all metallic substances. The chart indicates the commonly-used metals in their order of suitability as paths for electric current. Silver is the best, but being expensive is used only in special cases. Copper, the second best conducting material, is plentiful and inexpensive; hence, is used most often. At the bottom of the list is Nichrome, a special alloy manufactured specifically to perform as an inferior conductor. It is one of numerous alloys that find special use in electrical systems.



Insulators

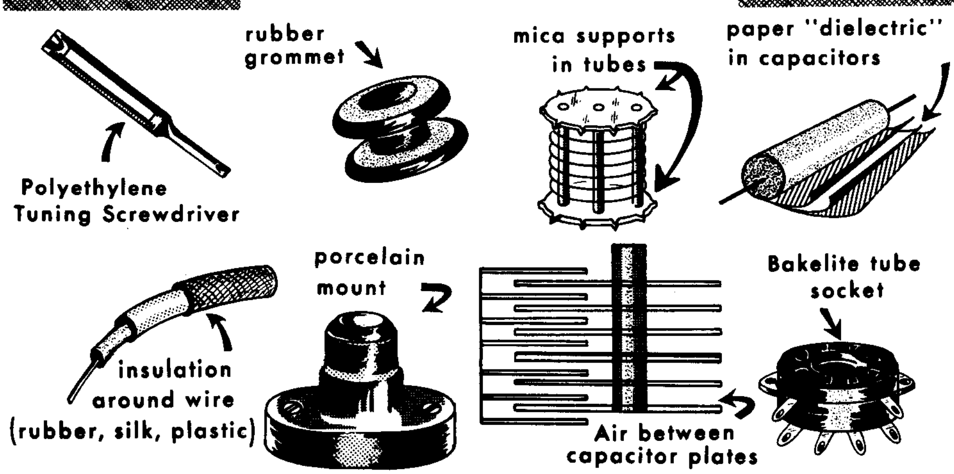
Insulators is the name given to a special group of materials that provide extremely poor paths for electric currents under all normal conditions. In fact, their function is to prevent the flow of electric current. To understand the basis of action of insulator materials, think of an atom whose electrons are bound to the atomic structure; in other words, the material contains very few free electrons. Since there are very few free electrons per given length and cross section of the material, there is very little charge which can be delivered from one point to another. No material is completely void of free electrons. But if they are so few in number, relatively speaking, that a practical and useful amount of electric current cannot flow under normal conditions, we consider the material to be an insulator. Examples of such substances are plastics, glass, mica, mineral oil, rubber, dry paper, dry wood, cotton, and ceramic substances. The above references are not in the order of their suitability as insulators.

INSULATORS Provide A Poor Path For Electricity



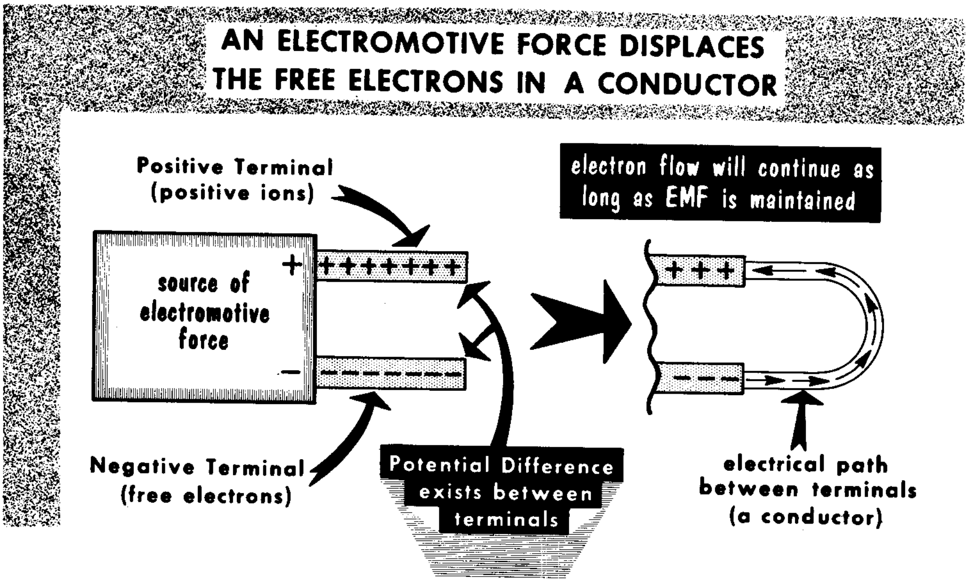
Let us clarify some points regarding the names associated with insulator materials. The material itself is called an insulating material, but when it is shaped into some form--large or small--and sometimes used as a support for wires carrying electric current, it is called an insulator. Another word for an insulator is dielectric. If the material is used as a covering around wires that carry electric current, it is called insulation.

ELECTRICAL INSULATION USED IN RADIO



Electrical Pressure and Electromotive Force

Q: How is the random motion of free electrons in a conductor changed to the controlled motion that is electric current? A: By the application of electrical pressure which is known as electromotive force. It is abbreviated emf, and pronounced ee-em-eff.



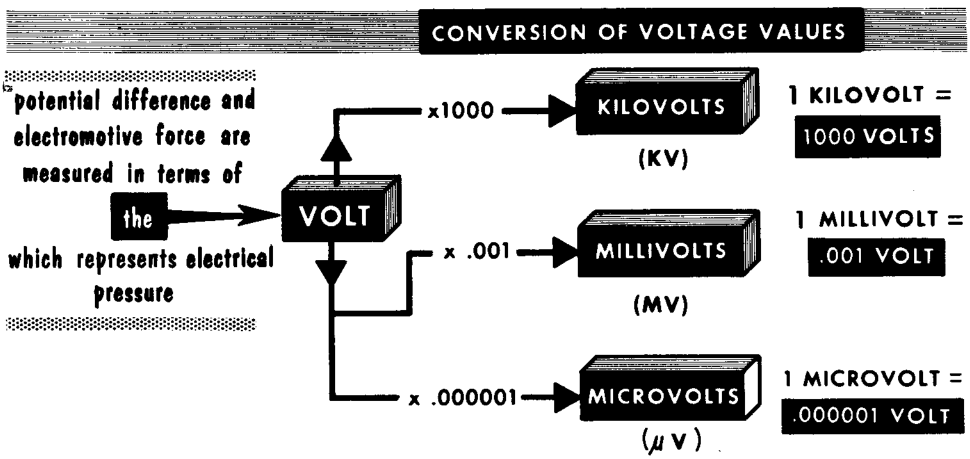
A source of electromotive force can be described as a device in which electrons are forcibly separated from atoms. This creates free electrons and atoms shy electrons or positive ions. The conventional cell or battery used in flashlights and portable radio receivers is an example of sources of electrical pressure or electromotive force. There are other sources about which you will study later.

The separating action referred to above takes place inside the device continuously while the device is functioning. The result corresponds to an accumulation of free electrons on the "negative" terminal (usually designated by the symbol -) and atoms shy electrons on the "positive" terminal (usually designated by the symbol +). The displaced free electrons are attracted to the atoms that are shy electrons (unlike charges attract each other), but they cannot do so by any path inside the device. The chemical action inside a battery prevents this. But if we provide some sort of electrical path outside the battery, connected between the negative and positive terminals, there will be a movement of free electrons between the battery terminals via the external path in a particular direction -- from the negative to the positive terminal. This directional quality of the action is called polarity. The electrical force acting on the electrons accumulated on the negative terminal urging them to the atoms that are shy electrons on the positive terminal is the electromotive force developed by the chemical action in the battery.

Unit of Electromotive Force (the Volt)

If we were speaking about water pressure or air pressure, we would refer to the amount of pressure in terms of "pounds per square inch". In the case of electrical pressure, or more correctly stated, electromotive force, the unit used is the volt. The actual amount of voltage is expressed by a number. Thus, the output of a flashlight cell is rated at an electromotive force of 1.5 volts; the modern automobile battery is rated at an electromotive force of 12 volts. Some other sources of electromotive force may be rated at 10 volts, 120 volts, or 5000 volts.

The difference of potential between two points in an electrical system can also be identified in terms of volts. It has become accepted practice to refer to the electromotive force of a device in terms of voltage output, the presence of electromotive force being understood when the voltage reference is made. Thus, by saying that the voltage output of a flashlight cell is 1.5 volts, we mean that it develops an electromotive force of 1.5 volts.



The voltages encountered in radio equipment involve a very wide range. Voltages may be as high as several thousand volts or as low as a fraction of a millionth of a volt. Sometimes, it is convenient to state them as a number and a word prefix having a numerical significance. For instance, it is quite common to use the prefix "kilo" to mean 1000. In other words, 1 kilovolt (abbreviated kv) means 1000 volts, and 10 kilovolts means 10,000 volts. When the voltage value is between 1 and 999, the amount is expressed as a simple number; beyond 999, the prefix kilo can be used.

Voltages less than 1 volt are sometimes stated as a decimal and sometimes by a number associated with a prefix. For instance, the prefix "milli" means one-thousandth; the prefix "micro" means one-millionth. To state three one-thousandths of a volt, it is customary to say 3 millivolts (3 mv) and, when writing the amount, the decimal .003 volt can be used. In like manner, 100 millionths of a volt would be stated as 100 microvolts (100 μv) and, when shown in a computation, it might appear as .0001 volt.

Many materials, when rubbed with other materials, not only attract tiny objects, but exert forces of attraction and repulsion on each other.

Bodies charged with unlike electricity attract each other; bodies charged with the same kind of electricity repel each other; positively-and-negatively-charged bodies attract each other.

Everything is made of two kinds of electricity--positive and negative--and one kind can be separated from the other.

Protons are the fundamental charge of positive electricity; electrons are the fundamental charge of negative electricity.

Electrons are held in their orbits against the pull of centrifugal force by the electrical force of attraction between the protons in the nucleus of the atom and the orbiting electrons.

All matter is composed of one or more of 102 substances known as chemical elements, which are comprised of atoms.

Matter or substances with an excess of electrons are said to be negatively-charged; matter or substances with a deficiency of electrons are said to be positively charged.

Atoms are comprised of positively-charged particles called protons, negatively-charged particles called electrons, and uncharged particles called neutrons.

Metallic objects can be charged by contact or by induction.

Objects bearing unlike charges can be discharged (made electrically neutral) through air (arc discharge), by direct contact, or through a wire.

Every electron and proton has an electric field of its own, which occupies the space around it. The energy of fundamental charge is in this field.

Potential energy is the energy of position; kinetic energy is the energy of motion.

Conductors are materials through which electric current flows under normal conditions; insulators prevent the flow of electric current.

An electromotive force changes the random movement of electrons through a wire to controlled movement (electric current). The unit of emf is the volt.

A difference of potential exists between two points or places in an electrical system and is identified in terms of voltage.

"Potential" and "voltage" are terms which are used interchangeably.

REVIEW QUESTIONS

1. What are two kinds of electricity called?
2. Define the fundamental laws of attraction and repulsion between two electrical charges.
3. How many elements are there? What is the smallest part of an element?
4. What are atoms comprised of?
5. What is the difference between charging by contact and by induction?
6. Explain what free electrons are.
7. What is an electric current?
8. What is the name given to electricity at rest?
9. Explain what is meant by the "lines of force concept".
10. Define a conductor. Give examples of good conductors.
11. Define an insulator. Give examples of good insulators.
12. Which is the better conductor, copper or silver? Which is more widely used and why?