Things a boy can do *with* ELECTRICITY

by ALFRED MORGAN

AUTHOR *of* A FIRST ELECTRICAL BOOK *for* BOYS

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Books by Alfred Morgan

THINGS A BOY CAN DO WITH ELECTRICITY
A FIRST ELECTRICAL BOOK FOR BOYS
AN AQUARIUM BOOK FOR BOYS AND GIRLS

Charles Scribner's Sons

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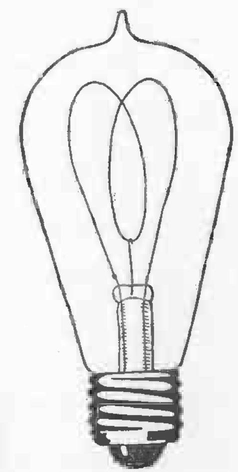

CHARLES SCRIBNER'S SONS · NEW YORK

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I

BECOMING ACQUAINTED WITH ELECTRICITY

The Electrical Age

You were born during an electrical age. The dynamo, motor, telephone, telegraph, electric light, radio, x-ray, almost all of the magical electrical devices which serve you at every turn, were here before you. The news of your birth could have been flashed across a continent in less time than it takes for your voice to travel across a playground. A letter or a package can reach you overnight from a city 2000 miles away. This evening, if you wish to work or play after sundown, you need only press an electric switch to secure light whereby to see.

Within a few decades, electricity has become more useful than the genii of Aladdin's lamp. It has added immeasurably to the power, safety, comforts and pleasures of mankind. Whether you are at home or travelling, studying, working, playing or resting, sick or well, you are continually depending upon some device utilizing electricity. Many things which you take for granted because they have always been part of the world of your experience are the gift of electricity.

These things were not always possible. They are among electricity's recent gifts.

Until the time when your great-grandfather was a boy or young man, messages, people and merchandise travelled slowly. It was not electricity, it was muscle-power that bore letters and messages about the world, the muscle-power in the legs of couriers or the horses that carried couriers and hauled stage coaches.

Seventy-five years ago, the crews of great whaling fleets were scouring the seas in search of whales from which to obtain oil and spermaceti.[1] Other men were drilling into the earth seeking "rock oil" or petroleum which could be pumped from the ground. Spermaceti, whale oil and petroleum were sought for making candles and for burning in lamps. Many older people can remember when the unsteady flame of oil or gas furnished light at night and when journeys which we make in a day required several days or even weeks.

Not Long Ago Electricity Was a Stranger

And one of the most amazing things of all about electricity is that hardly more than a hundred years ago it was merely a plaything. It could be made to do a few tricks, give shocks and produce sparks, but that was all. Gentlemen in powdered wigs and silken breeches rubbed glass rods and drew forth sparks to awe and amuse the ladies. No one knew how to make electricity do anything useful. There was not a single penny in all the world invested in any form of electrical enterprise. There were no dynamos, no electric lights, no radios, no telephones, no x-rays, no motors.

Men had known something about electricity for many

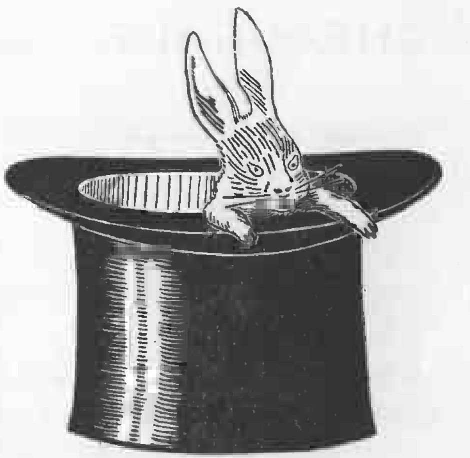
[1]Spermaceti is a fatty substance obtained from the head of a whale. It was used in the manufacture of ointments, cosmetics and candles.

centuries. Why did they not find some useful purpose for it sooner?

Because, until little more than a century ago, electricity was a stranger. No one was really acquainted with it. There was little knowledge of those rules or laws which electricity always obeys.

Where Our Knowledge of Electricity Came From

It is our acquaintance with electricity, our knowledge of how and why it behaves as it does, that has made it man's most valuable servant.



HIDDEN

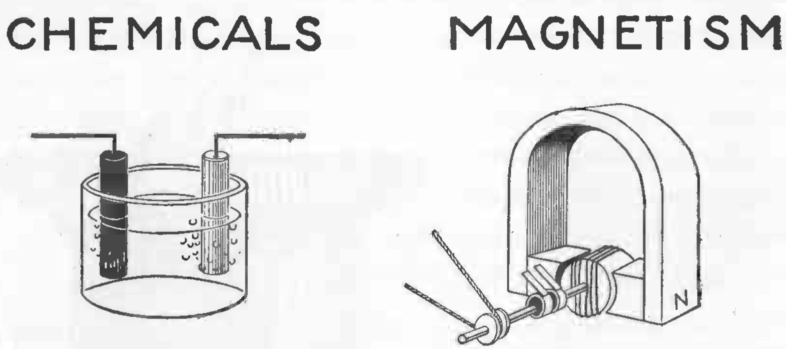
Like the rabbit which a magician pulls out of a hat, electricity is not created; it is merely revealed or released.

This knowledge came from experiments. An experiment is an exploring trip, an adventure in the land of science. Thousands of men made countless experiments — went exploring in unknown electrical territory looking for new knowledge. They brought back with them telegraph instruments, telephones, x-ray tubes, electric eyes, a host of other wonders.

Some of these scientific adventurers won fame, some fortunes; others only the pleasure of discovery. Many obscure men, whose names we have never heard, discovered and are still finding scientific nuggets by experimenting in electricity's goldfields. Others, and from a long list we might mention Volta, Franklin, Faraday, Ampere, Morse, Bell, Edison, Kelvin and Tesla, were electrical adventurers whose experiments made them world famous.

What Is Electricity?

A most amazing fact is that not one of these men, not even Faraday or Edison, ever saw or felt or heard the wonderful



THE MOST PRACTICAL

Batteries making use of chemicals and dynamos employing magnets are the most practical for producing large quantities of electricity.

force which he helped to master. *Not one of them even knew what it was.*

Neither can we hope to see or feel or hear electricity itself. It is invisible. It is somewhat like the wind. It is a force—a form of energy. We can see only the effects of the wind—those things which the wind does. We can hear leaves rustle, feel pressure against our faces, see trees sway, smoke swirl and waves and ripples sweep over the water, yet we will be

only hearing, feeling and seeing the effects of the wind and not hearing, feeling or seeing the wind itself.

In our own electrical experiments—adventures in which we become acquainted with electricity and make it do as we ask—we will never see or feel or hear electricity itself. We will be aware only of its effects, of the things that electricity does.

No one knows the answer to the question, *what is electricity?* We know where and how to get it and what to do with it—that is all.

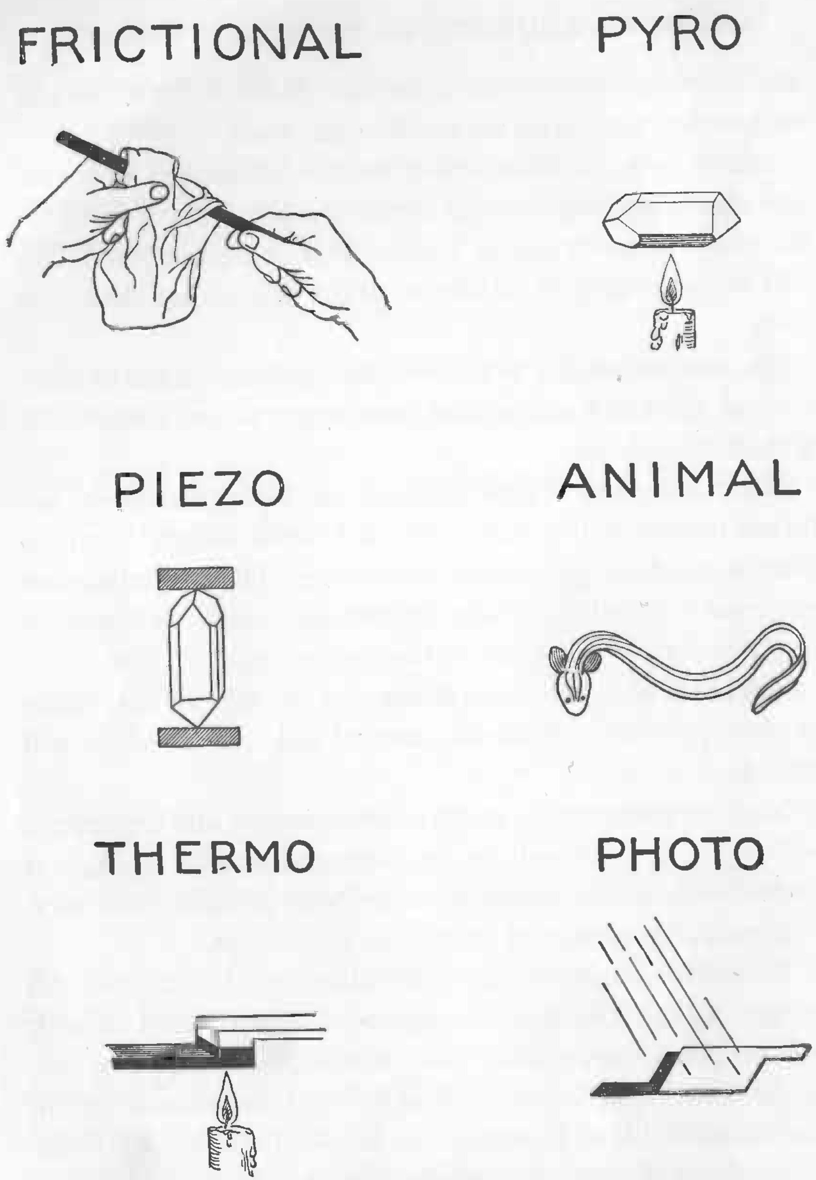
When we speak of generating or producing electricity, we do not mean *creating* it. It is like the rabbit which the magician pretends to pull out of your collar. The magician does not create the rabbit. It was hidden somewhere. It is merely revealed by the magician at the proper time.

Scientists of a few generations ago thought of and spoke of electricity as a mysterious sort of fluid. Electricians still refer to it as "juice."

Modern science, by a series of experiments and arguments which are too difficult to be discussed in this book, has undoubtedly found a more accurate conception of electricity.

It probably consists of infinitesimal particles.

Electricity is not created. Electricity itself is a creator. All matter, all substances, are composed of electricity. It is built up as a part of every little bit of matter, solid, liquid or gas, in the universe. Electricity is, in the end, responsible for all the varied kinds of light that we know, the light of a flame as much as that of an electric light. At least that is what scientists have good reasons to believe. It is the only way in which they can logically explain the behavior of electricity.



PRODUCING ELECTRICITY

Piezo electricity (electricity from pressure) is used in radio transmitters and phonographs. Thermo-electricity (electricity from heat) is used for measuring high temperatures. Photo-electricity (electricity from light) is useful for measuring the intensity of light.

Such an explanation is a *theory.* A theory is sort of a mental tool or implement useful to scientists. It is a plan or scheme which subsists in the mind only, but it is based on observation and experiment.

How Electricity Is Produced

When we generate or produce electricity, we do something which concentrates, pulls it out of its hiding place and sets it in motion. It then reveals its presence. We are like the magician with the rabbit. When we generate electricity, we merely reveal something which was around all the time.

On another page are pictures showing the several methods by which electricity may be produced. All methods of producing electricity require some form of energy. We cannot produce electricity without paying for it with energy. Electricity itself is energy and to produce it we must use some other form of energy. Heat, light, mechanical force, animal energy, chemicals and magnetism will all produce electricity.

Chemical action (batteries) and magnetism combined with motion (dynamos) produce the most electricity. The most useful electricity is that which we call an electric current. Dynamos and batteries are the commercial sources of electric currents. The electricity which we use to light our homes and factories is produced by dynamos driven by water power, steam or combustion engines. A battery is a source of electricity that may be readily carried or moved about. Light and friction produce only small amounts of electricity—not enough for practical purposes. Perhaps some future scientist will discover how to secure large quantities of electric current directly from sunshine or heat.

The electricity produced by dynamos is in most cases *indirectly* from heat. Heat generates the steam which drives the engines or turbines that turn the dynamos in the power stations. Using an idea suggested by "The House that Jack Built," the process of generating electricity indirectly from heat might be described in this manner:

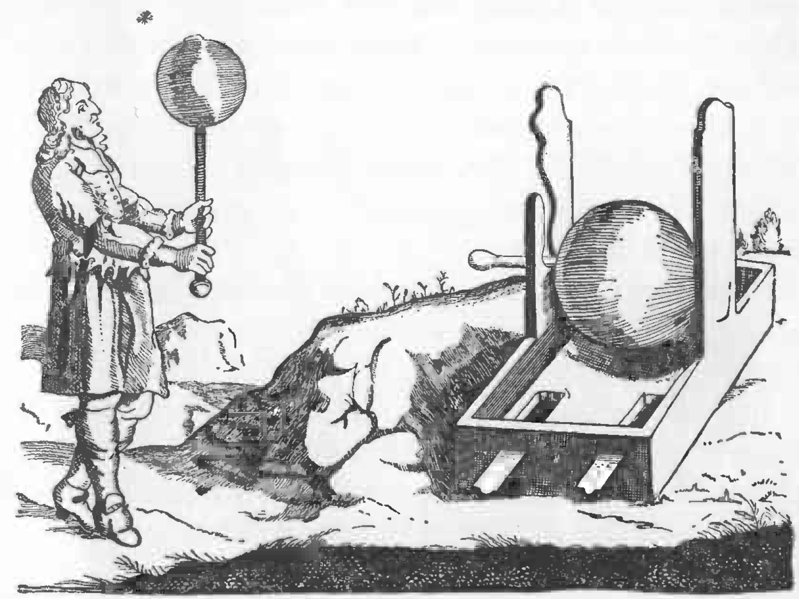
This is the cinder
Which came from the coal
That burned in the fire
Which boiled the water
That made the steam
Which drove the engine
That turned the dynamo
Which produced the current
That made the light
Which shone in the
House that Jack Built.

To produce large quantities of electricity directly from heat is a hope and dream which has not been achieved.

In the first part of the last century, Volta, the Italian scientist who invented the electric battery, discovered that combustion, the process we usually speak of as burning, generates electricity. A piece of burning charcoal connected to an instrument called an electroscope[2] shows an electric

[2]An instrument for detecting the presence of electricity.

charge. Edison puttered with the idea of producing electricity directly from burning coal but did not discover anything useful.



PROGRESS

Here is the first *machine* for generating electricity. It was built nearly three hundred years ago by Otto von Guericke and consisted of a ball of sulphur cast on a wooden axle. When the ball was revolved and the hand held against it, static electricity was produced. There is no resemblance between this crude machine and a modern generator.

However, there are two other methods of making electricity directly from heat, one of which is useful. Heat applied to the juncture of two dissimilar metals produces an electric current called thermoelectricity. This makes it possible to build instruments called pyrometers for measuring high temperatures.

It is not possible to explain how or why heat can produce thermoelectricity nor why certain crystals generate electrical charges known as pyroelectricity while their temperature is rising or falling. Chief of these is the interesting mineral called tourmaline. Tourmaline is a complex mineral composed of the elements boron, silicon and aluminum. It is sometimes transparent but is more commonly black, brown, bluish-black, blue, green or red. Transparent tourmaline is cut for use as a gem and is used in scientific instruments to polarize light.

Other crystals which produce pyroelectricity are those of silicate of zinc, quartz, sulphate of quinine, cane sugar, boracite, tartrate of potash, topaz prehnite and scolecite.

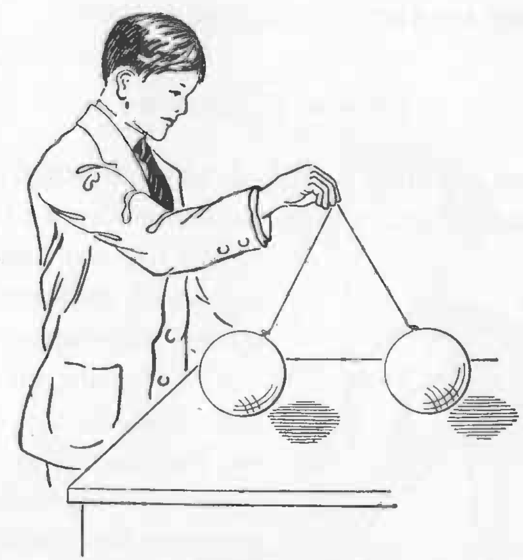
It would appear that electricity is almost whimsical. It comes forth at such unexpected times and from such strange places. Many substances in passing from a liquid to a solid state become charged with electricity. Sulphur becomes violently electrified when it cools. Who would ever think of candy as a generator of electricity? Well, chocolate becomes electrically charged as it changes from a hot liquid to a solid.

Pressure applied to certain crystals produces electricity. Rochelle salts, or a crystal of calspar pressed between the dry fingers will generate electric currents called piezoelectricity. Piezo means *press.* A piezo crystal properly connected to an amplifier and loud speaker will produce loud shrieks when squeezed, just as if it objected to the pinching.

Muscles and nerves are another source of electricity. There are certain fishes which can give very powerful electric shocks. The most famous of these, the electric eel or *Gymnotus,* lives in small rivers in the northern part of South Amer-

ica. The electric eel can give a shock sufficiently powerful to stun any near-by animal or fish.

Experiments have shown that the electricity of the electric eel produces exactly the same effects upon electrical instruments as other electricity—in other words, it is ordinary electricity.



AN EXPERIMENT

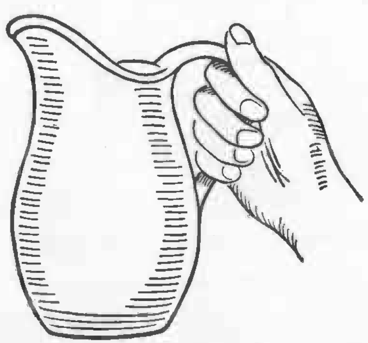
If you rub an inflated toy balloon with fur or wool it will become charged with static electricity. Charged balloons tied to threads will not hang straight down if near one another because they repel each other.

The electric eel and a few other fishes are the only animals that can give electric shocks but the nerves and muscles of every animal, man included, produce electric currents as they perform their normal functions. These currents are usually so small that very sensitive instruments are required to show that they are there. The beatings of the heart create rhythmical electric currents which can be recorded on an instrument called the cardiograph. The feeble heart currents are an important guide to the behavior of the heart. Those produced by a person with a sound heart differ considerably from those of a person with heart disease.

The first electricity which any one knew anything about was gathered together by means of friction.

Finding Electricity

Whenever anything is rubbed, torn, stretched or broken, in fact disturbed in any way, we find evidence of electricity which was not noticeable before. Such ordinary actions as tearing the wrapper off a package of chewing gum, pouring coffee into a cup, shovelling dry snow, combing one's hair, sharpening a pencil, countless commonplace activities produce electricity. The quantity of electricity thus produced may be so small that it can be detected only by means of extremely sensitive instruments. On the other hand, there may be a sufficient amount to reveal itself without the aid of instruments.



UNSEEN

Static electricity is always generated when liquids are poured. It is usually unnoticed but may be detected with sensitive instruments.

There is no mystery about the means of producing electricity. It is really a simple matter.

Static Electricity

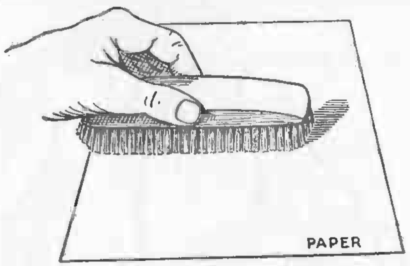
It is also simple to produce electricity in sufficient quantities for experimenting. There are a number of common

JUMPING CATS

This is an experiment for a dry, cold day. A piece of clean, warm window glass supported by two books is electrified or charged with static electricity when rubbed with a piece of wool or fur. The small paper cats (cut from tissue paper) jump up and down in the space between the table and glass when the latter is charged.

things which will produce enough electricity to experiment with when merely rubbed with a piece of flannel or fur. Some article made of hard rubber such as a comb, pipe stem or fountain pen, a stick of sealing wax or a glass rod—even a strip of dry paper will produce enough electricity for many experiments.

Electricity which is generated when two substances are rubbed together or when something is torn or stretched or broken is not the form of electricity used for operating telephones, electric lights and other useful things. It is *static* electricity which is "standing" or more or less at rest on the surface of things. Static electricity is not of much practical use. In order for electricity to be useful, in order for it to move trains, carry messages or heat flat irons, it must move. It



AN EXPERIMENT

Brush a sheet of warm paper with a clothesbrush. It will become charged with static electricity and cling to the table. If the charged sheet is placed against the wall, it will stick there.

must be the form of electricity called an electric current—electricity produced by magnetism or batteries—not by friction.

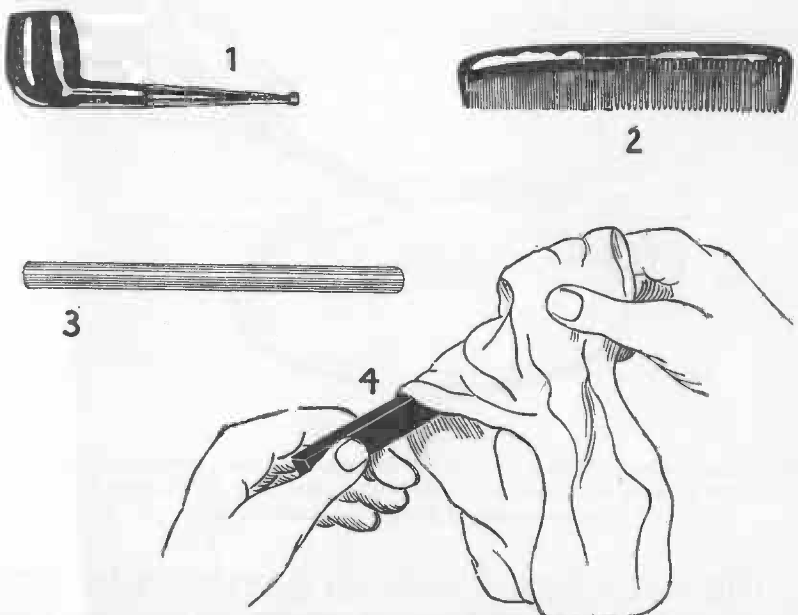
But static electricity is interesting and amusing. It does tricks. It provides a great deal of intelligent fun.

However, you won't have much luck experimenting with static electricity in the summer. In summer the air is damp. Damp air is a partial conductor and carries static electricity away as fast as you can produce it. Experimenting with static electricity is a winter amusement. Cold, winter air is much drier, it is a better insulator than the warmer air of summer.

Electrified Paper

Static electricity is a nuisance in some industries. In paper manufacturing and printing, static electricity generated by friction causes the sheets to cling and drag.

You can prove that paper is easily charged with static

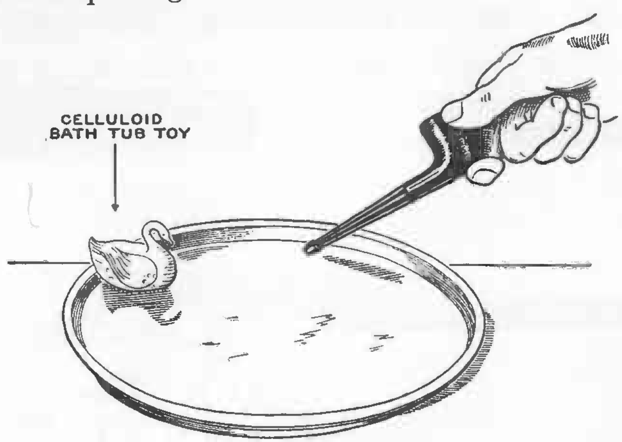


EASILY ELECTRIFIED

A glass tube, a pipe stem, hard-rubber comb or stick of sealing wax are easily electrified by rubbing with a warm, dry, woolen cloth.

electricity. Warm a sheet of typewriter paper, then lay it on a wooden table or desk and brush it briskly with a stiff clothes-brush. Pick the paper up by one corner. Notice it resists being picked up and tries to cling to the table. It will tend to cling to the hands and clothing. If held near the face it will produce a tickling sensation. If placed against the wall, it will not slide down but stick there for a minute or two before it falls to the floor.

Try this same experiment with different kinds of paper. Notice which kind gives the best results. Brush it on the wall without first placing it on the table.



AN EXPERIMENT

A celluloid bathtub toy floating in a pan of water will move toward an electrified pipe stem or stick of sealing wax. See if the same thing will happen when you use an electrified glass rod or rubber comb.

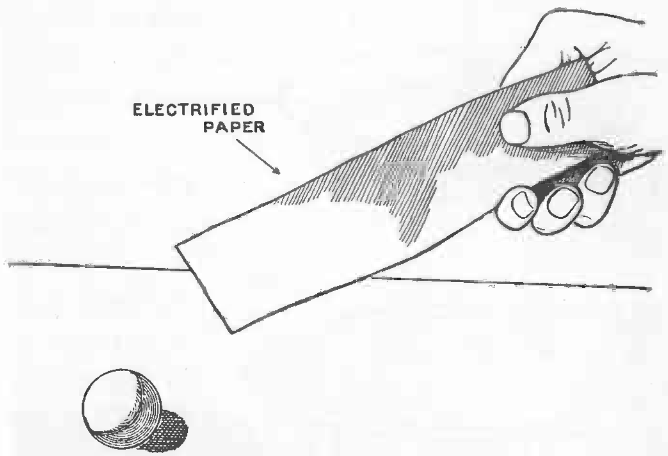
Why does a sheet of warm, dry paper which has been brushed cling to the table and the wall? The answer is that the friction of the brush produced static electricity on the paper. Making the paper cling is one of the ways in which electricity reveals itself, one of the things electricity does, but just why this is, no one knows.

A Simple Experiment

A stick of sealing wax, a hard rubber comb, a glass tube, or a rubber pipe stem held in the hand and rubbed briskly

with a piece of warm, dry, woolen cloth, flannel or fur will become strongly charged with electricity.

A hollow celluloid swan or fish (bath-tub toy) floating in a pan of water will be attracted by an electrified stick of sealing wax and will follow it around. See if the same thing will happen in the case of an electrified glass rod or hard rubber comb. Try a ping-pong ball in place of the swan or fish.

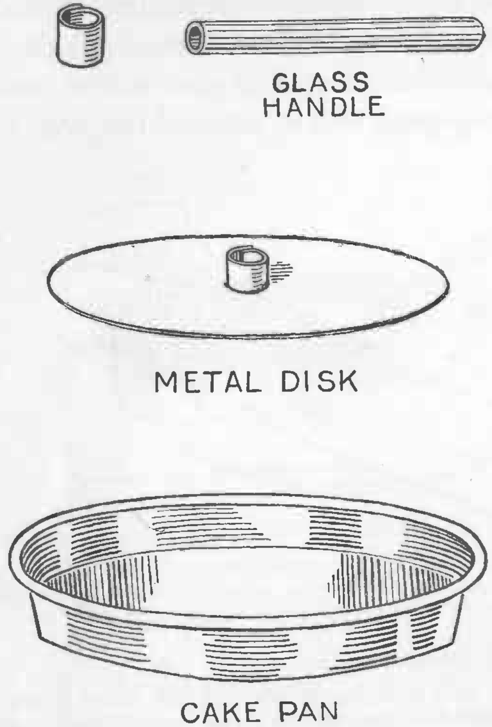


THE OBEDIENT BALL

A strip of dry paper which has been electrified by brushing will attract a ping-pong ball. The ball will roll and follow the paper until they touch. Then it will be repelled.

An Electrical Machine

Alessandro Volta, the Italian scientist who showed the world how to produce electricity with chemicals, was an ingenious man. The Voltaic cell which bears his name was not his only invention. Among the many devices he gave to science is an interesting contrivance called the electrophorous. About twenty-five years before he made the first battery, Volta devised the electrophorous for the purpose of obtaining static electricity. Once the electrophorous was of scientific value, but today it is only a curious plaything.



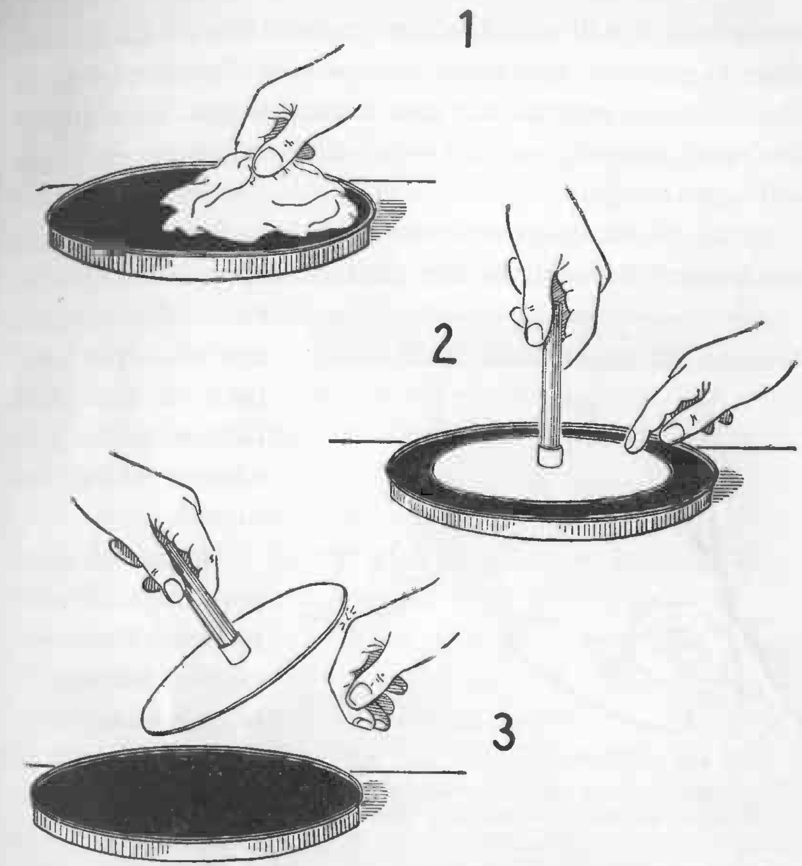
PARTS OF THE ELECTROPHOROUS

It is ideal as the young experimenter's first electrical machine. It will generate much more electricity than rubbing glass rods, sticks of sealing wax, pipe stems and fountain pens.

An electrophorous is easily constructed. It is merely a round cake of resinous material cast in a flat pan and a metal disk fitted with an insulating handle.

The pan may be a cake tin about nine inches in diameter. It will cost ten cents. About two pounds of resin such as plumbers use for soldering and two or three sticks of sealing wax will be needed. You can use resin alone without the sealing wax, but sealing wax or dry shellac added to the resin makes a better electrophorous.

Fill the cake tin with broken bits of sealing wax and resin

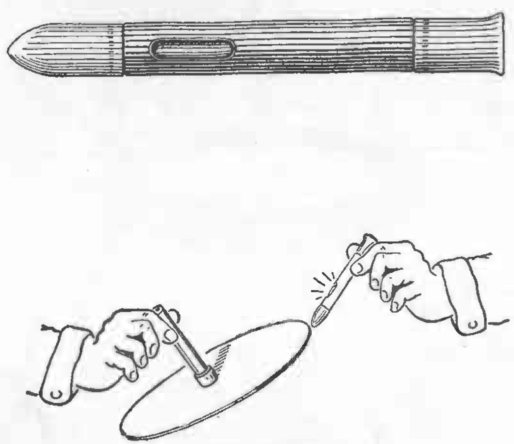


HOW TO OPERATE THE ELECTROPHOROUS

First, rub the resin briskly with a piece of warm woolen cloth or fur. Second, place the disk on the resin and touch the metal with the finger. Third, lift the disk by means of the insulating handle. The disk is now charged and if the knuckles are brought near the disk a spark will jump. The disk may then be placed on the resin again, touched, lifted and found to be charged dozens of times before it is necessary to rub the resin once more.

and place it on a gas stove or electric stove over a *gentle heat*. This operation requires a considerable amount of care. The resin and wax should be melted very slowly because if it is overheated it will take fire and you will have a dangerous blaze to combat. The safest way to melt the mixture is to place a large piece of sheet iron under the pan. Then if you don't use too much heat and hasten the melting process, there will be no danger.

As the resin and wax melt, slowly add small pieces until the pan is nearly full of the molten mixture. When all has melted, turn off the heat and allow the mixture to cool and harden in the pan without being disturbed.



NEON LIGHT
The charge from the electrophorous disk will light the neon tube in a spark-plug tester.

The metal plate may be a circular piece of sheet tin, copper, brass, zinc or galvanized iron. It should be about one inch smaller in diameter than the cake of resin. The only difficulty in making this part of the equipment lies in the fact that the edge of the disk should be turned over so as to be perfectly smooth. A plain disk cut out of sheet metal with a pair of snips and having the edge smoothed with sandpaper may be used, but the efficiency of the electrophorous will be greatly increased by a rounded edge. Should the young experimenter have difficulty in performing this operation, the nearest tinsmith can exercise the necessary sleight of hand in a few minutes.

It is necessary to solder a small cylinder of sheet tin to the center of the plate to support the handle. The handle is a piece of glass tubing one-half inch in diameter and four and one-half inches long. The sharp edges are eliminated by holding in the flame of a Bunsen burner or alcohol lamp. The handle is cemented to the plate with molten sealing wax.

To put the electrophorous into action, rub the surface of the resinous cake briskly with a piece of warm flannel or fur. Fur is best. Then place the plate in the center of the cake and touch the metal with the tip of the finger. Remove the finger and raise the disk from the cake by picking it up with the glass insulating handle.

The plate is now heavily charged with positive electricity and in a dark room the electricity can be seen escaping from the edge in the form of a purple brush discharge.

If the knuckles are brought near the edge of the metal plate, a snapping spark will jump out to meet them.

The plate may then be replaced on the resin cake, touched, lifted off quickly with the insulating handle and found charged again. This process may be repeated dozens of times before it will be necessary to rub the resin with the fur again.

The automobile supply stores sell a "spark plug tester," for twenty cents. It consists of a tiny neon tube encased in an insulating handle resembling a pencil or fountain pen. If you touch the charged plate with one of the spark plug testers, the neon tube will glow with a brilliant orange light.

Man-made Lightning

The most striking display of nature's electricity takes place in the atmosphere.

Since time unknown, great bolts of lightning have flashed across angry skies. Blinding flashes, deafening thunder, trees

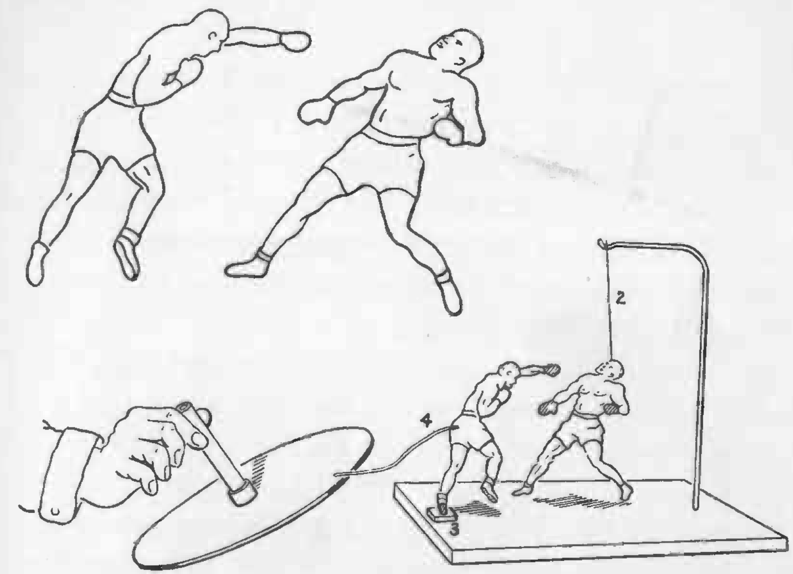
FLYING FISH

Small paper fish, cut from tissue paper and slightly dampened by breathing on them, refuse to stay on the electrophorous disk when it is charged. Place the fish on the disk while it is resting on the resin. Touch the metal and lift it with the handle. The fish will fly off.

shattered and broken, buildings afire, swift death—it is no wonder lightning makes men and animals uneasy.

Lightning is the discharge of static electricity in the clouds or from the clouds to earth. The electricity is produced by tiny particles of moisture as they join together and become drops.

To protect high buildings, tall chimneys, steeples and towers from being struck by lightning they are provided with



Trace the figures of the boxers in the upper left corner of the illustration on tissue paper and transfer the sketch to thin cardboard. Cut the boxers out of the cardboard and cover with thin tinfoil or paint with aluminum or bronze paint. Suspend one boxer with a silk thread (2). Support the other boxer on a small block of sealing wax by sticking his foot to it. Fasten a wire (4) to him and place him near the suspended boxer. When the charged electrophorous disk is held against the wire the suspended boxer will swing back and forth at his opponent.

lightning rods. A lightning rod is a metal conductor passing down the side of a building. The upper end projects above the highest point of the building and the lower end is buried in the earth.

Power lines, telephone and telegraph wires are protected against lightning by devices called lightning arrestors.

Large steel frame buildings, buildings protected by lightning rods, large unprotected buildings, in the order named, are the safest shelters during a thunderstorm. If you seek safety during a storm keep away from trees, flag-poles, steeples, wire fences, chimneys and small sheds in an exposed position.

Although lightning is static electricity, lightning flashes are so much bigger than the electric sparks produced by static machines it was not realized that they are really the same kind of thing until about two hundred years ago. Benjamin Franklin was the experimenter who showed us that lightning is of the same nature as that which we can produce in a smaller way by friction.

From wondering what lightning might be and being afraid of it, scientists have progressed to the point where they have lost their unreasonable fear and produce artificial lightning in their own laboratories. Ten million volt bolts of artificial lightning are hurled at models of skyscrapers, power lines, etc., to teach engineers how best to gain protection from those mightier charges which leap from the heavens.

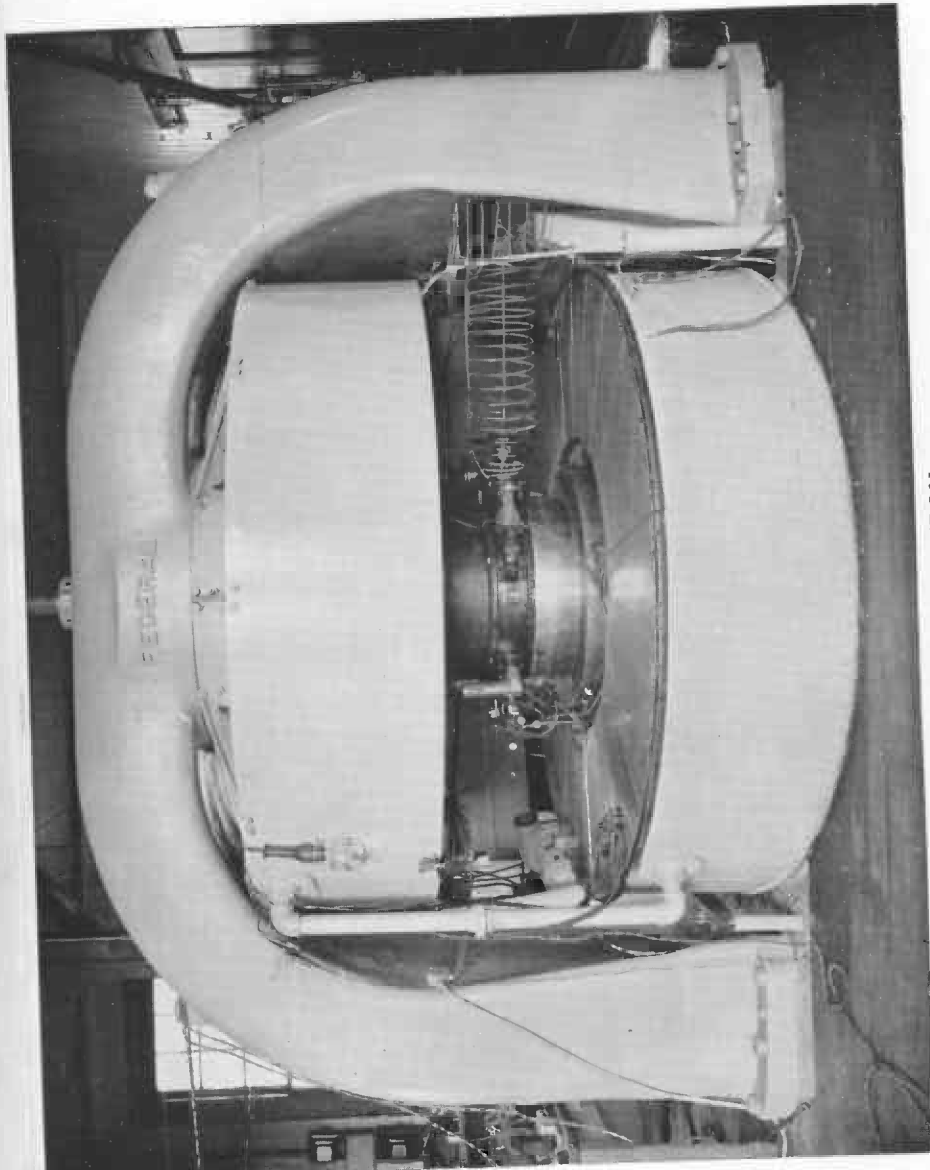
More recently man-made lightning has been put to a new use.

One of the dreams of medieval chemists was the search for a process by which it was hoped to change common metals into gold. The experiments of the alchemists, as these men are called, in their attempt to make artificial gold were the infancy of modern chemistry. The alchemists were not scientists working to enrich our knowledge, they were seekers of riches in the form of a precious metal.

Within recent years, Science has looked inside the atom. It has found the composition of the atom to be purely electrical. The atoms of the different elements are different ar-

RESEARCH

Doctor Irving Langmuir at work in his laboratory



THE CYCLOTRON

Professor E. O. Lawrence's electromagnetic atom-smashing machine. (See p. 25)
The two flat cylinders enclose the coils

rangements of positive and negative electrical charges. The negative particles present in the atom are called *electrons.* The positives are called *protons.*

The atoms of lighter chemical elements such as hydrogen, helium, lithium, etc., contain the smallest number of protons and electrons. The atoms of the heavier elements, such as radium, thorium and uranium, contain the largest number of protons and electrons.

Uranium is the heaviest of the elements. When Science looks into an atom of uranium, a tiny body, one-millionth the diameter of a pin head, there is found a still smaller nucleus one-ten-thousandth the diameter of the atom. Arranged about this nucleus are found ninety-two electrons or particles of negative electricity. Inside the nucleus are 238 positives and 146 negatives. If any one of these positives or negatives drops out, the atom of uranium changes to something else. After losing eight particles, an atom which was initially uranium changes to lead.

Uranium is one of the elements which is radioactive. Radium is a radioactive substance. In the atoms of the radioactive elements the nuclei are undergoing spontaneous disruption, losing particles and energy. Radioactivity is nature's process of changing one element into another.

The alchemists failed in their search for a process of changing one element into another. The modern scientist, aided by man-made lightning, has found a way. He has built atom-smashing machines—instruments for disrupting the nuclei of atoms. He has succeeded in making a few atoms of gold. The few atoms of gold were not worth a fraction of the energy used in manufacturing them or even the few platinum atoms out of which they were made, but the scientific information which is being gained is worth more than precious metals. Most of the atom-smashing machines make use of static electricity.

The atom-smashing machine called the cyclotron, developed by Professor Ernest O. Lawrence at the University of California, employs comparatively low voltages (50,000). It is also different from other atom-smashers in that it utilizes a strong magnetic field.

Static electricity built up into a charge of 2,000,000 to 7,000,000 volts is used to hurl the nucleus of hydrogen at the atoms of other elements. When struck, the atom target is smashed into invisible pieces. The fragments are new elements.

The immediate purpose of atom smashing is not to produce gold but to find out more about atoms and artificially to create substances which can be used in place of radium in the world of physics and medicine.

II

A CURIOUS MINERAL WHICH LEADS TO ADVENTURES WITH MAGNETISM

Long before the Christian era, the Greeks and Romans knew that a black stone called magnetite[1] has the strange ability to attract and pick up small pieces of iron. This magnetic stone is by no means rare. It is a chemical compound of the metal iron and the gas oxygen, and is found in nearly all parts of the world.

THE FIRST MAGNET

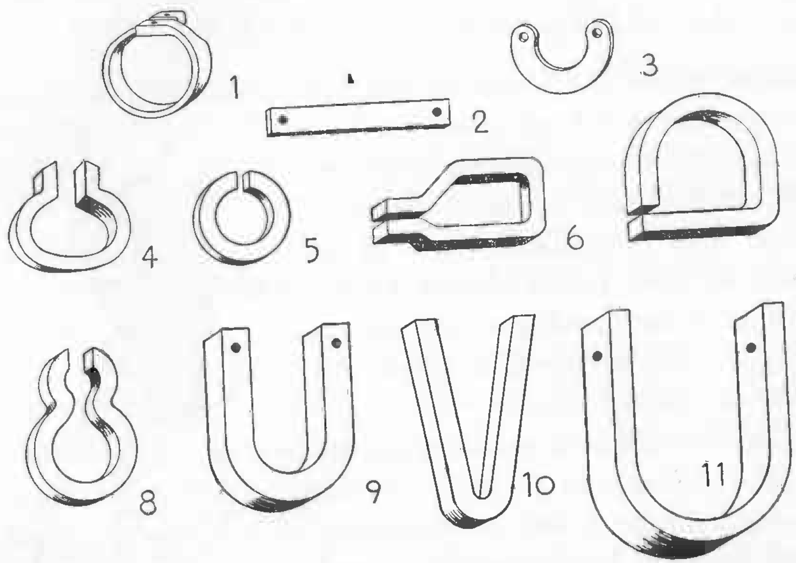
The mineral called magnetite has the strange power to attract and pick up small bits of iron and steel.

For thousands of years, magnetite was a complete mystery. It was thought to be a sort of connecting link between inanimate things and living objects. It was believed that a magnet would cure gout, headache, cramps, prevent baldness and draw poisons from wounds. A magnet carried in the pocket was supposed to render a person gracious, persuasive and elegant in his conversation. Of course such ideas as these were just a lot of pure nonsense and nothing else.

[1]Formerly it was called lodestone (leading-stone).

Until about six hundred years ago no one knew how to employ the curious power of magnetite or lodestone for any useful purpose.

Then some unknown inventor rubbed a piece of steel with magnetite and noticed that *the steel became a magnet.*



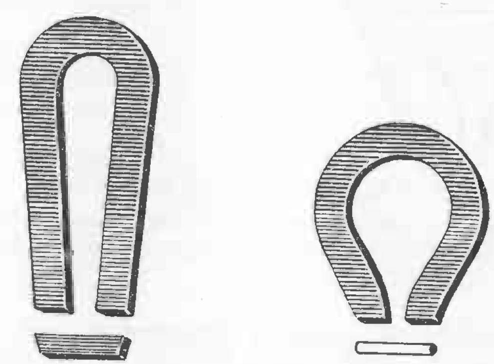
PERMANENT MAGNETS

Magnets made of steel are an essential part of many electrical devices. 1, 2 and 3 are telephone receiver magnets. 4, 5 and 8 are voltmeter or ammeter magnets. 6 and 7 are used in electric-light meters. 9 is a loud-speaker magnet. 10 and 11 are magneto magnets.

Magnets are an important part of telephone receivers, compasses, radio speakers, magnetos, and electric measuring instruments. There is a magnet in the little ammeter on the instrument board of every automobile. There is another in

the generator which charges the storage battery. Magnets differ greatly in size and shape so as to serve best the particular purpose or instrument for which they were made. The most common are horseshoe-shaped or like the letter "C." Magnets are also frequently made in the form of a straight bar.

You can buy a toy magnet at almost any "dime store" for five cents. This horseshoe-shaped piece of hardened cast-steel or iron will provide many scientific adventures. It is called an artificial magnet because it is made by an art and

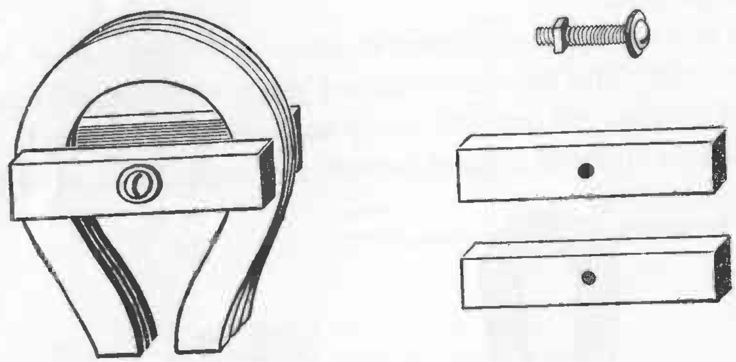


TOY MAGNETS

is not a natural magnet like the lodestone. It is no longer customary to make artificial magnets by rubbing steel with lodestone. The steel magnets used in electrical instruments are magnetized with the aid of an electric current. They are more powerful than the lodestone or magnetite. An experiment showing how to do this will be found in another chapter. When an artificial magnet is not mistreated it will retain its power many years.

An Experiment Hundreds of Years Old

One magnet will make another. Any piece of steel which has been hardened will become magnetized if it is properly



A COMPOUND MAGNET

If you clamp several toy magnets together with brass or wooden strips, the compound magnet formed will be much stronger than a single magnet of the same size.

rubbed on one of the poles of another magnet. The same magnet may be used for this purpose many times without losing its strength. Screw-drivers, scissors, knives, drills, knitting needles, sewing needles, saw blades, can be magnetized.

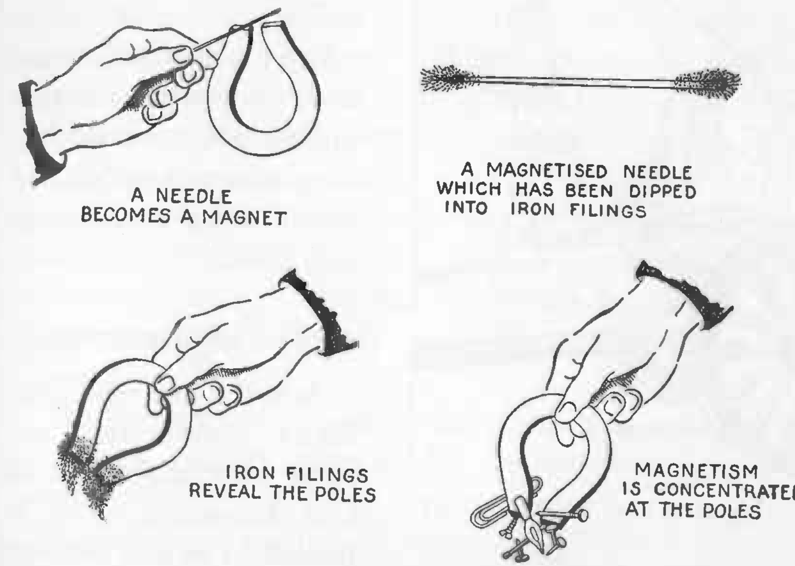
If you rub a large sewing needle across one pole of a toy horseshoe magnet and then dip the needle into some iron filings,[1] the filings will cling to the needle in a tuft at each end. No filings will adhere to the central part. The ends where the filings cling are the *poles* of the magnetized needle. Small nails, tacks, paper clips, pens and other objects made of iron

[1]Make these by filing a piece of cast iron or wrought iron with a coarse file.

or steel are attracted most strongly at the poles of a magnet. The magnetism is most intense at the poles.

Magnetic Substances

Iron and steel are the only substances strongly attracted by a magnet. Cobalt, nickel, aluminum and platinum are



EXPERIMENT

One magnet will make another. The poles are revealed by dipping a magnet into iron filings. The magnetism is concentrated at the poles and the filings form tufts there.

slightly attracted but not sufficiently so that you are apt to discover it with an ordinary horseshoe magnet.

Try picking up small bits of paper, wood, brass, coal, glass, etc., with a horseshoe magnet. You will not find anything which will be attracted except iron or steel. If you find that a bit of brass or copper is attracted it is because the article is not really brass or copper. It is steel-coated or plated with brass or copper. A great many cheap hardware fittings are made of imitation brass or copper. They are plated steel.

A magnet will stick to a "tin can" but the can is really steel beneath the tin surface.

OLD CHINESE SOUTH-POINTING COMPASS

This illustration originally appeared in a Chinese encyclopedia published in 1341. It shows one of the first compasses, a pivoted manikin made of jade standing on a cart or chariot. Within the extended right arm was a magnet which caused the manikin always to point to the south.

Dip a horseshoe magnet in iron filings and the whisker-like tufts which cling to its ends will plainly reveal the horseshoe magnet's poles.

What Is Magnetism?

As is the case with electricity, science does not know what magnetism is. Our knowledge of it is limited to how it behaves and what it does. There is a strange, unexplained relation between light, electricity and magnetism which scientists and mathematicians may think they understand but they actually don't know any more about the *final* answer than you or I do. Their theories or explanations of the nature of things are like a calendar. They have to be changed frequently.

Magnetism is of special interest to engineers and to all of us for that matter, because it is by means of magnets and magnetism that the electricity we use for power and light is generated.

We Live on a Magnet

We are whirling around through space on the surface of an enormous magnet. The earth is a magnet—at least it behaves like a great magnet—and consequently, it and the space about it are filled with magnetism. The cause of the magnetism of the earth itself is an unsolved scientific problem. Magnetism is constantly passing through the air we breathe, the food we eat, the clothing we wear, through our bodies. We don't feel, see or hear the earth's magnetism. We are unaware that it exists, that we are actually soaking in it until we look for it. In order to find it we must know how to search.

The simplest way to look for and discover that the earth's magnetism actually exists is with the aid of a magnetized needle.

If you hang a magnetiezd sewing needle with a long silk fibre tied to it so that the needle will balance, the needle will swing around a bit at first but finally come to rest pointing toward the north-and-south position.

It is the earth's magnetism which pulls the needle around to the same position of rest each time.

A magnetized needle which is arranged to swing easily so that the earth's magnetic force can pull it around until it points north and south is a magnetic compass.

The compass was the first practical use found for magnetism. The swinging magnetic needle is an admirable guide with which to direct a ship's course. No one knows who made the first compass or when it was first used. It is mentioned in some old Chinese writings of the eleventh century. Before it was known how to make a compass, vessels hardly dared

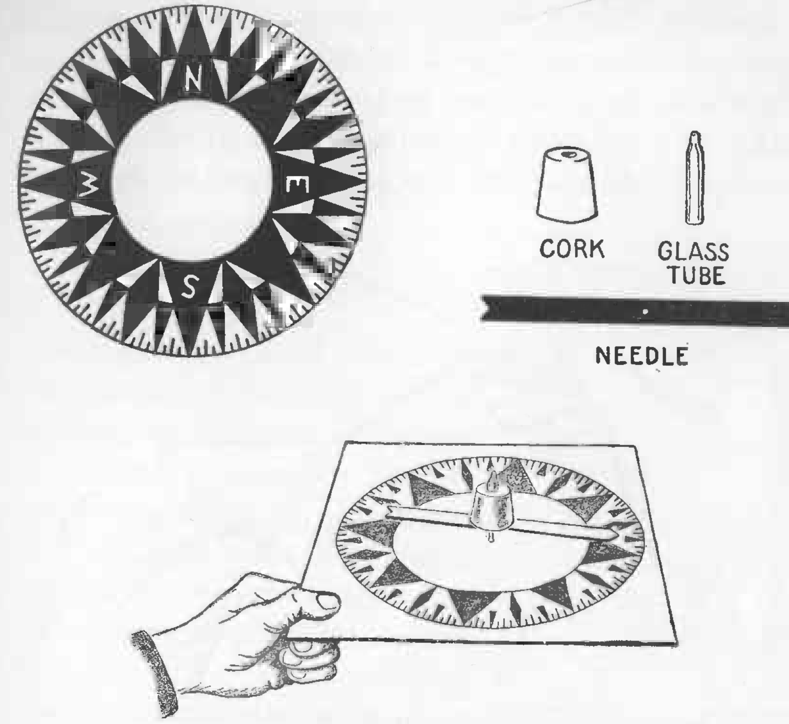
IGNORANCE AND SUPERSTITION

Research and experiment destroy ignorance. Once it was believed that eating onions would disturb a compass. This drawing, copied from an old engraving published in 1555, shows the punishment inflicted upon a compass-falsifier. A knife has been thrust through his hand and into the mast.

venture out of sight of land because it was difficult to find the way back.

Making a Compass

Floating compasses were the first kind used by sailors. In fact, the mariner's or ship's compass has always been and is still of the floating type. By attaching the needles to a

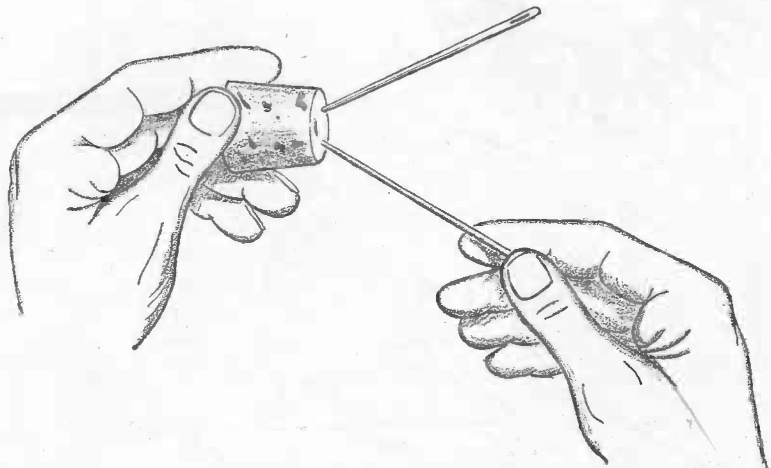


MAKING A MARINER'S COMPASS

In the upper left-hand corner of the illustration is the circular card divided into degrees and the 32 points of the compass, as represented by the triangles. Use a protractor and make one out of cardboard. The needle is a piece of magnetized clock spring cemented to a cork. The pivot is a piece of glass tube closed at one end and thrust through the cork. The pivot rests upon the point of an upright pin in the center of the card.

card and floating the arrangement in alcohol considerable weight is taken off the pivot and the friction reduced. However, the larger ships no longer use a magnetic compass. An electrically driven gyroscope whose position is controlled by the revolution of the earth is a more accurate instrument for indicating north and south than the magnetic compass.

You can make a floating compass. Place a magnetized sewing needle on a flat cork floating in a saucer of water. If you wish, the needle may be permanently fastened to the cork with a few drops of melted paraffin. It will be found that the needle and cork turn until one end of the needle



EXPERIMENT

Two magnetized darning-needles with their points thrust into a cork. The eye of one is a north pole and the eye of the other a south pole. The needles will act as a horseshoe magnet and may be used to support other magnetized needles arranged to form geometrical figures as shown in the next illustration.

points toward the north. If the needle and cork are then turned around into some other position and released, the same end will always come back and point towards the north.

You wonder, perhaps, why, if the earth's magnetism pulls the needle around, it does not pull the needle, as a whole, either to the north or the south? The answer is that the south pole of the needle is pulled as strongly to the south as the north pole is to the north.

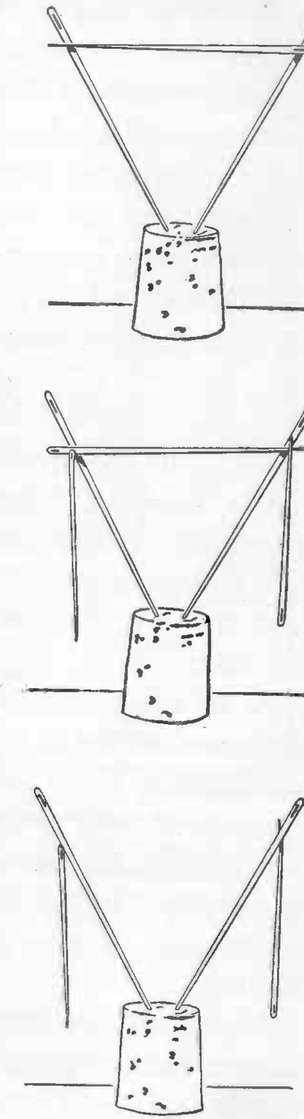
One particular end of a magnet always seeks the north. It is called the north-seeking end of the magnet, or for short, the north pole. The other end of the magnet is called the south pole.

Making a Magnet

Any piece of steel which has been hardened and tempered will become magnetized if it is rubbed on the poles of another magnet. Soft steel will not retain magnetism. The quality of hardness gives steel the ability to retain its magnetism.

Sewing needles, knitting needles, files, chisels, screw-driver blades, scissors, knife blades, drills, pieces of clock spring and hacksaw blades are some of the common objects made of hardened carbon steel which can be magnetized. After rubbing any of these against one pole of a horseshoe magnet you can test for magnetism with some small iron tacks or iron filings.

Soft iron becomes magnetized when it is touched by or held close to another magnet. However, it does not retain its magnetism.



MAGNETIZED SEWING NEEDLES

It loses it as soon as it is moved away from the magnet.

Cast iron may be magnetized but does not retain much magnetism unless it is cast iron which has been hardened by suddenly chilling while red hot.

Toy magnets are often made of chilled cast iron. The best magnets, those used in electrical instruments, are made of hardened steel containing tungsten, chromium or cobalt.[1] Approximately $2,000,000 worth of special steels for making magnets is produced in the U. S. A. every year.

An Adventure

An experiment is really a question—a search for information or knowledge. In making an experiment we carry out a carefully planned trial or test to answer a question in our minds. By proper experiment we may learn the truth, prove that our own ideas have been right or wrong and obtain new facts.

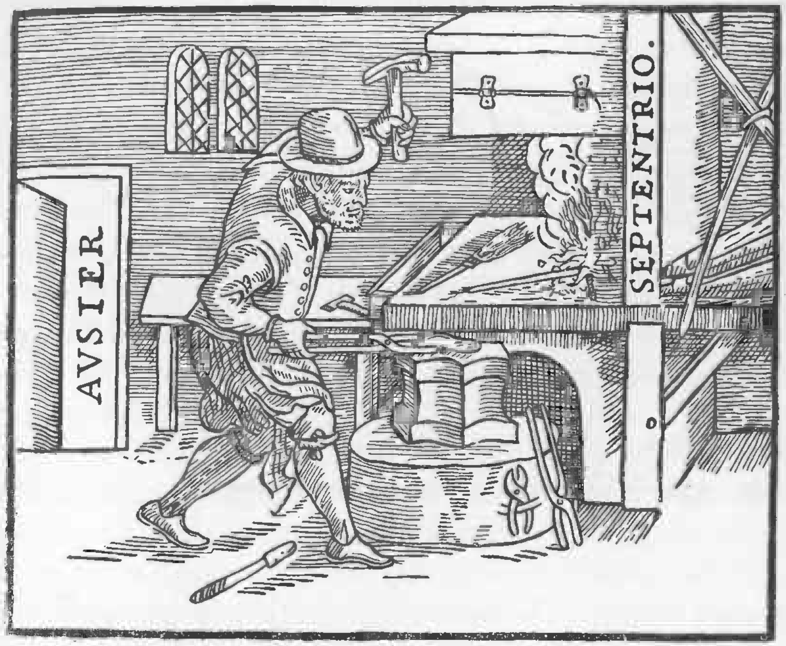
As the result of the experiments of countless scientists and engineers we live in a period in which the common man is privileged to enjoy an ease of living denied to kings and emperors of other times. Those things which enrich our lives —knowledge, art, medicine, modern surgery, electric lights, automobiles, the telephone, all of that long list of devices which make us more comfortable—came to us from experimenting.

Experiment conducted for the purpose of discovering new facts and determining their relation to other facts is scientific research.

The pages of this book are filled with experiments in-

[1]Tungsten, chromium and cobalt are metals.

tended to entertain and instruct. They are not real scientific research inasmuch as they will not add new facts to the world's scientific knowledge, but from the standpoint that



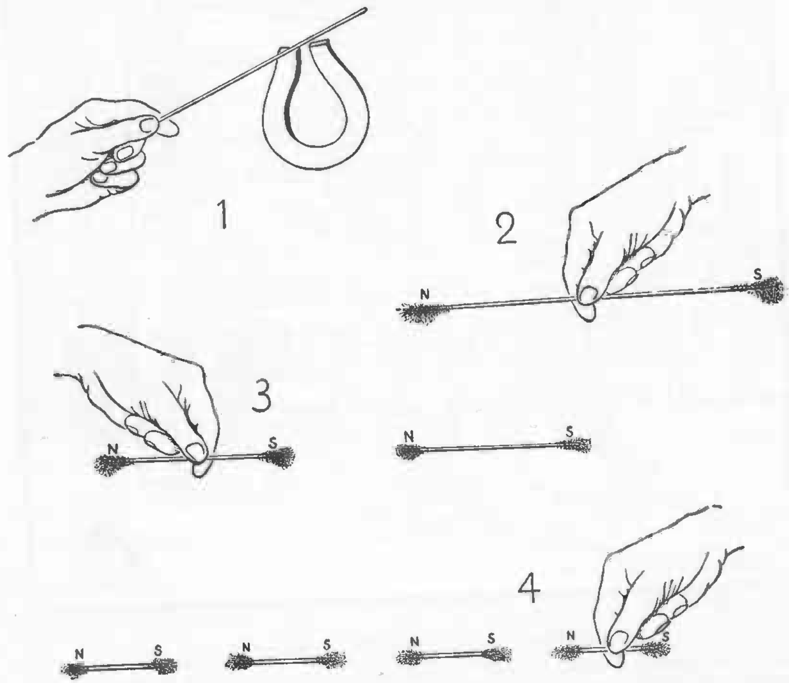
A MEDIEVAL EXPERIMENTER

This illustration was copied from William Gilbert's book about magnetism published in 1600 and shows a method of making a magnet by hammering a piece of steel while it is held in the magnetic meridian (North and South position). A magnet made in such manner had little strength. An electric current is used to make modern magnets.

they will add to the scientific knowledge of countless boys and girls they may be considered scientific research.

In our modern world, industry depends upon constant research. Every year, more men and women become engaged in the sort of experiment which is research. Some of the young readers of this book may be the scientists of tomorrow.

Successful research calls for trained observation and all the faculties of an alert mind. The research worker, like any good general, has a well-thought-out plan which he follows.



EXPERIMENT

This experiment is explained in detail in the text. (1) shows the steel knitting needle being magnetized; (2) illustrates the two poles, one at each end of the needle as indicated by the tufts of iron filings. When the needle is broken in half each piece also has two poles as shown at (3). When the halves are broken, each of the four pieces has two poles.

If unexpected situations arise, he changes his plan to meet them. He knows that Nature can answer but one question at a time, and that in seeking facts he must not allow his own

opinions to outweigh the truth. Not all research brings an answer to the question which was desired in the beginning.

In the next experiment, instead of following instructions to "do this" or "do that," let us undertake some simple research in an imaginary way.

First, let us suppose that we have been thinking about the earth's magnetism and how it pulls a compass needle around. Then we will further suppose that thinking about the earth's magnetism and the compass needle has set us to wondering why we cannot use the earth's magnetism to pull a tiny cork boat bearing a magnetized needle through the water toward the north or the south. In other words, instead of a tiny motor or sail, the boat would be moved along by the earth's magnetism.

We have already learned that although the earth's magnetism pulls a magnetized needle around into a north-and-south position, it does not pull the needle as a whole, either to the north or the south. We also know the reason—which is that the south pole of the needle is pulled as strongly toward the south as the north pole is to the north. If we take this knowledge into consideration we will suddenly arrive at what seems to be the solution. *We will make a magnet with only one pole.* The end with the pole will be dragged toward the north or south, depending upon whether it is a north or a south seeking pole. There will be no pull on the other end of the magnet because it is not a pole. It would appear that we have solved our problem. The next thing to do is to make a magnet with only one pole. We have our plan, so now the experimenting commences. We magnetize all sorts of needles and small steel bars in various ways and test each one by dipping in iron filings to find the pole. But two tufts of filings always appear on each magnetized needle or bar showing that *there are two poles.* Try as we may, we are unable to produce a magnet with only one pole. We are "stumped" for a while.

But suddenly a new idea flashes into our mind. We have a new plan. We will magnetize a long needle such as a steel knitting needle. It will have a north pole at one end and a south pole at the other, in the usual manner. Then we will break the needle in half. We will have two pieces of knitting needle. One piece will have a north pole at one end. The south pole will be at one end of the other piece.

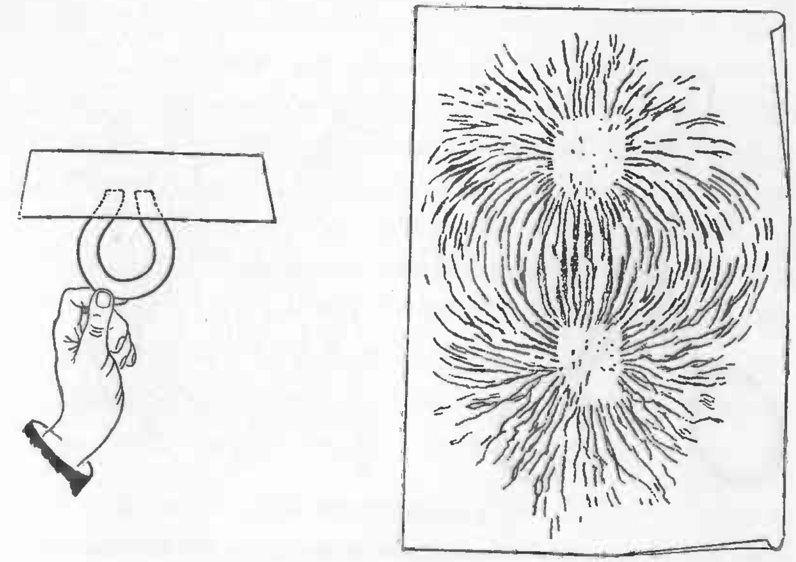
We actually experiment according to our plan and test each piece of knitting needle by dipping it in iron filings. We are surprised to find that each piece of the broken needle has two poles. We are nonplussed for the moment. Then we break each piece in half and test again. Now we have four pieces of needle and *each piece has two poles.*

We have learned a truth—a law of magnetism—which is that every magnet has two poles. There has never been a magnet with only one pole. In fact it is impossible.

Our research has not been a success insofar as accomplishing the result we had hoped to attain is concerned. But we have learned something and if we are capable research workers we spend a great deal of time and thought in trying to find some useful purpose or application for our new knowledge.

So we reason something like this: breaking a piece of steel which is magnetized always produces a pole on each side of the break where there was no pole before. A piece of

steel, an important part of some machine, is often cracked or broken, but the crack is so small it cannot be seen with the eye. If, however, iron filings will form a tuft on each side



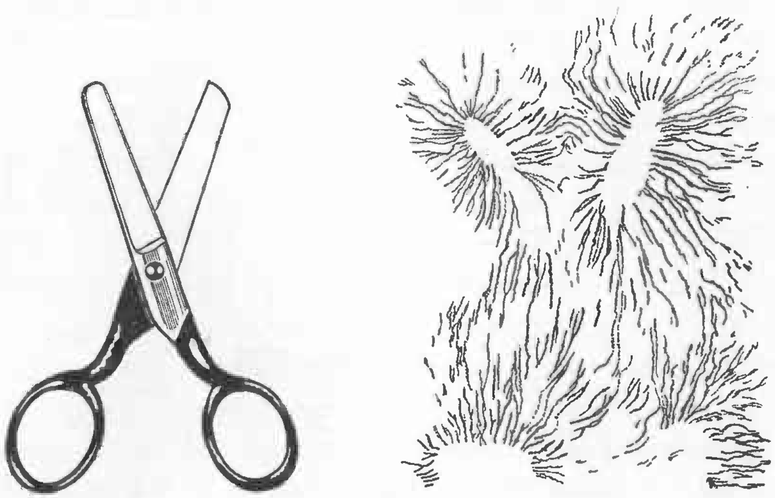
EXPERIMENT

The phantom formed at the poles of a toy horseshoe magnet by iron filings sprinkled on a piece of stiff paper over the magnet. This is a simple method of revealing the paths of the magnetic forces in the space around a magnet.

of the crack, we may have found a useful method of testing for faults in machinery which cannot be seen easily with the eye.

Now we have a new plan and are ready to experiment again. We crack but do not actually break some bits of steel and then magnetize them. We find that our idea is correct. Small tufts or ridges of filings form along the edges of the practically invisible crack. We have discovered something useful. We have invented a testing device which we will call the Magnaflux.

All of this research work which we have just accomplished



EXPERIMENT

The pair of magnetized scissors shown at the left formed this phantom. Make some phantoms, using magnetized scissors, pocket knives, nails and other steel implements.

has been imaginary. Its purpose has been to give the young experimenter an idea of the manner in which scientific research is carried on. Our imaginary problem was a comparatively simple one and did not take long to investigate. Real research often goes on for years and years.

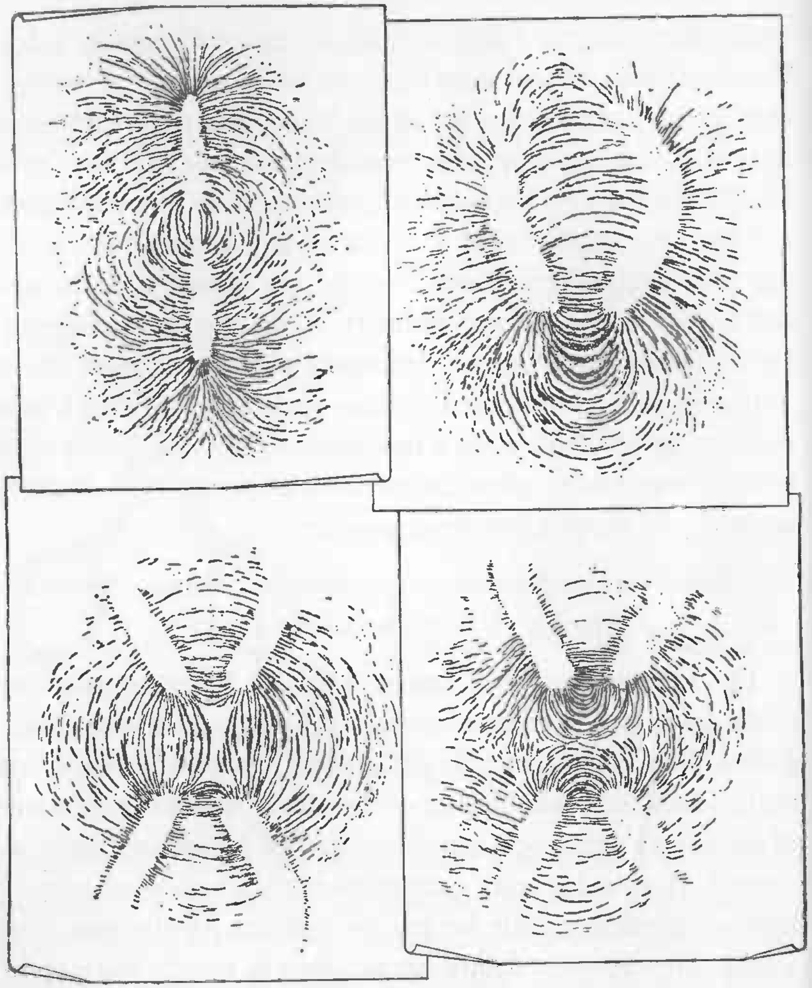
A modern, educated, scientific worker would not investigate the imaginary problem to which we have just given our time and attention. His accurate knowledge of electricity would have led him direct to the result which we reached by experiment and investigation. He would know in the very

beginning that every magnet has two poles. However, a few hundred years ago, or even more recently, such an investigation as we have pretended to perform would have resulted in new knowledge to an observant scientist just as it may now have unfolded new knowledge to the youthful experimenter.

There is actually such a device as the Magnaflux for inspecting parts of machines. We did not invent it. It is used a great deal in the aircraft industry. After 300 hours of operation, the engines of the big transport planes are taken down and each part is inspected. A flaw such as a tiny crack in a connecting rod, finer than a hair line and not easy to see even with a magnifying glass, is revealed when the rod is magnetized and dipped into iron powder.

An Experiment Showing Something Which Appears to Exist but Does Not Exist

The famous English scientist, Michael Faraday, was one of the great benefactors of mankind. This modest, self-taught philosopher was a scientific pathfinder. His persistence, often maintained for years in spite of the almost continuous failure of his experiments, was usually rewarded by an amazing discovery. It was Faraday's experiments that showed science how magnetism might be put to real use in the practical world. He discovered how to produce a steady current of electricity without a battery. He used magnetism and motion to replace expensive chemicals. He devised the first electric motor and in so doing again found a practical use for magnetism. All electric motors and dynamos utilize magnetism. It is magnetism that hitches the wheels of industry to all the coal fields and waterfalls of the world.



PHANTOMS

The phantom in the upper left corner was formed by a magnetized bar. At its right is the phantom made by a toy horseshoe magnet. In the lower left corner, the filings show the phantom of two toy horseshoe magnets with their north and south poles opposite. The lines of force stretch between the magnets. The phantom in the lower right-hand corner was made by two toy horseshoe magnets with a north pole opposed to a north pole and a south pole to a south pole. The curving lines show the repelling action of similar poles. Try these experiments with your own magnets.

Faraday performed hundreds of experiments with magnetism. He carried a magnet in his pocket. As he pondered and wondered about the mysterious power of a piece of magnetized steel, he found the space in the neighborhood of a magnet to be as interesting as the magnet itself. Something invisible reached out from the steel, passed through space and exerted its influence at a distance. Persistent experiment maintained during twenty years of repeated failures revealed a relation between magnetism and light.

There is a simple and interesting method of revealing the force in the space about a magnet. Place a magnet under a still piece of paper and sprinkle some iron filings over the paper. Each particle of iron becomes a magnet by induction and when the paper is gently tapped something curious happens. The filings arrange themselves in curved lines spreading out from one pole of the magnet and curving around back to the opposite pole. The filings show the direction of the lines of magnetic force sweeping out into space and curving around back to the magnet again.

The magnetic figures formed by the filings are called phantoms, because they exist only in appearance. The lines shown by the filings do not actually exist as separate and distinct lines. The actual magnetic forces themselves are not distributed in lines, but fill the entire space around the magnet, which space is called the magnetic field.

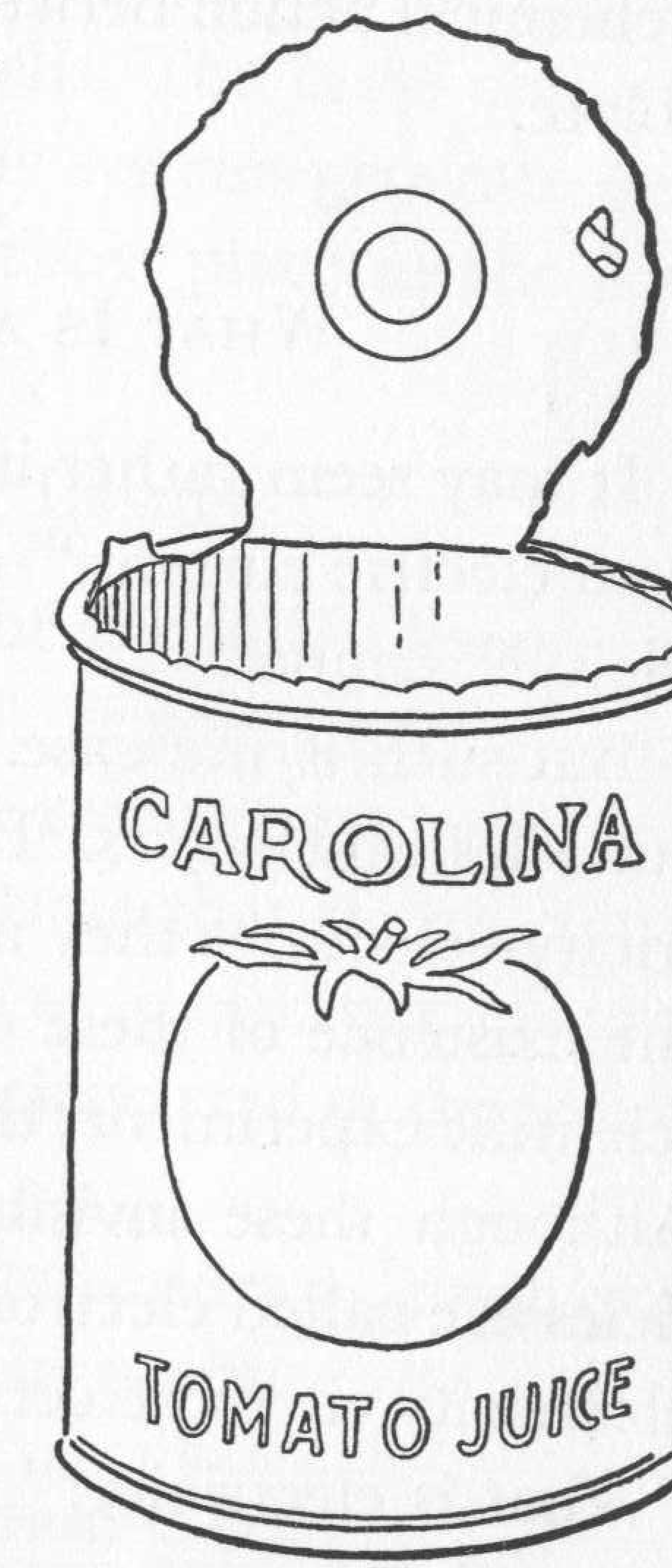
III

BUILDING AND USING ELECTRIC BATTERIES

IN northern Italy, at the foot of the Etruscan Apennines, lies an old and wealthy city. Not quite so well known as its more famous neighbors, Florence and Venice, Bologna can, however, claim an eminence outrivaling the mere possession of old cathedrals and canals. In Bologna, one hundred and fifty years ago, occurred an event which is not mentioned in political histories of the world's affairs. No king or general or dictator played a part. In a room fitted up for scientific experiments, Nature whispered one of her greatest secrets. She showed an Italian scientist how an electric current could be produced.

Perhaps you have heard the story, how in 1780 Luigi Galvani, puttering at his laboratory table with the legs of a dead frog, saw them kick and twitch when touched with two pieces of metal. Then, how a few years later, another Italian scientist, Alessandro Volta, repeated the experiments and showed that an electric current was produced not from the frog's legs but from the *two different metals*. Volta made a pile of a large number of alternate silver and zinc disks saturated with salt water and in so doing made the first battery, *the first device for producing a steady electric current*. Previously all electricity produced by scientists and experimenters was static electricity. For the first time, scientists had command

of a steady supply of electricity. This marked an epoch in removing drudgery from human life. The most familiar aspects of electricity nowadays are connected with electric *currents*. The same force which caused the feeble twitchings in the legs of the dead frog, the same energy produced by Volta's silver and zinc disks, comes travelling silently and invisibly into our homes and factories to perform heavy labor and glow in the night with the warm radiance of the sun. It pulls heavy trains over the mountains; it leaps into space and mimics our voices a thousand miles away.



UNSUSPECTED

Electrical action occurs in places we little suspect. The rusting of an old tin can is an electrical action.

Electrical science really began with the invention of the Voltaic cell. A steady current of electricity which would last for hours could be used for practical purposes. Unlike a restless static charge ready to be gone in the flash of a spark, it remained long enough to become acquainted with. It could be harnessed and put to work.

The electricity produced by a battery cell is the result of chemical action. In order for a cell to produce electricity chemical action must take place. When the chemical action takes place energy is released. Part of the energy is released in the form of heat and part of it in the form of an electric current. In every battery cell there must be two different metals, elements or chemical compounds called the cell *elements,* and a liquid or solution called the electrolyte. There is chemical action between one of the elements and the electrolyte.

What Is an Electric Current?

It may seem rather inconsistent that the question, "What is an electric current?" can be answered and, "What is electricity?" cannot.

But such is the case. Science says that electricity is both particles and waves. The particles are tiny specks of electricity—electrons they are called. Too small even to be seen, the existence of these electrons has been proven by careful scientific experiment; they have been measured and weighed. Although these invisible, weighable and measurable particles are called electrons and said to be particles of negative electricity, it most certainly does not answer the question, "What is electricity?" to reply, "Electricity is particles and waves."

On the other hand, an electric current is definitely a movement or steady procession of electrons. A Voltaic cell is, by means of its chemical action, one method of bringing about a procession of electrons. Under its steady urge, billions of electrons will march each second around the circuit formed by wires or other conductors.

Electrical currents are produced by chemical activity in places we little suspect. When there are two kinds of fillings in our teeth, gold and silver for example, the gold and silver

act as the elements of a battery cell. The saliva is the electrolyte and an electrical current is produced.

The rusting of iron and steel is an electrical action. The iron and small particles of carbon and impurities are the elements of myriads of tiny battery cells. The brass and iron fittings in plumbing and water supply systems generate electrical currents. Electrolytic action takes place in the steel plates of ships.

Electricity from a Lemon

Stick a strip of copper and a strip of zinc into a lemon and you have made a form of Voltaic cell. If you connect a wire from each of the strips to a telephone receiver, you will hear a strong click in the receiver every time that the circuit is made or broken, showing that a current of electricity is produced by the chemical action of the citric acid in the lemon juice on the zinc strip.

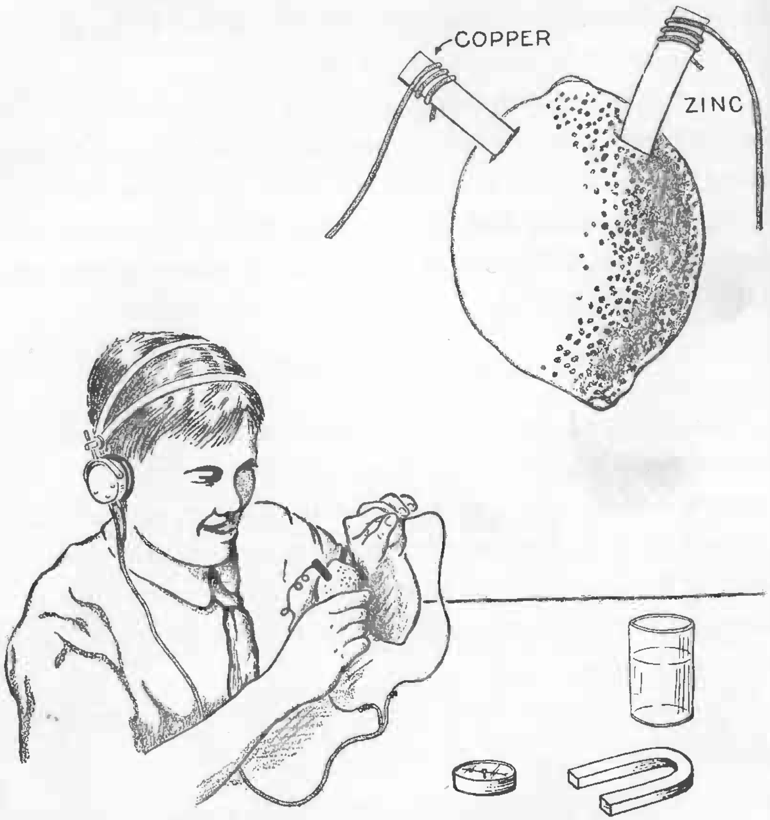
If you experiment with other fruits besides a lemon you will find that they will all produce electricity.

An Experimental Voltaic Cell

One of the first problems of the young electrical experimenter is to provide himself with a satisfactory source of current for his various devices.

The 110-volt electric lighting current is necessary to operate the blue glow lamp and the rectifier, but the other apparatus described in this book is designed for batteries.

Homemade cells are not as convenient or efficient as ready made dry cells but there is a great deal of pleasure and valuable experience in constructing them.



ELECTRICITY FROM A LEMON

Stick a strip of copper and a strip of zinc into a lemon and electricity will be produced.

Voltaic cells which utilize sulphuric or nitric acid in the electrolyte give the most current and the highest voltage. However, such cells are messy and sometimes do damage. An acid electrolyte eats holes in a great many substances.

Therefore when you make an experimental Voltaic cell to experiment with, choose the type invented by a Frenchman

named Leclanché. This uses a chemical called sal ammoniac or ammonium chloride dissolved in water as the electrolyte. Sal ammoniac is a white powder. It is a much milder, safer chemical than an active acid. Sal ammoniac is not expensive. You can buy it at a hardware store, electrical shop or drug store. Two or three ounces of sal ammoniac dissolved in a pint of water makes a solution of the proper strength. To make a solution it is simply necessary to shake the sal ammoniac into water and stir it with a clean stick until dissolved. Use a glass jar.

A Leclanché cell delivers about one and one-half volts and sufficient current to ring bells, operate telegraph instruments, telephones, flashlight bulbs and perform most of the experiments described in this book.

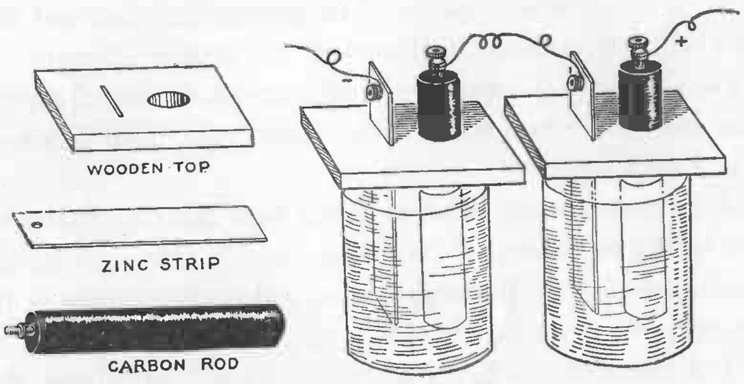
The elements of a Leclanché cell are zinc and carbon. You can usually buy sheet zinc at a plumbing shop. It is a soft metal easily cut into strips with a pair of snips. You will need a strip about seven inches long and one inch wide for each cell.

Each cell should have a wooden cover to support the elements and prevent the electrolyte from evaporating. Make a hole through the cover into which the carbon rod will fit tightly. About one inch from the hole, cut a slot with a jigsaw blade so that the zinc strip will slip through the cover. Paint the wood with hot paraffin. This will prevent the electrolyte from soaking into the wood and forming a conducting path which will act as a short circuit or current leak.

A brass screw, hexagonal nut and the thumbnut from an old dry cell will make a good terminal for the zinc. A short length of wire soldered to the zinc at the upper edge is another simple way of making a connection.

When the zinc and carbon rod are slipped into place on the cover and immersed in the solution, the battery is ready.

Two Leclanché cells connected in series will deliver about



AN EXPERIMENTAL LECLANCHÉ BATTERY

three volts. When too much current is drawn from the battery, or it is used steadily for too long, the cells will act as though tired. This is due to an action termed polarization which is the accumulation of oxygen gas upon the carbon element. In order to refresh the battery, it is necessary to let it rest. Eventually the zinc strip and the sal ammoniac in the electrolyte will become exhausted. It will be necessary to replace them. The carbon rod will last indefinitely.

A Few Facts about Dry Cells

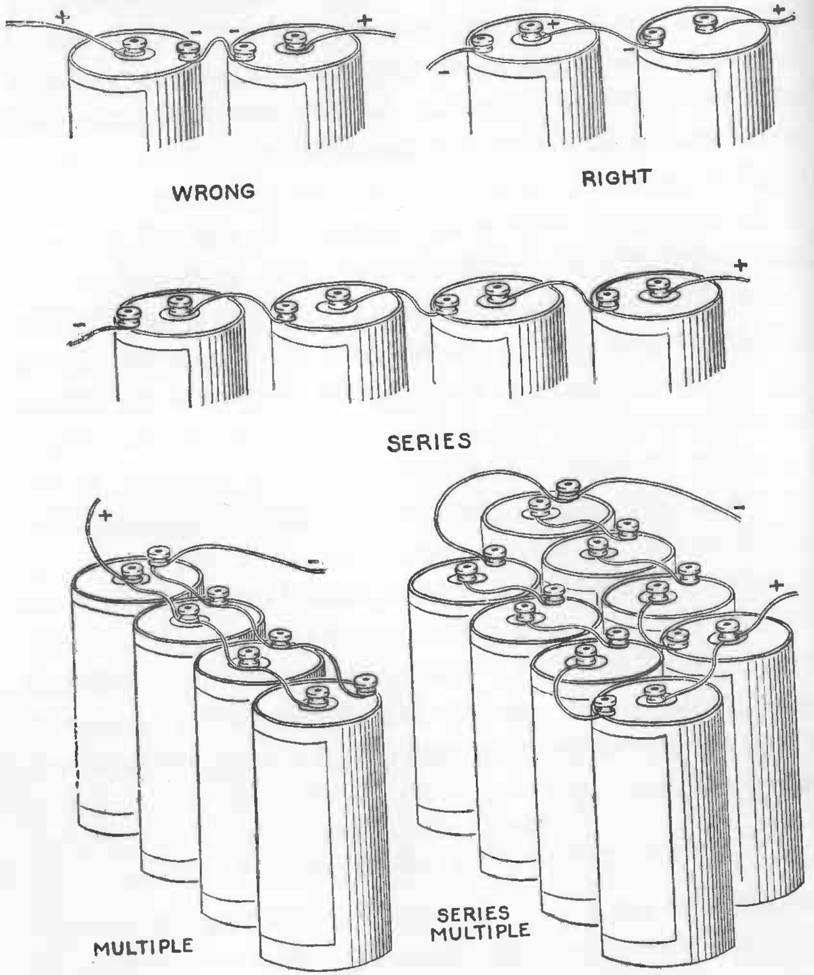
For all experiments in which a battery is used, except those which require a great deal of electricity, dry cells are the most convenient.

A dry cell should be considered as simply a package of chemicals which will produce electricity. The amount of electricity which a dry cell will produce depends primarily on the size of the cell and the skill and technical knowledge of the manufacturer. A new dry cell has a voltage or electrical pressure of about 1.5 volts. Size makes no difference in the voltage. It is the same whether the dry cell is a very small one like a pen-lite battery or a No. 6 dry cell.

The amount of electricity which you can get out of a dry cell depends to a large extent upon the rate at which the cell is called upon to deliver current. Dry cells apparently have the longest life when they are not required to deliver a current of more than one-quarter of an ampere. If the current or amperage required is too great for the size of the cell, then the cell will be overloaded. Overloading will reduce its capacity. This can be explained in another way by saying if you use a flashlight cell for some purpose for which the larger No. 6 cell was intended, the flashlight cell will be overloaded and you will not obtain all the electricity which the chemicals are capable of producing under favorable conditions.

How to Connect a Battery of Cells

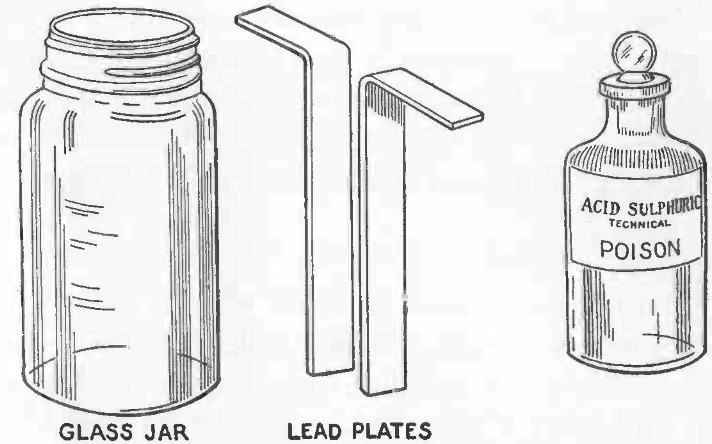
There are three ways to connect cells: in series, in multiple or in series-multiple, depending upon the number of cells to be used and the amperage and voltage desired. Cells are in series when a wire leads from the negative pole of one to the positive pole of another, so that the current flows through each one in turn. Cells are connected in series when voltage is the most important factor. The total voltage of



HOW TO CONNECT A BATTERY OF CELLS

Use No. 16 B. S. gauge wire. Scrape and tighten all connections. To obtain voltage, connect the cells in series. To obtain greater amperage, connect the cells in multiple or series multiple.

the battery is then equal to the sum of the voltages of the separate cells. The voltage of the ordinary dry cell is about 1.5 and therefore if four dry cells are connected in series the total voltage of the battery will be six. If six dry cells are connected in series the voltage at the terminals will be about nine.



MATERIALS FOR AN EXPERIMENTAL STORAGE CELL

When amperage is desired rather than voltage, cells are connected in multiple. All the negative poles are connected togther to form one terminal while all the positive poles form another.

If a cell is discharged at a high rate, its life is not only shorter but the total amount of energy it delivers will be much less than if the discharge rate is low. In order to secure the most economical service from cells, it is advisable to lighten the load as much as possible and cells are consequently often connected in series-multiple with that result in view.

Always use No. 16 B. S. gauge wire, or larger, in connecting cells. Finer wire offers considerable resistance to the current and full benefit of a battery cannot be secured when it is used.

Scrape all connections so that they are clean and bright. Tighten the binding posts with a pair of pliers so that there is no chance of their coming loose by accident.

Another wise precaution is always to arrange a battery so that there is a small space between two cells and no likelihood that any of the wires or binding posts can come into contact with one another so as to form a short circuit.

What Is a Storage Battery?

The term storage battery is slightly misleading. A storage battery does not actually store electricity. It stores chemical energy which can be changed back into electrical energy. When the battery is used, the chemical energy changes into electrical energy.

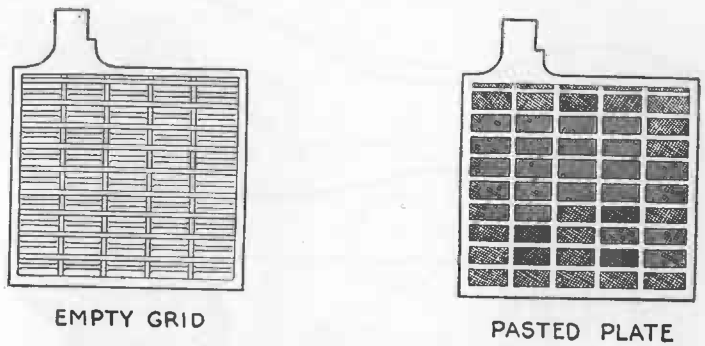
Before a storage battery will produce a current of electricity, it must have a current sent through it from a battery or direct current dynamo. This charging current, as it is called, passing through the storage battery creates chemical changes in the battery plates. The chemical changes absorb the electrical energy and store it as chemical energy. Then the battery will produce electricity in the same way as a battery of the cells invented by Volta produces electricity.

The principle of the storage cell was discovered in 1802 but the first practical storage cell was made about seventy-five years ago by a Frenchman named Planté.

Planté's storage cell consisted of two lead plates immersed

in dilute sulphuric acid. Although a great many improvements have been made, the principle is still the same in the modern storage battery used in automobiles to furnish electricity for starting, lighting and ignition.

A storage cell made of two lead plates immersed in dilute



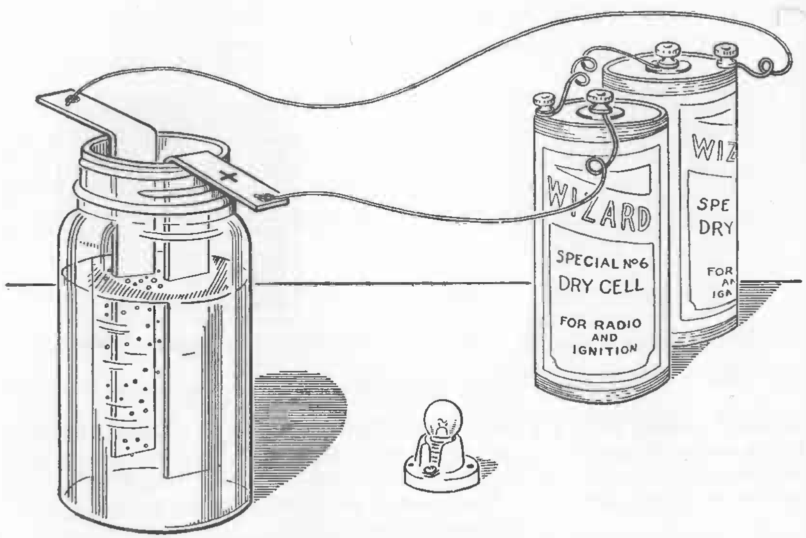
EMPTY GRID AND PASTED PLATE

A storage-battery plate is a skeleton framework or grid of lead, filled or pasted with a lead compound. The paste in the positive plate changes into peroxide of lead and that in the negative plate becomes lead when the battery is "formed" by passing an electric current through it. The positive plate becomes dark brown in color. The negative plate is gray.

sulphuric acid does not deliver enough electricity to make the arrangement as practical as might be desired. So, instead of a single pair of solid flat plates, several gridlike lead frameworks filled with a paste made of lead oxides are used. There are usually from eleven to nineteen "grids" or pasted plates in each cell of an automobile storage battery. Each cell delivers about two volts. This is one-third greater than the voltage of a dry cell. Three storage cells connected in series so as to give six volts are universally employed as automobile batteries.

An Experimental Storage Cell

Cut two strips, about one and one-half inches wide and seven inches long out of sheet lead. Solder a wire to each of the strips and immerse them in a pint fruit jar. Bend the



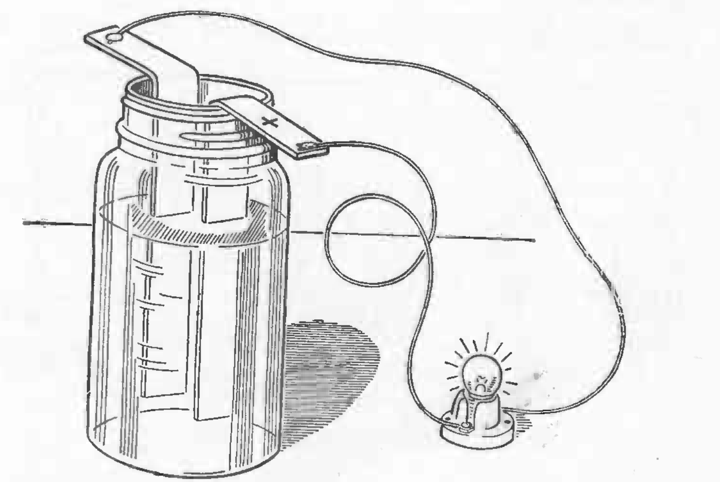
CHARGING AN EXPERIMENTAL STORAGE CELL

upper ends of the strips down over the outside of the jar. Fill the jar to within an inch of the top with an electrolyte composed of sulphuric acid and water. (For instructions how to mix acid and water see page 156.)

The plates, as we will now call the strips, should be kept separated in the solution and not allowed to touch one another. This arrangement of two lead plates immersed in an acid solution is a simple storage cell. It will not deliver any current until it has been charged.

Connect the wires soldered to the plates to a galvanometer, then to an electric doorbell or a 2.5-volt flashlight lamp. The galvanometer needle will not be deflected, the bell will not ring. The storage cell does not give forth any current.

To charge the cell, first mark a cross on one of the plates



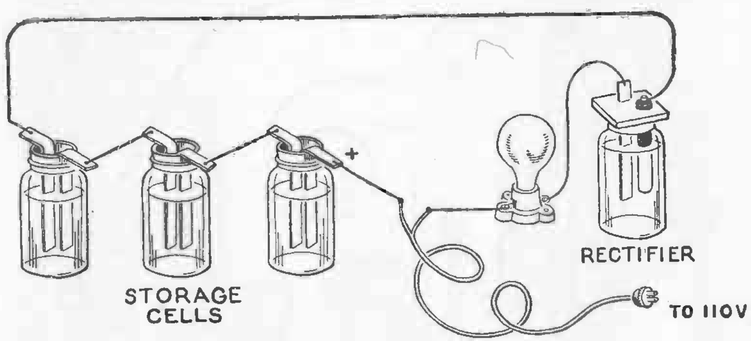
The current from the dry battery has changed the two strips of lead into the plates of a storage cell. The cell will light a small lamp, ring a bell, etc.

to indicate that it is to be positive. Mark the other plate with a straight line to indicate that it will be negative. Connect the plate marked with a cross to the carbon or positive terminal of two or three dry cells connected in series. Connect the negatively marked plate to the zinc or negative terminal of the dry cell battery.

Current from the dry cell battery will flow through the storage cell and charge it. Bubbles of gas will rise from the lead plates. Hydrogen gas is released from the negative plate

—oxygen from the positive. The hydrogen gas may be readily seen immediately, but at first the oxygen is not noticeable. Until the cell has been charging a long time, the oxygen is absorbed by the surface of the lead plate and combines with the metal to form a chocolate colored chemical compound called lead peroxide.

When the storage cell has "charged" for ten or fifteen



TRICKLE CHARGING

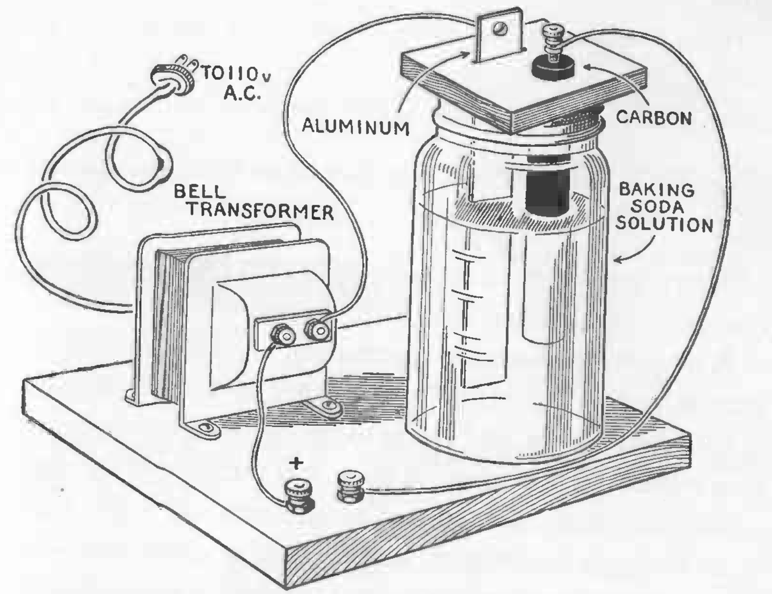
minutes, disconnect it from the dry battery. Now if you connect the storage cell to an electric door bell, the bell will ring. A 2.5-volt flashlight lamp can be lighted.

The "charge" in the storage cell will last only a short time. It is necessary to recharge it for more than ten or fifteen minutes in order to secure any appreciable amount of current.

A dry battery used to charge a storage cell will soon become exhausted. Direct current is necessary. Alternating current cannot be used until it has been rectified or changed into direct current.

If you connect the storage cell to an electrolytic "trickle"

rectifier and charge for several hours or overnight, it will give forth considerable current. In fact, a very convenient small power plant can be set up by connecting two experi-



EXPERIMENTAL RECTIFIER

The bell transformer reduces the voltage of the lighting current and makes the rectifier more efficient. Connect the positive terminal of the storage battery to the terminal marked with a plus sign in the sketch.

mental storage cells such as just described to a rectifier.

Current may be drawn from the cells while they are recharging. This is called "floating the battery on the line." The storage battery in an automobile is charged when the engine is running and "floats on the line."

The capacity of a homemade storage battery improves with use. After it has been charged and discharged fifteen or twenty times it will give out current for a longer period. It can be improved somewhat by scoring or crisscrossing the surface of the lead plates with the point of a knife or some other sharp tool.

After the battery has been charged and discharged several times you will notice that when it is charged, the negative plate is slate gray in color while the positive is dark brown.

How an Alternating Current May Be Changed into a Direct Current

There are several methods by which an alternating current may be changed into a direct current.

A device for changing alternating current into direct current is called a rectifier. A rectifier is a sort of electrical valve which opens and closes to let current pass in one direction but not in the other. A *chemical* rectifier is the simplest.

Certain chemicals will act as an electrical valve because:

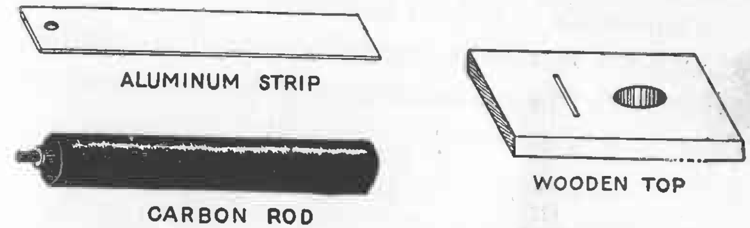
1. Oxygen is released at the positive electrode when an electric current is passed through a suitable solution.
2. A coating of aluminum oxide forms instantly on aluminum.
3. Aluminum oxide is an insulator.

A simple chemical or electrolytic rectifier consists of a strip of aluminum and a carbon rod dipping into a solution of baking soda in water.

Here is an explanation of what happens when the rectifier is in operation. If a rectifier cell is connected to an alternating current, whenever the aluminum electrode is positive oxygen gas is released on the surface of the metal. The oxygen combines with the aluminum and forms a thin coat-

ing of aluminum oxide on the electrode. Since aluminum oxide is an insulator, it shields the electrode from contact with the solution and stops the passage of current.

When the current impulse is in the opposite direction so that the aluminum becomes negative, the aluminum oxide disappears and the aluminum is in contact with the solution.



PARTS FOR AN ELECTROLYTIC RECTIFIER CELL

In simpler words, a current can pass when the aluminum electrode is negative but not while it is positive.

How to Make a Chemical Rectifier

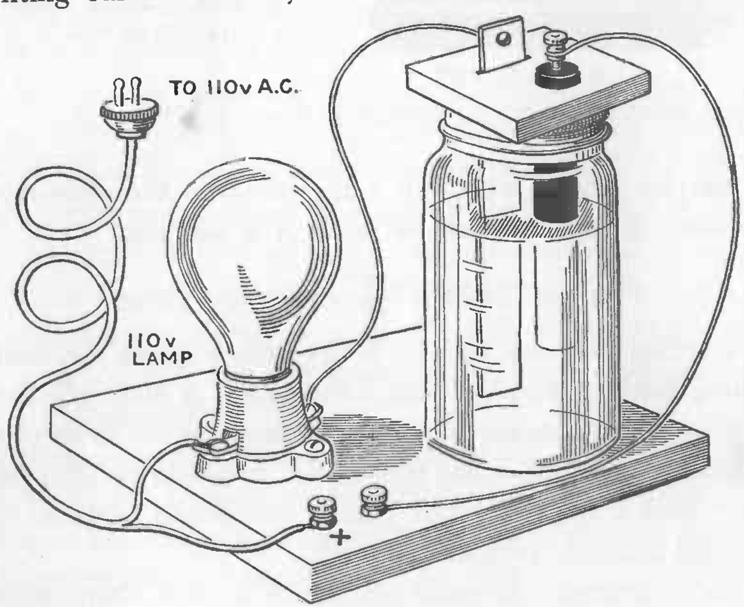
A carbon rod from a No. 6 dry cell, a quart jar, some baking soda, a doorbell transformer and a strip of sheet aluminum are the only materials necessary to make an electrolytic rectifier. It is the type called a trickle rectifier because only a small amount (about one-fourth ampere) of rectified current "trickles" through.

The aluminum electrode should be a strip about seven inches long and one inch wide. It may be cut out of an aluminum pan or pot cover purchased at a "dime store." An 8-32 brass screw slipped through a hole near the end, a hexagonal brass nut and knurled thumbnut from a dry cell will provide means for connecting a wire.

The cell should have a wooden cover which has been painted with hot paraffin to prevent the wood from absorbing any of the electrolyte. Make a hole for the carbon rod which is a tight fit. Cut a slot with a jigsaw blade so that the aluminum strip can be slipped through.

Fill the quart jar nearly full of water and add three or four teaspoonfuls of sodium bicarbonate.

A chemical rectifier is most efficient when operated at low voltage. A doorbell transformer will reduce the 110-volt lighting current suitably.



ELECTROLYTIC RECTIFIER

This sketch shows how a 110-volt lamp may be used to replace a bell transformer to reduce the voltage of a trickle charger.

IV

DISCOVERING THINGS WHICH ELECTRICITY WILL DO

To a scientist, progress in Science is merely the growth of man's understanding of his world and hence greater ability to live wisely.

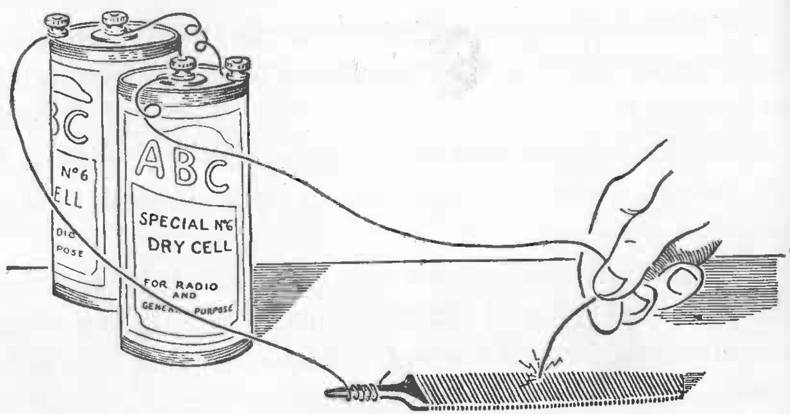
Electrical science is the knowledge of what electricity will do, how to command it and how to utilize its services in a practical way.

Electricity is often called a servant. That is because it can do so many things and will obey and do those things when commanded wisely. It is scientific knowledge that has made electricity a servant—knowledge almost entirely acquired since Benjamin Franklin deciphered a flash of lightning.

You can discover for yourself many of the things which electricity will do.

Discovering a Spark

Perhaps most easily discovered is the fact that an electric current makes a spark. The current from a small battery will not jump through the air and make a spark like the static electricity from an electrophorous. The voltage or electrical pressure is not high enough. About 350 volts is the lowest voltage which can jump through the air. To produce 350 volts requires approximately 235 cells. You can, however, make a spark with a smaller number. All you need to do is to bring together and then draw apart the ends of two wires connected to three or four cells of battery. When you separate the ends of the wires, or break the circuit, as it is called, you will see a small spark. No spark occurs unless a current is flowing through the circuit when it is broken.



DISCOVERING A SPARK

If one of the wires leading from the battery is connected to a file, and the other wire is scratched across the teeth of the file, you will see a succession of sparks.

Each time an electric circuit, through which a current is flowing, is broken, a spark is produced. The current tries to keep flowing after the circuit is broken and it partially succeeds in so doing. For a tiny fraction of a second, for a short space of time which we may literally call a "flash," the electric current succeeds in passing across the break. Its passage produces heat sufficient to give forth light, and we

see a spark. The spark is hot enough to ignite inflammable gases and vapors. It can cause fires and explosions.

When there is enough current and also sufficient voltage, the current can flow across a break in the circuit more than momentarily. The spark which occurs produces an intense heat, sufficient to tear off and vaporize tiny particles of copper from the ends of the wires. The space which forms the break in the circuit becomes so hot that it is a conductor of electricity. The spark changes into a flame of very high temperature—a flame which, if uncontrolled, would quickly injure an electrical circuit and cause a fire. For this reason the switches used to turn the electric lights on and off are designed and built to "snap," that is to snap open and closed. If an electric light switch is opened slowly, the spark which occurs is almost certain to develop into a flame. But when a switch is opened very rapidly there is no opportunity for the flame to become established—the spark is kept small and harmless.

When very high voltages and large currents flow through wires, as in a power house, switches immersed in oil are used. Oil is an insulator. It also absorbs heat quickly. It immediately quenches the spark and flame at the switch in a power circuit.

Of What Use Is a Spark?

Although an electric spark and flame must be guarded against wherever it might cause damage, it is useful in the proper place. It is an electric spark which ignites the gasoline vapor in the cylinders of an automobile engine. An electric spark jumping between two brass balls provided the first means of sending telegraph messages without wires. It was the clue to the knowledge which brought us radio.

From experimenting, investigating and thinking about the electric spark came the first electric light. Nearly a century and a half ago an English lad, eighteen-year-old apothecary's apprentice in far off Cornwall, puttered and played making electric sparks with a Voltaic pile. He tucked away some thoughts about sparks in the back of his mind. Digging them out a few years later he astonished the scientific world with the first electric light. (See Chapter Eight.)

Discovering Electric Light

With our present knowledge, as we look back, it seems a simple trick to make an electric light, but it is much easier to have "hindsight" than foresight. Suppose you putter with a spark and figure out how to turn a spark into a useful electric light.

The spark formed between the ends of two copper wires connected to a few cells of battery does not give much light. But attach the wires to two pieces of pencil lead and see what happens. Pencil lead (graphite) is more easily vaporized by the sparks than copper. The lead and the vapor become white hot. There is considerable light produced. With a battery of thirty cells (forty volts are required) the pencil leads could be separated a fraction of an inch and a dazzling electric flame called an arc would sizzle across the gap between. The pencil leads would gradually burn up, but as long as they lasted, and the current supply kept up, an intense light would fill the room.

So, one of the things which electricity will do is make an intensely hot electric flame called an arc. And the arc will produce light—a form of light which happens to be rich in

AN EXPERIMENT

A short piece of iron wire of small diameter connected to the terminals of a battery will reveal that electricity can produce heat. The iron wire will become red hot and melt. It is electricity's property of producing heat that makes possible the incandescent lamp, electric ovens, furnaces, fuses, flatirons, toasters, etc.

violet and ultra-violet rays and an excellent substitute for sunshine. It is particularly useful for taking photographs indoors and for treating certain diseases. The heat developed by an arc is so intense that it is used for welding metals and making chemical compounds.

Making Electricity Produce Heat

You might try another experiment and find for yourself another one of the things which electricity does.

It is a simple experiment. You will need two cells of dry battery, two pieces of copper wire, not smaller than No. 18 B. S. and a piece of picture wire or "cord." Picture cord is a cable made of eight or ten strands of small iron wire.

Separate a single wire strand from the rest of the cord and connect a short piece to the copper wires. Connect the other ends of the copper wires to the battery. The iron wire will become very hot. If it is a short piece, two or three inches long, it will become red hot when connected to the battery. If the iron wire is quite short, from one-quarter to half an inch long, it will become white hot and melt. Before the iron melts, it will glow with a bright light. It has become *incandescent,* which means that it has been "caused to give light by heat." The meaning of the word incandescent explains how the incandescent electric lamp produces light.

When the wire melts, the electric circuit is broken and the current ceases to flow. The end of the wire becomes cool again.

Electricity from the dry cells has produced heat and light.

Iron wire does not provide a good path for electricity. Iron is a poor conductor. It offers resistance to the flow of current.

Sending current from a comparatively good conductor such as the copper wires into a poor conductor such as a thin iron wire crowds the electrons into an obstructed path. The

energy which the electrons use in trying to crowd and push through the narrow path offered by the iron develops heat. If there is sufficient heat to raise the temperature of the iron so that it glows, there is also light produced.

The fact that electricity will produce heat when it meets with resistance is used to make fuses, electric irons, toasters, stoves, ovens, percolators, etc. Wires made of a mixture of nickel and chromium called Nichrome have more than fifty times the resistance to the electric current that a copper wire of the same size has. By means of Nichrome it is possible to concentrate the heat produced by electricity in a small space. The heating element of electric toasters, irons, etc., is made of Nichrome wire or ribbon.

Finding Treasure

A rough diamond, uncut and unpolished, has the appearance of an ordinary pebble. You would probably toss it aside unrecognized as anything of value.

There is an unpolished "scientific diamond" in the experiment with the iron picture wire. Did you recognize it? It is the fact that:

For a second or so before the wire melted, it gave forth light. Electricity can make a wire hot enough to glow and produce light.

This fact is worth more than all the real diamonds in the world, for by proper "cutting and polishing" at the hands of Sir William Grove, Frederick de Moleyns, Joseph Swan and Thomas A. Edison, it became the electric incandescent lamp.

It required painstaking labor, tens of thousands of experiments, vast sums of money and a great deal of time to make a practical electric light out of a bit of glowing wire.

A glowing iron wire would not make a practicable electric light for several reasons, but chiefly because iron melts at 2745 degrees Fahrenheit, a temperature which is not high enough to produce much light.

The pioneer electricians who experimented to perfect an electric incandescent light all used a glowing platinum wire. Platinum melts at 5742 degrees Fahrenheit. It possesses considerable resistance, heats readily when an electric current passes through it and glows brilliantly without melting.

A hundred years ago, Sir William Grove, an English judge and scientist of great ability, built experimental lamps using platinum wire. He attached the ends of a coil of platinum wire to copper wires connected to a powerful battery. The platinum coil was covered with an inverted glass tumbler resting in a glass dish partly filled with water. There was a good reason for this arrangement. The glass tumbler protected the hot platinum wire from draughts which would tend to cool it. Furthermore, the small amount of oxygen in the tumbler reduced the tendency of the platinum to burn up.

The lamps which Judge Grove made gave feeble light and the cost of electric current supplied by batteries was too great for his invention to have commercial value. It was of scientific value however. Grove made the first lamp, crude as it was, which contained all the essential elements of those which we use today.

Several decades later, Edison and his assistants worked

day and night for thirteen months experimenting with incandescent lamps using platinum wire before they abandoned it as unsatisfactory and started a search for other materials.

Finally, Edison found carbon to be superior to platinum. He sealed a carbon wire or "filament," as he called it, inside a glass bulb from which the air was pumped. The absence of oxygen inside the bulb prevented the carbon filament from burning up. Carbon filament lamps were in use for many years. Then research and experiment found a better material than carbon.

Modern electric incandescent lights use a filament made of a metal called tungsten. Tungsten does not melt until it reaches the amazing temperature of 10,908 degrees Fahrenheit. It produces a brilliant light and uses a small amount of electric current. The tungsten filament is enclosed in a glass bulb containing nitrogen and argon gas. Nitrogen and argon are inert, which means they do not have any effect upon the tungsten. Tungsten cannot burn up in an atmosphere of nitrogen and argon.

A Glowing Hairpin in a Glass Bottle

On New Year's Eve, 1879–80, special trains were run from Jersey City to Menlo Park, N. J., by the Pennsylvania Railroad. Menlo Park, about twenty-five miles beyond Newark, N. J., is little more than a railroad station. It would not ordinarily be noticed if you were riding by. But it was here —in a two-story wooden building which looked like a country meeting house minus its steeple—that a former newsboy became world-famous as "The Wizard of Menlo Park."

The "Wizard" was Thomas A. Edison and on the evening in question 3000 people journeyed to gawk and stare at a new wonder which one newspaper reporter described as "a glowing hairpin in a glass bottle." Public officials, bankers, scientists, and many prominent people were in the crowd that went to see Edison's first public exhibition of his incandescent electric lamp and system of electric lighting.

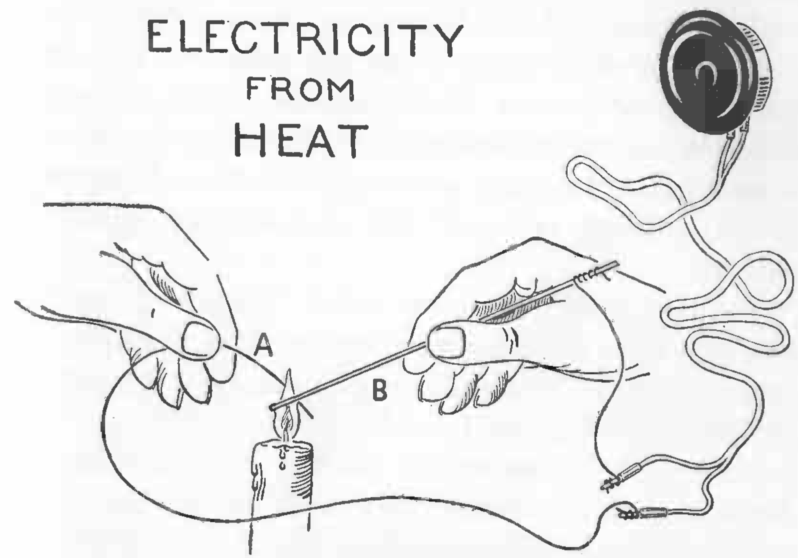
An incandescent lamp is a simple-appearing bit of metal and glass—merely a filament of tungsten wire sealed inside a glass bulb exhausted of air. This lamp and the system of generating and distributing electric current which was developed with it are undoubtedly electricity's greatest contribution to human comfort and progress.

As you already know, the first practicable incandescent lamp and the first commercial system of generating and distributing electrical power were the work of Thomas A. Edison and his able assistants. In an age of smoking candles, oil lamps, gas flames and arc lights, Edison conceived a vast and daring plan for a new system of lighting which would be safe, silent, flameless, smokeless and always available. He made his vision a reality.

Grosvenor P. Lowry, Henry Villard, J. P. Morgan and other financiers participated in furnishing the money required for the research which Edison carried on. If he had never done anything else, the result of his vision, labor and patience in this one thing alone would have placed Edison among the world's great men.

The Amazing Incandescent Lamp

An incandescent lamp probably does not amaze you. You first saw one when you were a baby—the electric light was



EXPERIMENT

Electrical actions are reversible. Electricity will produce magnetism and magnetism is a means of producing electricity. Electricity will produce heat and heat will produce electricity. When the juncture between two different metals is heated an electric current is generated. Connect a steel rod and a copper wire to a telephone receiver. Heat the ends and rub them together. The electric currents thus generated will produce sounds in the telephone receiver.

here before you—so you accept it as part of your world along with trees, rocks, rivers and mud.

You can't be expected to show the same amazement that grown-ups did two generations ago when they first heard about "the new light" and perhaps saw one for the first time. But an incandescent lamp is just as amazing today as it was nearly sixty years ago if you think about it as suggested in our jingle about "the light which shone in the house that Jack built."

If you connect a little 2.5-v flashlight lamp to two cells of dry battery the tiny filament will send out a brilliant light. Isn't that amazing? If it does not seem so consider this:

Inside the dry cells, although you cannot see or hear it, there is great activity. It is chemical activity, a process which in this case consists mainly in changing the zinc shell from a shining metal into a white powder. The white powder is the chemical union of zinc and chlorine called zinc chloride.

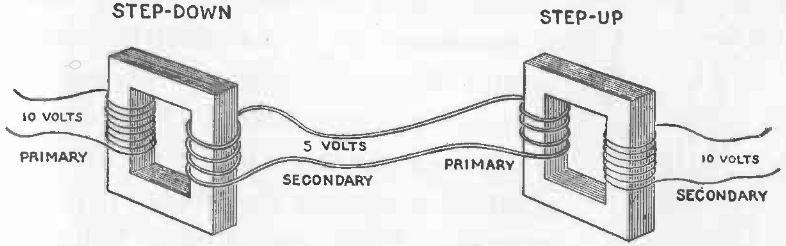
You have played the game called "Going to Jerusalem" in which there is always some one left with no chair to sit upon. When chemical activity takes place in a dry cell it is like playing "Going to Jerusalem." There is always "some one" left. The "some one" is the tiny electrically charged particle called an electron. Whereas the electron had a place to sit before the chemical activity started, it is left standing on its feet seeking a place to go.

It rushes out of the dry cell through the solid copper wire followed by countless of its brother electrons who also have been left without a place to sit. When the stream of rushing electrons reach the lamp filament there is congestion. Some of the electrons go popping out through the surface of the filament. The crowding and pushing of the electrons through the filament makes it hot—so hot that *light* is shot away from the filament.[1] Travelling at a rate of 186,326 miles per

[1]The electrons do not pass out through the glass bulb. They are caught in an electric field which exists around the filament, whisked about over a curved path and sent back into the filament.

second, the light shoots through the glass bulb, across the space between you and the lamp and into your eyes. Heat and light are not different substances, nor do they fall in different categories. Radio waves, light and heat are indistinguishable from one another save for wave length.

The light reaching the delicate rods and cones on that little screen called the retina in the back of your eye produces therein *electrical changes.* These are communicated to the intricate apparatus of nerve cells and filaments con-



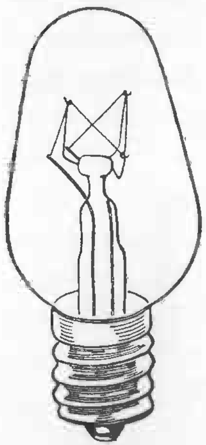
THE ACTION OF THE TRANSFORMER

This diagram shows how the relative number of turns in the primary and secondary determines whether a transformer is a "step-down" or a "step-up."

nected to the optic nerve and ultimately to the brain. Thereupon *you see.* The act of seeing is an electro-chemical action.

Take your tiny lamp and batteries into a dark room where there is no other light. The electric current (moving electrons) coming from the battery and passing through the lamp send you a picture of the battery, wire, lamp and other objects in the room. The picture is received by your own electrical system of nerves and brain of which the eye is an instrument. Here truly is television—electricity sending images. So, an electric lamp really is amazing even though you may not have thought so at first.

The first Edison power stations generated direct current. The stations were located in thickly populated areas of cities where it was not necessary to send the current a great distance in order to secure enough customers. It was a problem how to send the current far without either raising the voltage of the system so high that the wires and cables were dangerous or else employing large copper wires of a size too great to be practicable.

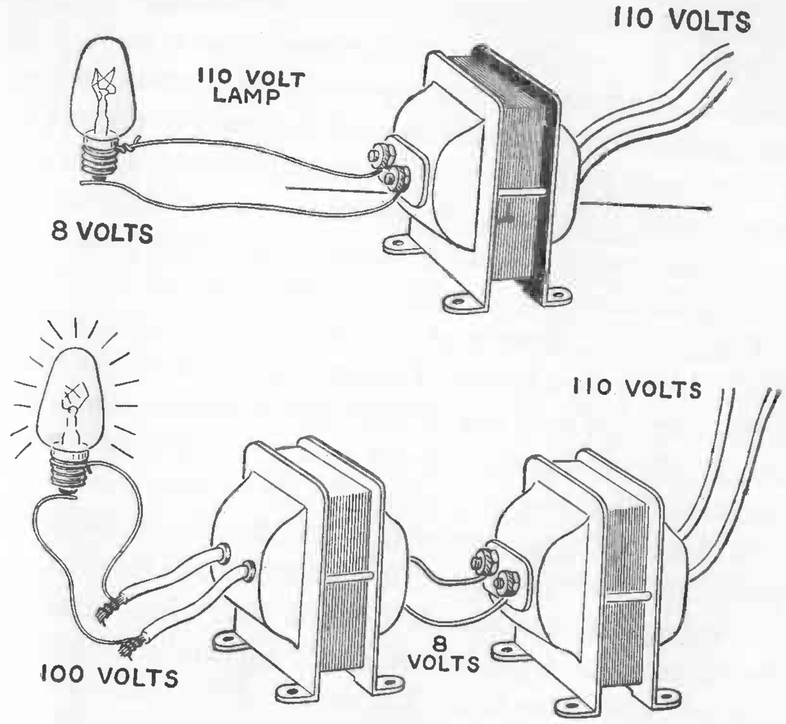


Sewing-Machine Lamp

When power companies began to look farther afield for customers and found it necessary to send electric current greater distances, engineers devised the alternating current system. Direct current is still used on many electric railways but alternating current has replaced it for general lighting and power purposes. Alternating current can be sent out at a high voltage and conveniently reduced to a low voltage again by means of a transformer outside each home or building.

The transformers used on an alternating current system make it a simple matter to maintain a constant voltage along the lines so that customers near the power station receive power of no higher voltage than those farther away.

Transformers may be called the backbone of our power distribution system. In principle a transformer consists of two coils of wire wound around an iron ring. If an alternating current is sent through one of these coils, called the *primary*, an alternating current will be created in the other or *secondary* coil. If the secondary coil contains twice as



EXPERIMENT

The step-down bell transformer reduces the 110-volt current to approximately 8 volts. The sewing-machine lamp connected to the secondary will not light because of the reduced voltage. But if a second transformer, connected so as to step up the voltage, is added to the circuit the 110-volt lamp will be lighted.

many turns as the primary, the voltage of the current in the secondary will be doubled. If the number of turns in the secondary is half the number in the primary, the voltage will be halved. In other words, the voltage change is the same as the ratio of the turns in the primary and secondary. A transformer which reduces voltage is called a step-down transformer. A step-up transformer raises the voltage.

The principle of both types of transformers may be demonstrated by two fifty-cent "bell-ringers" and a seven watt, 110-volt, candelabra base lamp of the type used as a sewing machine light. A bell-ringer is designed to operate as a step-down transformer, to reduce the 110 volts to approximately eight volts. Its action can be reversed and it can be used as a step-up transformer although it will not operate as efficiently in its unintended role.

Connect the primary of one bell-ringer to the 110-volt A. C. electric light circuit. The secondary will deliver about eight volts and will ring a bell, light a six-volt lamp, etc. But it will not light the seven watt 110-volt lamp. There is insufficient voltage.

If, however, you connect the secondary terminals of another bell-ringer to the secondary terminals of the first, the voltage of the current obtained from the primary of the second bell-ringer will be nearly 110 and will light the 110-volt, seven watt lamp. The current is not quite 110 volts because of losses which occur in each transformer.

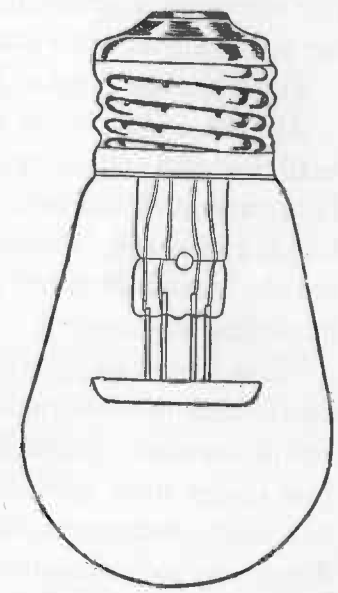
Glow Lamps

Ever since Edison tackled the job of making an incandescent lamp, research and experiment have continued in an effort to produce better lamps.

The modern tungsten filament, sealed in a glass bulb containing nitrogen and argon gas, makes an infinitely better lamp than the older carbon filament sealed in a vacuum. The light is whiter, the bulb does not become blackened as

quickly and less current is consumed in proportion to the light given.

In the search for a better lamp, some scientific trails led to a different form of lamp—a lamp without a filament. Lamps filled with a vapor of some metal or a gas which glows may be the principal means of furnishing artificial light in the future.



NEON GLOW LAMP

This type of lamp does not contain a filament. The light is emitted from the sensitive chemical surfaces of metal electrodes.

The sodium lamps, used for highway lighting, are a step in that direction.

An interesting modern development called the negative glow lamp makes it a simple matter to experiment with fluorescence and to build that amazing device called a stroboscope.

Glow lamps are unique light producers wherein light is produced through the agency of rare gases electrically excited. Like the Geissler tube and commercial neon signs, glow lamps contain no filaments and generate a negligible amount of heat. The light comes from the electrical discharge emitted from extremely sensitive chemical surfaces on ordinary nickel-plated iron electrodes. Unlike Geissler tubes and neon signs, however, glow lamps operate on a low voltage (under 110 volts).

You can buy a small Glow Lamp provided with a base to fit the ordinary electric light socket for fifty cents. Since the lamps actually operate in a range of forty-five to sixty volts A. C. and sixty-five to eighty-five D. C., a tiny protective resistance is sealed in the base to give the proper ballast for operating on 110 volts.

There are two types of glow lamps, neon and blue.

The neon glow lamps give forth a light which is mainly in the red and yellow regions of the spectrum. There is some light present of the infra red variety but it is of course invisible to the eye. There is also a little invisible violet light but the glass bulb filters out or shuts off any ultra violet if it is actually generated.

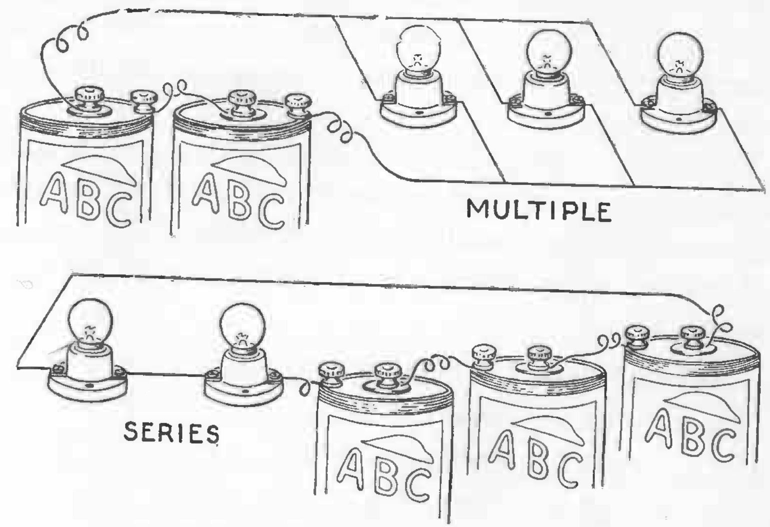
Neon glow lamps are used for various purposes in industry and the laboratory. For radio purposes there is an infinite number of uses. In the home, low current consumption makes neon glow lamps practicable as night lights in bedrooms, bathrooms, hallways and many other locations. The young experimenter will probably be most interested in using this unique light in building a stroboscope.

Fluorescence

Blue glow lamps contain a mixture of gases which include argon. The light given forth is mainly blue, violet and near ultra violet. Because there is considerable near ultra violet given forth by these lamps, they may be used to demonstrate fluorescence.

The blue glow lamp is relatively weak in visible light and if in an otherwise darkened room a piece of the mineral

called willemite is brought near a lighted blue glow lamp, it will fluoresce bright green. In like manner, the chemical called anthracene glows bluish-white. Many other minerals, dyes and chemicals are known to fluoresce. Several common



MINIATURE LIGHTING CIRCUITS

Miniature lamps may be connected in series or in multiple. The circuit at the top shows three 2.8v lamps in multiple connected to two dry cells in series. The lower diagram shows two 2.2v lamps connected in series with three dry cells in series. The lamps are arranged so that the voltage of the battery is the voltage required by the lamps.

substances will give amazing effects. The inexpensive yellow-green glassware obtained in the "dime" stores will glow vividly.

A solution made by pouring boiling water on the shredded inner bark of a horse-chestnut tree, kerosene, lubricating oil, vaseline, natural teeth and artificial pearl buttons will all fluoresce when brought near a blue glow lamp.

Miniature Lighting

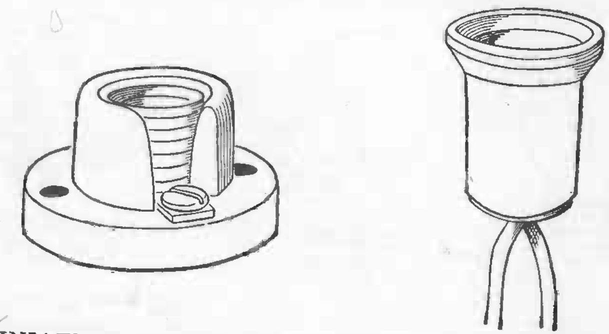
Miniature lamps, supplied with current from dry cells or homemade Leclanché cells, are a convenient means of lighting dark closets, hallways, cellars, etc., where a light is often wanted for a few moments and where candles or matches would be dangerous.

The small tungsten filament lamps made for flashlights are intended to use with batteries and give considerable light in return for a small amount of current. The voltage and number of dry cells to use are given below for the most common sizes.

Voltage	*Number of Cells*
1.2	one small cell
2.2	two small cells
2.3	two " "
2.5	two type D flashlight cells
2.8	" " " " "
	or 2 No. 6 dry cells
3.8	three type D flashlight cells

All flashlight and standard dry cells give the same voltage regardless of size. But when a lamp or any other device draws current from the cell, the voltage drops. The voltage of the small cells used in penlites, and vest pocket flashlights drops lower than the voltage of a larger cell under the same conditions. That is why the 1.2-, 2.2-, and 2.3-volt lamps are manufactured. They are intended for the smaller sizes of flashlight cells.

Flashlight lamps are fitted with a miniature base. This is a threaded brass shell with a contact button at the end—actually a miniature edition of the base found on standard



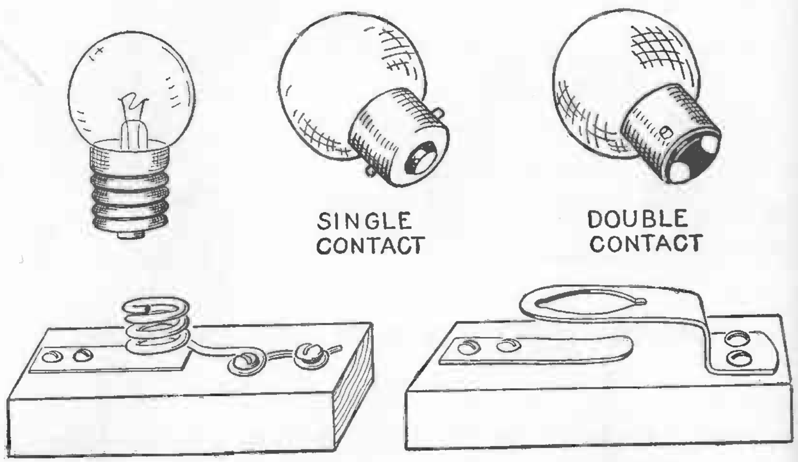
MINIATURE PORCELAIN RECEPTACLE AND SOCKET

110-volt Mazda lamps. In order to form a good electrical connection between the base of the lamp and the current supply, a socket is necessary. Christmas tree lamp sockets with the wires attached or a miniature flat-base porcelain receptacle are suitable for miniature lighting.

A homemade socket is shown in one of the near-by illustrations. The spiral is formed by wrapping a piece of heavy copper wire (No. 14 to 16 B. S.) around the threads of a lamp base. The lamp is then screwed out of the coil so that the latter may be attached to a wooden block. Contact with the button on the bottom of the lamp base is established by a small strip of spring brass.

Some of the small sizes of lamps used on automobiles for parking lamps, dash lights, etc., are useful for miniature lighting systems. The little 6-8-volt, three-candle-power lamp known as No. 63, consumes approximately one-half ampere and gives considerable light.

Automobile lamps are fitted with an Ediswan base. This is a brass shell having two pins on the side and either one



MINIATURE BATTERY LAMPS AND SOCKETS

The lamp at the left has a miniature Edison base. Those at the right have Ediswan bases. At the bottom are homemade sockets.

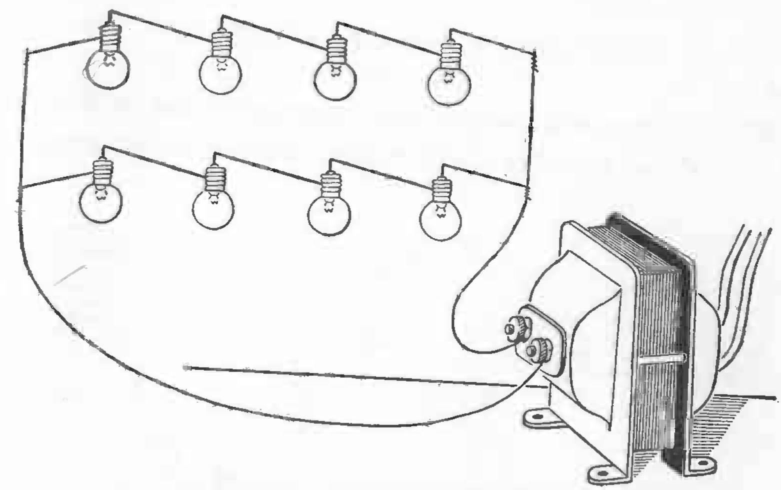
or two contact buttons on the bottom. The single button type is called "single Ediswan" and the two button "double Ediswan." Ediswan is a combination of the names Edison and Swann.

A simple method of making a socket for a single Ediswan lamp is illustrated.

Lighting a Doll House

A doorbell transformer makes an excellent power supply for lighting a doll house. These little transformers are con-

structed so that the secondary delivers a current of approximately eight volts. Eight volts will burn out a single flashlight lamp. It is necessary to connect several small lamps in series. If 2.4-volt lamps are used, three or four should be placed in series. Six to eight 1.2-volt lamps are required in series.



MINIATURE LIGHTING CIRCUIT

Eight 2.4v lamps are shown in two series of four lamps connected to a bell transformer. This is a good arrangement for lighting a doll house.

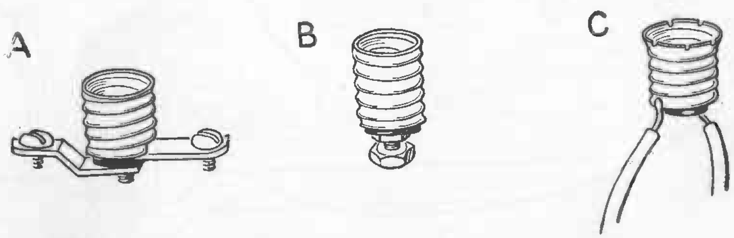
A "bell-ringer" will deliver enough current to light two series of flashlight lamps at the same time. A doll house seldom has more than six rooms, so two circuits with three or four lamps in series in each circuit will provide a lamp for each room and also for the halls, if there are any.

The ordinary miniature socket is too large and conspicuous to look well on the ceiling or walls of a doll house.

If you dig the wax out of the underside of a miniature flat-base porcelain receptacle, you can remove the screws and secure the essential metal parts to make a socket more suitable for a doll house. The metal parts of a Christmas tree lamp socket may be secured by carefully cracking the bakelite shell in which they are enclosed.

Miniature Lighting for Models

The tiny lamps known as "pea" lamps and also as "grains of wheat" are of a size which makes them in better propor-



SOCKETS FOR DOLL HOUSE

The parts shown at *A* are the metal fittings from a miniature porcelain receptacle. *B* shows the same parts with the connector strips removed. *C* shows the interior of an Xmas tree lighting socket, obtained by breaking the shell.

tion to most scale models than flashlight lamps. They are very realistic when used on model ships, railways, doll houses and miniature buildings.

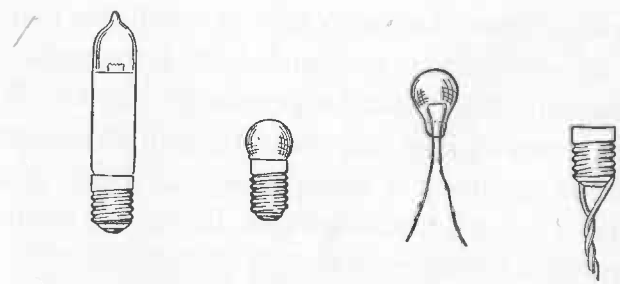
It is possible to buy three different types, a round lamp either with or without a tiny screw base and a candle-shaped lamp.

When used on ships and airplanes for running lights or as obstruction lights on a model airfield, the lamps may be

suitably colored red or green with a touch of colored "dope."

If you like to make small objects and are handy at shaping small pieces of sheet metal you can easily make pleasing table lamps, floor lamps, wall brackets, ceiling fixtures, etc., for doll houses and model buildings.

The lamps come in several different voltages and should of course be connected only to a battery suitable to furnish proper light without burning out the filaments. If you are contented not to burn the lamps too brightly, they will last indefinitely.



PEA LAMPS AND SOCKET FOR MODEL LIGHTING

V

MAKING ELECTRICITY SHOW ITS MUSCLE

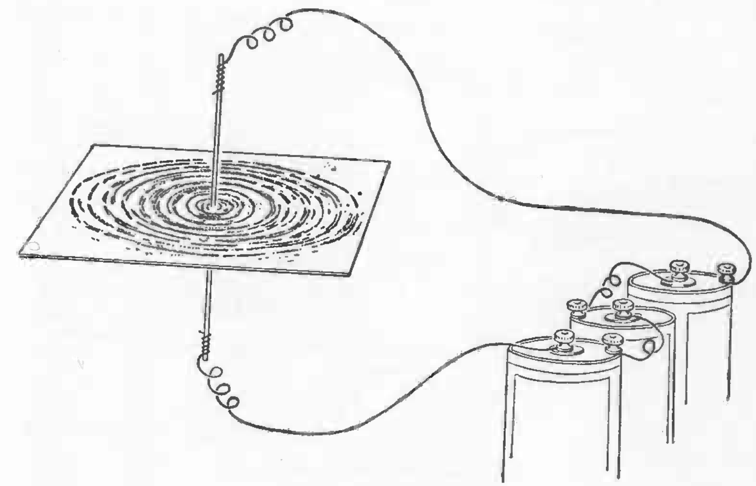
OF ALL the amazing things that electricity does, perhaps the most useful is to produce magnetism. Why it does so is just as much a mystery as the answer to the question, "Why is magnetism able to produce electricity?"

However, we know that every wire or conductor carrying a current of electricity is surrounded by a magnetic field like the magnetic field around a permanent magnet. When the current ceases to flow, the magnetic field disappears. A strong current produces a strong magnetic field; a weak current makes a weak field. Fine iron filings will cluster on a wire carrying a strong current.

For many years there was a restaurant in downtown New York City next door to a power station. The powerful magnetic field of the cables in the power house did strange antics in the restaurant. Iron skillets would not hang straight and steel knives on the dining tables would swing around and point toward the wall.

If you bring a magnetic compass close to a wire carrying current from a battery, the compass needle will swing around at right angles to the wire. Something overcomes the pull of the earth's magnetism and swings the needle away from its usual north and south position. The "something"

is a magnetic field with greater influence than that of the earth. It is the magnetic field about the wire. When no current flows through the wire, there is no effect upon the needle. The action of the compass needle shows that a



EXPERIMENT

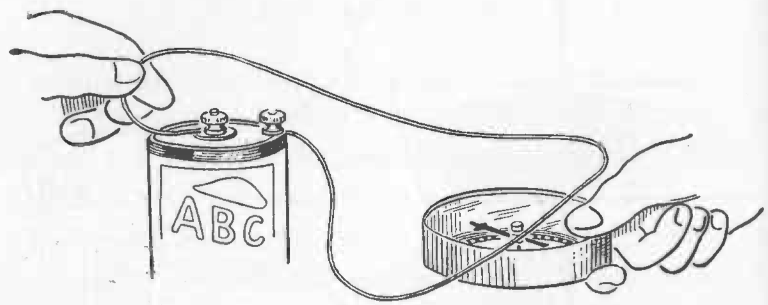
A wire carrying an electric current is a magnet and will produce a magnetic phantom.

wire carrying a current of electricity produces magnetism.

The magnetic field around a wire will form a phantom. This may be seen by passing a wire carrying a strong current of electricity through a small hole in a piece of cardboard. When a few iron filings are sifted on the cardboard and the latter jarred slightly, the filings will arrange themselves in circles with the wire as the center.

The magnetic field produced by a single wire is not very strong unless the wire carries a very large current. A magnetic field is one of the most useful things in this world but the field around a single wire is not strong enough to be of much value.

Hans Christian Oersted, a Danish chemist, was the first to discover that electricity produces magnetism. It was he who found that when a wire carrying a current of electricity



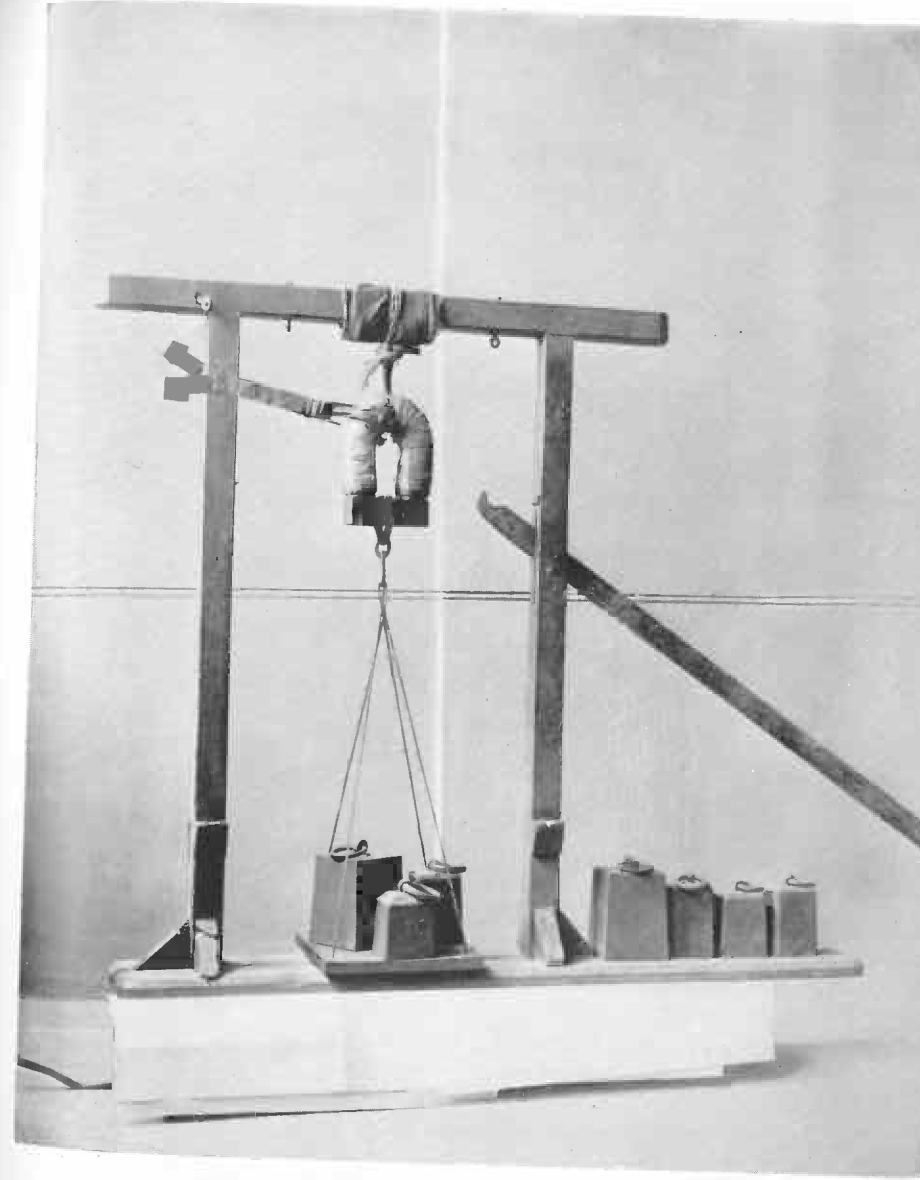
OERSTED'S DISCOVERY

When a wire carrying an electric current is brought near a compass needle it will move the needle.

is brought near a compass needle the needle moves, just as it does when a steel magnet is brought close.

Most progress in electrical science dates from the discovery of the Voltaic cell and electromagnetism. Not long after Oersted made his discovery, William Sturgeon,[1] a soldier who carried on his experiments in an army barracks, learned how to make the magnetism produced by electricity useful. He wound wire into a coil so that the magnetic field became more concentrated. By forming a coil, a magnetic field was

[1]Joseph Henry, a professor at Princeton, also discovered how to make an electromagnet. He made better electromagnets than Sturgeon. Sturgeon used one layer of wire. Henry used several.



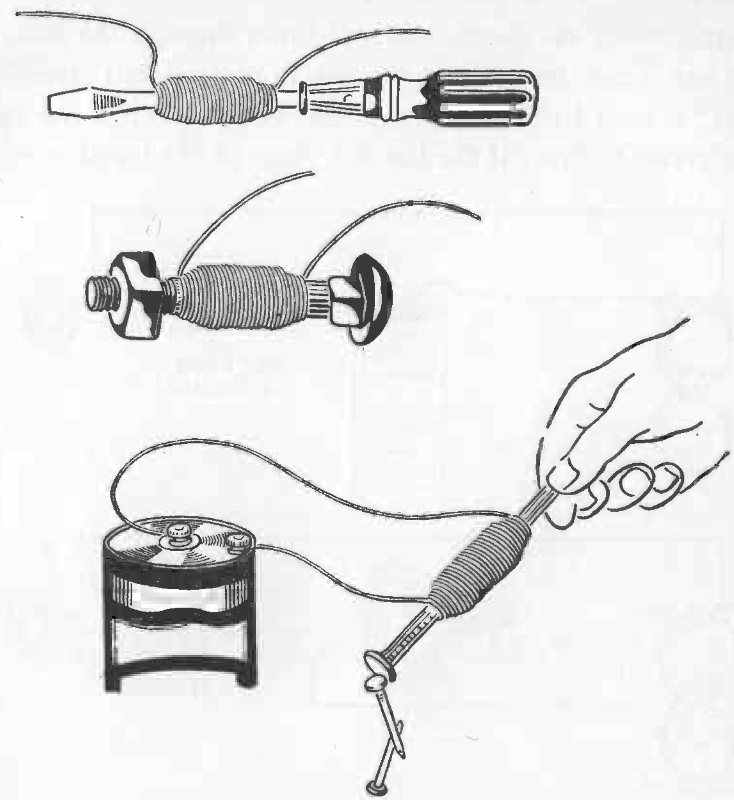
THE FIRST ELECTROMAGNET IN AMERICA

Professor Joseph Henry's original electromagnet built in 1828 is in the Smithsonian Institute. This was the first electromagnet with more than one layer of wire

(*See p. 94*)

THE FIRST ELECTRICAL RAILWAY

Thomas Davenport's model built in 1834. The battery for operating the motor is in the box at the center (*See p. 115*)

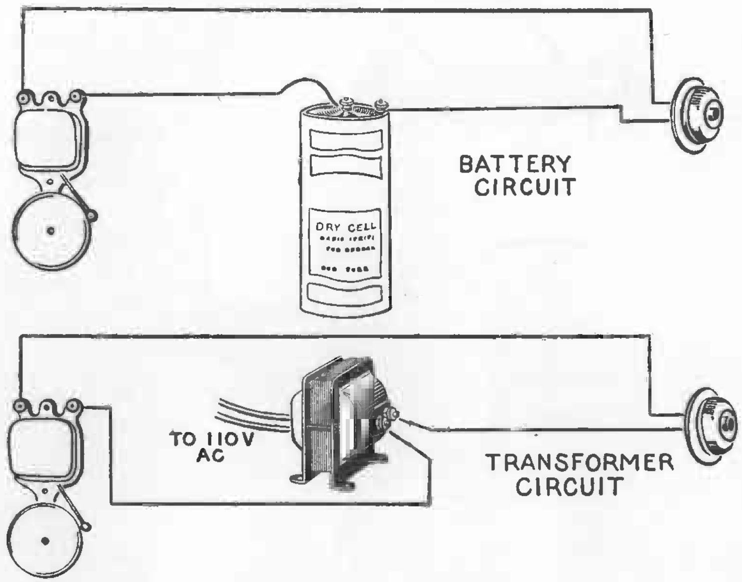


EXPERIMENTAL ELECTROMAGNETS

If you wrap some insulated wire around an iron nail and connect it to a battery, you will have made an electromagnet which will pick up pieces of iron and steel. Try the same experiment with an iron bolt and a screw-driver. A bolt is made of iron and will lose most of its magnetism when the current ceases to flow but a screw-driver is made of steel and will become permanently magnetized. Permanent magnets for electrical apparatus are made by magnetizing steel with an electric current.

secured which was equal in strength to the combined fields of many wires.

Sturgeon further learned that when a coil of wire is wrapped around an iron bar, the iron becomes a powerful magnet while an electric current flows through the coil. If the bar is soft iron or the variety of steel called electrical steel,[2] it loses its magnetism almost instantly when the current ceases to flow. If the bar is a piece of hardened or tem-



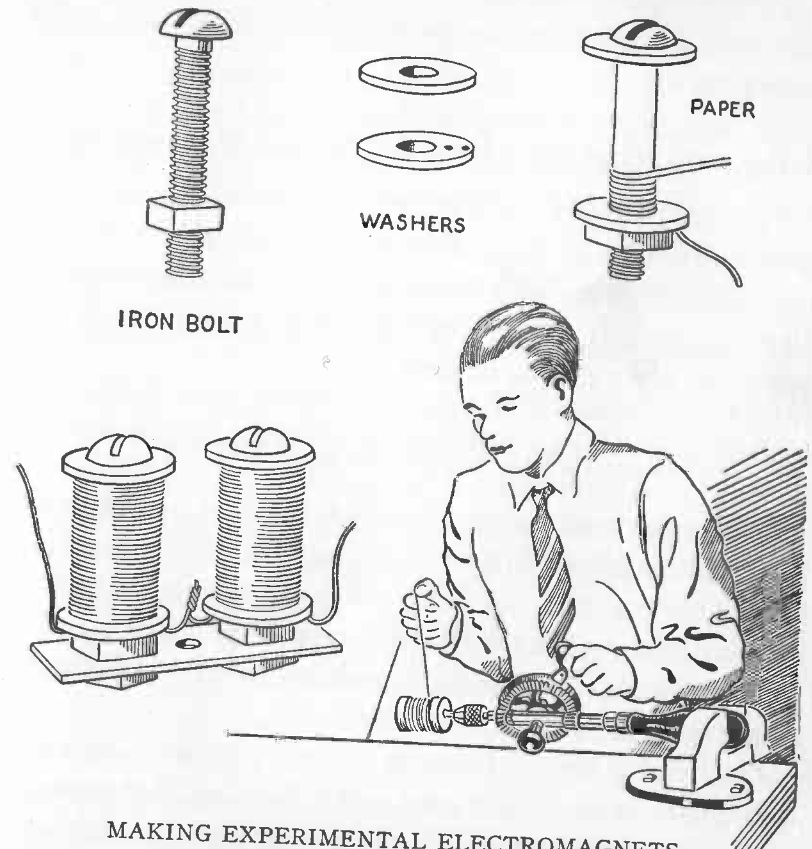
ELECTRIC BELL CIRCUITS

One of the familiar things that electromagnets do is ring bells. The upper circuit shows how to connect a bell and push button in a battery circuit. The lower circuit shows a step-down transformer as the source of current.

pered steel, or chilled cast iron, it will become permanently magnetized. It will then remain a magnet after the current has ceased to flow.

The magnetism produced by an electric current is called

[2]A steel containing from 2½ to 4½ per cent of silicon made especially to secure desirable magnetic qualities.



MAKING EXPERIMENTAL ELECTROMAGNETS

With electromagnets you can make an almost unending list of electrical instruments and toys. Iron bolts, ¼ to ⅜ of an inch in diameter, make suitable cores. Wind the wire in smooth even layers. A hand drill supported in a vise may be used as a winding machine. Two electromagnets, mounted on an iron strip called a yoke and so connected that the head of one is a north pole and the head of the other a south pole are a horseshoe electromagnet.

electromagnetism. A coil of wire wound around an iron core is called an electromagnet. Small electromagnets can be made more powerful than natural magnets or the best permanent magnets. The strength of a large electromagnet is enormous. Electromagnets can be made strong enough to lift several tons.

A Piece of Wire and a Nail Become an Electromagnet

You can make an electromagnet in a few minutes. Wrap some insulated wire around an iron nail, screw or bolt, connect the ends of the wire to a battery and you have made an electromagnet. It will pick up iron filings, nails, tacks, in fact any small piece of iron or steel.

Why Is Electromagnetism Useful?

Electromagnets are an invaluable part of almost every electrical machine. Whenever we ask electricity to work for us and some part of the electrical apparatus moves in performing its duty, we are almost certain to find that a coil of wire produces magnetism in responding to the task. Electromagnets are a sort of "electric muscle."

Electromagnets are made in a great variety of sizes and forms, each best suited to some particular duty. For example, in order to reproduce speech, the diaphragm of a telephone receiver must move. Inside a telephone receiver are two small electromagnets which move the diaphragm. The cone-shaped diaphragm of a radio-speaker is moved by at least one electromagnet. Telegraph sounders, relays, bells, stock tickers, autohorns, many other instruments depend upon electromagnetism for their operation. In every motor, whether it is a tiny one such as turns the hands of an electric clock or a huge one driving the propellers of a battleship, there are electromagnets.

It is by means of electromagnets that we are able to use electricity's strength. That is why the most useful thing that electricity does is undoubtedly to produce magnetism.

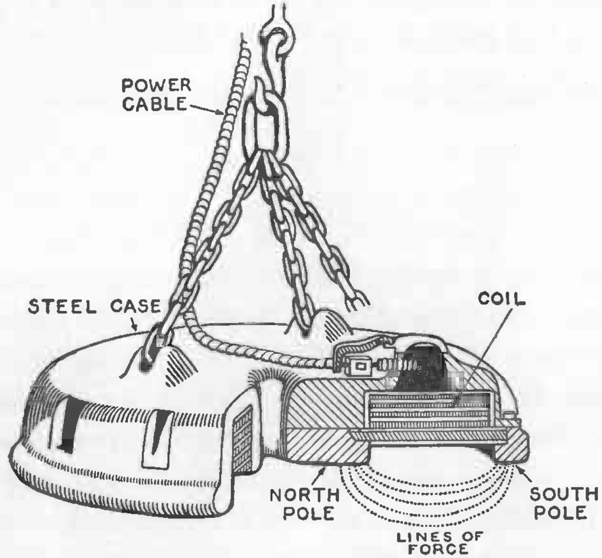
Any boy can make telegraph instruments, small motors, in fact an almost unending list of electrical instruments and toys with electromagnets. In order to build such apparatus, he should first know certain things about electromagnets.

Things You Should Know about Electromagnets

In order to get as much copper wire as possible in a small space, electromagnets are wound with *magnet* wire. Magnet wire is soft copper, insulated with a thin covering of cotton, silk, enamel or a combination of cotton and enamel or silk and enamel. The insulation on magnet wires is thinner than on other types of wire.

You can buy magnet wire on one-fourth pound spools at most radio repair shops. Cotton or enamel covered wire will serve for building any of the instruments described in this book. The different sizes of wire are identified by number. The smaller numbers indicate the larger sizes of wire. No. 40 B. S. is the smallest common size of magnet wire. It is only slightly more than three-thousandths of an inch in diameter. It offers a great deal of resistance and will carry only a small amount of current without becoming heated. No. 40 B. S. magnet wire is used for the windings of sensitive telephone receivers, voltmeters, galvanometers and other instruments used for making electrical measurements. Wires ranging in size from No. 16 B. S. to No. 30 B. S. are the most useful to the young experimenter for winding electromagnets.

The iron core of an electromagnet is usually insulated from the wire by two or three layers of paper. The wire should be wound on in smooth, even layers so as to secure as many turns as possible within a given space. An electromagnet wound in helter-skelter fashion is not as powerful

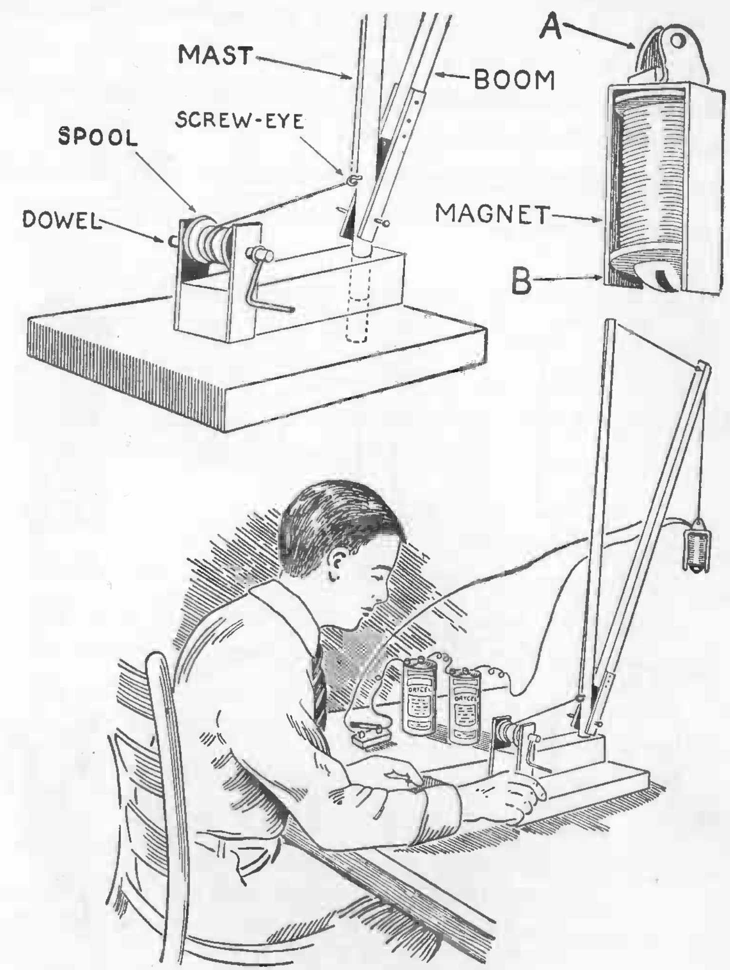


LIFTING MAGNET

Powerful electromagnets attached to cranes are used in the iron and steel industry for lifting heavy loads. In the illustration, part of the case is cut away so as to show the construction.

as the same magnet wound smoothly. The outside diameter of an electromagnet should not be more than twice the diameter of the core.

You cannot lift or pull as hard with one hand as you can with two. Similarly, an electromagnet cannot attract a piece of iron or steel with its full strength unless it can pull with

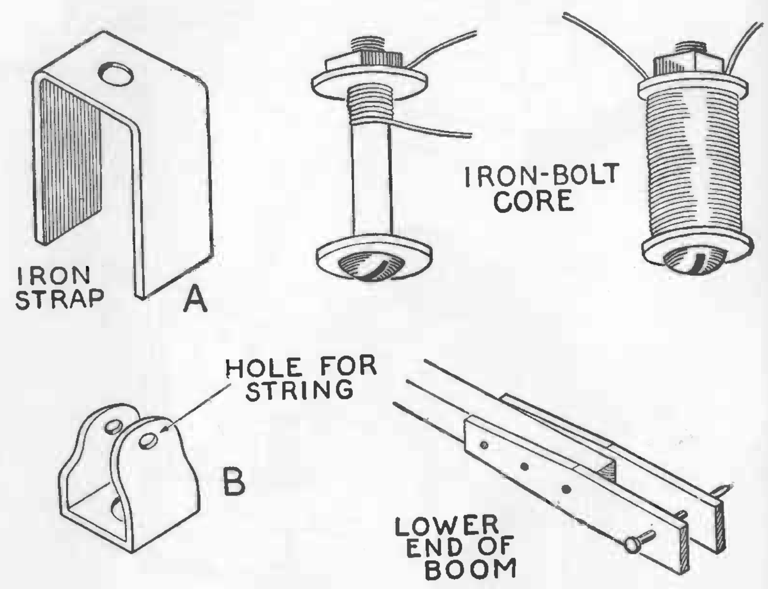


A TOY LIFTING MAGNET

The windlass is a spool mounted on a dowel-rod shaft and having a bent wire as the crank. The mast and boom are made of wood. The electromagnet is an iron bolt wound with No. 20–25 B. S. gauge wire. The boom is pivoted so that it will move in toward the mast when the windlass pulls in the string cable. Two dry cells connected to the magnet and including a switch in the circuit provide the current.

both poles. That is the reason why permanent magnets are usually made in the form of a horseshoe. The pulling power of both poles of a horseshoe can be brought against a piece of iron.

Electromagnets also are usually made so that the attractive power of both poles is used. A simple way of doing this



DETAILS OF THE TOY LIFTING MAGNET

The iron strap around the magnet (see preceding illustration) increases its lifting power.

is to arrange two electromagnets on a small iron bar called a yoke. This is a horseshoe electromagnet and is much stronger than a single magnet of the same size.

The piece of iron attracted by an electromagnet is called the armature.

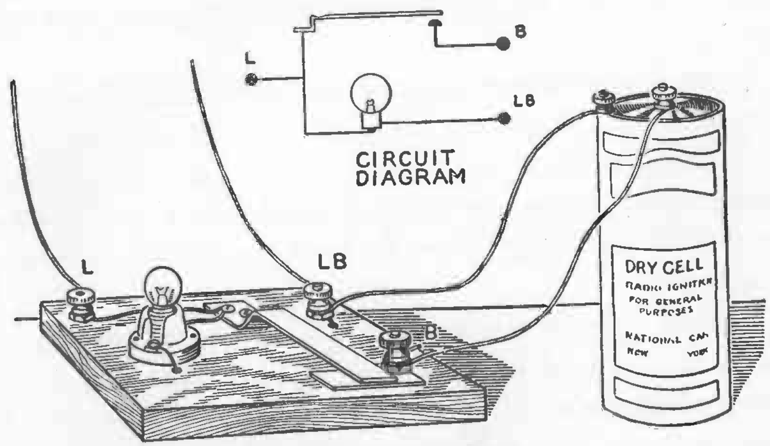
A Toy-Lifting Magnet

Rugged, powerful electromagnets, called lifting magnets, and attached to cranes or derricks, are extensively used in the steel and iron industry for handling pig iron, scrap, rails, billets, etc., and for loading and unloading cars and ore vessels.

Large lifting magnets are also used for breaking up scrap iron and steel. Huge steel balls called "skull crackers" and weighing as much as ten tons apiece, are picked up by the magnets and dropped on the scrap metal from a considerable height. Needless to say, when the skull cracker drops, "something busts."

It is not difficult to make a toy lifting magnet and a derrick which can be used for loading and unloading small pieces of iron in or out of toy trucks or the freight cars of a model railway. You can change it into a model scrap-breaker by using a large steel ball-bearing as a skull cracker. The details are so simple that no explanation other than that given in the drawings should be necessary.

If the wooden parts of the derrick are painted with flat-black paint it will make them look somewhat like iron and more realistic. The magnet is the most important part of the toy and will require the most care in its construction. The round-headed bolt which forms the core should be wrapped with two layers of newspaper, held in place with shellac. A cardboard washer slipped over the core will insulate the wire from the bolt head. If each layer of wire is painted with shellac it will bind the coil tightly together when dry. The ends of the wire, or leads as they are called, should be about twenty inches long. These wires carry current to the coil and must follow the magnet wherever it is moved. In order to make the leads flexible, wrap them around a knitting needle or a pencil. When slipped off they will be in the form of a spiral or coiled spring.



BLINKER SIGNALING

You can send and receive signals in the Morse or Continental Code with a lamp connected to a key. The apparatus illustrated above is arranged so that two stations may be connected together. Connect the line wires to *L* and *LB* and the battery to *LB* and *B*. A quick flash of the light is a dot. A longer flash is a dash. Ships often signal back and forth with blinker lights.

The lifting power of the magnet may be considerably increased by bending a piece of iron into the proper shape so as to make an "iron-clad" electromagnet. This puts both poles of the electromagnet to work.

Messages by Electricity

A beacon fire upon a hill, a mirror flashing in the sunshine, a swift runner dashing by or a rider on a galloping horse once meant urgent news. An important message was on its

way and only the most important matters were worth such trouble.

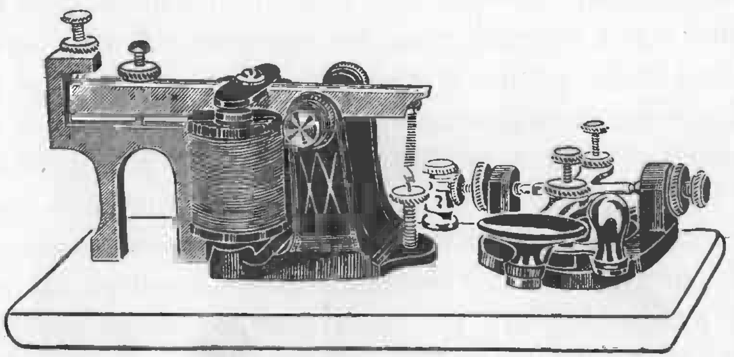
There was a time when the youth of America thrilled at tales of the Pony Express. At the height of its prosperity there were eighty saddle-hardened riders and 800 half-breed racing mustangs in the Pony Express. Men and horses were strung out over the trail which commenced at the Western terminus of the railroad at St. Joseph, Mo., and led to Fort Kearny, Fort Laramie, Salt Lake City, Carson City, Placerville and San Francisco. Every twenty-five miles along this route was a stopping place for changing riders or horses. About twelve pounds of mail (the carrying charge was *five dollars* per letter), wrapped in oil silk, was carried in the pockets of a leather saddle bag called a *mochilla*. At the end of each stage only two minutes were allowed to change horses or throw the mochilla to a fresh rider, ready to mount and dash away. Each rider covered seventy-five miles a day but, by means of relays, the mails travelled about two hundred and fifty. Letters were carried the nineteen hundred miles between St. Joe and Sacramento in eight days. Winter, summer, raining or snowing, over straight roads, crazy trails and mountain crags, by daylight, moonlight, starlight or through the darkness—horses and riders sped on. How different things are now!

You can write a message on a piece of paper, take it or telephone it to a telegraph office and in a few minutes a copy of your communication will be delivered at its destination thousands of miles away.

Signal fires have ceased to burn, mirrors no longer flash messages, express riders are forgotten, all because electricity flowing through a coil of wire makes magnetism. Electricity, speeding instantly and silently over thousands of miles of wires and into the electromagnets at 26,000 telegraph offices in the United States, carries our important messages.

You Can Learn to Telegraph

A generation ago, the lads who liked to tinker with coils and batteries could not amuse themselves with an old ja-



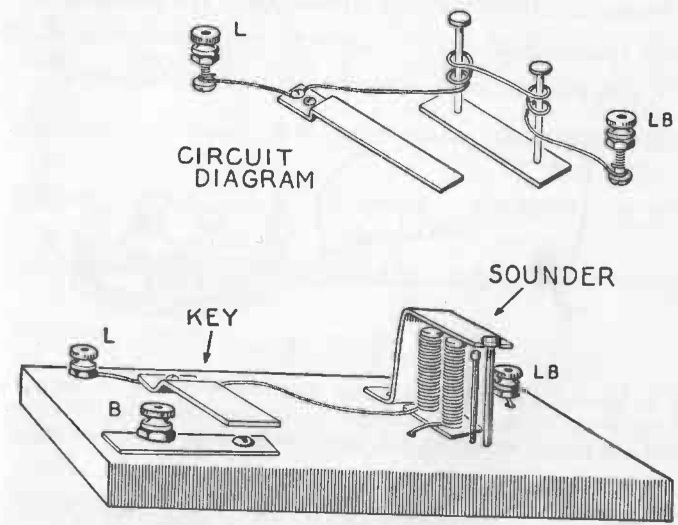
LEARNER'S SET

This instrument consists of a standard telegraph key and sounder mounted on a mahogany base. It is far superior to a homemade instrument for learning to telegraph.

loppy, a model gasoline engine or a radio set. Instead they saved their pennies and bought a telegraph key and sounder. These were usually in the form of a "learner's set" bearing the inspiring name "Eureka" or "Excelsior." The fellows who had no financial worries bought a "main-liner." In any event, as soon as acquired, the key and sounder were set up on a table or workbench, a copy of the Morse code tacked

on the wall and the lads who had real stuff in them soon learned to telegraph.

Before many days had passed, the chances were that there

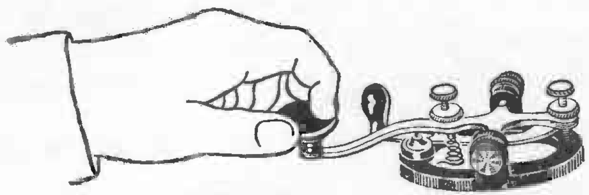


HOMEMADE TELEGRAPH SET

This simple arrangement may be used for practising the code or may be connected to a similar instrument and messages sent back and forth. The line wires should be connected to *L* and *LB* and the battery to *B* and *LB*.

would be great activity in the neighborhood tree tops. A couple of young linemen in their first and best pair of long pants would be busy putting up a telegraph line. Hay bale wire, fence wire, odds and ends carefully spliced and supported on bottle necks for insulators would soon carry messages between two chums living in the same neighborhood. Some of these telegraph lines in the suburbs ran for several miles and included a dozen stations. Many boys developed real skill as telegraph operators and could readily read the messages clicked out by the sounders in the railroad stations.

It requires a first-class mechanic to make a telegraph key and sounder like those used in commercial work but it is not difficult to make toy instruments that will show how easy it is to make electricity carry messages. Two nails and some wire will make two electromagnets and with two electromagnets you can make a simple telegraph instrument.



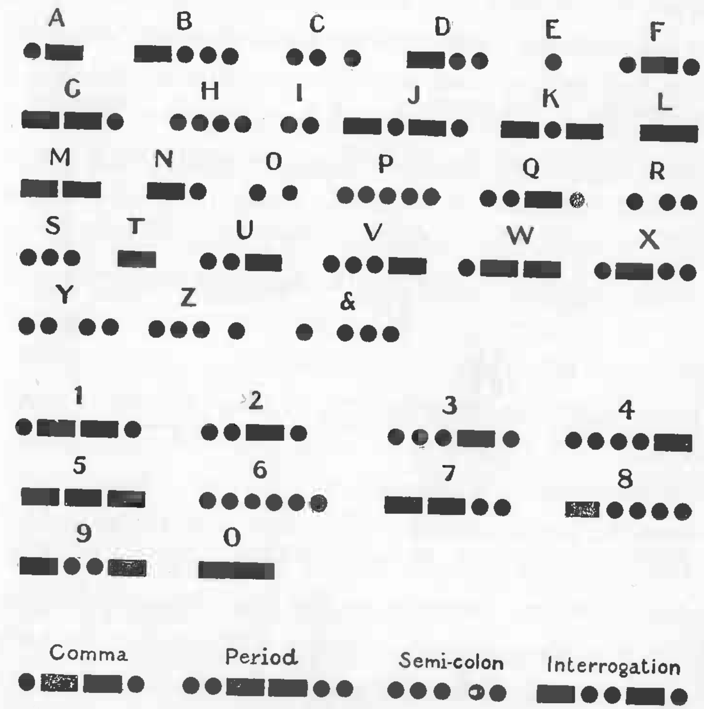
HOW TO HOLD A KEY

In order to become a skillful telegrapher it is first necessary to learn how to hold the key properly. Rest the forefinger on the knob and grasp the under edge of the knob with the thumb and second finger.

A telegraph instrument consists of a key and a sounder. The key is a switch for shutting the current off and on with the finger tips. The sounder is a pair of electromagnets arranged so that every time the current is switched on or off with the key, they move an iron armature and make a "click" sound.

Drive two nails part way into a block of soft pine. Set them about an inch apart. About one inch of each should remain above the base. The nails should pass through a strip of "tin" cut from a tin can. This is really soft iron coated with tin and serves as a yoke to form a horseshoe electromagnet. Wrap each nail with one or two layers of paper and then wind with four layers of magnet wire. Any size ranging from No. 20 B. S. to No. 26 B. S. will be satisfactory. Wind one

coil and then without cutting the wire wind the second but wind it in the *opposite* direction from the first. Connect each of the terminal wires to a binding post mounted on the base.



MORSE CODE

The Morse Code or telegraph alphabet is used in the United States on land lines.

The armature is a piece of banding iron such as is used on packing boxes. A strip of heavy galvanized iron may be used in place of banding iron. One of the illustrations shows how to cut and bend the iron. Fasten the armature to the base with two small screws so that the free end will be directly above the magnets. Drive a nail into the wooden base near one of the magnets so that when you push the armature down with your finger it will strike this nail and not the magnets. Adjust the height of the nail so that the armature comes very close to the magnets but does not quite touch them. Bend the armature so that when you push it down it will spring back up. Then drive a fourth nail into the base near the end of the armature so that the head of the nail will prevent the latter from springing up more than three thirty-seconds of an inch away from the magnets. Adjust the tension or spring of the armature so that when two dry cells are connected to the magnets, they will draw it down with a sharp click and it will move up again as soon as the circuit is broken.

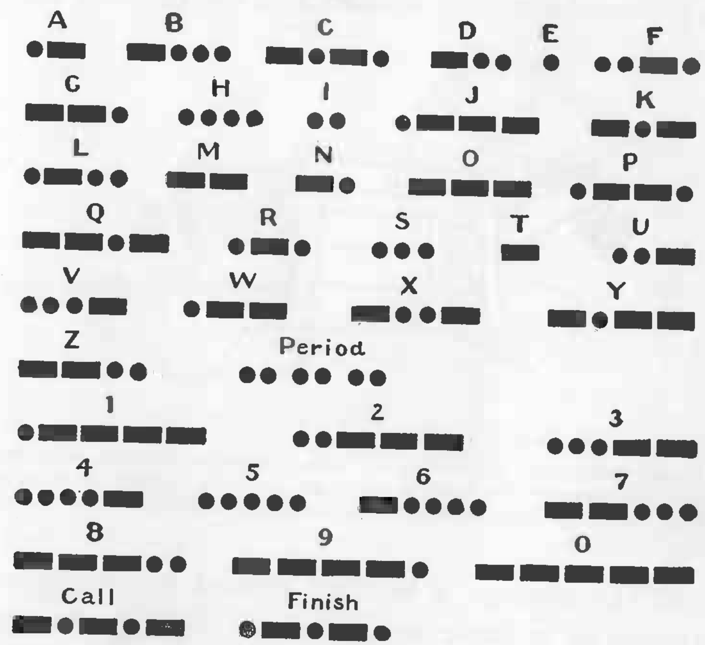
You will need a sending key. A strip of tin, a block of wood and two upholsterers nails are the only materials needed for making a simple key.

When the key is connected in series with the sounder and two dry cells, the sounder should click when you press the key down. When you release the key the sounder should click again as the armature moves up. By timing the interval between the two clicks you can telegraph.

Two clicks coming close together, made by pressing the key down and releasing it as quickly as possible, are a *dot.* Holding the key down and then releasing it so as to make the interval of time between the two clicks of the sounder three times as long as the interval between the dot clicks make a *dash.*

The Morse Code or telegraph alphabet is made up of dots and dashes. Before you can telegraph intelligently or with any degree of speed, you must memorize the Morse Code.

Notice that some of the letters, C, O and R are "space" letters. C is two dots made close together, a slight pause and then a dot. R is the opposite of C. The space comes after the



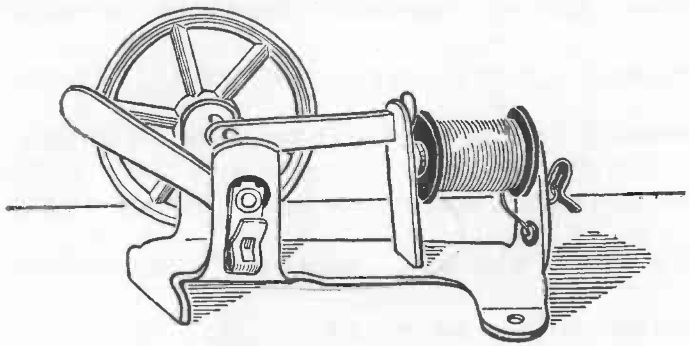
CONTINENTAL OR INTERNATIONAL CODE

This differs from Morse in that there are no space letters. The Continental Code is used in radio work. To learn Continental, connect a key and a buzzer to a battery. A dot is a short "dit" sound while a dash is made by holding the key down for a slightly longer time and producing a "dar" sound.

first dot. O and I are each two dots but there is a space made between the two dots in sending an O.

If you make two sets of instruments you can locate them in different rooms or at opposite ends of the same room and send messages back and forth.

A large proportion of the telegrams handled by the commercial telegraph offices are now sent and received on a machine called the "Simplex Printer." It does not require an operator who can send and receive dots and dashes. Messages are sent by striking lettered keys like those on a type-



AN ELECTROMAGNET TURNS A WHEEL

This toy electric engine, a plaything for boys, is constructed in the same manner as the electric motors of one hundred years ago. An electromagnet moves an armature *back and forth.* The armature is connected to a crank and turns the wheel.

writer. The message is received printed in plain Roman characters on a paper tape. Perhaps, before many more years have passed, the telegraph key and sounder will have entirely disappeared from commercial telegraph offices.

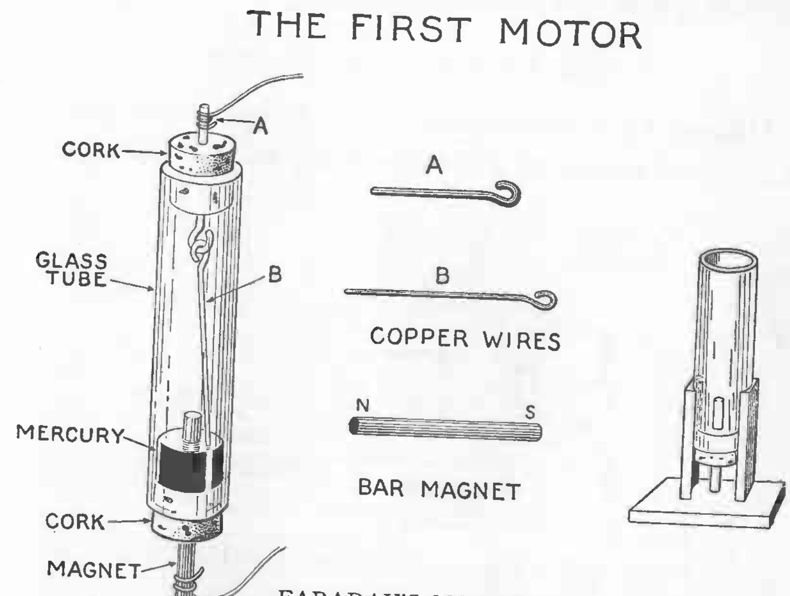
Electromagnets Turn Wheels

Few things are so important to modern life as the electric motor.

Electric motors run practically every mechanical device in use today. They turn the wheels of industry. One of the large manufacturers of electric motors in this country makes more than 20,000 different types, sizes and ratings. That will

give you a good idea of the number of different tasks that motors perform.

Not many years ago, machinery was driven by steam



FARADAY'S MOTOR

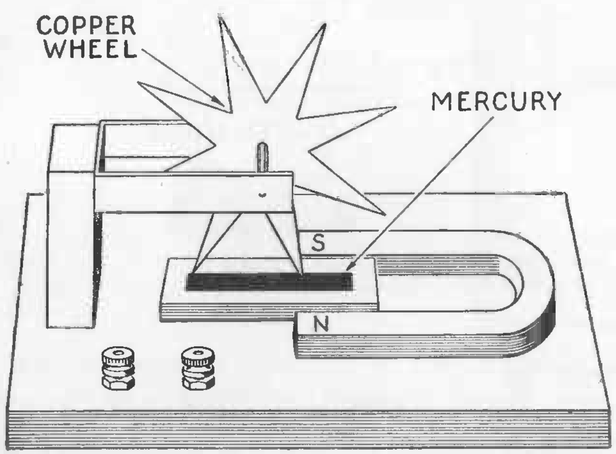
Though exceedingly simple in its construction, this motor, invented by Faraday in 1821, possesses the fundamental principles of the electric motor of today. It consisted of a copper wire suspended so that it could move around the pole of a bar magnet. The magnet was inserted in a cork which closed the bottom of the glass tube. A small quantity of mercury was poured into the tube, leaving the magnet projecting slightly above its surface. The lower end of the movable copper wire dipped into the mercury. When an electric current was passed through the magnet into the mercury and out through the wire, the wire revolved around the magnet.

engines and in some cases by electric motors. But in either case, leather belts conveyed the power to the machine to be driven. Factories were full of dangerous shafting, whirling pulleys and slapping belts which slipped, broke and caused many accidents.

Steam engines have disappeared. Motors are now connected directly to machines by means of gears. Direct-connected motors bring better control over machinery. They increase speeds and production.

The First Electric Motors

Michael Faraday invented the first electric motor in 1821. It consisted merely of a wire revolving around a permanent



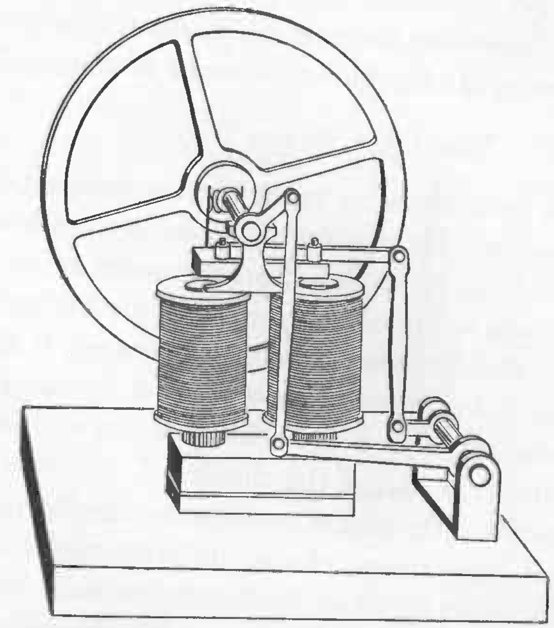
BARLOW'S STAR-WHEEL MOTOR

The next early motor of importance after Faraday found how to make a wire revolve around a magnet was the arrangement shown above. It consisted of a star-shaped copper wheel whose points dipped into a pool of mercury. The trough containing the mercury was placed between the poles of a horseshoe magnet. When a battery was connected to the shaft of the wheel and the mercury, the wheel revolved.

magnet. It was rather a puny thing but it had great value. It showed for the first time that an electric current could be used to produce continuous motion.

The next early electric motor of importance was the

curious Star-Wheel invented by Barlow in 1831. Faraday's Motor and Barlow's Star-Wheel are both illustrated. The drawings have been simplified and are explained in the cap-



ONE OF THE FIRST USEFUL MOTORS

This "electro-motive machine," as it was called, was one of the first motors to be used for supplying power. It was built one hundred years ago by M. Froment, a French instrument maker, and used for driving a small machine he used in making microscopes and astronomical instruments.

tions so that you can make models of these historical devices if you wish.

Faraday and Barlow were followed by a long list of inventors, each of whom tried to improve the curious contraptions which they called "electro-motive machines" and were destined to become electric motors some day. Some of these motors of a hundred years ago looked like steam engines. They were fitted with flywheels and worked on the same principle as the toy electric engines still made for boys to play with.

The first American patentee of an electric motor was a young Vermont blacksmith by the name of Thomas Davenport.

The First Model Railway

Davenport's motors were much like the compact, efficient machines we use. He was the first person to own a model railway. In 1834, he built a working model of an electric railway. It was not intended as a plaything but as the pattern for a full-sized passenger-carrying system. It depended upon batteries for current, but embodied for the first time the fundamental idea of a car driven by an electric motor, using the tracks as part of the circuit.

Davenport's little model, the great-grandfather of our trolley cars, tube trains, electric railways and boys' playthings, was in the Smithsonian Institution until 1900. Then it was loaned to the Paris Exposition. The steamer carrying it across the Atlantic foundered on the way over and the first electric railway is now in Davy Jones' locker.

In looking about for tasks for his motor to perform, other than to propel a railway car, Davenport selected the printing press. He was the first man to apply the new form of power to printing. Today, almost every printing press is motor driven.

But battery current has always been too expensive to use for operating motors for power purposes. Motors were not of much practical use until electricity became cheap. Elec-

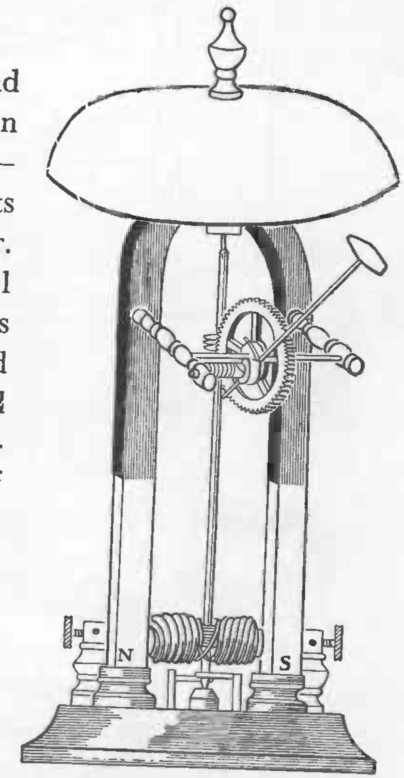
tricity became cheap when dynamos were perfected and power lines were extended through the country.

You Can Make a Motor

With three iron nails and some magnet wire, you can make three electromagnets—and with three electromagnets you can make an electric motor.

The current from a bell transformer or several dry cells will whirl the motor around at a good rate of speed and show how simple it is to produce motion with the aid of electromagnetism. The motor will not develop enough power for any useful purpose.

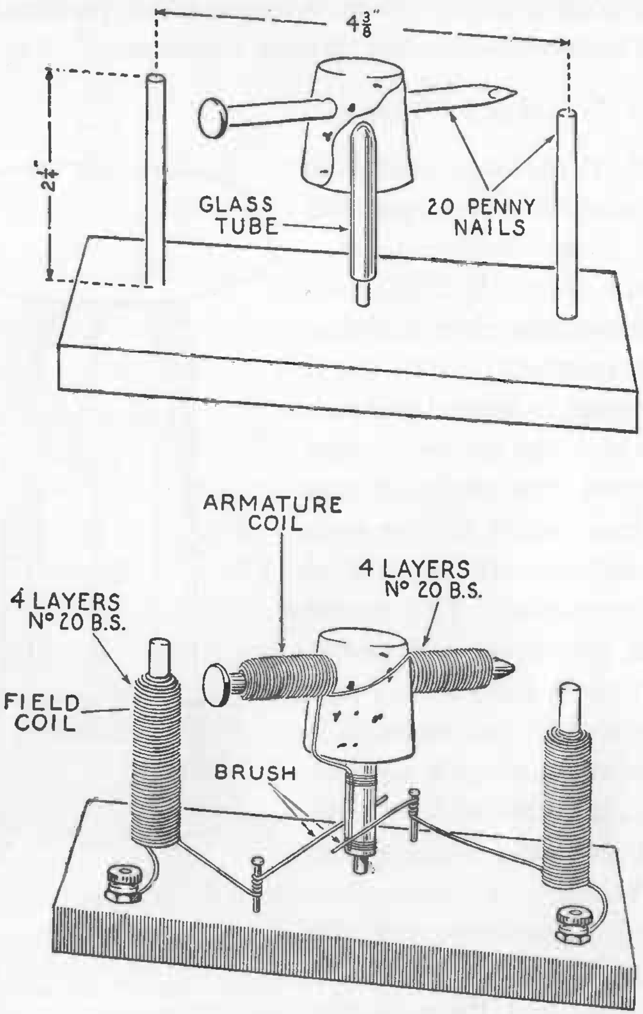
The base of the motor is a block of wood about 6 x 4 x ¾ inches. Any kind of wood will do but soft pine is the easiest to work.



AN EARLY AMERICAN MOTOR

There were few machines which could be driven by a small electric motor a century ago and so Page arranged one of his first motors to ring a bell.

Using a hacksaw, cut the heads off two twenty-penny nails two and three-quarter inches from the point. Drill two small holes into the base on centers four and three-eighth inches apart. Drive the cut nails into these holes until they stand two and one-quarter inches high above the base. These

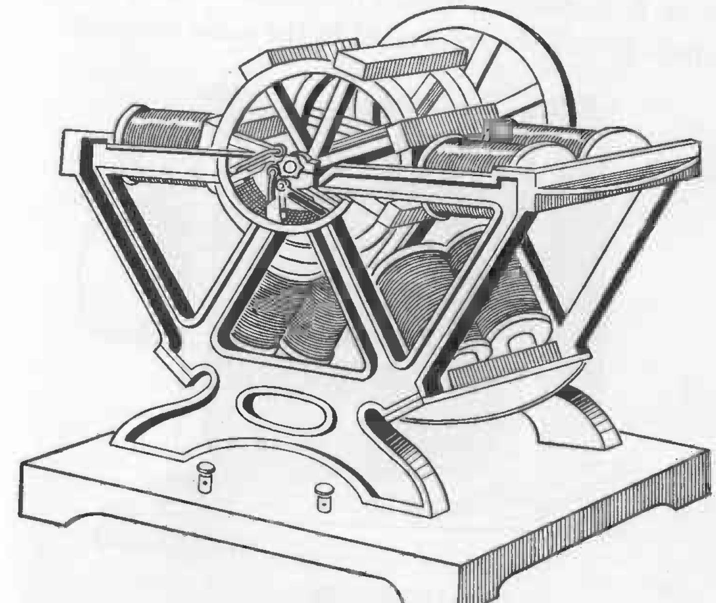


EXPERIMENTAL MOTOR

In the sketch at the top, the cork is shown partly cut away so as to reveal the upper end of the glass tubing which serves as a bearing. Instructions for working glass tubing are given in the last chapter.

nails form the cores of the field magnets. The field magnets supply the magnetic field in which the armature revolves.

The motor armature is a twenty-penny nail pushed into a hole in a large cork. The cork is provided with a bearing



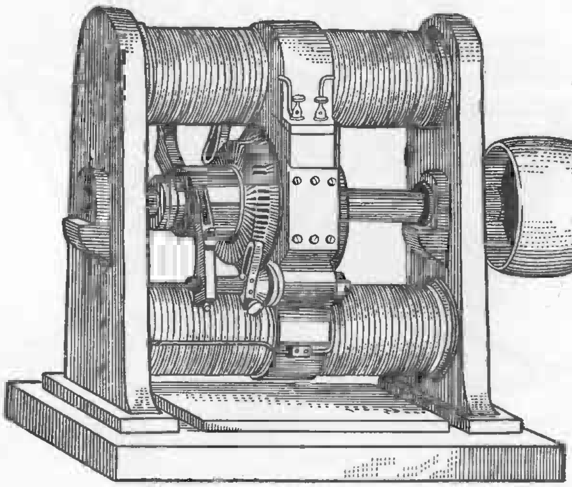
RESEARCH AND EXPERIMENT BRING PROGRESS

This clumsy machine, an early motor built by M. Froment, was considered a marvel one hundred years ago. Research and experiment made it possible to develop this inefficient design into the compact powerful motors of today.

made of glass tubing which has been closed at one end by holding in a flame. The piece of tubing should be about one and three-quarter inches long and one-quarter of an inch in diameter.

A nail, driven through from the underside of the base exactly halfway between the two field cores is the pivot upon which the armature turns. Adjust the glass tubing in the cork until the ends of the armature (nail) are level with the upper ends of the field core (nails).

Each field core is wound with four layers of No. 20 B. S. to No. 24 B. S. magnet wire. The insulation may be cotton or enamel. Both coils are wound in the same direction.



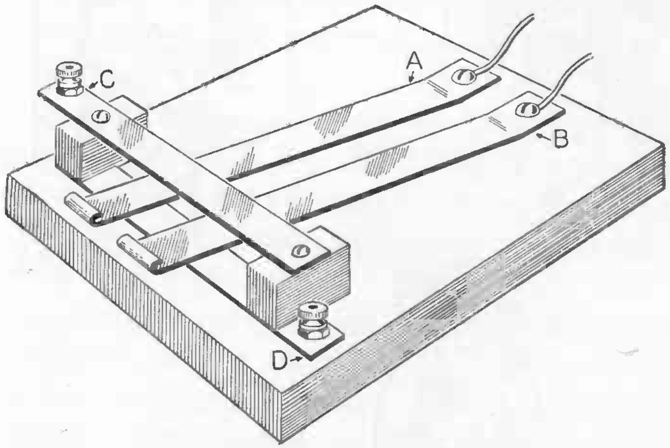
PROGRESS

The motor shown in the preceding illustration had no wire on its armature. The first great improvement in motor design was to make an electromagnet of the armature by winding it with wire, resulting in a machine like that shown above.

The armature is also wound with four layers of wire (of the same size as that used for the field). The armature winding is divided into two sections, one on each side of the cork. Both sections are wound in the same direction. The nail should be wrapped with two or three layers of thin paper before the wire is wound in place.

The terminals of the armature winding are scraped bare

of insulation and fastened to the glass tube so as to form what is known as a commutator. It is by means of the commutator and the brushes bearing against the commutator that electrical connection is established with the revolving



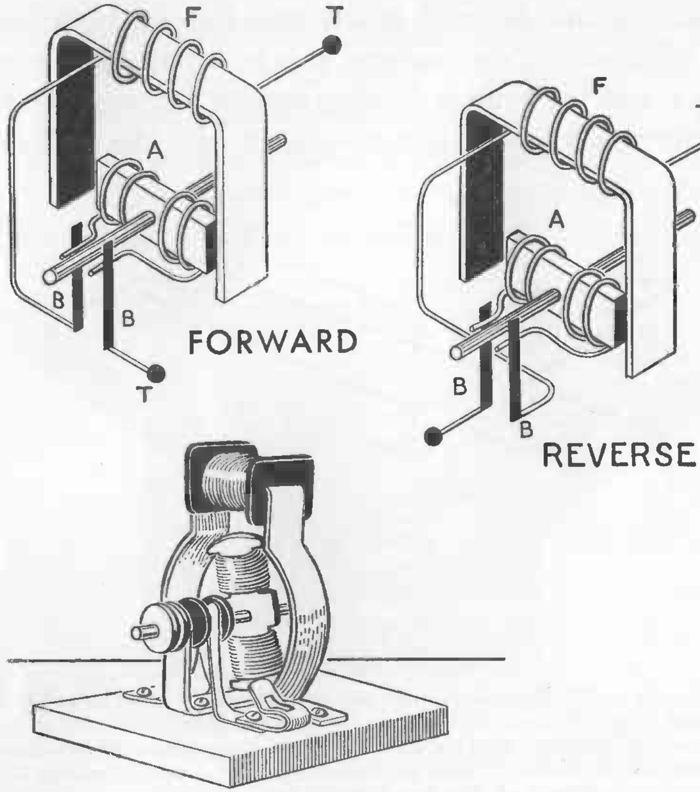
REVERSING SWITCH

You can easily make a reversing switch like this. The strips *A, B, C,* and *D* are sheet metal. *A* and *B* should be bent so as to press against and make contact with *C* when not pressed down with the finger. If *C* and *D* are connected to a battery and *A* and *B* to an electrical device, the current can be reversed by pressing down either *A* or *B* so that it makes contact with *D*.

armature coils. The wires are fastened to the tubing with thread or narrow strips of adhesive tape.

The outside terminals of the field windings should each be connected to a binding post. The inside terminals are scraped bare of insulation and used as brushes. The brushes are fastened in position by wrapping each one around a small nail or brad driven into the wooden base.

Let us see how the motor works and how it must be adjusted. Connect several dry cells to the binding posts. Then



REVERSING A MOTOR

A motor is reversed by changing the connections so that the current flows through either the field or armature coils in the opposite direction. In the sketch above, the black dots marked *T* represent the terminals. *A* is the armature, *B* a brush and *F* the field.

trace the path which the current takes from the battery and through the motor. Start at the positive pole of the battery. The current follows the wire to one of the binding posts. From there it goes into one of the field coils, travels around and around through all the turns of wire and out along the wire forming one of the brushes. If the brush is in the correct

position and you give the armature a twirl with your fingers, the brush should make contact with one of the wires on the commutator just before the ends of the armature reach the field magnets as they swing around. When the armature is exactly opposite the field magnets and about to swing past, the wire on the commutator should break its contact with the brush.

Thus, as the armature whirls around, just before it reaches the field, the current will flow from the brush into the armature winding. If the second brush is also in the proper position, the current will continue through into the second field coil and so back to the battery.

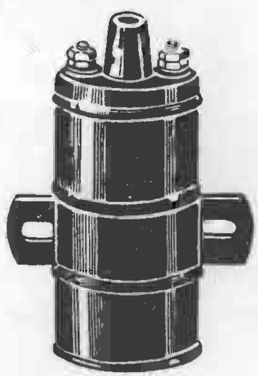
If the armature and field coils are wound and connected as shown in the diagram, one of the field magnets will present a north pole and the other a south pole to the armature. As the armature swings around, the end approaching the north pole of the field will be a south pole. The other end of the armature will be a north pole as it approaches the south pole of the field. Thus, the field will exercise a strong pull upon the armature and cause it to turn. As the armature reaches the field poles, the action of the commutator and brushes shuts off the current and the magnetism ceases. But the weight of the moving armature carries it past the fields and keeps it whirling around until it receives another strong pull. Twice every revolution, the armature is given a pull and so it keeps on whirling around.

So, you see, any bright boy can make a motor. Not a man-size one to be sure, but a toy which runs and shows how the big fellows work—which shows how electricity produces magnetism and magnetism can produce a whirling motion.

VI

FUN WITH A SPARK COIL

UNDER the hood of almost every automobile is a small cylindrical case containing an ignition or spark coil. This is a simple arrangement for increasing the potential or electrical pressure of a six-volt storage battery to the point where it will jump across the spark plugs and explode the mixture of gasoline and air in the engine cylinders.

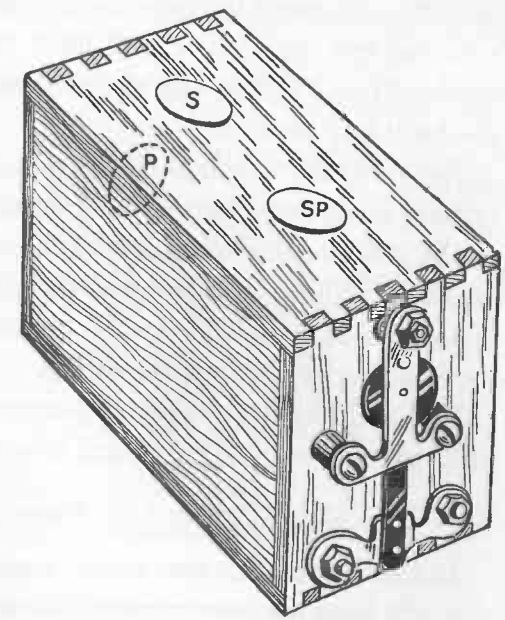


IGNITION COIL

An automobile ignition coil is a special form of the extremely useful electrical device called an induction coil. An induction coil is a simple form of transformer. It consists of two coils of wire wound around an iron core. One coil, called the primary, is formed of a few turns of comparatively coarse wire. The other coil, known as the secondary, contains several thousand turns of fine hair-like wire. Michael Faraday discovered the principle upon which the induction coil operates. A German-French mechanician named Heinrich Ruhmkorf was the first to make a satisfactory spark coil. Tens of millions of spark coils have been manufactured for use as ignition coils for gasoline engines during the past thirty years.

The first spark coils were laboratory devices, used to supply high voltage currents for experimental work. It was

while experimenting with a vacuum tube connected to a Ruhmkorf coil that Wilhelm Roentgen discovered a new form of radiant energy known as Roentgen rays. Because he did not understand the nature of these rays Roentgen called them x-rays—and it is by this name that they are best known.



MODEL "T" SPARK COIL

S and *SP* are secondary terminals. *SP* is also a primary terminal. The other primary terminal is at the back.

For some time after Roentgen's discovery, Ruhmkorf coils were built especially for x-ray work. Coils which would give sparks more than four feet long were developed. After the advent of wireless telegraphy forty years ago, Ruhmkorf coils were used for a time as an important part of the transmitting equipment of wireless telegraph stations.

A SPARK COIL FOR $1.25

There is no piece of electrical apparatus quite as fascinating to the young experimenter as a spark coil. A great many spectacular and interesting demonstrations of electricity's magical activities can be made with the aid of a spark coil.

To build a home-made spark coil requires patience and careful workmanship. But you do not have to make one. You can buy an ignition coil built for a model "T" Ford car for $1.25. This is less than the materials would cost if you built one yourself.

The ordinary automobile ignition coil will not serve because it is not fitted with an interrupter or breaker as a part of the coil itself. The model "T" ignition coil is, however, provided with an interrupter of the vibrator type on one end of the box in which the coil is enclosed and this is exactly what is needed for experimenting.

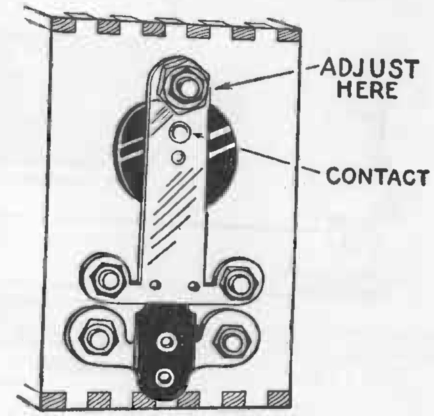
You will understand the importance and purpose of the interrupter when it is explained how the coil operates.

How a Spark Coil Produces Sparks

Inside the wooden box which encloses a model "T" ignition coil is an iron core upon which is wound a coil of heavy wire called the primary. Around the primary and insulated from it is a coil, called the secondary, consisting of many turns of fine wire. When the terminals of the primary coil are connected to a battery, the circuit also includes the interrupter. The instant the iron core is magnetized by the battery current flowing through the primary, the magnetism pulls the armature or spring of the interrupter and separates the contact points. Thus the contact points constitute a switch which shuts off or interrupts the battery current flowing through the primary. When the points are separated and the current is shut off the core loses its magnetism and stops

pulling on the spring. Then the latter can move back again and close the circuit permitting the current to flow once more. This happens very rapidly, several hundred times a minute. You can see, feel and hear the interrupter "buzz" back and forth.

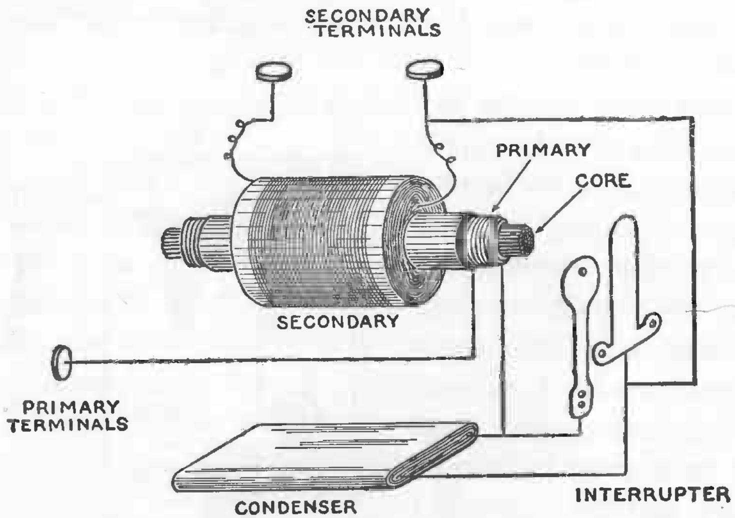
Now let us consider the things happening inside the box. Each time that the core is magnetized by the battery current flowing through the primary, the magnetism also passes through the secondary coil and generates therein a current. When the interrupter shuts off the current in the primary and the magnetism in the coil is extinguished, the collapse of the magnetism which has been passing through the secondary coil, again generates a current in the primary and secondary coils.



THE INTERRUPTER

The interrupter on the end of the coil box is adjustable by turning the brass nut.

Inside the wooden box, in addition to the core and primary and secondary windings, is a device called a condenser. It consists of alternate layers of paper and tinfoil. Its purpose is to store up the electrical energy released when the magnetic field collapses which would otherwise be wasted in the form of sparks at the interrupter contacts. Before the contacts can close again the condenser discharges this energy through the primary winding. This gives the primary an extra "kick" or impulse of current and greatly raises the potential or voltage of the current that is set up in and by



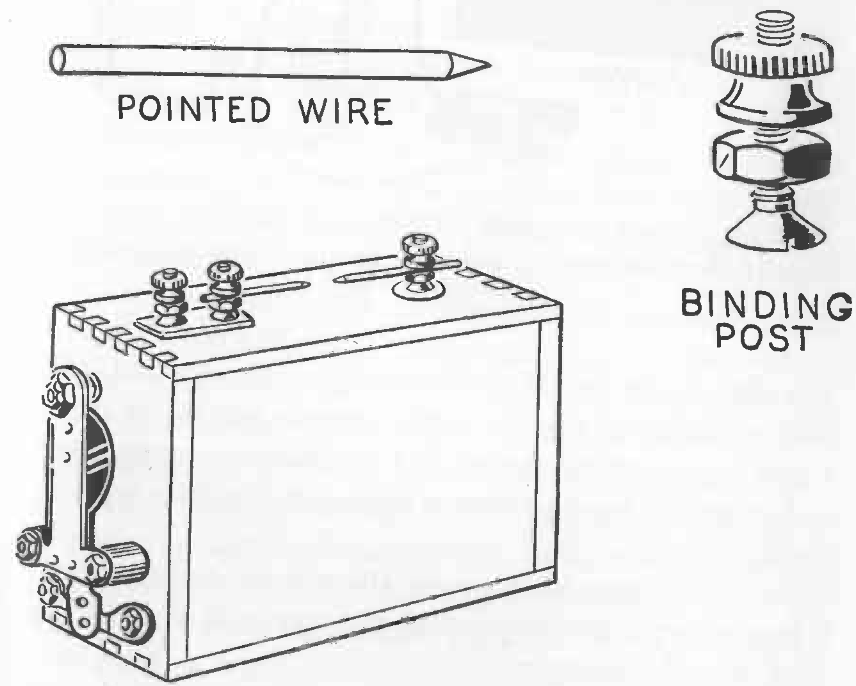
INSIDE THE MODEL "T" SPARK COIL

The condenser, primary, secondary and coil inside the wooden box are connected together as shown in the diagram above.

the secondary coil. None of the battery current passes into the secondary winding. The current in the secondary is produced by the magnetic field created by the battery current flowing through the primary. The secondary current is produced by what is called induction. That is why the coil is called an induction coil. When a model "T" Ford ignition coil is connected to a six-volt battery, the secondary will generate a current having a potential somewhere in the neighborhood of 10,000 volts. This voltage will produce a spark about one-half inch long between needle points.

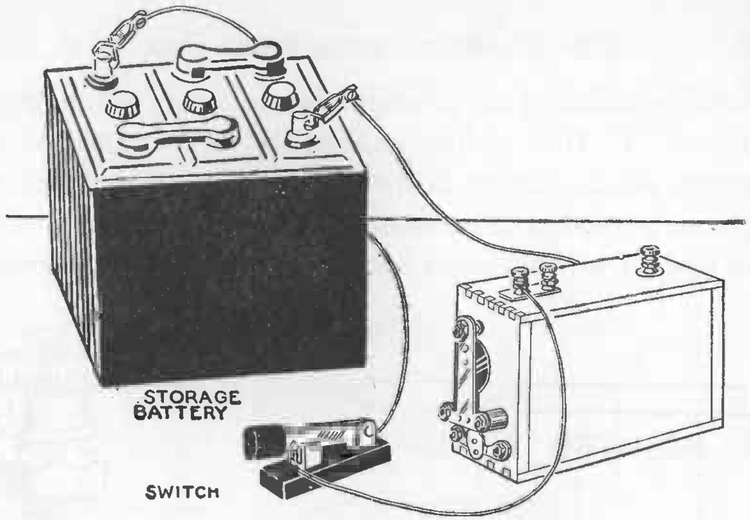
How to Connect the Spark Coil

The terminals of the primary and secondary windings of a model "T" Ford ignition coil are the three brass disks or contacts on the outside of the box. The coil is designed to slip into a wooden case mounted on the dash of a "flivver" and contact with the disks established by means of springs.



FITTING UP THE COIL FOR EXPERIMENT

In order to use a model "T" Ford coil for experimenting, fit it with binding post terminals. These may be conveniently made from a flat-head brass screw, hexagonal nut and a battery thumbnut. Solder the flat-head screws to the terminal disks. Notice that the common primary and secondary terminal is provided with two binding posts. Two pieces of wire, pointed at one end, make a suitable spark gap.



READY FOR EXPERIMENTING

The coil is shown connected to a six-volt storage battery. A switch is included in the primary circuit.

The disk on the end of the box is a primary terminal. The disk on the top of the box at the opposite end to the interrupter is a secondary terminal. One primary terminal and one secondary have a common ending in the disk closest to the interrupter.

In order conveniently to use the coil for experimenting it is necessary to provide binding post terminals so that wires may be easily connected.

A six-volt storage battery is the most satisfactory source of electric current for operating a spark coil but four No. 6 dry cells connected in series will serve well.

Number 16 or No. 18 B. S. gauge wire should be used to connect the primary terminals to the battery. Smaller

wire will offer resistance and cut down the current so that the spark will not be lively. A key or a switch is included in the circuit so that the battery current can be shut off when adjusting the spark gap. Keep your fingers away from the secondary terminals when the current is on unless you want a surprising and uncomfortable shock of electricity.

Experiments with Electric Sparks

Now that we know how a spark coil produces sparks and how to connect it, we are ready to experiment.

The first thing of interest is the spark itself.

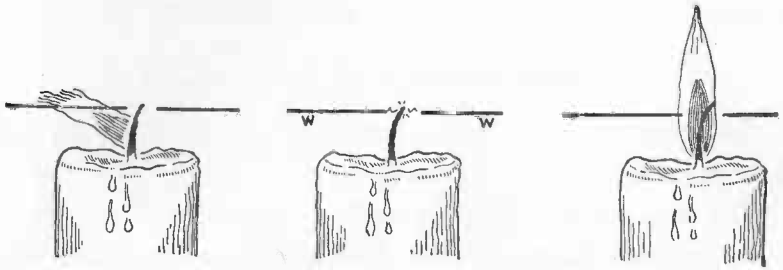
If the spark gap terminals are too far apart, no spark will be produced; but in the dark, there will be a purple brush discharge like that from the electrophorous terminals, especially where there is a point or sharp edge.

Bring the spark gap terminals nearer together and sparks are produced; bluish-white, thin, noisy and seldom straight at first—often in the form of a broken line. Here in fact is a sort of miniature lightning playing before your eyes.

Bringing the terminals still nearer together causes the sparks to become thicker and noisier. At this point, if a piece of paper or thin cardboard is held between the terminals, it will be pierced by the spark. Hold the paper up to the light and you can see the tiny pin holes which were made.

Further shortening of the distance which the sparks must jump causes them to become thicker and less noisy; they become reddish-yellow in color. Finally, with a very short gap about one-eighth of an inch long, the spark discharge is quite thick, makes a hissing noise and appears like a light yellow flame. This type of spark is very hot; it ignites paper instantly. If you hold a strip of paper in the flaming spark, the paper will take fire.

Here are other experiments. Blow out a lighted candle and immediately touch the wick with the spark. The candle will be lighted again.



EXPERIMENTING WITH A SPARK AND A CANDLE

Arrange two wires from the secondary terminals of the spark coil so that there is a short gap between the ends. Blow out a lighted candle and bring the smoldering wick close to the gap while sparks are jumping across. The candle will be ignited again. The principal use for induction coils is igniting the gasoline vapor in automobile engines.

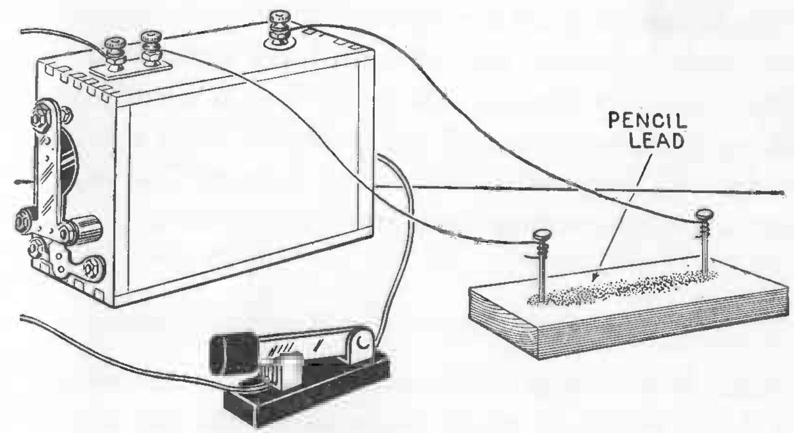
Dip the end of a glass rod in alcohol and touch the spark with it. The alcohol will be ignited.

When the spark gap is short and is formed by two pieces of fine wire (No. 34 or No. 36 B. S. gauge) one of the wires will become very hot and finally melt, forming a little ball of molten metal. It is the positive wire which becomes the hotter. Reversing the wires connecting the coil to the battery will cause the current passing across the spark gap to change its polarity and the other wire will become the hotter.

Copper does not melt until it reaches a temperature of 1,981 degrees Fahrenheit. This will give you an idea of the heating power of the spark.

The color of the electric flame jumping across a short gap between two fine wires depends upon the material of the wires. Copper wires give the spark a greenish hue. Iron wires produce a reddish-yellow and zinc a bluish-white color.

Heated air and the hot gases of a flame conduct electricity better than cool air and this fact can be demonstrated if



EXPERIMENT WITH THE SPARK

The path of the spark may be lengthened by powdered pencil lead. The spark will zigzag among the particles of graphite.

you hold the flame of a candle or lighted match near the spark gap. The sparks will be attracted to the flame and pulled out of their regular path.

The longest spark through air is obtained from a Ruhmkorf coil when the positive side of the spark gap is a needle point and the negative is a small ball or disk. The spark will be jagged and a bluish color.

Another method of greatly lengthening the spark is to dampen or slightly moisten a visiting card and lay it on top of the coil under the spark gap. Bend the wires down so that they touch the card. The surface of the dampened card is a better conductor than dry air and with the correct amount of moisture on the card, the spark can be increased two or three times its normal length. The spark will be thin at first, but it will thicken gradually as the moisture dries.

The path of the spark may also be lengthened by sprinkling some powdered pencil lead on a card and laying it on top of the coil under the gap. The pencil lead is a fairly good conductor of electricity and the spark will select a zig-zag route among the powder in a peculiar manner. This experiment is more interesting if performed in the dark.

The Unseen Wonder of an Electric Spark

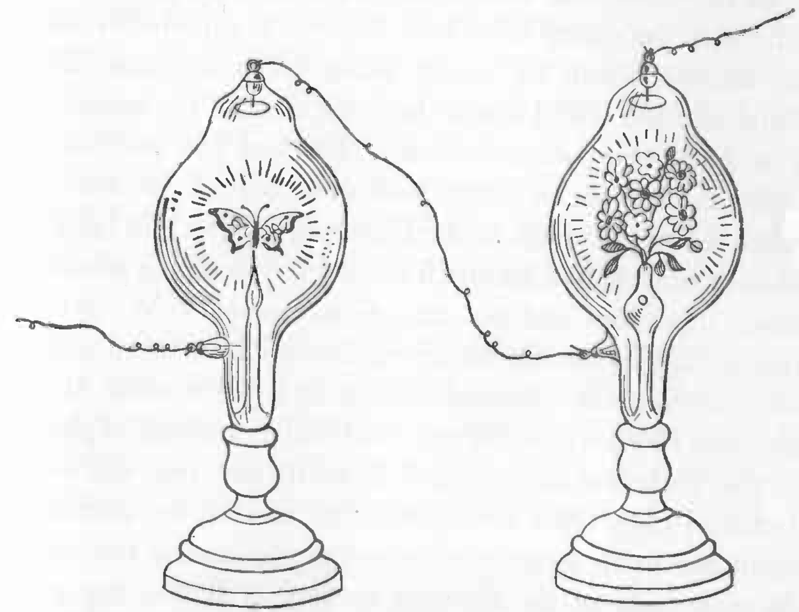
Many of the things which electricity does are invisible.

When a stream of sparks jumps across the gap in your coil, you see and hear the sparks but you do not see the invisible commotion or disturbance which is set up for a considerable distance in the neighboring space. When an electric spark occurs, portions of the electrical energy which create the spark are thrown off into space. This energy moves away from the spark in widening circles like the little ripples on the surface of a pond where a stone has been thrown.

If there is a radio receiving set in another part of your home and it is in operation when you are experimenting with a spark coil, it is likely that the disturbance created by the sparks can be distinctly heard in the radio, even though it is some distance away. The unseen "commotion" set up

by the spark passes through walls and ceilings and reaches and disturbs the radio.

The famous Thomas A. Edison was the first experimenter to notice that electric sparks apparently produced some sort



FLUORESCENCE

These vacuum tubes contain artificial flowers, shells, butterflies and other objects coated with fluorescent chemicals. When the high-voltage currents from the secondary of the spark coil pass through the tube, the electrons strike the sensitive chemicals and cause the objects to glow with beautiful colors.

of disturbance in space. Unfortunately the real nature of this discovery—that the "commotion" might be electric waves—did not occur to his inventive mind and he could find no practical application for it. Edison, who as a lad had almost never been to school but taught himself by research and experiment, missed adding another glorious scientific achievement to his long list.

The answer to the mystery came from another part of the world.

In 1857 there was born in the city of Hamburg, Germany, a healthy, red-faced baby boy. There was apparently nothing unusual about the event. Many other German babies came into the world about the same time in the same city. This particular infant bawled and kicked and gurgled exactly like billions of others had done before. He was just another boy who went to the Hamburg schools and behaved like the rest. And so Heinrich Hertz grew to young manhood much unnoticed and not out of the ordinary. We are interested in him because his determination, keen mind, energy and perseverance unlocked a scientific treasure chest. It was not until Hertz was thirty years old and a professor of physics at the Technical High School at Karlsruhe, that the world heard of him. On a memorable day in 1887 an announcement was made which thrilled every physicist in the world. At a meeting of the Physical Society in Berlin, the great scientist von Helmholtz announced that young Hertz, a former pupil of his, had succeeded in producing *electric waves* which much resembled the ordinary waves called *light*.

The Hertz electric waves possessed many of the same properties as light. They travelled at the same speed, were capable of being reflected, etc.

It was Faraday who first suspected that there is something in common between electricity and other forms of energy—that light is identified with electrical energy.

Radio Developed from a Spark

From Hertz's discovery of a method for producing electrical waves came wireless telegraphy and from wireless telegraphy radio developed. Many men had a part in developing and perfecting radio but its wonders are fundamentally a direct consequence of the experiments of the thirty-one-year-old professor of physics at Karlsruhe.

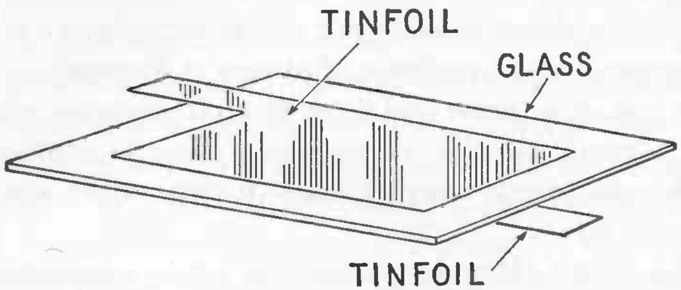
As you sit at home and listen to a play-by-play account of a football game or an orchestra program coming via radio, your entertainment is borne to you on the wings of Hertzian waves.

The electric (Hertzian) waves sent out by a broadcasting station are generated by vacuum tubes connected to coils and condensers. The first transmitters for sending wireless telegraph messages were spark coils. Later coils and condensers were added to the circuit to increase its efficiency.

Storing Up Sparks

Condensers are a valuable electrical device which are an essential part of radio and telephone circuits, high tension magnetos, automobile ignition systems, etc. A condenser stores an electric charge. Condensers are usually made of sheets of metal or metal foil separated by a layer of paper, mica, air, oil, glass or some other insulating material. When a condenser is charged, the insulating material is put under a strain or stress just like a steel spring which is compressed. When the strain is released, it produces an electrical charge on the conducting surfaces of the condenser. The charge may be sufficiently great to produce sparks. Leyden jars are one form of condenser. When a condenser is connected across a spark gap, it makes a very noticeable change in the nature and appearance of the sparks.

A piece of window glass three inches wide and four inches long with a sheet of tinfoil two by three inches cemented



A CONDENSER

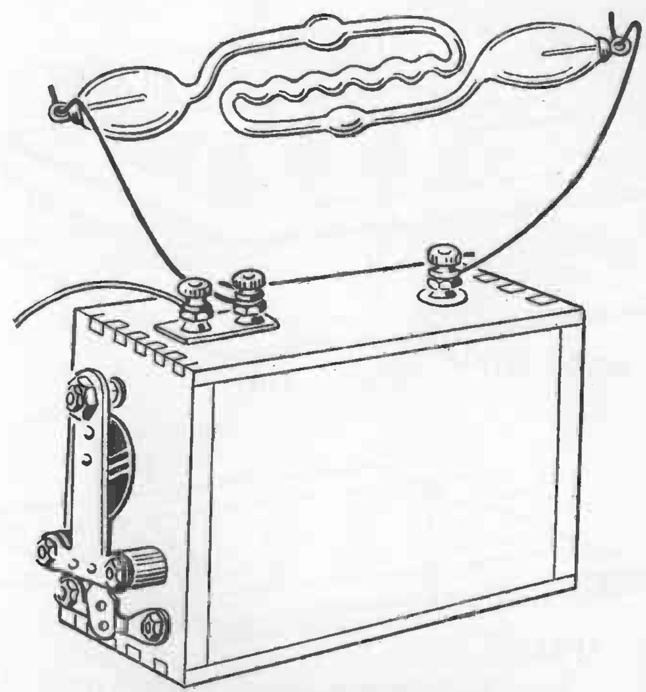
A condenser built of glass and tinfoil connected to the secondary of the coil changes the nature of the spark. It is a form of Leyden Jar and produces oscillatory currents.

to each side of the glass with shellac is a suitable condenser for a model "T" Ford spark coil. The tinfoil sheets should be in the center of the glass so as to leave a one-half inch margin around the edges.

When the condenser is connected to the spark gap (one sheet of tinfoil to each side of the gap) the sparks from the coil will be considerably shortened. It will be necessary to make the gap quite short before they will jump.

The condenser stores up the energy of the high voltage currents in the secondary until enough pressure has been built to force a spark across the gap. Then a noisy, snapping white spark jumps across. The snapping sound and the white appearance of a condenser spark are very distinctive. Each

spark actually seen by the eye consists of a number of excessively rapid surgings or series of sparks in reverse directions and is known as an oscillatory spark. The surgings of



LIGHTING A GEISSLER TUBE

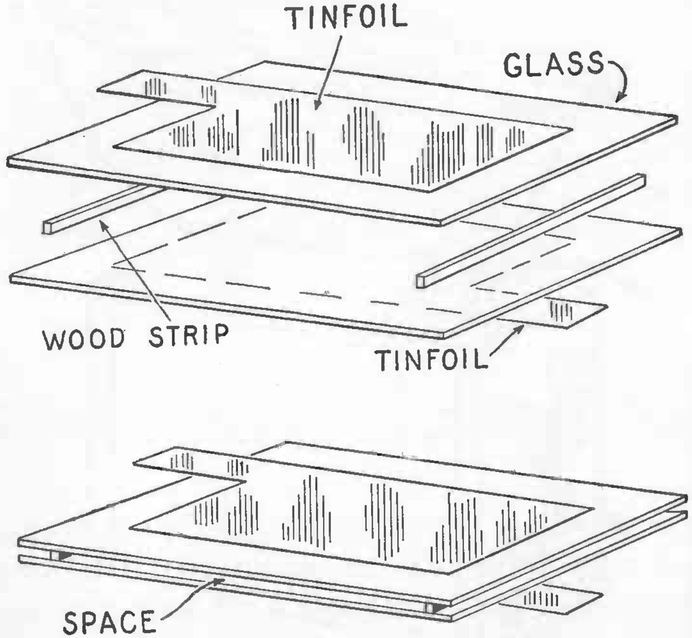
The tubes are connected to the spark coil by wires hooked into the small brass terminal rings on the ends of the tubes.

the current in the condenser, connecting wires and gap are called oscillations or oscillatory currents.

It is the oscillatory currents that generate electric waves, making radio telephony, television, etc., possible.

WHAT IS THAT ODOR?

Before you have experimented long with a spark coil you will probably notice a strange odor. About 150 years ago,

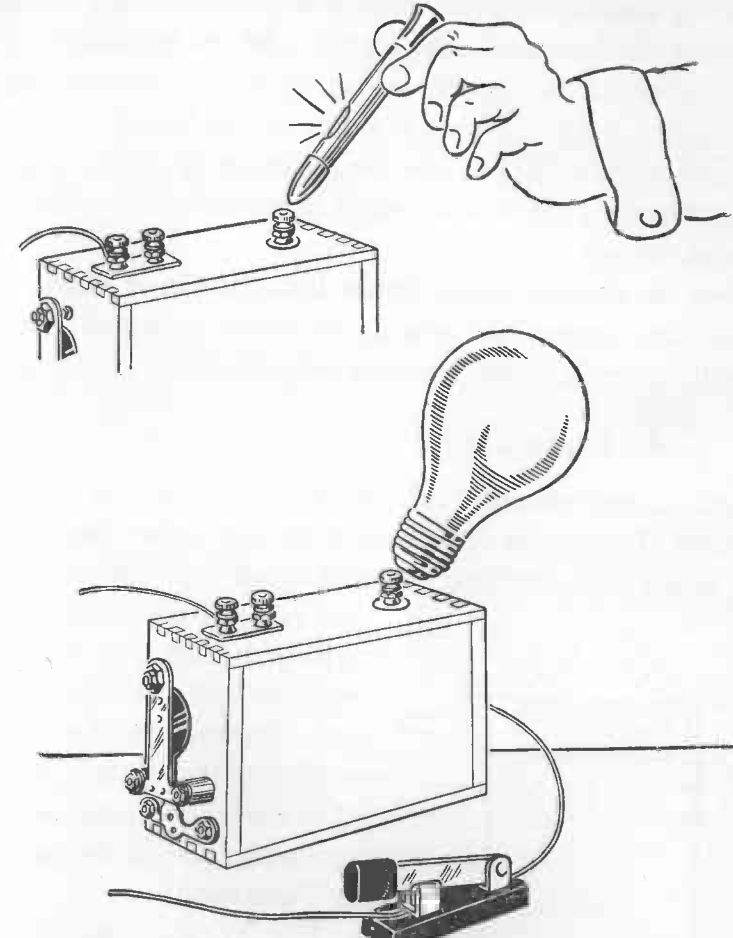


AN EXPERIMENTAL OZONE GENERATOR

The tinfoil sheets are separated by two panes of glass with a small air space between. When the generator is connected to a spark coil, ozone is produced in the space between the glass panes.

a scientist named Van Marum first observed the same thing —a fresh, penetrating odor, resembling that of very dilute chlorine—as being perceptible when operating an electrical machine.

Many years later (1840) another scientist, a chemist



ELECTRONS IN A VACUUM

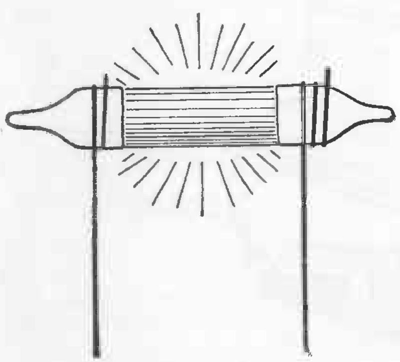
The neon tube in a sparkplug tester will light brilliantly when in contact with the secondary terminal of the spark coil. A 15-watt, 25-watt or 40-watt Mazda lamp held in the fingers will glow with a strange purple light when the metal base is touched to the secondary terminals. There is a vacuum in the glass envelope of 15-watt, 25-watt and 40-watt lamps. Larger lamps will not glow in this manner because their glass envelope contains a gas and not a vacuum.

named Christian Frederick Schönbein, Professor at Basel University, Switzerland, showed the odor to be a distinct substance which he named *ozone,* after the Greek word meaning "to smell."[1] Ozone is a sort of condensed or concentrated oxygen. There are two atoms in a molecule of ordinary oxygen but in a molecule of ozone there are three atoms of oxygen.

When an electric spark passes through air, it changes oxygen into ozone. The amount of ozone produced haphazardly by sparks from a coil is very small.

An Experimental Ozone Generator

Much larger amounts can be produced with an ozone generator. Two pieces of window glass four inches long and three inches wide, and two pieces of tinfoil three inches long and two inches wide are the principal parts of a simple experimental ozone generator. Instructions for assembling the tinfoil and glass are given in the caption under one of the nearby illustrations.



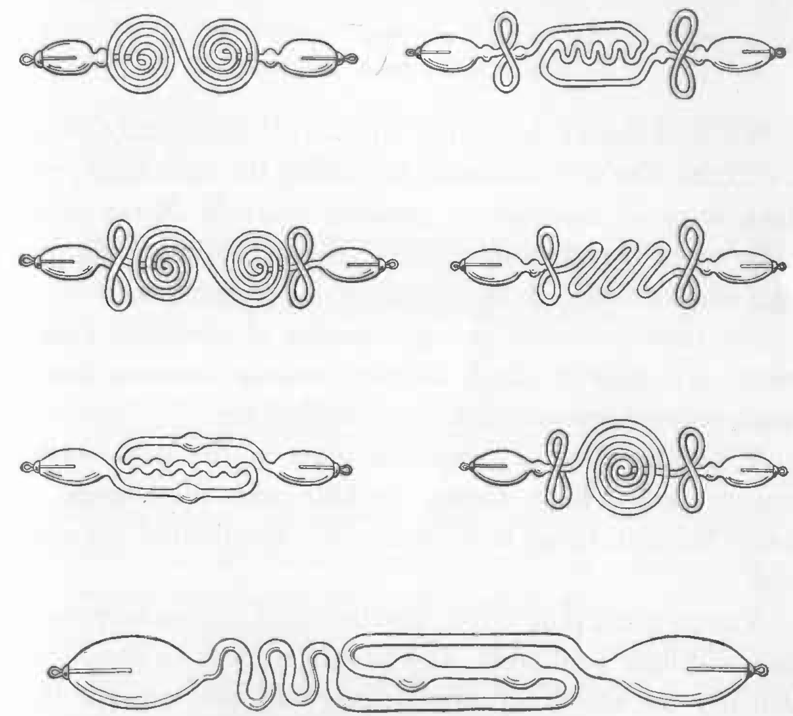
NEON TUBE

You can secure a neon tube by prying off the end of a spark-plug tester. Attach a fine wire to the metallized ends. When connected to the secondary of the coil, the tube will light brilliantly.

The arrangement is quite similar to the condenser which has already been described. Instead of two sheets of tinfoil separated by a glass plate as

[1]Schönbein also discovered guncotton and collodion.

in the condenser, the ozone generator consists of two sheets of tinfoil separated by two glass plates with an air space between.



GEISSLER TUBES

They are made in almost endless shapes and sizes.

If you connect a wire from each of the tinfoil sheets to the secondary terminals of the coil, you will notice a strong odor of ozone as soon as the coil has been in operation a few seconds. If in a dark room, you can see a brilliant voilet colored electrical discharge in the space between the plates.

Ozone is produced commercially in this manner by using powerful high voltage transformers instead of a spark coil. Dry, cold oxygen is forced between large plates. Ozone is used commercially in bleaching oils and purifying starch.

Electrons in a Vacuum

When an electric current of suitable voltage is sent through a vacuum, the tiny electrons, streaming through space, produce some of electricity's greatest marvels. X-ray tubes, radio tubes, the tubes used in television, even the lowly neon sign employ electrons in a vacuum or rarefied gas.

The most beautiful and spectacular of electrical experiments are those in which the high voltage currents from a spark coil are passed through a rarefied gas.

A 60-watt Mazda lamp will glow in the dark with a strange purple light. Grasp the bulb with the fingers and touch the metal base to the secondary terminal of the spark coil.

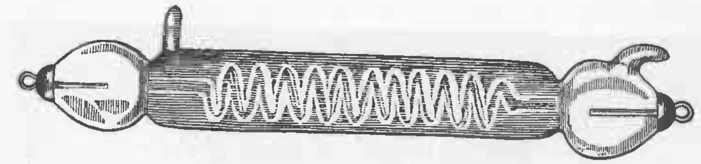
A neon spark plug tester, touched to the secondary terminal, will light brilliantly. The best effect will be obtained if you pry the metal cap off the case and take out the little neon tube. The ends of the tube are metallized to form contact terminals. Wrap a short piece of fine wire around each end and connect to the spark coil secondary.

When the coil is operated, the tube will glow brilliantly. In this arrangement you have a miniature Geissler tube, the device from which the neon lights used for signs were developed.

Wonderful color effects are obtained from Geissler tubes. They contain various gases in a rarefied state and are made

in an almost endless variety of forms. Some Geissler tubes are ordinary glass while others are made of glass containing certain metallic oxides. Beautiful luminous colors are also secured by making tubes with an outside jacket filled with a fluorescent liquid.

Geissler tubes are made in Germany. They are more easily obtained in Europe than America. The next time friends or



GEISSLER TUBE WITH LIQUID

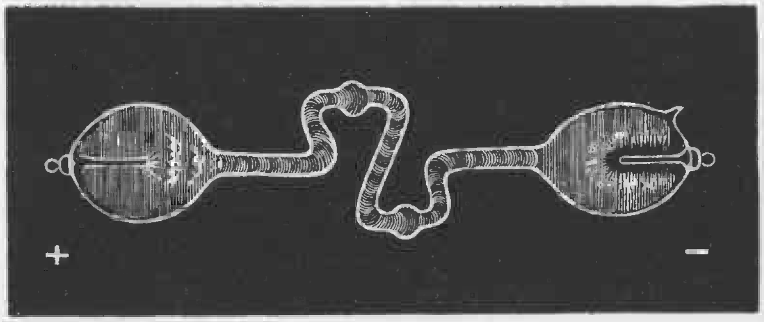
The glass jacket around the tube is filled with a fluorescing chemical solution which glows brilliantly when the tube is operated.

relatives go abroad, ask them to bring you back a few Geissler tubes. They are inexpensive. Some firms that deal in laboratory supplies in this country carry them in stock.

The tubes are lighted by connecting a fine wire from each of the small rings at the ends of the tubes to the secondary terminals of the spark coil. Four or five medium sized tubes may be connected in series and lighted simultaneously from one coil. In some parts of the tubes, the soft radiant colored light is stratified or broken up into separate parts. The colors depend upon the nature of the rarefied gas inside and the minerals in the glass of which the tubes are made.

The Aurora Borealis, or Northern Lights, whose beautiful glowing draperies are seen at night in the skies of northern latitudes, may be due to electrical charges in the rarefied gas of the upper atmosphere and akin to the phenomena which you can produce on a smaller scale with a Geissler tube and a Ford spark coil.

The light produced by a Geissler tube connected to a spark coil is intermittent. It flickers rapidly—there is actually a short flash of light each time that the interrupter breaks the circuit. The impression of the light remains upon the retina of the eye for a time after each flash.



ELECTRICAL DISCHARGE IN A GEISSLER TUBE

If you are a good observer you will notice that the terminal of the tube attached to the negative (cathode) of the spark coil glows with a beautiful violet light while at the positive or anode there is only a single bright star of light. If the interrupter of the coil is adjusted so as to vibrate slowly and the vacuum in the tube is just right, the glow in the tube breaks up into patches called striæ.

If you spread your fingers and wave your hand from side to side in front of a lighted Geissler tube, your hand will appear to have ten or twelve fingers instead of five. This experiment must be performed in a dark room. A pencil waved back and forth in front of the tube will appear like several pencils.

Here is the explanation. During the interval of time between flashes the moving object cannot be seen in the dark,

but each time the light flashes on, the object is seen in a new position.

The image of the pencil or fingers remains in the eye long enough so that there are several blurred images retained at the same time.

Many minerals and chemical solutions fluoresce in the light of a Geissler tube. Fluorescence is the mysterious power by which some substances, when illuminated, give off light of a different color from that with which they are illuminated. For example, a solution of sulphate of quinine illuminated with the light from a Geissler tube will give forth a strange bluish light. Kerosene and most mineral lubricating oils fluoresce. Amber colored motor oil poured in a test tube will appear green.

Dissolve some sulphate of quinine in water and draw a design or print a word (using a new pen) on a piece of white paper. Allow it to dry. The design or word will be invisible in ordinary light but when illuminated with the light from a Geissler tube, the design or printing will be visible and appear as if written with a beautiful blue ink.

VII

ELECTROCHEMISTRY, THE PARTNERSHIP OF ELECTRICITY AND CHEMISTRY

IT COULD hardly be expected that the curiosity which led scientists to search out the elements would stop there. The quest for knowledge would bring the elements themselves under constant examination. What are they? Why are they? Where did they come from? Why cannot one element be turned into another? These and many other questions would be constantly asked.

For many years such questions were unanswerable. Then Science found that matter is of an electrical nature. The different elements are different arrangements of electrical charges. At least, that is the opinion Science now has. If true, one atom could be changed into another. Since Science does actually change one element into another, since the electrical charges of the elements can be measured and since with the aid of mathematics it is possible to make predictions regarding them, perhaps Science is not far wrong in its conception of the electrical nature of things.

Our world might be called a world of disguise. We cannot tell what anything is actually made of by looking at it. That is a job for the chemist. Chemists have found out how to take substances apart, find out what they are made of, and in most cases put them together again.

If you set before a chemist a piece of the silvery, waxlike metal called sodium, a pinch of salt and some of the greenish-colored gas called chlorine, he will tell you that you are showing him only two distinct kinds of matter. Although you can apparently see three, the chemist is correct. *He can make salt* from the matter furnished by the metal sodium and the gas chlorine. Sodium and chlorine are elements. Salt is a substance. By careful and patient searching, chemists have discovered and isolated ninety-two elements. The tens of thousands of different substances in the universe are but different combinations of the elements.

The chemist does in a few moments many things which, to the best of our belief, Nature has required long ages to perform. In this work, one of the chemist's most indispensable tools is electricity. Many large industries have grown from the union of chemistry and electricity. More than $350,000,000 worth of chemical products are manufactured every year with the aid of an electric current.

PIONEERS

It is always interesting to know about the beginning of things. So in order to know about the beginning of the science of electrochemistry we turn time back for a moment to the beginning of the nineteenth century and look in upon a small laboratory at the Royal Institution, London. We find at work a famous English scientist, Sir Humphrey Davy. A few years before, he was the eighteen-year-old apothecary's apprentice mentioned in Chapter IV.

He has just made an astonishing discovery. He has connected two sticks of charcoal to a powerful battery of Voltaic cells and brought them into contact for a moment. When the sticks are drawn apart, a blinding electric flame fills the room with a dazzling blue-white light.

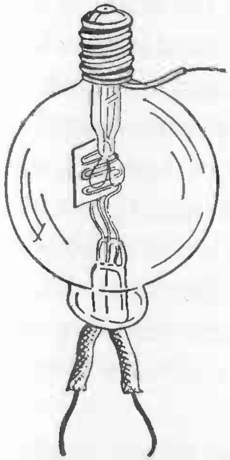
Thus, in the year 1800, the first electric light was discovered. Because the amazing electric flame always takes the form of a curve, it became known as the electric *arc*. Many people remember when "arcs" were used for street lighting. They gave many times as much light as a gas burner or oil lamp. In the large cities each street arc lamp was rated as equal to three policemen in adding to the safety of property and citizens. The silent and steady incandescent lamp has now replaced the noisy and sputtering arc for illuminating purposes. Today the arc is known to most people only as a form of therapeutic lamp used to generate ultra violet rays as a substitute for those of the sun.

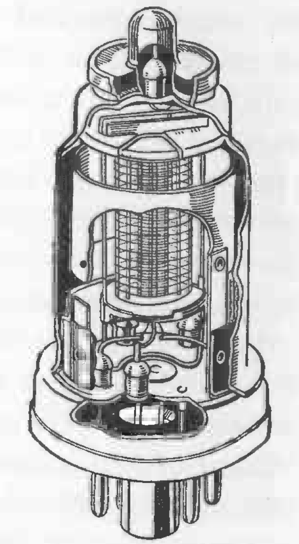
Although it is no longer used for lighting purposes, Sir Humphrey Davy's arc is one of the most powerful tools that the modern chemist possesses. The chemist's control over many of the materials of nature requires seething temperatures. In the flame of the electric arc is the intense heat of a miniature sun, and therewith the sun's alchemy can be duplicated in the laboratory.

Temperatures of 7,000 to 14,000 degrees Fahrenheit can be generated with an electric arc. Such terrific heat will tear minerals apart and put them together again in new forms. It is thus many of our most useful substances have been created.

Some of the best lubricants consist largely of graphite made in the electric furnace. The diamond is the hardest substance found in nature, but chemists make an inexpensive

and satisfactory substitute in the form of the modern artificial abrasives or grinding materials known under the trade names of Carborundum, Alundum, Aloxite and Crystolon, produced by the intense heat of the electric current.





Modern radio is the result of research. At the left is shown the interesting, cranky and undependable little vacuum tube called an audion, which Doctor Lee DeForest devised for receiving radio signals. At the right is shown a modern metal radiotron, "a grandchild" of the original audion. The researches of countless chemists, electrical engineers, metallurgists, physicists not only produced a better tube but perfected other uses for the descendants of the audion.

The glistening stainless steels and the modern engineering steels of enormous strength can only be made in quantities with the aid of the electric furnace.

But generating high temperatures with the arc is not the only method of using electricity in a chemical factory. An electric current passing through a solution[1] will break up or change many chemical substances. Long rows of tanks called "cells," containing solutions through which thousands of amperes of current pass, are the principal machinery of many chemical plants. It is by such means that the copper[2] for electric wires and the nickel for plating the handlebars of your bicycle are refined. The precious metals, silver and gold, are secured in refined form largely as the result of the electrical refining of copper. The aluminum used in pots and pans, those unique metals which float on water known as potassium,[3] sodium, rubidium and caesium, the raw materials for the manufacture of antiknock gasoline compounds, can be produced commercially only by electrochemical processes.

When Volta found that electricity could be obtained with the aid of chemicals it was quite natural for some one to wonder what would take place if the process were reversed. What could be accomplished by sending a current of electricity through chemicals?

Two pioneering English scientists, Sir Anthony Carlisle and William Nicholson, were the first electrochemists. In May, 1800, they sent an electric current through water containing a small amount of sulphuric acid and were astonished to find that the water was separated into two gases—hydrogen and oxygen. These men were the first to discover that

[1]A solution is a liquid formed by dissolving a substance in a solvent (a fluid capable of dissolving substances), as salt dissolved in water.

[2]A German chemist named Ritter observed in September, 1800, that copper sulphate could be separated into copper and sulphuric acid with an electric current.

[3]Potassium and sodium were discovered by Davy with the aid of an electric current in 1807.

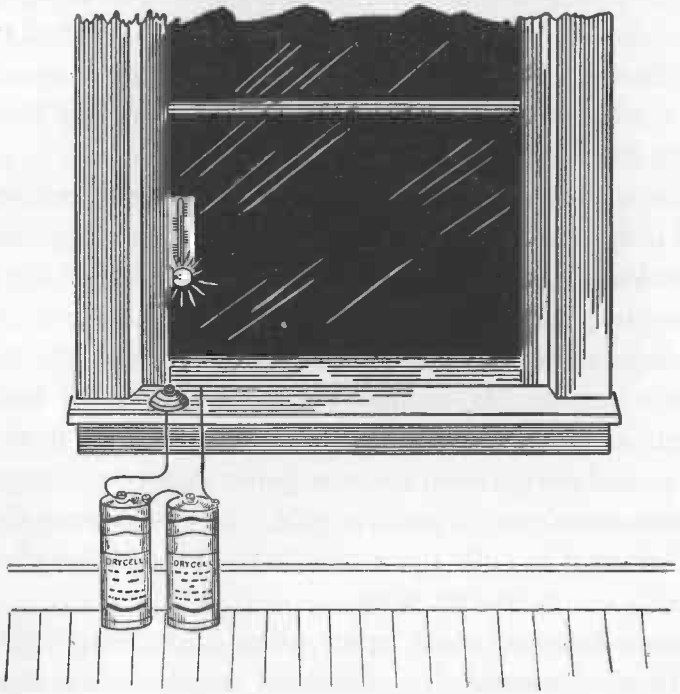
a current of electricity could be used to separate chemicals.

The fact that water could be broken up into two gases was an amazing bit of scientific news in the year 1800. When it reached a young medical student named Johan Berzelius at the University of Upsala in Sweden he determined to try the effects of electricity upon other chemical solutions. He saw the immense possibilities which electricity had brought to the chemist.

The electric current, thought Berzelius, could perhaps be used to split or break substances which heretofore could not be broken down. Young Berzelius went to work at the idea. Before long he published an account of his experiments in dividing or splitting chemical compounds with the aid of Volta's battery. He explained that he had found that the metals in a solution through which a current of electricity was passed always went to the negative pole of a battery and the non-metals to the positive pole. The vast science of electrochemistry is built upon this fact—disclosed for the first time by a very young man.

Later Berzelius made many other important discoveries in chemical science. He discovered selenium, thorium and cerium. He was the first to exhibit calcium, barium, strontium, columbium, tantalum, silicon and zirconium as elements. The name Johan Berzelius shines in chemical science. The whole interesting story of his life and his experiments properly belongs to a book on chemistry, and so is omitted from these pages. However, every young experimenter is advised to find a book at a public library which recounts the romantic and inspiring story of the Swedish farm boy who became one of the world's greatest chemists a hundred years ago.

Today many a skillful chemist at work in a well-equipped laboratory where almost every modern appliance of science is at his disposal, would shrink from undertaking some of the



THERMOMETER LIGHT

Two dry cells, a push button, a socket and a 2.8v bulb make a handy light for reading an outdoor thermometer at night.

chemical problems which Berzelius solved in a bare room with only homemade apparatus and chemicals.

An electric arc is not a plaything for a boy. The current and voltage required to operate an arc, the high temperatures generated, and the harmful rays emitted make it unsafe for boys. But this does not mean that the young experi-

menter cannot experiment with electrochemistry. Some of the magical processes of electrochemistry may be experimented with in your own kitchen or cellar. You will not need an arc. You will need a source of direct current. This can be supplied by several dry cells or a storage battery. Alternating current cannot be used. Toy transformers are useless because they deliver alternating current.

An Experiment Which Changes Water into Hydrogen and Oxygen Gas

Without water, all animal and vegetable life soon ceases.

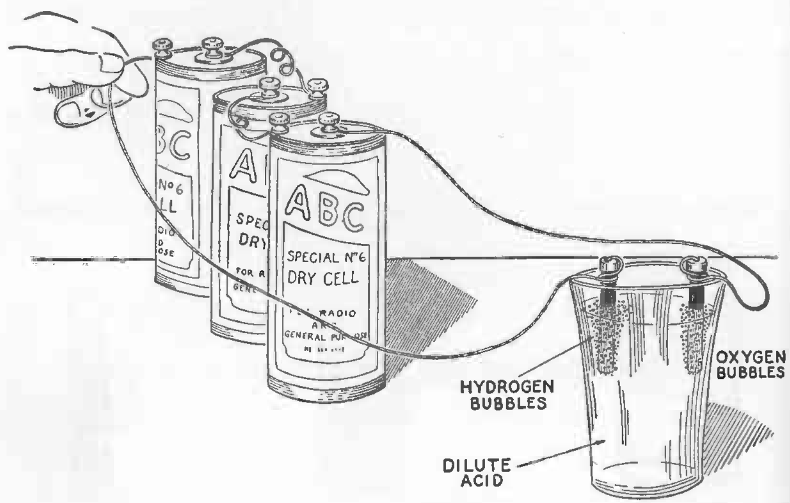
CARBON ROD

If you remove the cardboard wrapper and zinc shell from an old flashlight cell you will find a small carbon rod packed in the center of a mass of powdered carbon and manganese dioxide. Remove the rod (shown at right), wash it thoroughly and use it for your electrical chemical experiments. You will need two such rods.

It is difficult to realize that this important liquid, heavy enough to support a steel battleship and fluid enough to pour out of a pitcher, is a substance entirely composed of two gases. But such is the case and you can prove it for yourself.

We are accustomed to think of water as a transparent, odorless, tasteless fluid. Although it is colorless in small quantities, if seen in large masses it appears to be blue like the atmosphere. When water has a taste or odor or a small quantity has color, it is impure. You see, smell or taste the impurities in the water, not the water itself.

You can prove water to be composed of two gases by repeating the experiment which Carlisle and Nicholson originated one hundred and thirty-seven years ago.



OXYGEN AND HYDROGEN FROM WATER

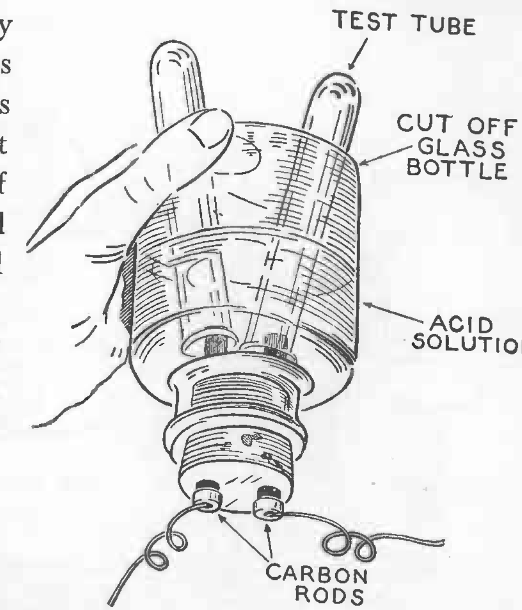
With two or three dry cells, two carbon rods from flashlight cells and some dilute acid you can perform an experiment proving that water is composed of oxygen and hydrogen.

You will need three or four active dry cells and two small carbon rods from old flash-light cells. Solder a piece of copper wire to the brass cap on one end of each carbon.

Fill a glass tumbler about two-thirds full of water and slowly add fifteen or twenty drops of sulphuric acid. Sulphuric acid is necessary in the water because pure water is not a conductor of electricity. You can obtain a suitable sulphuric acid solution already mixed by purchasing half a

pint of *electrolyte* at a storage battery service station. Electrolyte is the common name of the acid solution used in storage batteries. In electrochemistry it is also the name for any solution which is decomposed by an electric current.

If you purchase storage battery electrolyte it is ready for use as it is but will be less apt to do damage if spilled or splattered if you add an equal amount of water.



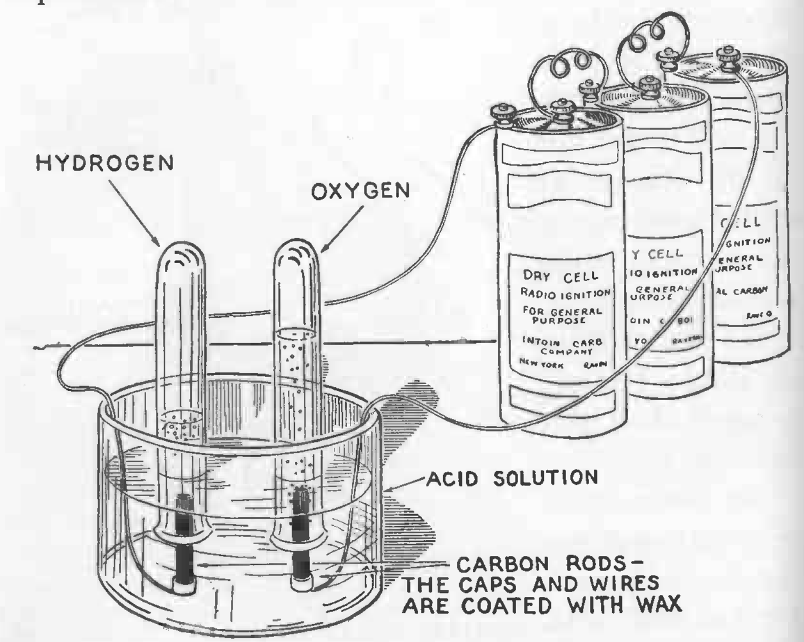
SIMPLE APPARATUS FOR PRODUCING OXYGEN AND HYDROGEN AND COLLECTING IN TEST TUBES

Fill the tumbler to within three-quarters of an inch from the top.

Sulphuric acid, or a mixture of sulphuric acid, must be handled with the utmost care. It should be kept in a glass bottle closed with a rubber or glass stopper. Danger lies in spilling or splattering it. Burns and holes in fingers, clothes, rugs and tables are the penalty for handling acid carelessly.

If sulphuric acid is spilled or splattered upon something which it will damage, quickly and gently wipe off the acid with a rag and then immediately flood the surface with water, using soap freely, and finally covering with moist baking soda. Color can sometimes be restored to fabrics which have been spotted with acid by wetting the spots with diluted household ammonia.

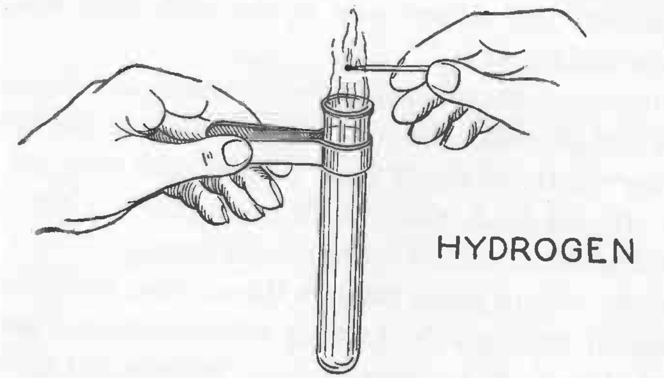
Now that you have been cautioned go ahead with your experiment.



Another arrangement for producing oxygen and hydrogen from water.

Connect the dry cells in series (you should use three or four dry cells or a 6-volt storage battery) and connect the wires attached to the carbon rods to the terminals of the dry battery. Place the rods in the electrolyte. They should be about an inch apart. Bend the wires so as to keep the wires and the brass caps on the rods out of the electrolyte, only the carbons being immersed. This is important.

Watch and you will see small bubbles forming on each of the rods. As they grow larger, the bubbles break away from the rods and float up to the surface. Those formed on the carbon connected to the negative terminal of the battery are hydrogen gas. Those connected to the positive terminal of the battery are oxygen.



TESTING THE HYDROGEN

Turn the test tube right side up and ignite the gas with a lighted match.

If the electric current passes through the sulphuric acid electrolyte for a sufficient length of time almost all the water will be decomposed into oxygen and hydrogen. Finally, all that remains will be sulphuric acid containing a small amount of water.

Decomposing a chemical solution with an electric current is called electrolysis.

If you collect some of the bubbles produced by the electrolysis of water, you can easily prove that they are hydrogen and oxygen. In order to collect the gases, a slightly different arrangement of apparatus from that just described is necessary. Instead of a tumbler, the top of a wide-mouthed bottle is used as a container for the sulphuric acid electrolyte. The carbon rods pass through two tight-fitting holes in the cork. If the cork is a two-holed rubber cork such as chemists use, the acid will not leak. If a vegetable cork is used, it is advisable to seal the carbon rods in the cork with melted paraffin or sealing wax.

Two test tubes should be filled with water and inverted over the carbon rods. The water can be held in the tubes by placing the thumbs over their mouths until they are in position. If you wash your hands immediately after, the weak acid solution will not harm your fingers.

When the current passes through the solution, the bubbles of gas which rise from the carbons will be collected under the tubes. There will be twice as much hydrogen as oxygen and consequently the test tube inverted over the carbon connected to the negative of the battery will be the first to be filled.

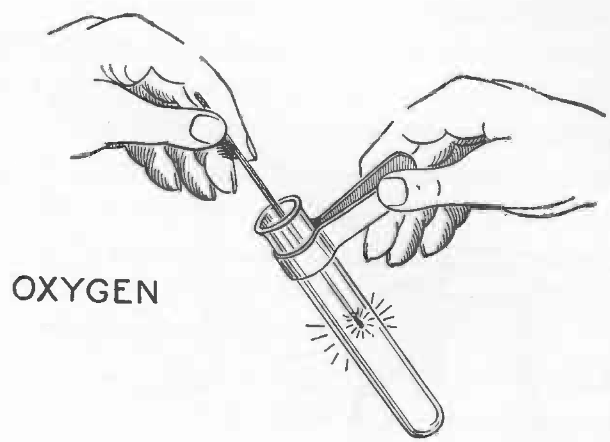
Hydrogen is transparent, colorless and tasteless. It is one of the lightest substances known. It is fourteen and one-half times lighter than air. It floats in the atmosphere. That is why airships and balloons are filled with hydrogen.

Hydrogen burns easily. When mixed with air or oxygen, it burns with an explosion.

As soon as the test tube inverted over the negative carbon becomes filled with hydrogen, close the mouth of the tube with the thumb so that none of the gas can escape while lifting it out of the electrolyte. Turn the tube rightside up,

remove the thumb and ignite the gas with a lighted match. It will take fire and burn.

Combustion, or burning, is simply a combination of two substances, one of which is oxygen. When the hydrogen escaping from the mouth of the test tube burns, it combines with the oxygen in the surrounding air.



TESTING THE OXYGEN

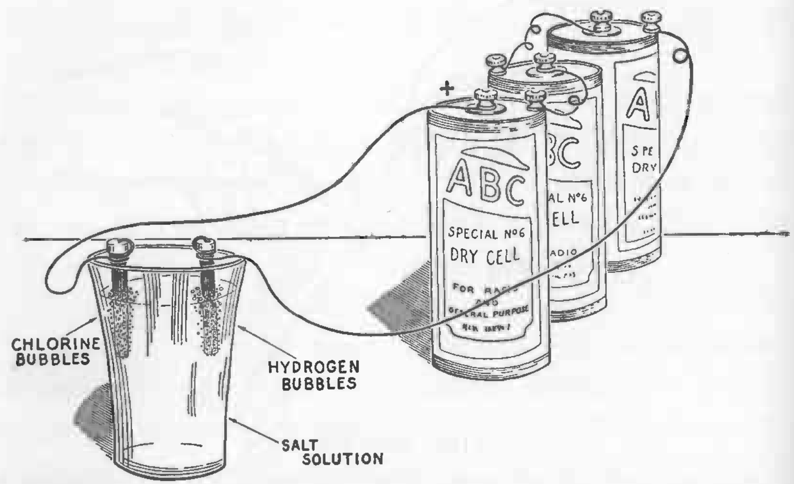
Turn the test tube right side up and thrust a glowing splinter into the oxygen. It will burst into flame.

In order to burn oxygen, it is necessary to supply something with which the gas will combine. When the test tube inverted over the positive carbon becomes filled with gas, lift it out of the electrolyte. Have ready a bit of smoldering string or a splinter of wood retaining but a single glowing spark. Thrust one of these into the tube and it will immediately glow more brilliantly and burst into flame.

Water is not the only substance which can be decomposed with an electric current.

The Electrolysis of Salt

Most common things are apt to occasion little thought and small wonder. We are usually most interested in something we have never seen before. Yet no farther away than the dining table or pantry shelf are a number of apparently



PRODUCING CHLORINE FROM SALT

The production of chlorine from salt by means of electricity, illustrated here by a simple experiment using dry cells, carbon rods and salt water, is an important industry. In this experiment, the sodium which is part of the salt combines with the water to form caustic soda.

commonplace substances which will supply many absorbing adventures in science. One of these is salt. Just because we eat salt, it is no less important and interesting as a chemical than some of those substances with more elaborate names to be found on the chemist's shelf. Salt is *sodium chloride* to the chemist. Aside from its importance in the food of men

and animals, salt is of great value as the raw material of some huge chemical industries.

By looking at water we cannot discern that it is composed of two gases. Neither does the appearance of salt tell us that it is composed of a soft, silvery metal called *sodium* combined with a greenish-yellow gas called *chlorine.*

Sodium and chlorine have a number of valuable uses. Both are produced commercially from salt by the electric current.

It would be difficult for the young experimenter to decompose a salt solution so as to obtain sodium and chlorine. You can, however, perform the simpler experiment of making chlorine, hydrogen and caustic soda from a salt solution. Sodium alone cannot exist in contact with air or water. It combines with water to form caustic soda or *sodium hydroxide* and hydrogen.

The same apparatus that was used for the electrolysis of water will serve. The electrolyte in this case is a strong solution of salt in water instead of sulphuric acid. The bubbles of gas which rise from the carbon rod connected to the negative terminal of the battery are hydrogen, while those from the other rod are chlorine. If you hold your nose close to the positive carbon you will be able to notice the disagreeable, irritating odor of chlorine.

Chlorine in large quantities is poisonous and very irritating to the nose, throat and lungs. The small amount produced in this experiment is not, however, sufficient to be harmful or dangerous in the slightest degree.

Textiles, particularly cotton, are made snow-white through the bleaching action of chlorine. This gas is also used to treat fine papers.

When chlorine is put under heavy pressure, it becomes a liquid. Less than one drop of liquid chlorine in fifty gallons of water frees the water of all disease germs. It is also one of the essential ingredients in making certain dyes, purifying oils, preserving timber, producing gasoline, chloroform and fire extinguisher liquid.

The caustic soda or sodium hydroxide which is formed during the experiment remains dissolved in the electrolyte. Caustic soda is of value in the production of soap, paper pulp and for other purposes.

VIII

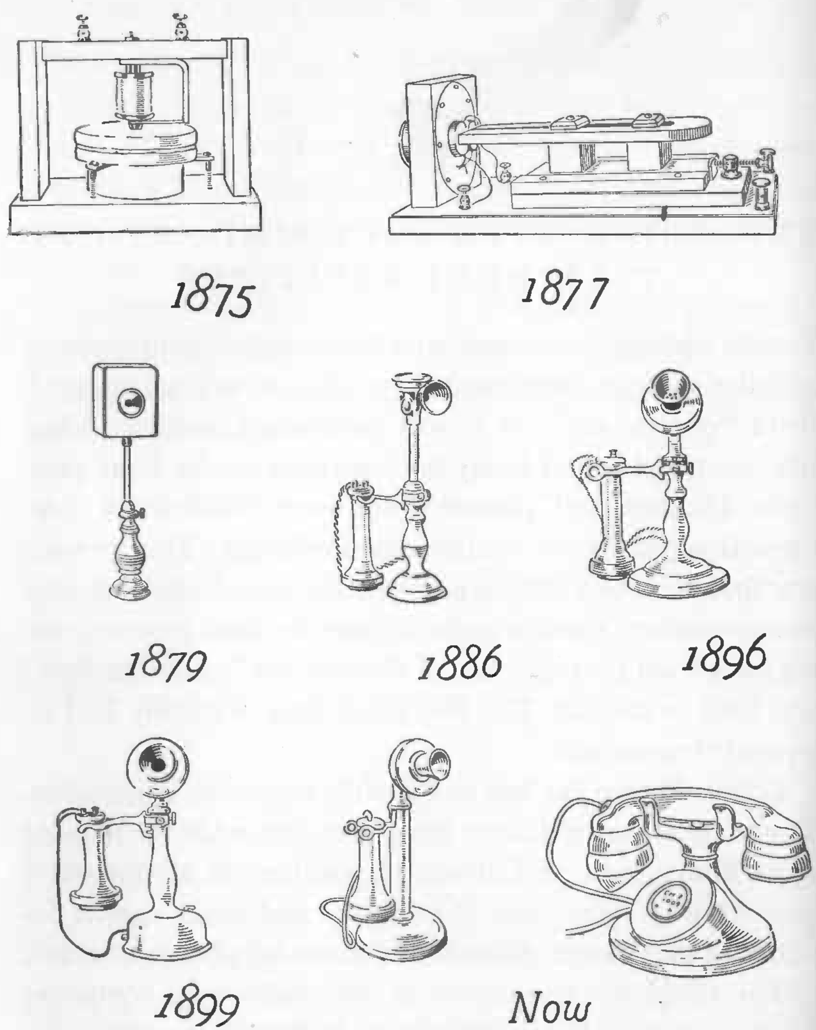
EXPLORING WITH MICROPHONES AND TELEPHONE RECEIVERS

THERE is almost no resemblance between the first telephone and the modern instrument to which you are accustomed. Bell's "electric ear," as it was nicknamed, neither looked like the telephone of today nor operated on the same principle. The first Bell 'phones which were installed for commercial service were clumsy and inefficient. The message was shouted into a curious affair which looked like a wooden potato masher. Then in order to hear the faint answer coming back from the other end of the line, the "potato masher" was held to the ear. The Bell telephones originally had no separate transmitter.

Edison devised the first worthwhile telephone transmitter. The telephone would never have come into wide use without some device such as Edison's transmitter. It eliminated a great deal of noise from the circuits and made speech intelligible over longer distances. It made telephony practical.

The telephone transmitter in use today is a composite development. It is a combination of the ideas evolved by Thomas A. Edison, Emil Berliner, David E. Hughes, Francis Blake, Reverend Henry Hunnings and an expert of the Bell Company named White.

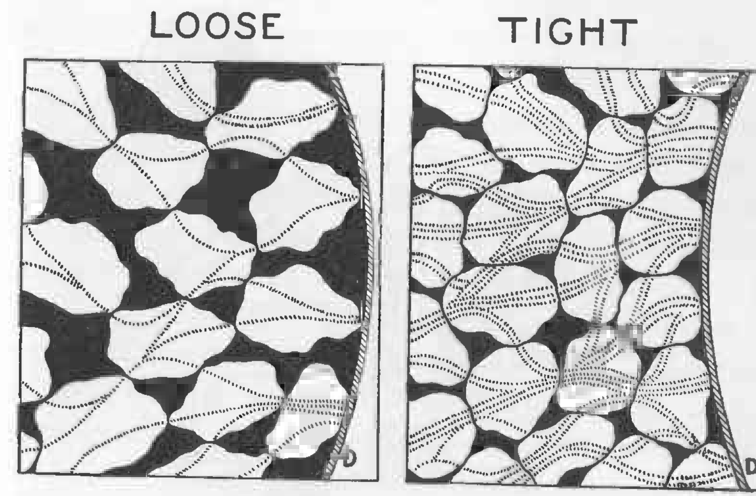
Emil Berliner came to this country as a poor immigrant boy from Germany. He invented a telephone transmitter



THE COST OF PROGRESS IS THE COST OF RESEARCH

These pictures show the progress which research has wrought in the telephone in sixty years. More marked developments have been made in central office and accessory equipment. The first telephones were limited to distances of a few miles. You can now talk to any part of the world. Research perfected the telephone. The telephone industry employs more than 325,000 persons in the U. S. Research is the great factor in providing employment.

identical in principle with that of Edison but could not gain immediate recognition for it. Eventually Berliner's claim of having invented the transmitter before Edison was upheld by a decision of the United States Supreme Court.

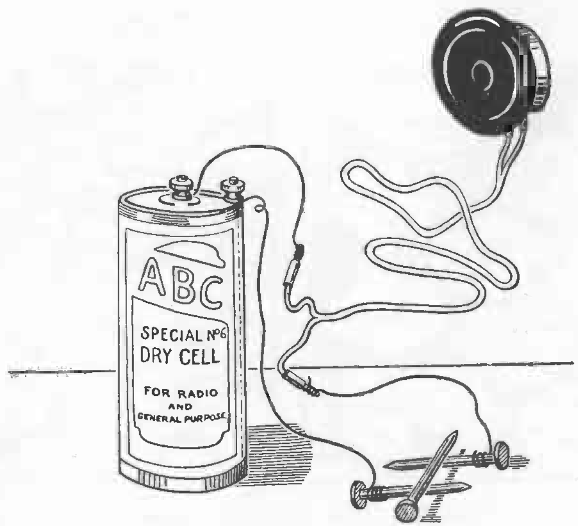


MAGNIFIED CARBON GRAINS

The carbon grains in a transmitter are shown here magnified about fifty times. The dotted lines represent electrons passing from one grain to another. *D* is the diaphragm of the transmitter. When the grains are loosely packed few electrons can pass from grain to grain. When the diaphragm is bent in by a sound wave and the grains are closely packed together, many electrons can pass through.

Edison's work on the transmitter was done without any knowledge of Berliner's device. Although it made use of the same basic principle that Berliner invented, the Edison instrument was an improvement. Edison used carbon in place of the steel used by Berliner.

Carbon, first employed in telephony by Edison, possesses great advantages over any other substance for making transmitters. It is still used. Nothing else has ever been found which is quite as good in a transmitter. Unlike most other substances, carbon remains unchanged in air at ordinary temperatures. It is not rusted or oxidized by air as are ordinary metals. In addition, when two pieces of carbon are



THE FIRST MICROPHONE

Three nails connected to a telephone receiver and a battery were the clue to the telephone transmitter. Sounds and vibrations striking the nails varied the current flowing in the circuit.

pressed against each other, the amount of electric current which will pass between them will depend upon how tightly they are pressed together.

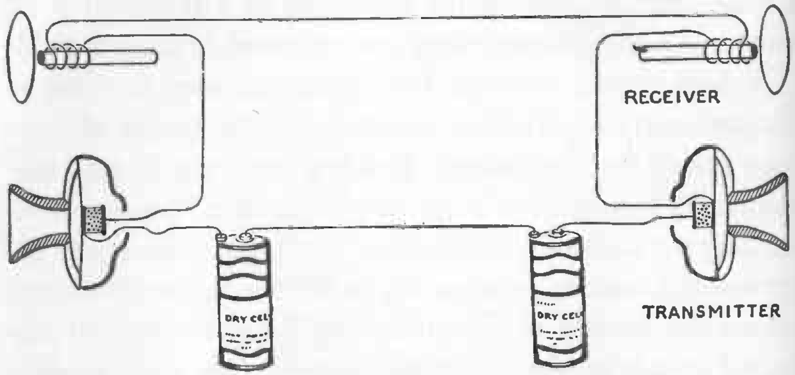
The transmitter devised by Edison was built to operate by changing the pressure between a small platinum disk and a carbon block. The platinum disk was secured to a diaphragm. The carbon block was rigidly fastened. The pressure between the platinum and carbon was changed by sound

waves striking against the diaphragm. In this manner, the current flowing in the circuit could be varied by the sound waves.

One of the most valuable contributions to the telephone transmitter was made by Professor David B. Hughes. By a series of interesting experiments, Hughes demonstrated that a loose contact between the electrodes of a transmitter, no matter of what substance they are composed, is far preferable to a firm, strong contact. The apparatus used in some of Hughes' early experiments (1878) consisted simply of three wire nails (see illustration) forming part of a circuit containing a battery and a telephone receiver. Sound waves striking the nails caused the latter to vibrate. Changes in the pressure of contact between the nails, due to the vibrations, varied the amount of current flowing in the circuit and produced sounds in the telephone receiver. The nails made a very inefficient form of transmitter but they demonstrated a principle which telephone engineers soon utilized.

Using Hughes' principle of loose contact, a minister, Reverend Henry Hunnings, made a transmitter consisting of a mass of finely divided granules resting between two conducting plates. That is the principle used today. The modern Bell system telephone transmitter consists essentially of two circular pieces of carbon, one of which is attached to the diaphragm, the other being rigidly mounted on a strip of metal called the "back bridge." Between the carbon disks, or electrodes, as they are called, is a mass of finely granulated carbon. Sounds coming into the transmitter mouthpiece strike against the diaphragm and make it vibrate. The vibrations of the diaphragm and consequent changes of pressure on the small carbon granules correspondingly change the electric current.

The story of the telephone transmitter is a good example of the fact that in nearly all great inventions, we cannot pick out a single individual and fairly ascribe to him the honor of having, unaided and alone, made an invention ready to



HOW DOES A TELEPHONE OPERATE?

The circuit includes two transmitters, two receivers and a battery. Sounds entering the transmitter vary the current flowing in the circuit. The fluctuating current produces changes in the pull of an electromagnet in the receivers and moves a diaphragm. The motion of the diaphragm creates sound waves like those which entered the transmitter.

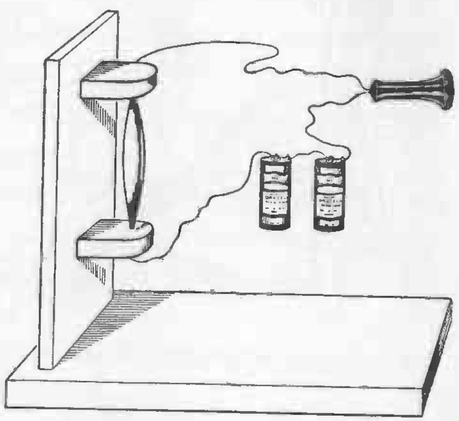
be put into the everyday service of man. It will almost always be found that there are several men who can properly claim a share in every great invention.

The story of the telephone transmitter is also a beautiful illustration of how seemingly unimportant things such as nails, pieces of carbon, pressure, etc., may be of the utmost importance in the development of ideas and new inventions. In experimenting, an unusual occurrence may be turned to good account. The troubles of one scientist may be put to

service by another. Electricians always try to avoid the troubles caused by loose contacts. Professor Hughes used the electrician's bane to make an efficient telephone transmitter.

The Hughes Microphone

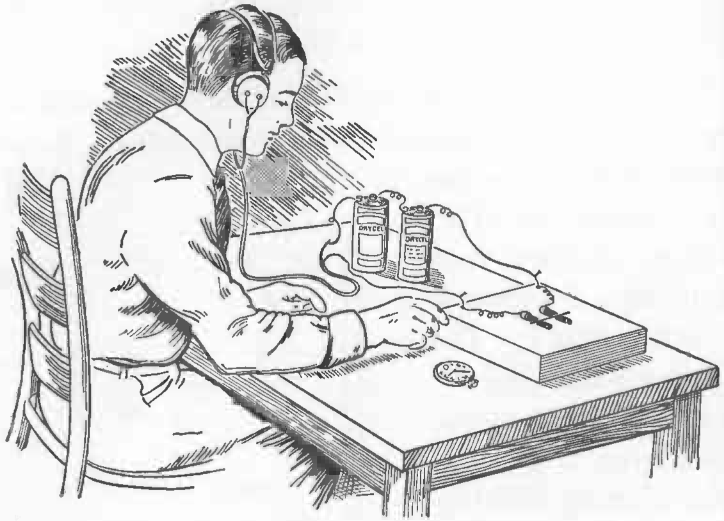
The simple apparatus consisting of three iron nails which Professor Hughes devised is called a microphone. A microphone may take a variety of forms. The Hughes carbon type microphone is shown in a sketch near by. The slightest sounds in the vicinity of this instrument, even those incapable of being heard by the ear alone, produce surprising effects in a telephone receiver. A carbon rod, pointed at both ends, is loosely held in small holes in two carbon blocks supported on a wooden sounding board. Faint sounds or vibrations picked up by the sounding board are sufficient to disturb the contact between the carbon rod and blocks. The disturbance of the contacts alters the resistance which they offer to an electric current. If the microphone is part of a circuit including a telephone receiver and a battery, sounds may be heard in the telephone receiver. Such an arrangement



HUGHES' CARBON MICROPHONE

This is an improved form of the original microphone. It is simple and easy to build and an interesting device to experiment with. Use the bottom of a cigar box for the sounding board.

may be made so sensitive that the footsteps of a fly walking on the sounding board may be heard. When a fly walks on the sounding board, part of the sound heard in the tele-



EXPERIMENTING WITH A MICROPHONE

phone receiver is probably due to vibrations which the microphone "feels" as well as the actual sounds of the footsteps.

Making a Microphone

Two pieces of carbon rod from a flashlight battery and a pencil lead resting on a cardboard box make a sensitive microphone. Each carbon rod is cut off so as to leave about three-quarters of an inch with the brass cap attached. File a shallow groove around each carbon. Solder a fine wire (Nos. 30 to 36 B. S.) about one foot long to each brass cap.

A cardboard box about ten or twelve inches long and eight or nine inches wide is the sounding-board to which

the carbons are attached. The box should be inverted and the carbons fastened in place near the center with a large drop of sealing wax. The carbons should be parallel and about one inch apart. A piece of pencil lead about four inches long is laid across the two carbons so as to rest in the grooves. The free ends of the wires connected to the carbons are anchored near the corners of the box with sealing wax.

The microphone is ready to test when it has been connected in a circuit which includes a telephone receiver and two or three cells of dry battery. The battery current flowing through the telephone receiver must flow through the pencil lead lying across the carbons.

The operation of the microphone is best appreciated when the wires leading to the telephone receiver are long enough so that the microphone can be located in one room and the receiver in a room adjoining.

The ticking of a watch lying on or near the box can be plainly heard in the telephone receiver.

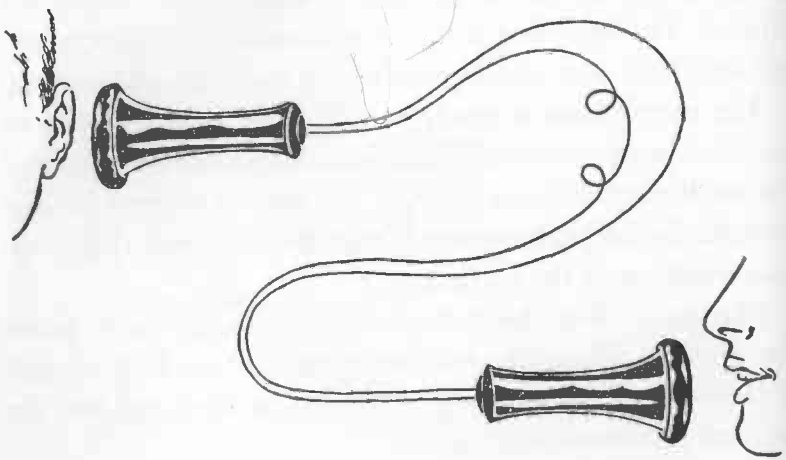
Words spoken close to the microphone will be picked up and reproduced by the receiver, distinctly enough to be understood, but not quite as clearly as would be the case if the microphone were a modern telephone transmitter.

A simple "two-way" telephone system permitting conversation back and forth over a circuit between different parts of the same house may be established by connecting two microphones and two telephone receivers in series.

Telephoning Without Batteries

Telephone transmitters and receivers will provide many interesting adventures in electricity.

You can telephone for a short distance without batteries if you connect two telephone receivers together, using each one as both a transmitter and receiver. When speaking, it will be necessary to shout in order to be heard in the receiver

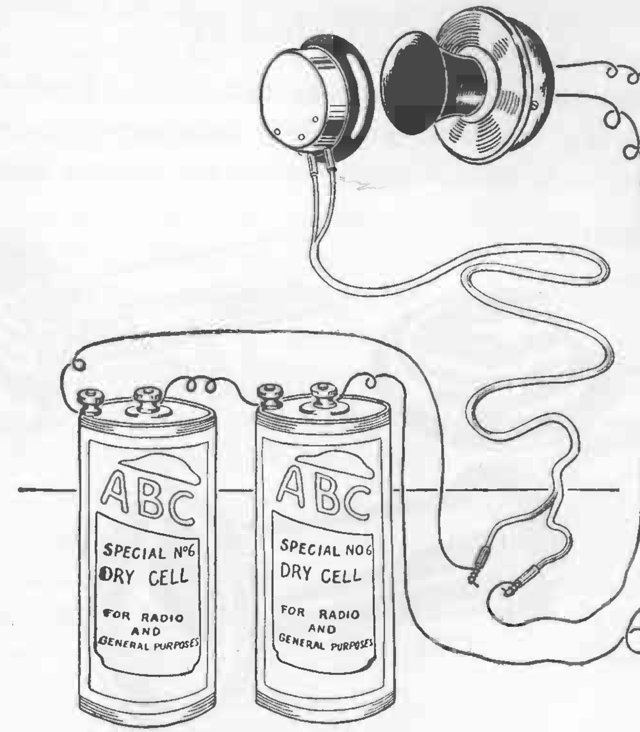


TELEPHONING WITHOUT BATTERIES

Connect two telephone receivers together and use each one both as a transmitter and a receiver. It will be necessary to shout but the system will actually operate and give you an idea of what telephoning was like with one of the early Bell phones.

at the other end. When a telephone receiver is used as a transmitter, by speaking into it, the sound waves of the voice strike against the diaphragm and make it vibrate. The moving diaphragm and the magnets are for the moment a tiny dynamo and they generate a feeble current of electricity. This current of electricity travels along the wires to the other receiver and moves its diaphragm. The second telephone receiver is for the moment an electric motor.

Try this experiment and it will give you an idea of what



TELEPHONE HOWLER

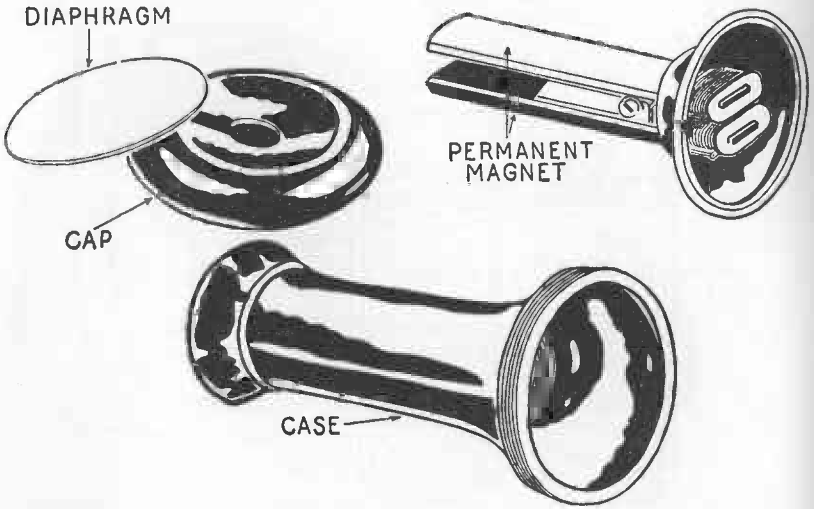
Sounds from the receiver are thrown into the transmitter and repeated back through the circuit so rapidly that the result is a shrill howl or whistle.

telephoning was like with one of the early Bell 'phones before the transmitter was invented.

You see the comparative value of a real transmitter if you substitute it for one of the receivers and include two or three cells of battery in the circuit. Words spoken into the transmitter will be heard in the receiver much more distinctly than when a receiver served as the transmitter.

A Telephone Howler

You can make what telephone men call a "howler" if you connect a telephone transmitter and receiver in series with six or eight cells of battery. Hold the receiver close to



THE PARTS OF A TELEPHONE RECEIVER

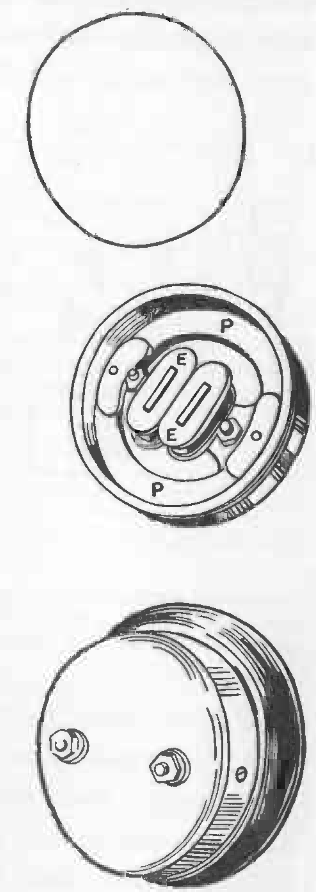
A telephone receiver consists of an iron diaphragm, a pair of electromagnets, and a permanent magnet enclosed in a case.

the transmitter so that the cap of the receiver rests on the mouthpiece. If the "howl" does not commence, tap the mouthpiece sharply and it will. The sound of the tapping will be reproduced in the receiver and thrown back into the transmitter where it will be picked up and sent back to the receiver through the wires. This "feed-back," as it is called technically, will take place so rapidly that the sound will become a loud shrill howl.

Feed-back was one of the difficulties which had to be overcome before the hand set or French type of 'phone now in wide use could be offered to the public. The transmitter and receiver are made in one piece and are so close together in a hand set that the vibrations of the receiver would sometimes be picked up by the transmitter if engineers had not found a way to prevent it.

The "howler" has a practical use. If you forget to replace the receiver of a Bell telephone or do not hang it properly on the hook when you are through using the 'phone, it keeps a light signal flashing at the central office. No one can call you because the central operator cannot ring your call bell unless the hook is down. But by connecting a "howler" at the central office, your receiver can be made to "howl" loud enough so that you will hear the sound and hang the receiver up properly. The "howl" is not produced by holding a transmitter close to a receiver but is made by connecting a special "howling" current to the line.

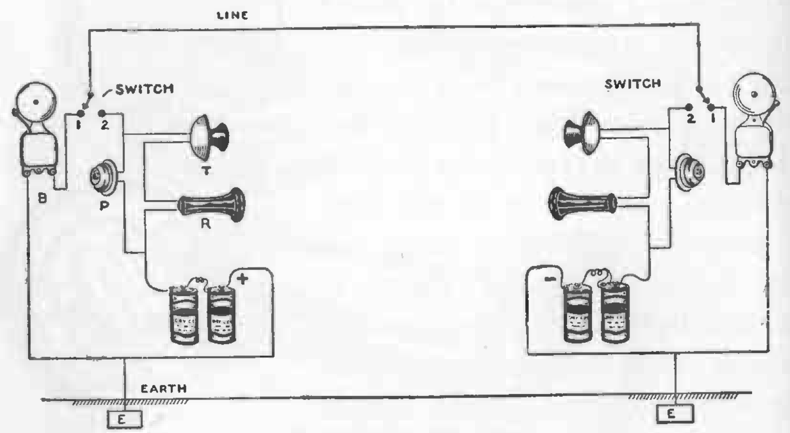
If you have a chum who lives in the same block, you can set up a



WATCHCASE RECEIVER

A compact edition of a receiver. *PP* are the permanent magnets and *EE* the electromagnets.

private telephone system between your homes. You have the right to string wires over some one else's property only if you obtain the owner's permission. Do not run them across a street or road without legal right to do so. It is usually necessary to obtain this permit from the municipal, county or state authorities, whichever has jurisdiction.



TELEPHONE CIRCUIT

Notice that the positive terminal of one battery and the negative of the other are connected to earth. 1 is the "Ring" position of the switch and 2 the "Talk" position. *B* is a doorbell, *P* a push button, *T* the transmitter and *R* a telephone receiver.

The line should be No. 14 B. S. gauge, hard-drawn copper wire. Soft-drawn wire will sag and break of its own weight. Wire smaller than No. 14 B. S. or iron wire will have too much resistance and make it difficult to ring the call bell. The telephone bell used by the telephone company is "polarized" and is very sensitive. It will ring on a small current, a much smaller current than is required to ring a doorbell. Only one line is necessary. The earth or ground can be used in place of the second wire.

The line should be supported on glass or porcelain insulators and should not touch any other wires, tree branches or parts of buildings.

You can use a set of toy telephones if you are able to understand gibberish, but a homemade system assembled

MICROPHONE BUTTONS

You can make a sensitive telephone transmitter by attaching a microphone button to the bottom of a cardboard box. The button on the left is from a toy phone. That at the right is a commercial transmitter button which may be used to make dictographs, phonograph pickups, etc.

from real telephone receivers and transmitters will produce clear understandable speech. You will need the following:

- 2 transmitters
- 2 receivers
- 2 doorbells
- 2 push buttons
- 2 single-pole, double-throw switches
- batteries

The transmitters do not need to be alike, neither do the telephone receivers, except that they should both have the same resistance. An ordinary telephone receiver (seventy-five ohms) will not work well on a line in series with a receiver wound for radio work (1000 ohms).

Connect the instruments to the line as shown in the circuit diagram. The best earth connection is a water pipe.

It will require only two or three batteries at each telephone to transmit speech clearly, but it will probably require more than this to ring the call bell.

When the 'phones are not in use, the single-pole, double-throw switch should be in position "Ring." This disconnects the receivers, transmitters and batteries from the line and connects the bells so that each station is ready for a call.

To call the other station, change the position of your switch to "Talk" and press the push button. Pressing the push button short-circuits the transmitter and receiver and allows the full strength of the battery to go out over the line and ring the bell at the other end. The transmitter and receiver have so much resistance that sufficient current to ring a bell cannot flow through them.

Allow the switch to remain in position, "Talk," while you are conversing. To answer a call when your bell rings, it is merely necessary to throw the switch to "Talk." Notice in the circuit diagram that the batteries are arranged so that the negative terminal is connected to the earth at one station and the positive at the other. This places both sets of batteries in series so that they do not oppose each other.

Broadcasting Your Own Voice

If you have ever wondered how your voice or the voices of your friends and family members might sound if broadcasting, you can satisfy your curiosity with a telephone transmitter and a radio receiver.

You will need the base of an old radio detector tube. Solder a wire to the plate pin on the base. Solder a second wire to the grid pin. Connect the other ends of the wires to a telephone transmitter. The wires should be long enough to reach from the radio set to an adjoining room.

Remove the detector tube from the radio set and insert in its place the tube base with wires attached. When the radio set is turned on, words spoken in the transmitter will be reproduced by the loud-speaker. In this way you can put on your own radio program. The amplifying tubes and transformers in the radio set will greatly magnify the sounds picked up by the transmitter.

An Electrical Stethoscope

A stethoscope is an instrument which doctors use to listen to the action of the heart and lungs.

These sounds can be greatly magnified with an amplifier. Place the mouthpiece of a telephone transmitter, connected to a radio set as described in the last experiment, against your chest directly over your heart. If the mouthpiece is held against the bare skin and you lean forward slightly, the experiment will work better. This electrical stethoscope will greatly magnify the "lub dub" beating of your heart and the sound of your breathing. A whole roomful of people can hear it at the same time.

IX

ELECTRIC "EYES"

A MICROPHONE can hear sounds which are too faint to be noticed by a human ear. It can feel the footfalls of tiny insects. Electromagnets can perform tasks too heavy for muscles. If electricity can be made to "hear," to "feel" and to "speak" why can it not be made to "see"? It can. Electric "eyes" can see better than human eyes. They can see things which the human eye does not perceive. The electric eye is so sensitive that it enables us to hear a faint ray of light fall upon a metal plate.

Electric "eye" is the popular name given without discrimination to three different electrical devices which are sensitive to light. They can tell the difference between darkness and light and distinguish the shades of colors and the varying degrees of light intensity better than human eyes.

When an electric "eye" is part of an electrical circuit, it changes the current flowing in the circuit whenever the strength or color of the light changes. This may seem mysterious and amazing but why should it be any more surprising than the fact that an electric "ear" or microphone changes fluctuations of sound into fluctuations of electric current.

Electric "eyes" are called *photoelectric devices* by engineers and scientists. *Photo* comes from the Greek word which means light. It would be rather difficult to make a list of all the uses to which photoelectric devices are put. The list would be a very long one. The widest use is adding music, speech and other sound effects to moving pictures. In various industries, photoelectric devices play the part of watchmen and inspectors.

An electric "eye" can be arranged so that if you pass in front of it and interrupt a beam of light, it will "see" you and open a door for you, or if you are an intruder it will sound an alarm. It can be connected to a counter or enumerator and will count the people or the automobiles passing by. It makes no difference what the object is, barrels, boxes, bottles or tooth brushes, the electric "eye," as a counting machine, will do its work far more accurately than a man. It will automatically turn on lights as the sun goes down. It will turn them off again when the sun comes up. It will watch for smoke and ring a fire alarm, inspect cloth and paper for imperfections, sort colors, in short do almost any job that the human eye can do.

That part of an electric "eye" circuit which is sensitive to light, which does the "seeing," is called the photoelectric *cell.*

PHOTOELECTRIC CELLS

Photoelectric cells were invented about sixty years ago. Their development was almost complete forty years ago. With the exception of a few scientists, no one took much interest in them until ten or twelve years ago.

The development of the sound film in connection with motion pictures created a demand for photoelectric cells and it became worth while for industrial firms to manufacture them in large quantities. Since research in television has gone ahead on a large scale, special photoelectric cells suited for that work have been developed.

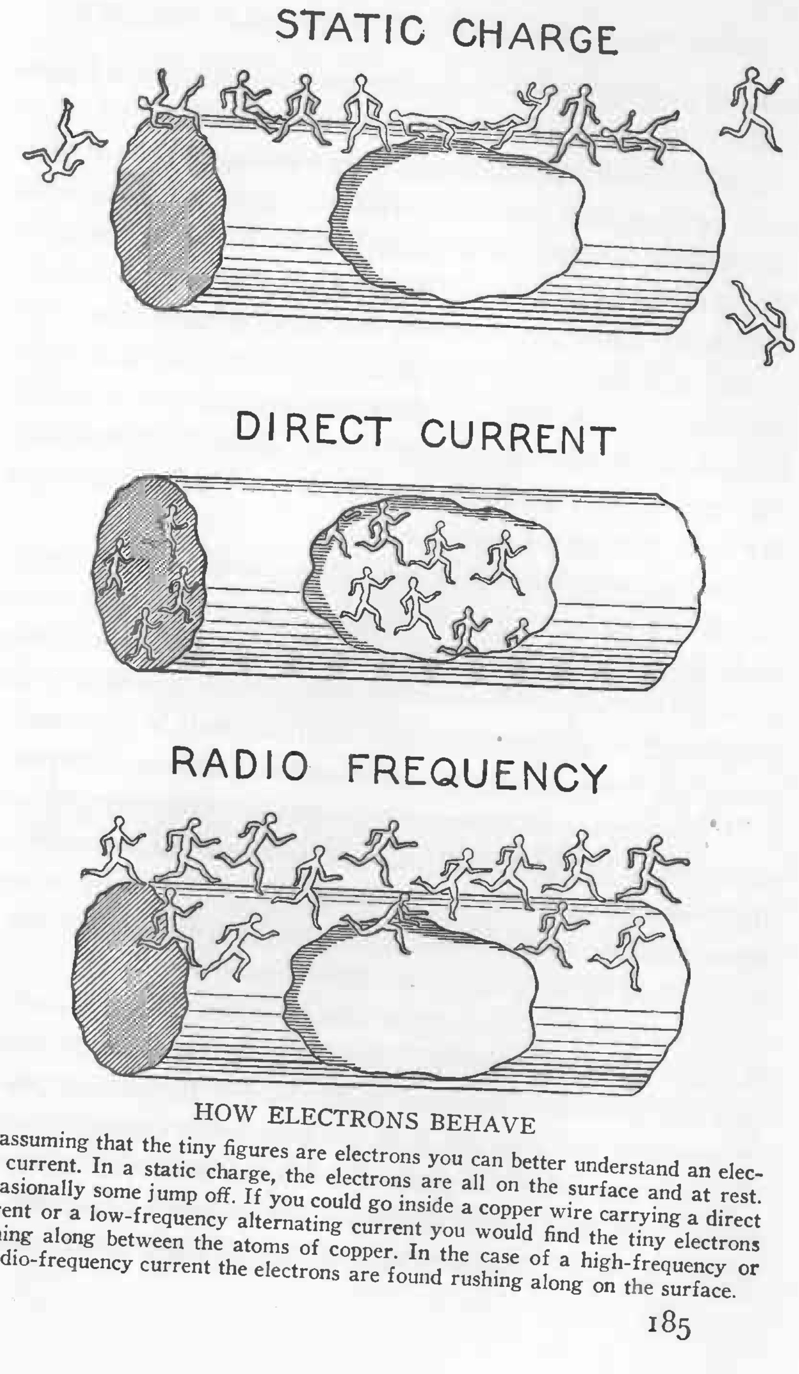
There are three types of photoelectric cells:

1. The Selenium Cell
2. The Alkaline Cell
3. The Cuprous Oxide Cell

The Selenium Cell

The selenium cell was the first photoelectric device to be perfected. Selenium is one of the chemical elements which belong to the sulphur family. There are two varieties of selenium. One is red and the other a dark color, almost black. When the dark variety is melted and slowly cooled, it crystallizes, turns lead-gray in color and becomes a partial conductor of electric current. The amazing thing about selenium is that it is a much better conductor of electricity when a light shines on it than it is when it is in the dark.

Bell, the ingenious inventor of the telephone, was the first to make useful selenium cells. Together with Sumner Tainter, he made the first practical application of the sensitivity of selenium to light. In 1878, Bell and Tainter constructed an apparatus called a *Photophone*. The Photophone was a remarkable form of telephone in which a message spoken into the transmitter travelled to the receiver *on a sunbeam* in-



HOW ELECTRONS BEHAVE

By assuming that the tiny figures are electrons you can better understand an electric current. In a static charge, the electrons are all on the surface and at rest. Occasionally some jump off. If you could go inside a copper wire carrying a direct current or a low-frequency alternating current you would find the tiny electrons rushing along between the atoms of copper. In the case of a high-frequency or radio-frequency current the electrons are found rushing along on the surface.

stead of a copper wire. A selenium cell was part of the Photophone.

A selenium cell is usually made by winding a piece of soapstone or unglazed porcelain with two parallel metal wires which do not touch each other but have a space between. These wires form the electrodes of the cell and lead to the terminals. The space between the wires is then filled with melted selenium which is kept hot for some time and cooled very slowly. A current can flow between the two wire electrodes only by passing through the selenium. The strength of that current will depend upon and vary with the intensity of the light shining on the selenium.

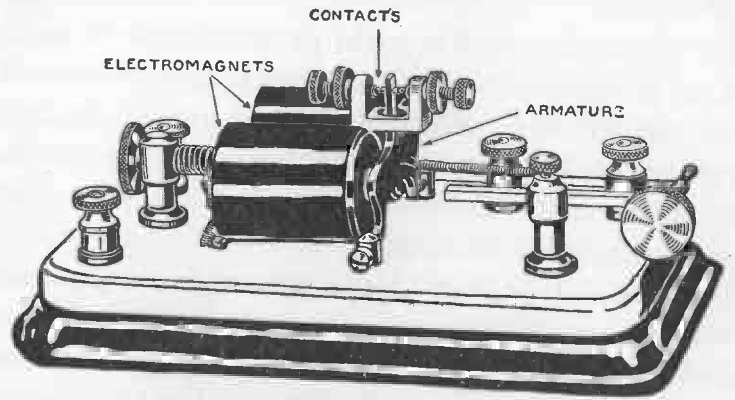
To put a selenium cell to work, it is connected to a battery and if it is to be used to open a door, operate a counter, or some mechanical device, the circuit includes an electromagnetic relay. A relay is necessary because the amount of current which will flow through a selenium cell is too small to move anything but a very light and delicate mechanism.

A relay is a sensitive electromagnetic switch wound with many turns of fine wire so that a feeble current will move its light-weight armature. The armature moves only a very short distance and is fitted with contact points which act as a switch to open or close another circuit.

When a light shines upon the selenium cell, the current flowing in the circuit will increase and the relay magnets will pull the armature over and open or close the contact points. When the light goes out or is weakened, the current flowing through the relay magnets will become so feeble that the spring attached to the armature will pull it away from the magnets. A bell may be connected to the relay so that it will

ring when light strikes the selenium cell or when a light shining on it is interrupted. Instead of a bell, a counter, a door-opening device, a motor or some other mechanism may be started or stopped by the relay.

A selenium cell is a simple thing but it requires more care and patience to construct than most boys usually bestow upon their experiments. It is not expensive to purchase ready made. It is the best type of photoelectric device for the beginner. Any sensitive relay suitable for use with photoelectric devices may be used. Some of these are discussed farther



A TELEGRAPH RELAY

A 250- to 300-ohm telegraph relay is satisfactory for use with an electric eye in some cases but is not as sensitive as some other types.

along in this chapter. There are two ways of arranging a selenium cell. One is called the interrupted beam circuit. The other is the flash circuit.

In the interrupted beam circuit, a light shines steadily on the selenium cell and the relay magnets hold the contact points open. When the beam of light is interrupted, the magnets release the relay armature and the spring pulls the contact points closed. This rings a bell or operates some other electrical device.

In the flash circuit the relay contacts are reversed. Then, if a match is lighted near the selenium cell or a light is flashed upon it, the contacts close and ring a bell, etc. In other words, one system is operated by cutting off the light and the other is operated by turning on a light.

The Alkaline Cell

The second and third types of photoelectric cells on our list work in an entirely different manner from a selenium cell. When light falls on a selenium cell under proper conditions its resistance to an electric current changes, but the alkaline and cuprous oxide cells *produce an electric current*. They transmute light into electricity.

The alkaline type of cell is the one used in adding music, speech and sound effects to moving pictures. Sound is recorded or printed photographically on the edge of the motion picture film in the form of a "track." The track consists of tiny light and dark cross lines or of tiny waves. When a spot of light is focused on the sound track the amount of light which passes through the film to an electric "eye" on the other side varies in strength as the film runs past. The variations in the light are exact counter-parts of the sound waves which made the track. The photoelectric cell sees these variations in the light and changes them into fluctuations of electric current. By means of an electron amplifier and loud speaker the electric currents are magnified and sent forth as

sound. The electron amplifier magnifies the feeble currents thousands of times so that there is enough volume of sound to fill a large theatre.

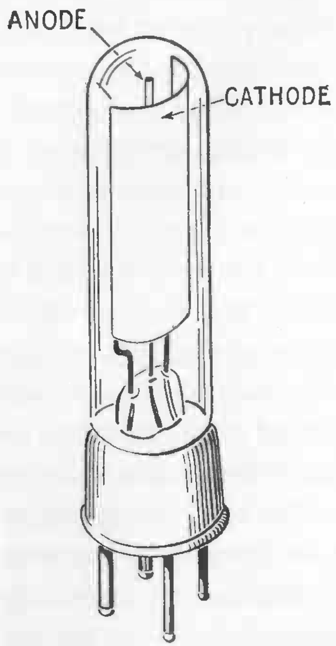
The alkaline photoelectric cell is also the type used most often in industry. It has the general appearance of a radio tube. It consists of a glass bulb, the inside surface of which is covered by a thin coating of one of several alkaline metals.[1] These metals have the property of emitting electrons when struck by light rays. Electrons, of course, are inside of everything, for they help to make up the atoms of matter, but the thin coating of alkaline metal inside of the bulb is a kind of "henroost for electrons." Many of them will fly off the roost if frightened and it happens that they can be frightened by light. They are sensitive to the light which human eyes can see and also to the invisible colors called ultra-violet and infra-red. The glass bulb may be no larger than a pea or it may be eight or ten inches in diameter. The usual photo-electric bulb is about the same size as the ordinary radio receiving tube. Not all cells are made with the sensitive coating on the inside of the bulb. They are also manufactured with the sensitive surface on a metal plate.

In the center of each bulb is an electrode which may be in the form of a wire loop or a straight piece of wire. It is connected to a contact button or stud on the base of the cell. The sensitive coating is connected to a second contact on the base.

The bulb itself is filled with an inert gas such as argon. When light enters the bulb through a window or spot on one side where there is no coating, electrons are released and dart

[1]Cæsium, rubidium, potassium, sodium and lithium are alkaline metals useful in photoelectric cells.

toward the center electrode. The stream of electrons is an electric current. If the cell is connected to a relay and a battery, the relay will operate when the light entering the cell is shut on or off.



AN ALKALINE PHOTO-ELECTRIC CELL OR ELECTRIC EYE

If the cell is connected to an amplifier, so as to magnify the electric current in the electron stream, the most minute changes in the intensity of the light reaching the cell may be detected.

In this way, colors may be matched, cigars graded, chemicals inspected, etc., more accurately than with human eyes.

In the Pennsylvania Railroad Station in New York City, an electric eye automatically opens the door as you approach. In order to reach the door you must pass through a beam of light which shines on a photoelectric cell. When you interrupt the light with your shadow, the door opens. The same device is used in many restaurants to open the doors between the dining room and kitchen for the waiters carrying a load of dishes.

Thousands of electric eyes watch and check manufacturing processes. For example, in preparing rubber for making auto tires it goes through a masticating mill. As the rubber is ground between two huge drums it must be "slashed" with

a large knife and doubled back on the drums about every four seconds. A beam of light passing across one of the drums and onto an electric eye is interrupted whenever the operator of the mill "slashes" and doubles back the rubber. The electric eye records each time this happens on a paper drum and gives the management a written record of whether or not the rubber has been properly worked.

Experimenting with a Photoelectric Cell

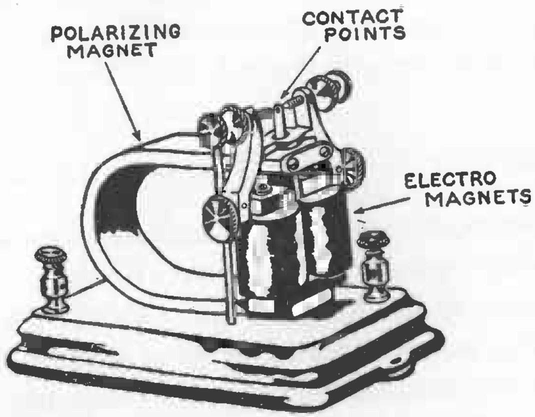
The young experimenter cannot make a photoelectric cell of the alkaline type. He can, however, purchase a sensitive factory-made tube for three dollars. This may be used for experimenting and amusement or set at some useful task.

The best results are secured when a photoelectric cell is used in connection with an electron amplifier so as to magnify the current which operates the relay. Various accessories such as a condenser, transformer, resistance units, etc., are then required. These are to be found in any radio shop. They are inexpensive, in fact are often obtainable at practically no cost by dismantling an old radio set. A circuit diagram furnished by the manufacturer is usually included with each photoelectric cell. A "hook-up" or circuit diagram is also given in these pages.

Success in experimenting with an electric "eye" will depend to a great extent upon a sensitive relay, properly adjusted.

A telegraph relay wound to a resistance of 250 to 300 ohms is satisfactory in some cases, but will not respond to the weak currents which will actuate a polarized relay. A sensitive, 1000-ohm polarized relay will respond to the feeble current produced by two wires placed on the tip of the tongue. A galvanometer relay is even more sensitive.

If you are a good mechanic, you can make a relay from



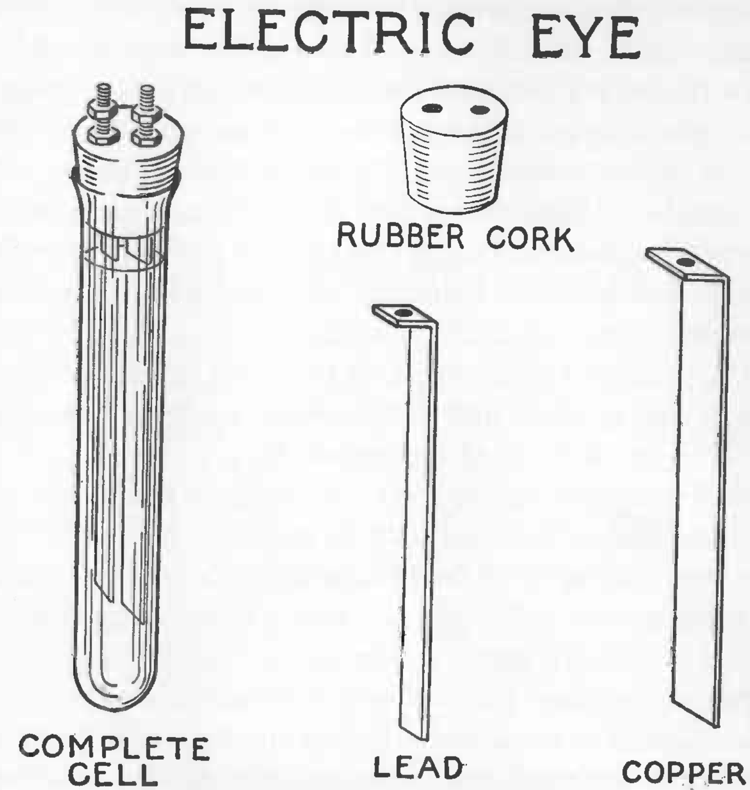
POLARIZED RELAY

A polarized telegraph relay is quite sensitive and will respond to a current of one milliampere or .001 amperes. It is a good type of relay to use with an electric eye.

an old loud speaker. Remove the cone and arrange two silver contacts so that they touch one another when a current flows through the coil. Silver is used for contacts because it makes a better contact than other metals. Since the loud speaker, like the sensitive relays, is a polarized device, the current must flow through it in a certain direction and it may be necessary to reverse the connections before it will operate.

A telephone relay will prove satisfactory for ordinary demonstrations of a photoelectric cell and may be purchased for $2.50. Procure a No. 5014-A-5 relay[1] wound to a resist-

[1]Manufactured by the Automatic Electric Co., Chicago, Ill.



A HOME-MADE ELECTRIC EYE

It consists of a lead and a copper electrode, the latter coated with cuprous oxide, immersed in a solution of lead nitrate.

ance of 3000 ohms and requiring only four milliamperes (four-thousandths of an ampere) to operate.

Cuprous Oxide Cells

Some day we may catch the enormous energy of the sunlight in gigantic banks of photoelectric cells and provide electric power without burning coal or oil. It can be done now on a small scale, not efficiently of course, but well enough to show that such a prophecy is much more than an idle dream. The light of a 40-watt lamp falling upon a copper plate a few inches square, coated with a layer of cuprous oxide, will transmute the light energy into electricity and run a small motor. The motor will not develop enough power to be useful but the demonstration is the germ of an idea which may grow into something immensely practical.

Copper unites with oxygen to form two different oxides, one which is black and called cupric oxide and another which is red and called cuprous oxide.

A Voltaic cell drives forth its electrons chemically. A dynamo pushes them out with its magnetic forces. But the electrons may be lured out of cuprous oxide with light-rays. A cuprous-oxide cell might be called a light-ray dynamo.

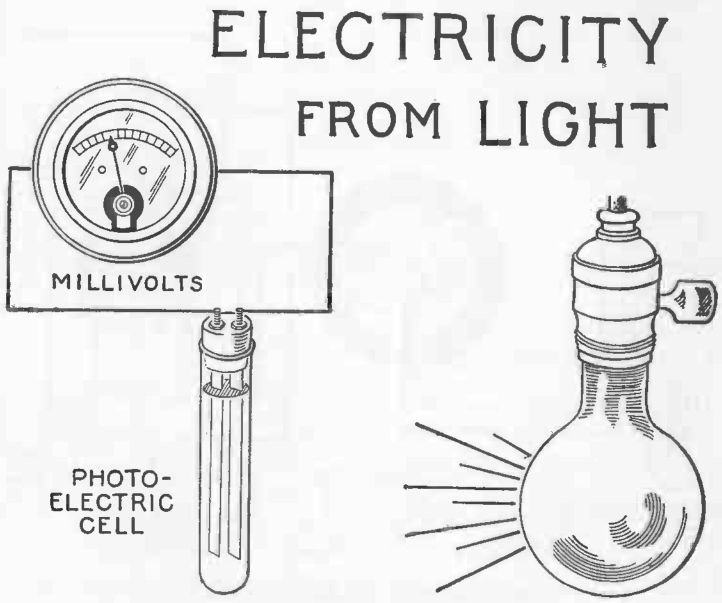
The electrical exposure meters used for measuring the light for picture making and the illumination meters used to ascertain whether or not a room, desk or machine is properly illuminated are small cuprous-oxide light-ray dynamos connected to an ammeter. The needle of the ammeter shows how much current is generated by the light and thus indicates its strength.

Here at last is a type of photoelectric cell which the young experimenter can make, if he is a careful mechanic.

A Homemade Photoelectric Cell

Cuprous oxide is used in two ways in making a photoelectric cell. In one, contact is made with the cuprous oxide

by a thin film of silver. In the other, contact is established by a liquid. This latter type is the easier to make. It looks like a small Voltaic cell having an electrode of copper and one of lead.



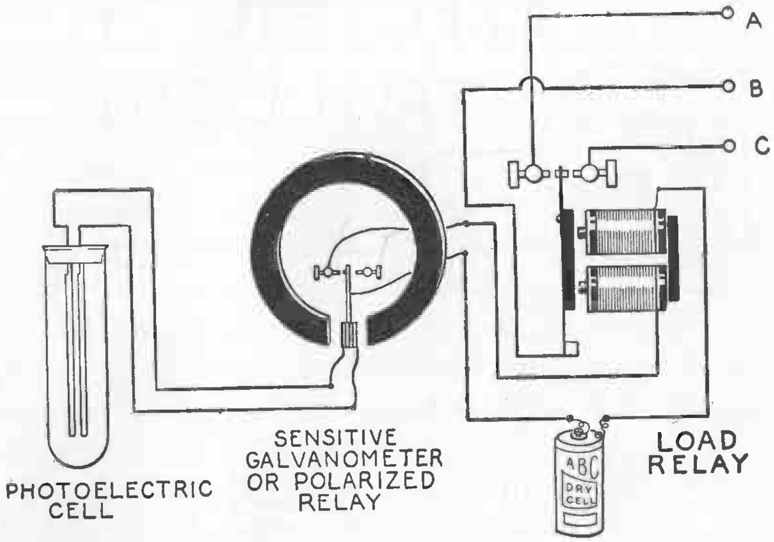
EXPERIMENT

When a lighted incandescent lamp is brought near the cuprous oxide cell electricity is generated. If the cell is connected to a millivoltmeter or milliammeter, the needle of the meter will move back and forth when the light is turned off and on.

A one-inch test tube, six inches long, will make a good jar. A two-hole rubber cork to fit the tube is also needed.

The lead element is a strip of sheet lead, five and one-quarter inches long and three-eighths of an inch wide. One end is bent over at right angles and drilled so that it can be fastened to the under side of the rubber cork with a 6-32 brass machine screw which passes all the way through one of the holes in the cork and is held in place with a nut.

The copper element is a strip of pure copper (electrolytic) one thirty-second of an inch thick, three-quarters of an inch

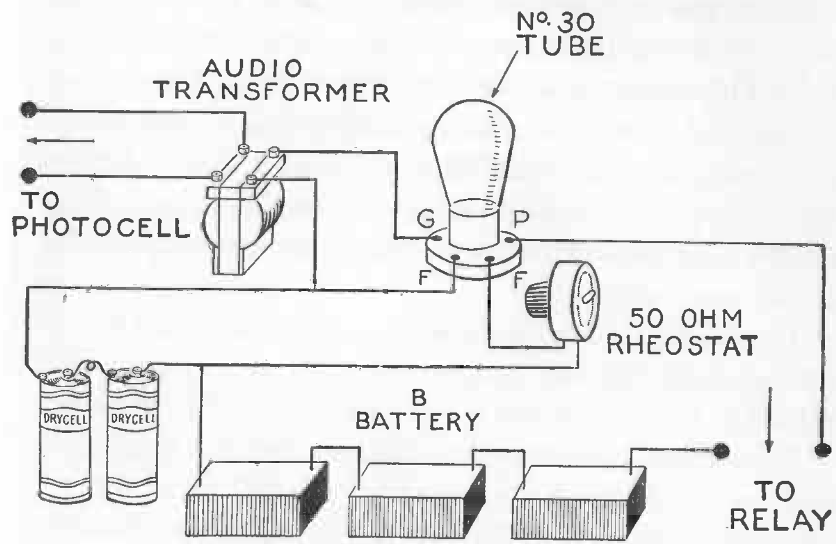


CIRCUIT FOR ELECTRIC EYE

This circuit shows how to connect the photoelectric cell to a sensitive relay and a power relay. The springs which pull the armatures back are not shown. *A* and *B* are the terminals for an interrupted beam circuit and *B* and *C* are the terminals for a flash circuit. An interrupted beam circuit is operated by shutting a light off and a flash circuit is put into operation by turning a light on.

wide and five and one-half inches long. It is fastened to the under side of the cork in the same manner as the lead strip. The copper strip must be smooth. The edges should be polished with a fine file and emery paper. If it is not smooth, you will have difficulty. The copper strip is prepared by first dipping it in nitric acid until the surface is absolutely clean. Then rinse it with water and dry with a clean cloth. The

strip is coated with cuprous oxide by bringing it to a red heat over the flame of a bunsen burner for several minutes and the copper has become thoroughly blackened. Then lay it on a cold, smooth, metal surface such as the bottom of a



CIRCUIT DIAGRAM

This shows how to arrange a vacuum tube amplifier so that it will intensify the currents generated by the electric eye. This is the most satisfactory way of using an electric eye.

flat iron. The black compound on the surface of the copper is cupric oxide. Cooling the strip by laying it on a piece of cold metal helps to loosen the cupric oxide so that you can brush it off with fine steel wool. The red layer immediately under the cupric oxide is the photoactive cuprous oxide and you must be very careful not to remove this. If the cuprous oxide becomes scratched or is brushed off so as to expose the metallic copper underneath, the strip will form a short circuit with the liquid in the cell and no current will be produced. It is not necessary to clean off all the black oxide on and near the edges of the strip. Examine the cuprous oxide surface and if it is broken anywhere so that copper is exposed, reheat it.

When you get a perfect coating, the strip will generate a current between the copper and the oxide when held in the light. The copper is positive and the oxide negative.

The lead electrode should be scraped and washed before it is mounted on the cork. When the copper and lead strips are in the proper position they should be parallel. A rubber band wound around the lower end of the lead will keep the strips from touching.

The electrolyte used in the cell is a solution formed by dissolving about one-half teaspoonful of chemically pure lead nitrate in enough distilled water almost to fill the test tube.

Paint the heads of the screws holding the strips to the cork and the top of the strips for about one-half inch with asphaltum varnish. When the varnish is dry, place the elements in the tube and push the cork down until it is snug. The cell then is ready to test.

If you can borrow a sensitive milliammeter from an amateur radio operator, you can see the effect of light upon the cell. Connect the terminals of the cell to the meter and bring a lighted 60-watt lamp close. If the cell has been constructed properly (it may be necessary to reverse the connections to the meter) the milliammeter will show an immediate increase in current flow. When the light is removed or extinquished, the current flow through the meter drops off immediately.

In order to use the cell as an electric "eye," it should be mounted in a cardboard or wooden (cigar-box wood) box

having a three-quarter inch slot cut in one side so that the cell is shielded from all light except that which comes through the slot.

If the cell is well made, it will give enough current to operate a polarized relay without an amplifier. By connecting the polarized relay to an auto horn relay the cell may be used for opening garage doors, turning on lights when it becomes dark outside, ringing bells when a beam of light is interrupted, etc. The contact points on an auto horn relay will carry a much heavier current than the points of a polarized relay, but the horn relay is not sensitive enough to work directly from the cell.

X

ALTERNATING CURRENTS

CURRENTS THAT SURGE TO AND FRO

IN MANY ways, the most interesting part of electrical science is the realm of alternating currents.

Alternating currents and alternating current circuits have qualities or characteristics which make them behave quite differently from direct currents and direct current circuits. For example, alternating current circuits may be tuned like a musical instrument. Some alternating currents will surge back and forth in a single wire; they do not require a complete circuit as a direct current does. Radio is a branch of the science of alternating currents.

An engineer can solve most of the problems dealing with direct currents by simple arithmetic. Alternating currents obey laws which must usually be expressed by more intricate mathematics than arithmetic. The electrical engineer who designs alternating current machinery and circuits uses calculus. Engineering students learn calculus after they have learned arithmetic, algebra, geometry and trigonometry.

WHAT IS AN ALTERNATING CURRENT?

Do you know what an alternating current is?

The electric current which comes into our homes from a large power station and is used for lighting, is, almost without exception, an alternating current.

An alternating current *changes* its direction of flow *at regular intervals.* Alternating current is produced by a special type of dynamo called an *alternator.*

Batteries and certain types of dynamos produce direct current. A direct current does not change its direction of flow at regular intervals but flows constantly in the same direction.

Alternating current is generated by the power companies because it can be distributed more conveniently and at less cost than direct current. Direct current power is used in the electro-chemical industry and for operating trolley cars and electric trains.

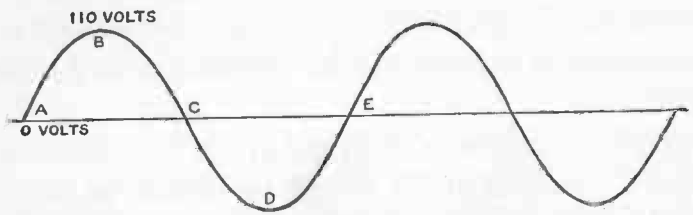
Alternating current is often called "A. C.," while direct current is spoken of as "D. C." These initials, on the name plate of a motor, indicate whether the motor was designed to be operated by alternating current (A. C.) or direct current (D. C.) An "universal" motor is one made to be operated on either direct or alternating current.

A thorough understanding of all that takes place in an alternating current circuit is beyond the ability of a boy. But there are many simple facts about alternating currents which a boy can understand and will find exceedingly interesting. In order to explain alternating currents it is necessary also to explain the meaning of certain technical terms such as *frequency, cycle, alternation* and *phase.*

In order to find out what these mean, when used by an electrical engineer, let us repeat the definition of an alternating current given on the first page of this chapter.

An alternating current of electricity *changes* its direction of flow *at regular intervals.*

Between these intervals, when the current reverses, or actually turns about and goes in the other direction, the strength of the current may vary in any way. The commercial alternating current used for power and light in our homes varies at regular intervals from zero to approximately 110 volts. It decreases at the same rate from 110 volts to zero, starts to flow in the opposite direction, rising to 110 volts and then falling off to zero again. This may sound complicated at



A PICTURE OF A SINGLE-PHASE ALTERNATING CURRENT

The curve shows the voltage rising from *A* to *B*, falling from *B* to *C* and rising in a reverse direction from *C* to *D*. Then it decreases from *D* to *E*. From *A* to *C* or from *C* to *E* is an alternation. From *A* to *E* is a cycle.

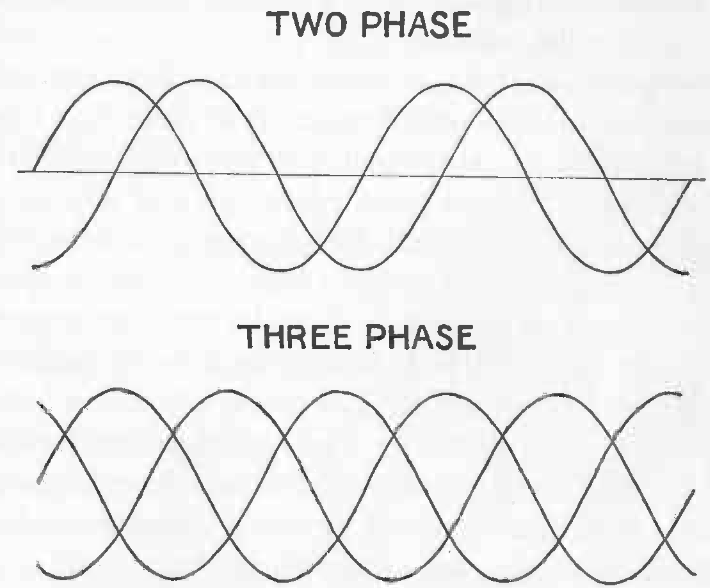
first, but think about it for a moment and you will understand.

Now we are ready for an explanation of a *cycle*.

When, as stated above, an alternating current has passed from zero to a maximum in one direction, died away to zero, risen to a maximum in the other direction and gone back to zero again, it has completed one *cycle*. An alternation is *one-half* a cycle.

It is possible to draw a simple picture of an alternating current. Engineers represent it as a waving line which crosses and recrosses a straight line. They can also make a moving

picture of an alternating current, and see exactly how it is acting, with an instrument called an *oscillograph*. A beam of light in the oscillograph traces a waving line, representing the current, on a screen.



PICTURES OF POLYPHASE CURRENTS

The waving lines represent overlapping currents of the same frequency. Two- and three-phase currents are used principally for power purposes.

The *frequency* of an alternating current is the number of complete cycles which take place in one second. Modern commercial frequencies in the United States are 25 cycles and 60 cycles. Lamps do not operate satisfactorily on 25 cycles. They flicker with every alternation of the current and the eye can see the flicker. Sixty-cycle current is the most common frequency. Lamps flicker slightly on 60 cycles but not enough to notice unless you know how to look for it.

Some electric railways in the United States use a frequency of 25 cycles.

In most countries other than the United States, 50 cycles per second is the usual frequency for power and lighting and 16-2/3 cycles for railways.

Frequencies of 16-2/3 to 120 cycles are called commercial frequencies. In radio work frequencies of more than 1,000,000 per second are not unusual. Currents which alternate at a frequency of 100,000 cycles per second and upwards are called *radio-frequency* and *high-frequency* currents. They are also spoken of as *oscillatory* currents. Radio-frequency currents travel on the surface of conductors. Low frequency and direct currents travel through the body of conductors. Oscillatory currents will oscillate or surge back and forth in an open circuit or single wire. There is still another classification for frequencies. Radio engineers call those frequencies below 100,000 per second which produce sounds which can be heard by human ears, *audio* frequencies.

One more definition and we are ready to experiment with alternating currents. You will often find the word *phase* on the name plates of transformers and motors. It is also used frequently in electrical books.

Here is the meaning. It is possible to send more than one alternating current through a circuit at the same time. Alternators are often built so as to produce two or three alternating currents at the same time which sort of overlap each other in a circuit. They are called *polyphase* currents.

When only one alternating current flows through a circuit it is single-phase current.

If there are two currents of the same frequency but slightly overlapping each other it is two-phase current.

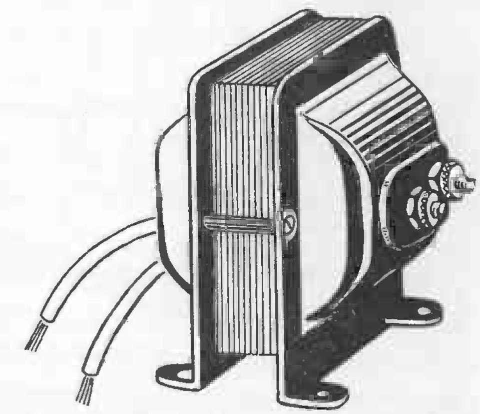
When there are three overlapping currents of the same frequency, it is three-phase current.

House-lighting current is usually single-phase current.

Two and three phase current is produced for power purposes. It has advantages which cannot be explained here.

Experimenting with A. C.

The safe way for a boy to use the 110-volt A. C. current for experimenting is to step-down or reduce the voltage by means of a step-down transformer. This may be a toy transformer of the type used for model railways. Since all boys do not own a toy transformer and they are expensive, a bell-ringing transformer has usually been recommended in these pages. A good bell ringer costs only fifty cents at a "dime store" or chain auto-supply store, and any boy should be able to afford one.

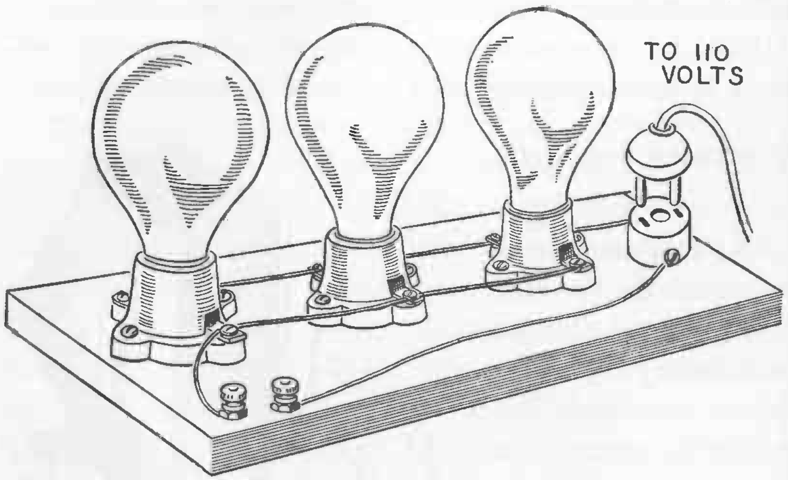


A BELL-RINGING TRANSFORMER

The secondary terminals are binding posts. The primary terminals are wires. Connect a flexible wire and attachment plug permanently to the primary terminals.

It is necessary to connect an attachment plug and a piece of flexible wire to the primary terminals of a bell ringer before it is ready to use. Solder the connections and cover them with tape.

Any of the experiments with alternating current described in this book, except that in Chapter IV showing the action of a transformer, may be performed with a "lamp bank" in place of a transformer.



A LAMP BANK

Apparatus connected to the two binding posts will be in series with the lamps. Screwing the lamps in and out of the sockets will regulate the current. The size of the lamps will also make a difference in the current. A 100-watt lamp will pass four times as much current as a 25-watt lamp.

A Lamp Bank

A lamp bank is a simple arrangement consisting of two or three 110-volt incandescent lamps arranged so that they can be connected in *series* with the experimental apparatus. The current must flow through the lamps and their resistance reduces the voltage slightly. More important than the slight reduction in voltage, however, is the fact that the lamps definitely limit the amount of current which can flow in the circuit.

Three ordinary flat-base, porcelain lamp sockets and the attachments shown in the illustration, mounted on a piece of board, are all that are needed for a lamp bank.

When connecting the lamp bank to any experimental apparatus, make certain to disconnect the 110-volt current by pulling out the plug. After the connections are made, replace the plug. This will avoid the risk of a shock. The shock from a lamp bank of two or three lamps is not dangerous to a normal person but it is uncomfortable.

Finding the Hum

There is often a distinct, characteristic humming sound in transformers, alternating-current motors and other machines operating on sixty-cycle A. C.

You can find out for yourself what makes the hum.

If you make an electromagnet by winding an iron nail with magnet wire and connect it to a battery, the magnetism will exert a steady, even pull as long as the current flows. The electromagnet will be silent. You may hear a slight click when a piece of iron is attracted and strikes against the nail, but that is all. An electromagnet connected to a battery is of course operating on direct current.

You can quickly demonstrate the different behavior of the electromagnet when operating on alternating current by connecting it to the secondary of a bell-ringing transformer or to a lamp bank. As you bring a piece of iron near the electromagnet you can feel a slight vibration. Just as the iron comes into contact with the nail, there is a distinct buzzing sound.

The vibrations and buzzing are caused by alternating current.

The alternating current is passing through sixty complete cycles per second, during which time it is fluctuating in strength and reversing its direction 120 times per second. The rapidly changing magnetism is the cause of the buzzing and hum you hear.

A Transformer Made from a Nail

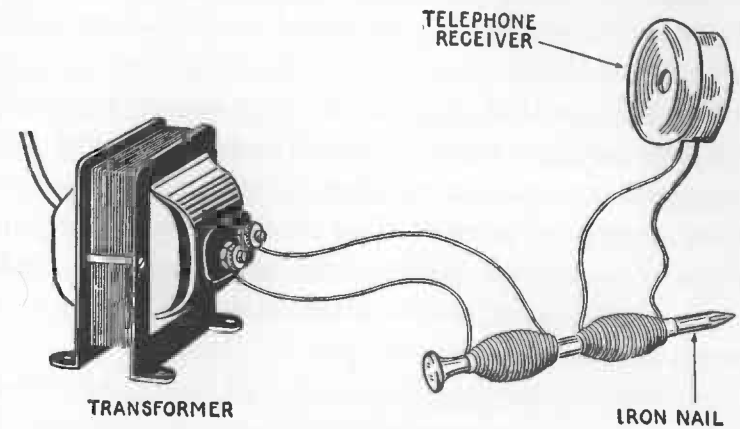
You can accomplish three things at the same time in this experiment. You can hear the "hum" produced by the sixty-cycle A. C. more distinctly, build a transformer and demonstrate the important action called electromagnetic induction.

Wrap two or three layers of paper around a large iron nail and then wind on about forty or fifty turns of magnet wire near one end. Wind a second and similar coil around the other end of the nail. Connect one coil to a telephone receiver and the other to the secondary of a bell-ringing transformer or to a lamp bank. Listen in the telephone receiver and you will hear the low-pitched musical note called the sixty-cycle "hum." This sound has a pitch of 120 vibrations per second. In the musical scale, the B which is an octave below the B just below middle C has a pitch of 120 vibrations per second. Test your piano and see if this note is in tune by comparing it with the sixty-cycle hum.

The hum in the telephone receiver is caused by a sixty-cycle A. C. current induced in the coil connected to the receiver.

The nail and the two coils are actually a small transformer, one of the most useful electrical devices known. As explained in a previous chapter, transformers are not only

a necessary part of the system used for distributing power over the vast network of wires which criss-cross the country but they are essential parts of radio transmitters, radio re-



EXPERIMENT

A transformer made from a nail will demonstrate the principle of electromagnetic induction and reveal the 60-cycle hum.

ceivers, television instruments and many important electrical devices.

The Stroboscope

Suppose that you are an engineer and you have designed a machine of some sort. The machine has been built and is running slowly under test. It is running so slowly that you can see the teeth on the gears as they turn. You can see the various cams, levers and springs doing their work and the oil coming through the various bearings. The machine operates properly when it runs slowly. But when you speed it up, when you put it under full load, there is faulty, noisy action somewhere. At full speed, the moving parts are only a blur. If you could see them when they are moving fast and watch how they work, you could locate the trouble and correct it.

Fortunately, you can. By means of an instrument called a stroboscope which is a sort of mechanical blinking light, you can make parts of machines that are moving as rapidly as several thousand times a minute appear to stand still. Cams, gears, springs, etc., running at high speed, have their motion apparently arrested. The elastic properties of parts and materials become visible under actual working conditions, and engineers obtain information which leads to stronger and more efficient designs.

The name stroboscope is made up of two Greek words and means "an instrument to watch a spinning object." It is a flashing light arranged so that the speed or rate at which the flashes occur can be varied. If the flashes are exactly synchronized (synchronous means at the same rate) with a moving mechanism, the mechanism seems to move backwards. If the flashes are slightly slower than the mechanism, it seems to move slowly forward.

Research has devised a stroboscope light which can be flashed on and off in one hundred-thousandth of a second. Stroboscopes do amazing things. A newspaper clipping whirled around in a circle on the end of an airplane propeller, revolving two thousand times a minute, can be read as if it were standing still.

Stroboscopes are not related to alternating currents in any way and are only included in this chapter because it so happens that the easiest and quickest way for the young ex-

perimenter to obtain a rapidly blinking light is to use alternating current.

The filament of an ordinary incandescent lamp becomes white hot and remains hot enough for a short time after the current is shut off to continue to emit light for a short time. Although the current supply in a sixty-cycle A. C. circuit is zero 120 times a second, at these times an incandescent lamp burning on sixty-cycle A. C. does not cease to give light.

THE ELECTRODES OF THE GLOW LAMP

Only one electrode (negative) of a glow lamp gives forth light on direct current. When a glow lamp is operated on alternating current both electrodes appear to give forth light but they are actually alternately flashing.

There is an almost imperceptible flicker or variation in the intensity of the light but it does not go entirely out.

On the other hand, glow-lamps, or vapor lamps, flash on and off 120 times per second on a sixty-cycle A. C. current. They cease to give light practically instantly when the current is shut off.

It happens that a small glow-lamp, containing Neon or argon gas, of the types already described in Chapter Four is ideal for simple stroboscopic experiments.

When connected to the sixty-cycle, 110-volt A. C. these lamps blink on and off 120 times a second. They burn steadily on direct current.

A Whirling Fan Appears to Stand Still

In order to get the best effects in your experiments with a stroboscope, it is well to have no source of light other than the glow-lamp. Perform them in a darkened room or at night.

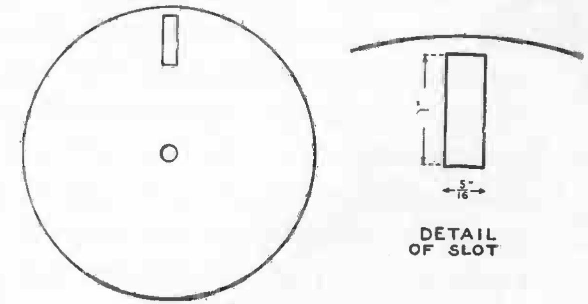
A whirling electric fan, viewed in a darkened room with the light from a neon or argon glow-lamp, will demonstrate the action of a stroboscope. Although the fan blades may be revolving 4,000 times a minute, you will be able to count the blades. You will not be able to see the blades as distinctly as with a regular stroboscope because you cannot bring the speed of the fan and the flashes of the glow-lamp into synchronism. The lamp is flashing at the rate of 7,200 times per minute, but the usual fan motor does not revolve that fast. If you turn the fan on and off with a switch so as to let its speed fall off and then pick up again, there will be times, when as the fan gains speed and loses it again, that it will revolve 1,800 times a minute.

Since there are four blades on a fan, that speed is equivalent to a blade passing a given point 7,200 times a minute. So, for a moment at least, you will be able to see a somewhat blurred image of the blades.

As the blades increase their speed and move past a greater rate than 7,200 blades per minute, they will appear, when viewed in the light of the glow lamp, to move slowly forward. When their speed is less than 7,200 they will seem to move backwards.

Fooling Your Eyes

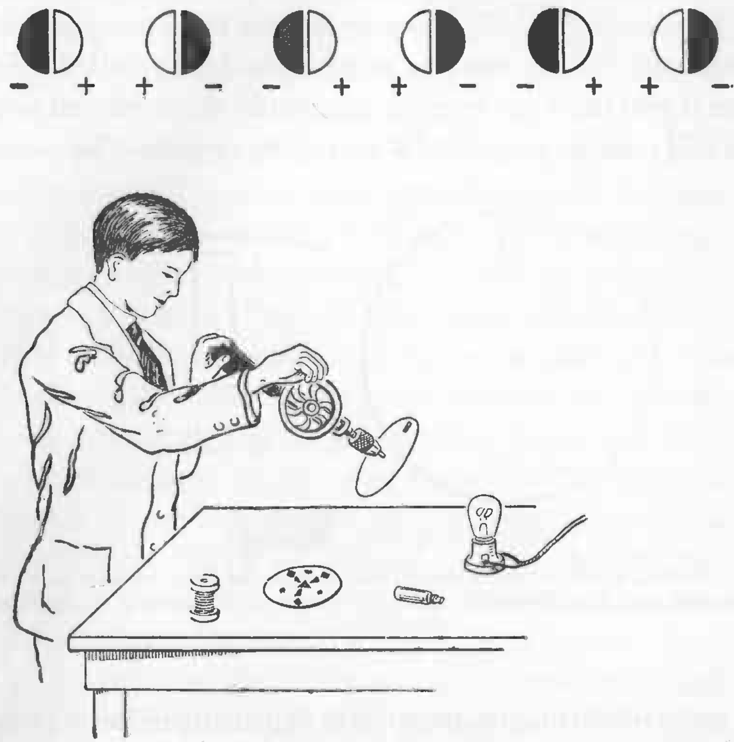
You have no doubt heard that worn-out old saying, "Seeing is believing." Well, you may believe everything you see if you wish to, but you are going to be badly fooled quite often if you do. Your eyes are constantly deceived and your eyes will deceive your mind if you allow them to. The amazing tricks which magicians perform depend upon fooling your eyes. A glowing ember, whirled rapidly around in a circle, appears like a continuous circle of fire. In order not to be fooled you have to know or find out that it is only a whirling ember. Truth and straight thinking will correct the wrong impressions that your eyes give you.



DISK FOR STROBOSCOPE

Cut a six-inch circle out of cardboard and make a slot near the edge as shown in detail at the right. Mount the disk in the chuck of a hand-drill so that it can be revolved.

A star appears much smaller than the lamplight on your street, but it is not. The star is billions of times larger than the lamplight. You know the lamp is smaller than the star because you have seen objects grow smaller in appearance and finally disappear as you moved away from them. You know that the star is very far away, much farther away than



THE STROBOSCOPE IN USE

The blinking of a glow lamp burning on alternating current can be "stopped" with the slotted disk. Looking at the end of the lamp through the revolving slot, the electrodes will flash back and forth as shown at the top of the sketch.

the lamp, and that it must be very large to be seen such a great distance. Straight thinking in this case corrects the wrong impression given by your eyes and discovers the truth.

Engineers and scientific research workers train themselves to think straight. They do not believe what their eyes see

until they prove that their eyes are not fooling them. At least the best of these men do not. That is why they are able to make new and amazing discoveries.

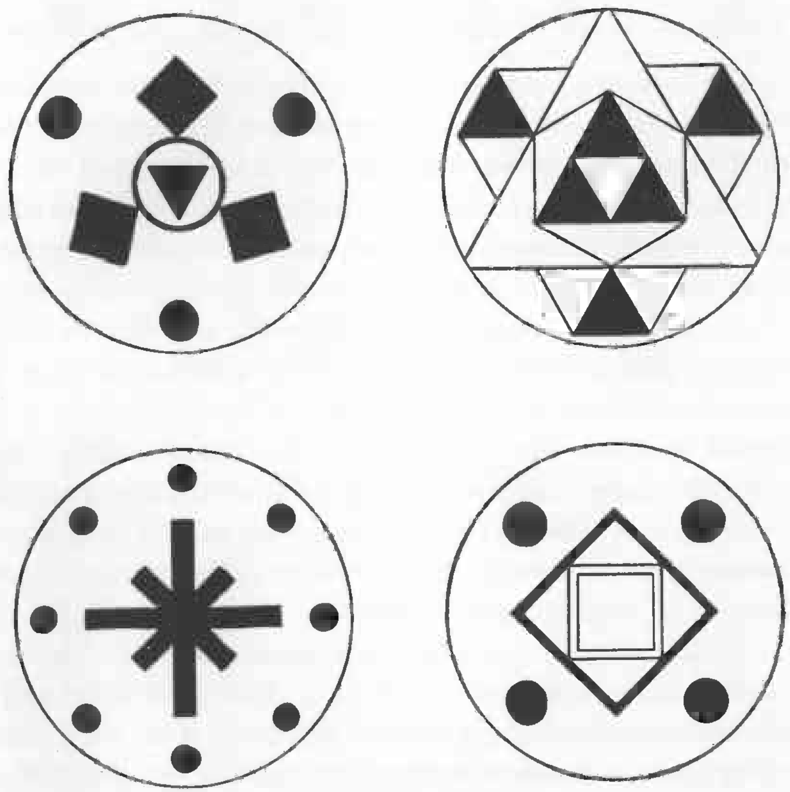
Teaching Your Eyes the Truth About a Glow Lamp

The light of a glow lamp comes entirely from the negative electrode. If the lamp is burning on direct current only one of the electrodes glows—that one which is connected to the negative side of the circuit. When the glow lamp is burning on sixty-cycle alternating current, each electrode is negative sixty times a second and consequently glows sixty times a second. The electrodes take turns glowing but they do it so rapidly that they both *appear* to glow constantly. That is because your eye is fooled and in this case the reason it is fooled is because the eye retains an image for a short time after the image disappears. This habit of the eye is called *persistence of vision.* If a light flashes on and off more than twenty times a second, the light appears to be continuous because of persistence of vision.

Motion pictures are flashed on the screen at the rate of twenty times a second. There is a short time after each picture when the light is shut off and there is no picture on the screen but the eye does not see that. The eye retains the image of the last picture long enough for a new picture to appear before the old image vanishes. It is the persistence of vision that makes motion pictures possible.

If you connect a glow lamp to the 110-volt A. C. and make and break the circuit rapidly by flicking two wires together, there will be times when the current is flowing only long enough for one electrode to glow.

With a simple stroboscope you can easily demonstrate how your eye is fooled by a negative glow lamp burning on alternating current.



STROBOSCOPE EXPERIMENT

Make some cardboard disks and mark them with geometrical figures. Mount the disks in the chuck of the hand drill and observe the patterns in the rapidly flickering light of a glow lamp operated on alternating current.

Cut a circle, six inches in diameter, out of cardboard. Cut a slot five-sixteenths of an inch wide in the circle, near the edge as shown in the drawing. Slip a machine screw with

two washers and a nut through a small hole in the cardboard circle and clamp the screw in the chuck of your hand drill, so that when you turn the handle the circle will revolve.

Hold the hand drill so that the revolving circle is between you and a negative glow lamp burning on alternating current.

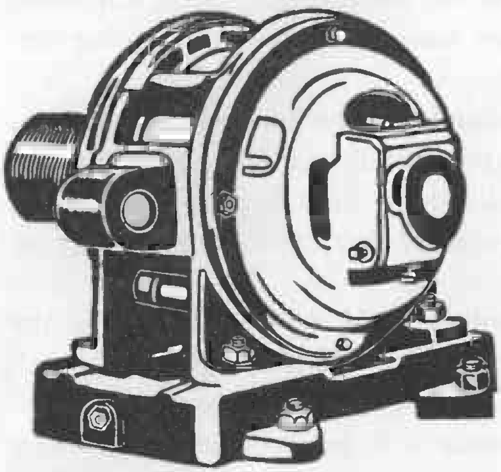
Peep through the slot and turn the handle slowly. Gradually increase the speed and carefully watch the lamp through the slot. You will see that both electrodes are not glowing at the same time. You can see them alternately flashing on and off.

If you mount the cardboard disk on the armature of the synchronous motor described later in this chapter and watch the lamp through the revolving slot, only one electrode will appear to glow. The motor is in perfect synchronism with the flashes, and the slot in the circle through which you see the lamp always comes around to your eye at the same point in an alternating-current cycle.

Motors Which Run on Alternating Current

The small motors used to turn electric fans, sewing machines, etc., are usually "universal" motors and will run equally well on either alternating or direct current. They are what are known as *series* motors. The motor described in Chapter V is a series motor. The armature and the field are connected in series so that all of the current that passes through the armature coils must also flow through the field winding.

The cores of the field magnets in a direct current motor may be cast iron and solid, but an alternating-current motor must have field cores which are laminated or built up in layers. Otherwise, currents called *eddy* currents would be induced in the core and it would become very hot.



A. C. POWER MOTOR

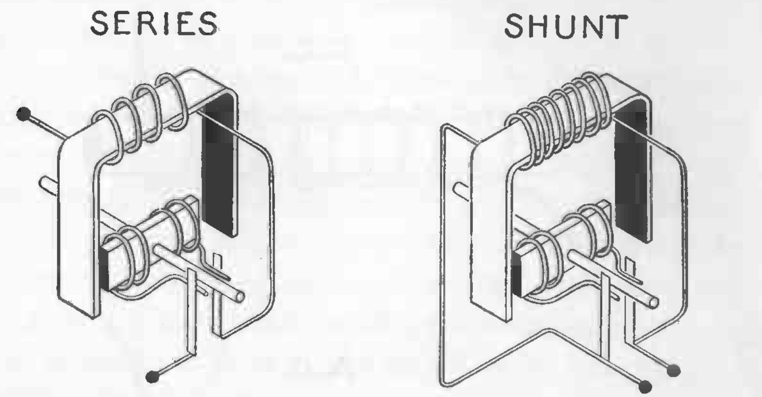
Compare this compact, efficient machine with the clumsy motors of a century ago, shown in Chapter V. Experiment and research produced the change.

Large power motors with commutators and series windings are not practical for alternating current because there is too much sparking at the commutator.

Large alternating-current motors are quite different from direct-current motors and small universal motors. Many alternating-current motors do not have brushes and commutators. Others have a commutator and brushes which are used only for starting. A centrifugal governor spinning around with the armature automatically disconnects the brushes and commutator when the motor reaches its proper running speed. The currents which flow in the armature are not conducted thereto by brushes and commutator but are induced. The field winding is like the primary of a transformer. It is connected to the A. C. power line. The armature is like the secondary of a transformer. There is no direct con-

nection between it and the power line. Its currents are induction currents and the motor is called an induction motor.

Alternating current motors are also built with "starting" coils and "running" coils in the field which are automatically



The field of a shunt motor is wound with more turns and with finer wire than a series motor of the same size. It is connected so that part of the current goes through the field and part through the armature. In a series motor all of the current that goes through the field also passes through the armature.

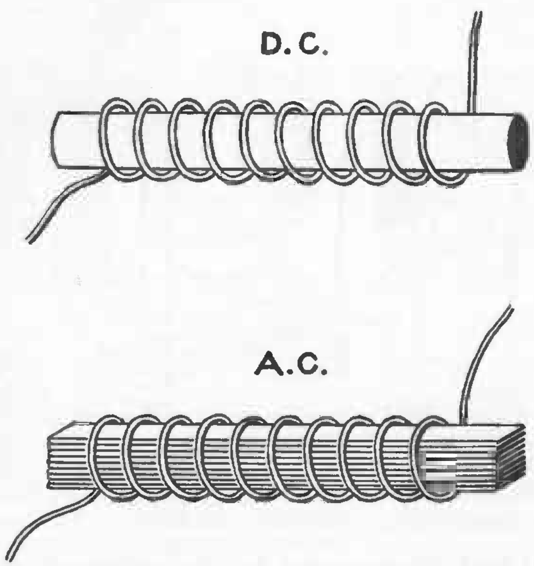
connected and disconnected by the action of a centrifugal switch.

A Toy Motor Changed into an Induction Motor

The small motors which are supplied with toy construction sets are series motors and will operate on either direct or alternating current. Some are wound so that they can be connected directly to the 110-volt current supply but the less expensive variety is intended to be connected to batteries or a toy transformer.

With one of these toy motors, having a three-pole armature, you can demonstrate the principle of an induction motor—a motor which runs without brushes or commutator.

Remove the brushes from the motor. Wind two or three turns of bare copper wire around the commutator so that the sections are short-circuited. Connect the terminals of



A DIFFERENCE BETWEEN A. C. AND D. C. MACHINES

Because alternating currents create (by electromagnetic induction) currents called eddy currents in the cores and frames of coils, the magnetic parts of alternating and universal (either A. C. or D. C.) machines are laminated. Laminated means made in layers. The laminations greatly reduce the eddy currents and consequently the losses they would produce.

the field winding to a toy transformer. Wind a string around the motor shaft, so that by pulling on the string you can spin the armature like a top.

Turn on the current and spin the armature. It will continue to run. The alternating current in the field induces currents in the armature. It is running as an induction motor.

An Experimental Synchronous Motor

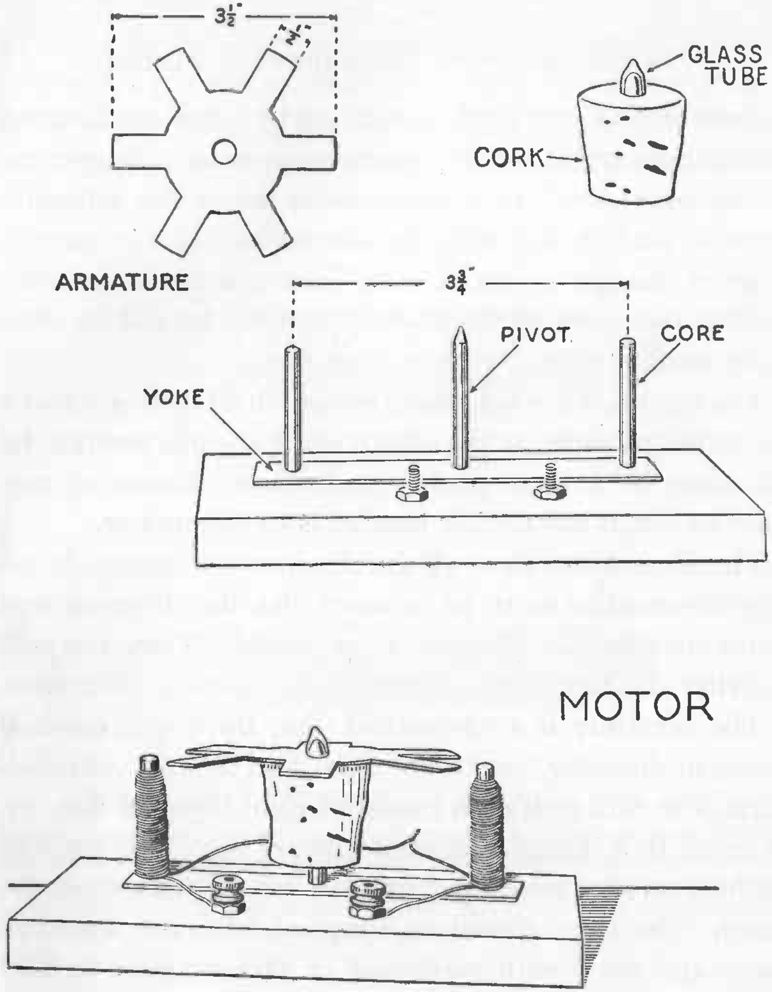
Telechron electric clocks are driven by a tiny synchronous alternating-current motor. Synchronous means "happening at the same rate." In a synchronous motor the armature keeps in perfect step with the alternations of the current. It never changes its speed. The Telechron clocks are self-starting but some of the lower-priced clocks sold in drug stores must be given a twist to start them.

You can make a synchronous motor which runs on exactly the same principle as the cheap electric clock motors. Its full name is "a single-phase, synchronous alternating current" motor. It has neither brushes nor commutator.

The illustrations show all the details of the motor. It has been designed so as to be as much like the direct-current motor described in Chapter V as possible. Thus, you will be better able to see and understand the essential differences.

The armature is a six-toothed disk, three and one-half inches in diameter, cut out of sheet iron at least .022 inch thick. The field coils each consist of eight layers of Nos. 24, 25 or 26 B. S. gauge enameled magnet wire. The cores of the field coils are twenty-penny nails, cut off as shown in the sketch. The cores should be wrapped with two layers of paper and fitted with cardboard or fibre washers to hold the wire in place. A small hand drill clamped in a vise makes a convenient winding machine. The field cores are held in the drill chuck and rotated by turning the handle of the drill.

The field coils are mounted in a vertical position by driving them into holes drilled in the wooden base on three and three-quarter inch centers. The yoke is a strip of sheet iron



SYNCHRONOUS MOTOR

This motor will run on alternating current only. It has no wire on the armature, no brushes and no commutator. It must be started by spinning the armature. It has been purposely designed along the same lines as the experimental motor in Chapter V, so that you may make a comparison. The motor in Chapter V is a series motor and will run on either A. C. or D. C. It has wire on the armature and brushes and a commutator.

about three-quarters of an inch wide and four and one-half inches long. If the field coils are both wound in the same direction, the inside terminals should be connected so that when a current flows through the windings, the top of one magnet will be a north pole when the other is a south pole.

The armature is cemented to a cork fitted with a piece of glass tubing which has been closed at one end to act as a bearing. A nail which has had its point sharpened with a file is driven through a hole in the base from the underside. It should be located exactly half-way between the field coils.

The motor may need adjusting before it will run. By moving the glass tube up or down in the cork, the armature may be adjusted so that its pole-pieces, as the teeth are called, will swing around just below the tops of the field cores. They should not quite touch as they revolve. Two or three drops of sewing-machine oil on the inside of the glass bearing will reduce friction.

The terminals of the field should be connected to binding posts and these in turn connected to the secondary of a toy transformer or to a lamp bank containing two seventy-five-watt lamps.

The motor will run at a speed of 1,200 R.P.M. (revolutions per minute) or twenty per second. It must be started by giving the end of the bearing a quick twist with the fingers so that the armature is set to spinning at a speed of more than 1,200 R.P.M. Then as it loses speed and drops to 1,200 R.P.M. it will fall in step with the alternations of the current and continue to run at that speed until the current is cut off.

Several attempts to start the motor may be necessary before it will run.

How Iron Makes a Circuit Obstinate

There is not enough space in this book to tell how to discover all the things that electricity will do and how it behaves under all conditions.

But it is important for the young experimenter, the boy who hopes to be an engineer some day, to understand one more characteristic of an electrical circuit. He should know something about the effect of iron upon a circuit, how a bit of iron changes a circuit carrying a direct current and how it also affects a circuit when the current is alternating.

Since you already know that electricity will make a spark, that it creates magnetism and that there is a magnetic field around a wire or coil carrying a current, you can discover and understand one of the important qualities or characteristics of an electric circuit which has not been mentioned before in this book.

It is called self-inductance. Don't let this strange name awe you. Self-inductance is very important to an electrical engineer who designs electrical apparatus or circuits, and, in spite of its name, it is quite simple.

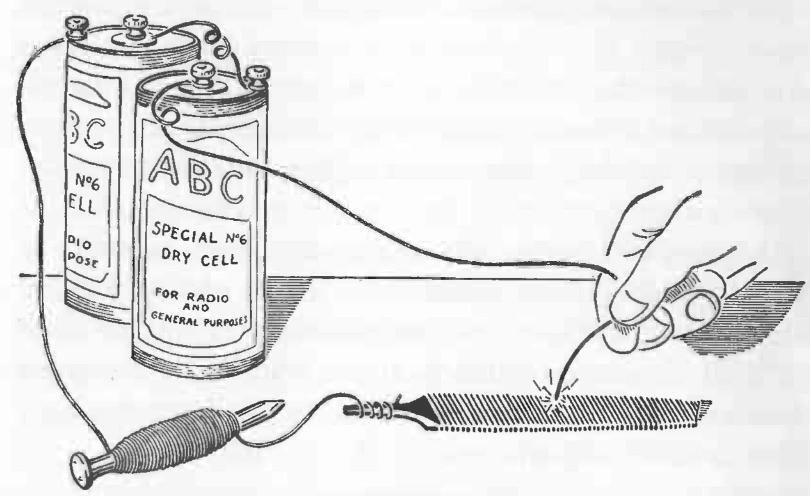
Do you remember "discovering a spark" back in the first part of Chapter IV? Do you remember the little sparks produced by scratching a wire across a file?

Try the experiment again. Then after you have particularly noticed the size and appearance of the sparks, include an electromagnet with an iron core in the circuit and try it again. *The sparks are larger,* they make a faint snapping sound. That is because the electromagnet has increased what is called the *self-inductance* of the circuit. A coil of wire

without an iron core adds self-inductance to a circuit but the effect is greatly increased when the coil has an iron core.

Here is an explanation. It will appear mysterious and complicated if you hurry through it, but study it slowly and it will really be simple.

When the battery current flows through the coil it builds



EXPERIMENT

Turn back to Chapter IV where this experiment was performed without the coil in the circuit. The wire wrapped around the nail makes the circuit obstinate and increases the size of the spark.

up a magnetic field. When the current ceases, so does the magnetic field. That you already know and understand.

But in ceasing to exist or collapsing, as it is called, the magnetic field moves in toward the coil. In so doing, it creates or *induces* a current of its own, a current which flows in the same direction as the original battery current. This induced current created by the collapsing magnetism tends to help the battery current continue to flow when the circuit is broken. It is largely responsible for the spark which is produced. Self-inductance means it *induces* a current *itself.*

A coil of wire has more self-inductance than a single wire and a coil of wire with an iron core has more than a coil without an iron core.

Self-inductance gives a circuit the characteristic of a heavy weight. It is like inertia. It opposes change. It tends to oppose the current and prevent it from flowing in a circuit as quickly as it would otherwise do. Then, when the current is stopped, self-inductance tends to help the current to continue flowing.

Do you know anyone who is *obstinate,* hard to start and hard to stop? Well, self-inductance is the *obstinacy* of an electric circuit. If you are a mule-driver you have to allow for a bit of animal obstinacy. If you want to be a capable electrical engineer you have to bear in mind the obstinacy of an electrical circuit.

Iron and an Alternating Current

The effect of iron in a circuit is greatly increased when the current is alternating. Since self-inductance opposes change, the iron opposes the rapid changes of the alternating current. It tends to "choke" the current. In fact a coil with an iron core which will permit a direct current to pass will sometimes completely choke or prevent an alternating current from passing.

You can see the choking effect of iron if you connect a twenty-five-watt 110-volt lamp in series with a spool containing about one pound of magnet wire. The wire may range

in size from No. 20 B. S. to No. 26 B. S. gauge. It should be wound on a wooden or fibre spool. Connect the spool and lamp to the 110-volt sixty-cycle A. C. The current flowing through the lamp must also flow through the coil of wire. The lamp will not burn to full brilliancy because the resistance of the coil cuts down the current slightly. The coil also has a slight amount of self-inductance which is effective in dimming the lamp.

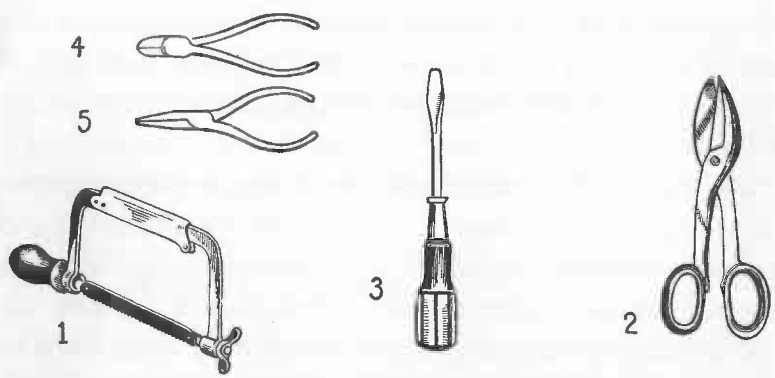
But thrust a steel screw driver or an iron rod into the hole in the spool so that it forms an iron core for the coil and watch the lamp. It will grow quite dim. The iron is helping to choke the alternating current. The combined resistance of the wire and its choking action are called *impedance.* When engineers design an electrical machine they can calculate how much impedance it will have before they actually build it.

An alternating current will pass through a condenser but direct current will not. It is therefore possible, by using proper condensers and impedance coils, to arrange some very useful and interesting circuits called "filters." Direct currents will flow through portions of the filter circuit but not through others because they are prevented by condensers. Alternating currents will flow where the direct current cannot go but are barred from the places where the direct current does flow by impedance coils.

XI

THINGS YOU SHOULD KNOW ABOUT TOOLS, WIRES, GLASS AND OTHER MATERIALS

Most boys know how to use a hammer, saw, chisel and plane and have enough skill with these tools to do a woodworking

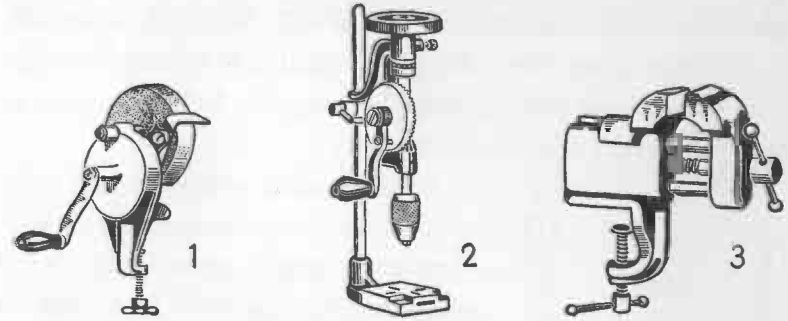


TOOLS FOR METAL WORKING

(1) Use a fine-toothed blade in the hack-saw frame. (2) Snips for cutting sheet metal. (3) Several sizes of screw-drivers are necessary. (4) Diagonal cutters. (5) Long-nosed pliers for bending wires.

job. Knowledge and skill in metal working are not as common.

Metal working is a slower process than woodworking. It requires more patience. In order to build your own apparatus it is not only necessary to be a woodworker but also to know



TOOLS FOR METAL WORKING

(1) Hand-driven emery wheel. (2) With a small drill press holes can be drilled more accurately than with a hand drill. (3) A vise is necessary.

how to use simple metal-working tools. It is necessary to cut, bend, drill, thread and solder metals.

A kit of fairly good tools for working in metal can be selected from the hardware counter at a "dime-store" at surprisingly little cost.

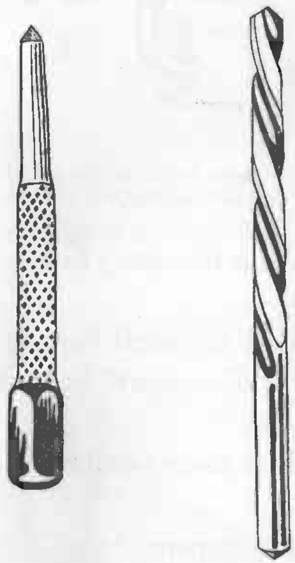
Here is a list of the tools most useful in making small metal parts:

Two and one-half inch Vise	A Micrometer
Hacksaw Frame with Blade	Six-inch Steel Scale
A pair of Snips	Soldering Iron
Hand-drill with Twist Drills	Center Punch
Small Taps	Small Cold Chisel
Tap Holder	Ball Peen Hammer
Small Dies	Files
Die Holder	Emery Wheel

Drilling

Small holes can be drilled in cast iron, soft steel and brass with a hand-drill. Care and patience are necessary. An attempt to force a small drill will usually break it, especially at the time when the point of the drill is breaking through. The piece to be drilled should always be held in a vise or firmly fastened with a clamp.

A small drill press can be purchased for $1.00. It is easier to drill accurately with a press than a hand drill because the drill is always in the same position relative to the hole. In simpler language, we might say the drill does not "wobble."



TWIST DRILL AND CENTER PUNCH

Some hand drills are fitted with a hollow handle containing a set of drills. Usually these are of the straight fluted type called "farmers" drills or the flattened and hollowed-out drills called "pods." They are suitable for drilling wood, fibre, hard rubber and soft materials but are unsatisfactory for metal. For metals, use ordinary twist drills.

Twist drills are arranged according to size in four different groups: Numerals, Letters, Fractions and Milliammeters.

The numerical and fractional sizes are the most useful to an electrical experimenter. The numerical sizes range from No. 1 (the largest) to No. 80 (the smallest). The fractional sizes vary by 1/64th of an inch.

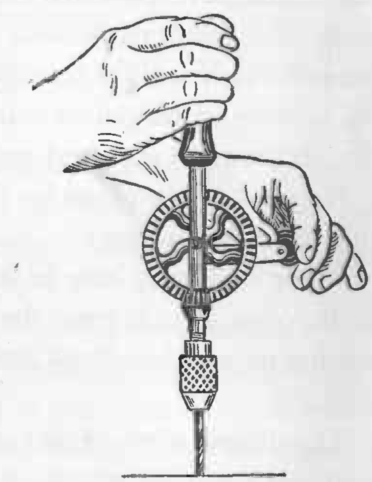
The table following shows the diameter in decimals of

those sizes of drills most useful in making the apparatus described in this book:

Number	*Size*	*Number*	*Size*
49	.073	30	.128
45	.082	29	.136
44	.086	28	.140
41	.096	21	.159
39	.099	19	.166
35	.110	11	.191
33	.113	10	.193

Measuring One-Thousandth of an Inch

A micrometer is also useful for measuring and identifying the various sizes of copper wires. It is an instrument for measuring very accurately. With it you can measure the thickness of a sheet of paper or the diameter of a hair. A micrometer such as used by machinists and tool makers costs $5.00. However, the "dime stores" sell a small die-cast micrometer for twenty-five cents. It will measure thickness or diameter up to one-half inch accurately to one-thousandth of an inch.



DRILLING

The piece to be drilled must be clamped down and the drill must not be allowed to wobble or be forced.

A micrometer consists of a frame, anvil, spindle, sleeve and thimble. One turn of the spindle opens or closes the micrometer opening 1/40 or 0.025 of an inch. The marks on the sleeve show the number of turns the screw is moved. Every fourth graduation is marked, 1, 2, 3, 4, etc., representing 1/10 of an inch or 0.100.

The table below shows when a lubricant on the drill is advisable and what it should be:

Material to be Drilled	*Lubricant*
Brass	None
Cast Iron	None
Soft Steel and Wrought Iron	Lard Oil or Machine Oil
Aluminum	Kerosene

The spot where a hole is to be drilled is located by scratching an X with a sharp-pointed tool or "scriber." A large darning-needle set in a wooden handle makes a good scriber. Then an indentation is made with a center punch and hammer at the exact center of the intended hole. The point of the drill is fed into the center punch mark. The mark starts the drill cutting in the right spot and prevents it from "walking."

No rules can be given for the speeds at which drills should run more than to say:

When making a hole in steel, the drill should run slowly. In the case of cast iron, the speed may be greater. A drill cutting its way into brass should turn faster than for iron or steel.

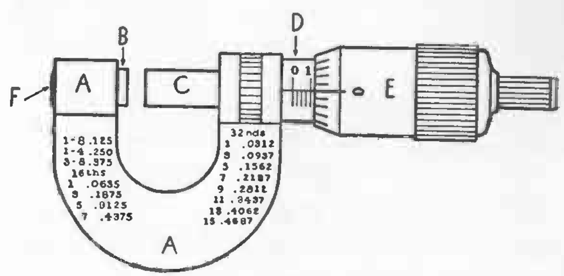
The larger sizes of the numerical drills have the size stamped upon the shank. In order to identify the smaller sizes, it is necessary to measure them with a drill gauge or a micrometer.

The thimble has a beveled edge divided into twenty-five

parts numbered 0, 5, 10, 15, 20 in groups of five. Each mark means $\frac{1}{1000}$ or 0.001 of an inch.

To Read the Micrometer

To use a micrometer it is merely necessary to turn the spindle until the wire or object to be measured is gently



SMALL MICROMETER

(*A*) Frame. (*B*) Anvil. (*C*) Spindle. (*D*) Sleeve. (*E*) Thimble. (*F*) Adjusting screw.

clamped between the anvil and spindle. Multiply the marks on the sleeve by twenty-five and add the graduations on the edge of the thimble. The answer is the thickness of the object in *one-thousandths of an inch.*

Embossed or engraved on the frame of the micrometer are the decimal equivalents of small fractions. You can of course find out the decimal equivalent of any fraction by dividing the numerator (the number above the line) by the denominator (the number below the line).

The following table shows the diameter of the various sizes of wire from No. 16 to No. 30 Brown and Sharp gauge. The diameter is given in decimals of an inch so as to indicate thousandths. With the aid of a micrometer and this table you can identify any size of wire from Nos. 16 to 30.

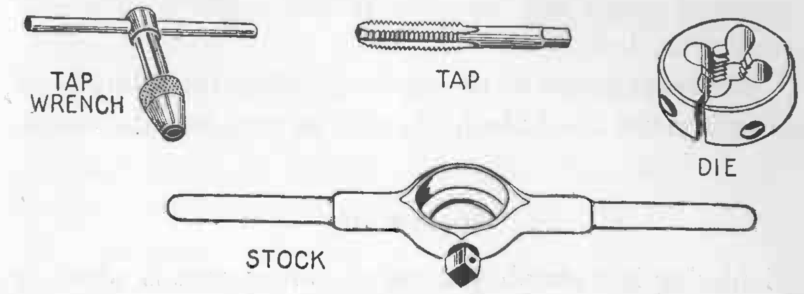
Gauge B. & S. No.	*Diameter in Decimals of an Inch*	*Feet per Pound*
14	.064	80
15	.057	101
16	.050	127
17	.045	161
18	.040	203
19	.035	256
20	.034	323
21	.028	407
22	.025	514
23	.022	648
24	.020	817
25	.017	1031
26	.0159	1300
27	.0141	1639
28	.0126	2067
29	.0112	2606
30	.0100	3287

THREADS

Screw threads are easily cut on metal rods of small diameter with the tool called a threading die. The die fits into a holder or handle called a stock. Small holes are threaded with a tap.

The most common threads used on small electrical parts

are machine screw sizes and are shown in the table below. The first number indicates the size or diameter and the second number the turns or threads in an inch. For example, an 8–32 (pronounced eight thirty-two, not eight thirty-seconds) thread means a diameter or size of a No. 8 machine screw



TAPPING AND THREADING TOOLS

and 32 threads for each inch of length. This size happens to be the one most commonly used on dry cells.

The table also shows the "tap drill" and "clearance drill" sizes for each thread. The clearance drill makes the smallest hole each particular size of screw will slip into.

The tap drill is the proper size to use when a hole is to be threaded.

Size	*Threads per inch*	*Tap Drill*	*Clearance Drill*
2	56	49	44
3	48	45	39
4	40	41	33
6	32	35	28
8	32	29	19
10	32	21	11

Holes are threaded by means of a tap, held in a tap wrench. It requires care and practice to cut good threads. The secret lies in not forcing the tap or die to cut too fast. It should be advanced only about one-half a turn, "backed off" or reversed one-quarter of a turn, advanced a half turn, backed off again and this slow process repeated until the thread is finished.

Oil is not required on the tap or die when threading brass or cast iron but should be freely used on steel and aluminum.

Soldering

Soldering is a simple process of joining metals which is easy to accomplish when you understand the principle.

To solder small parts, a soldering iron, flux and solder are required. A small blowtorch is helpful but not necessary. Wire solder is most convenient for small work.

An electric iron is the most desirable, but of course is impracticable where there is no electric power available. An old-fashioned soldering "copper" heated by a blow torch must then be used.

There are four steps in soldering.

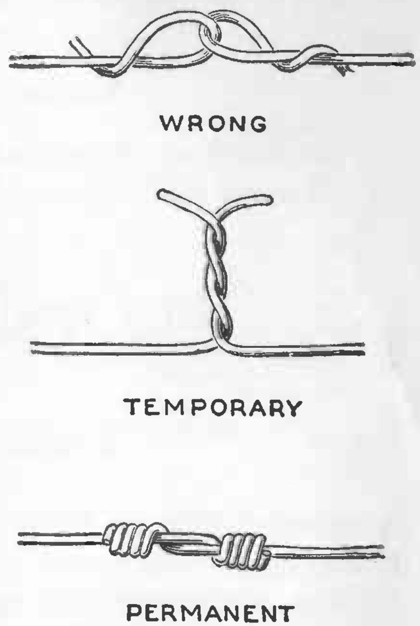
1. Cleaning the metal
2. Applying the flux
3. Heating the metal
4. Applying the solder

Solder will flow or stick only to bright, clean metal from which all dirt, scale, oxide and grease have been removed. For that reason it is necessary to scrape the surface of the

metal until it is bright and clean at the point where it is to be soldered. The best tool for this purpose is the blade of an old pocket knife.

The flux removes and prevents the formation of oxide on the surface of the metal during the operation of soldering and allows the solder to flow readily and unite more firmly with the surfaces to be joined.

The kind of flux to use depends upon the particular job to be done. Rosin is the flux for small wires, springs and delicate parts because soldering pastes and acid fluxes are slightly corrosive. An acid flux is necessary when soldering steel.



SPLICING WIRES

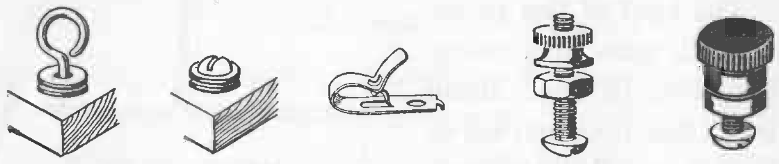
Powdered rosin may be bought at a hardware store, plumbing shop or even a drug store. Soldering paste comes prepared in small cans.

The surfaces to be soldered should be coated with a thin film of flux and the hot soldering iron applied. A drop of solder is then rubbed over the surfaces with the hot iron. It should melt and spread out or "sweat" into the metal. Then more solder can be added until enough has been applied to make a strong joint.

An electric soldering iron will automatically raise itself to the proper temperature. The proper heat for a soldering copper is discovered only by experience. The copper must be hot enough to melt the solder readily but not too hot or the point of the iron will become corroded and covered with scale.

Splicing Wires

If you watch an electrician when he connects two wires, you will notice that he scrapes them first. He also solders all



BINDING POSTS

connections which are to be permanent. He does both of these things in order to make a good connection—a connection which will not offer resistance to the electric current.

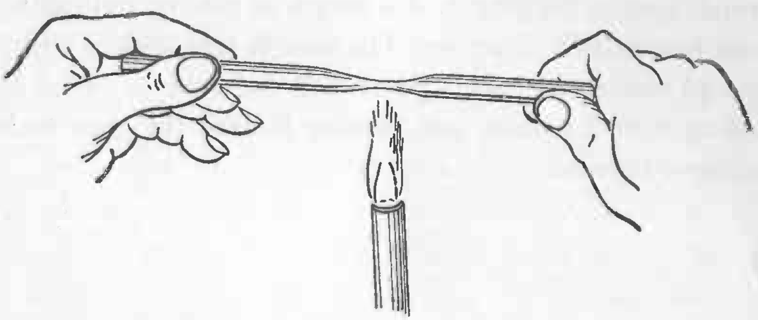
Metal surfaces become coated with a layer of oxide. The oxide cannot always be seen but it is present in the form of a thin film that offers considerable resistance to a current. Scraping with a knife or file removes the film so that wires, etc., are brought into more intimate electrical contact.

Twisting two wires together is called *splicing*. There are a wrong way and a right way of doing almost everything and splicing is no exception. The right way to splice makes a strong, low-resistance connection. The wrong way makes a loose, high-resistance connection.

Binding Posts

Binding posts are a convenient means of connecting wires to electrical instruments.

The knurled thumbnuts from old dry cells are excellent



CLOSING THE END OF A GLASS TUBE

binding posts when fitted with an 8–32 brass screw and hexagonal nut.

Two methods of making your own binding posts are illustrated. The screws, screw-eyes, washers, etc., should be brass. If iron, they will not establish a good connection.

Glass Tubing

Glass tubing or rods of small diameter may be easily cut to length by filing a small nick at the point where it is to be broken. It can then be snapped off by breaking it as if it were a stick.

The sharp edges of tubing or rod may be removed by holding in the flame of a bunsen burner or blow torch for a few seconds.

Tubing may be bent or even drawn down to smaller diameter by heating in a gas flame. The trick is to keep turning the tubing so that it is heated evenly on all sides.

The glass bearings for the motors are made by heating a small spot in the center of a length of tubing and pulling it out to a smaller diameter. The tube is then nicked with a file and broken in half. The end of the tube is closed by holding it in the flame and turning it until the glass melts and flows together.

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