American Boys' Book

of

Electricity

By

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PHILADELPHIA

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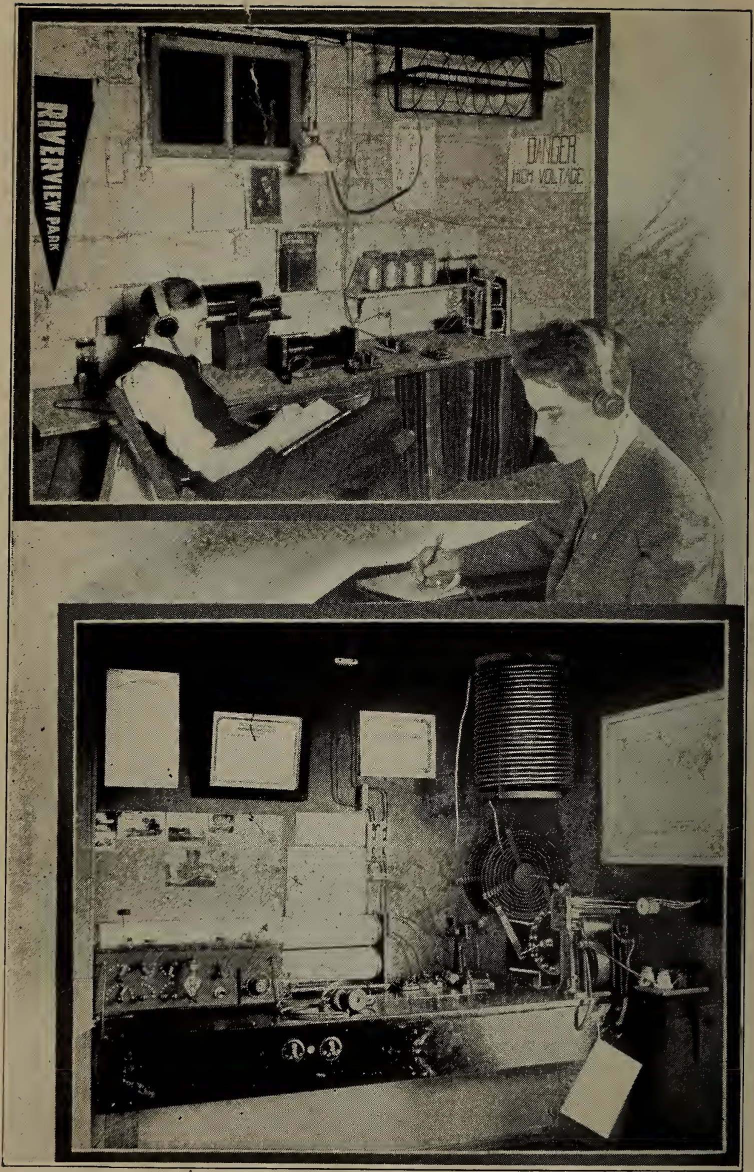

Two wireless outfits built by boys.

Frontispiece.

(Courtesy of the "Electrical Experimenter.")

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PREFACE

There were once two boys who were neighbors; both were about the same age, interested in the same things, and one neither any brighter, healthier, nor more energetic than the other. The main difference was that one lived in a big house and the other in a cottage. That is to say, one had spending money in plenty, the other had to scrape pretty closely for his dimes.

Their interest in telegraphy resulted in plans for a telegraph line between the big house and the cottage. Each boy was to supply his own instruments—the expense of the lines was to be divided.

All this was simple for the boy of the big house. He bought a sounder, key, batteries, and put aside a little money for the line; his end of the work was done. For the chum of the cottage every dollar spent meant many hours of hard work. He planned for days—then bought a few ounces of insulated wire. There was hammering and filing and activity in the basement of the cottage for a week after the instruments in the big house were all ready for business. When the last joint was soldered and the last screw driven home the boys were again equal. The cottage boy had made with his own hands the things he needed.

If you count the labor and thought and planning the home-made set required, it cost many times the sum paid out for the nicely finished instruments, but the roughly made key and magnets were worth the highest sum they could be valued at. Aside from learning how to build an instrument, the cottage boy had learned how to use his hands and his head—the boy of the big house learned only how the instruments looked, how they were connected, and how they worked.

The boy of the big house and his chum of the cottage are typical American boys; the boy who has things done for him and the one who does them for himself. It is easy to guess which one has the most fun. How much quicker the rainy, stay-at-home days pass by for the fellow who always has some interesting piece of work on his mind; how much better equipped for life's work he becomes. The question of what to do with yourself won't come up very often when you have a job of magnet winding or battery building in the basement or workshop.

Electricity offers a wonderful field for the boy who wants to know its hows and whys. Experiments without end can be made with the simplest sort of apparatus. With just such cheap material many of the greatest experiments have been made, and it is certain that fields just as great are still undeveloped.

As to cost: there are some cases where the expense for brand new material will come to more than the selling price of a tested piece of apparatus. Insulated wire and platinum contacts are not cheap in any sense. Even with this in mind, the time and money spent in making your own apparatus is well invested. New material is not always necessary either, for you can secure zinc and carbon from old batteries. They also supply good binding-posts. New wire should be used where it is at all possible to secure it. So much depends on this item that taking chances hardly pays.

In making drawings for the pages of this book the idea has been more to illustrate the principle and appearance of the finished article than to supply exact dimensions. With many of the articles a quarter or half an inch one way or the other except on actual working parts would hardly matter, so long as the parts were made square and fitted well. It is often better to use a little ingenuity and apply the material you have at hand rather than to try to build exactly to some fixed dimensions.

If through such changes and experiments any original apparatus is built by the reader, the author will feel more than repaid for the thought and effort put into this work.

You boys who read it, and love, as the writer did at your age, to work with tools, may develop into engineers. Some will desert science to become lawyers, merchants, and business men, but all are alike in being American Boys who will soon be American Men. As such you owe to yourselves the trained hands that work skilfully with trained minds. This is learning that profits in every walk of life.

Charles H. Seaver.

Chicago, *January 11, 1916.*

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CHAPTER I

Magnetism and Magnets

The magnet is the father of all our modern electrical apparatus, and it is very old. It is known to have been discovered at least 2500 years ago, for in 585 B. C. a Greek named Thales wrote of the lodestone, or natural magnet: "The stone has a soul, since it moves iron." This is the first known record of the magnet.

Many scientists put the date much earlier than Thales' time. There are many stories of the wonderful discovery. One is that when a shepherd named Magnus was guarding his flocks on the slopes of Mount Ida, in Greece, he found that the iron ferrule of his staff and the nails in his shoes clung to certain rocks. He told of his discovery and showed the stones, which were in time named Magnet stones or "Magnets," after their finder. A more popular belief is that the name at least was taken from the city of Magnesia, near which many such stones were found.

The lodestone about which Thales wrote is an oxide of iron called magnetite. It is very heavy, black in color, and is now somewhat rare. These stones were the only magnets known for centuries. The source of their magnetism is even now unknown. The effects were, in the dark ages, believed to be wonderful. Lodestones were offered as remedies for gout, rheumatism, and many other diseases. Their first real service was to make possible the discovery of the compass.

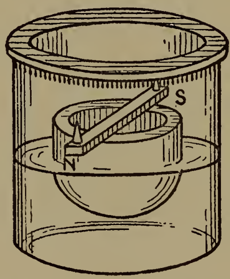


Fig. 1.—An early compass.

Stories of the compass are as varied as those of the lodestone. The Chinese are said to have had one variety as early as 1000 B. C. This was in the form of a little idol turning on a pivot and mounted on a cart. The lodestone was fitted in its hand so that the image always pointed northward.

If a compass did exist that long ago it must have been forgotten for many years. In 1180, over 2000 years later, Alexander Neckham, an English monk, wrote the first description of the mariner's compass.

The first real compasses were made of iron needles thrust through bits of wood, and floated in vessels of water. These were only used on shipboard when the weather was cloudy or foggy, so they were plainly not very reliable. The needles were not permanently magnetized, and had to be rubbed with a lodestone each time they were used.

Fig. 2.—Card of mariner's compass.

From these crude compasses the terms north pole and south pole originated, as used with a magnet. By north pole we mean the north-pointing pole, and by south pole, the south-pointing pole. Every lodestone and every magnet, whatever its shape, must have these two poles.

As in other electrical devices, there has been a great improvement in nautical compasses. Modern ones are delicately balanced, and are hung so that they are always level no matter how the ship may roll. In these the magnet is not visible, for it is covered by the compass card, marked with all the divisions. As the card is carried by the needle it indicates directly every point of the compass.

Even these perfect instruments do not point exactly north, for the magnetic poles of the earth are not at the geographic north and south poles. The magnetic north pole is really about 1400 miles south of the geographic pole; so the compass needle of a ship is seldom pointing due north. There is a line, however, along which the compass is correct. This is called the Agonic line. In the United States it passes through Charleston, S. C., Columbus, O., and Lansing, Mich. In these and the other points on the Agonic line the compass is correct.

The location of the Agonic line is not permanent, for the magnetic pole is constantly moving. This movement is carefully watched by the government, so that proper allowance may be made. A full movement of the pole takes about 320 years.

The compass has another motion. This is magnetic dip. If you were to start at the equator with a perfectly balanced compass, free to swing up and down instead of around, you would find that it tipped as you came near the magnetic north pole. This discovery was made by an Englishman named Robert

Norman, who described it in 1576. The unbalancing pull on the mariner's compass is now taken care of by a sliding weight on the frame which carries the needle.

EXPERIMENTS WITH THE MAGNET

A horseshoe or bar magnet will enable you in a few minutes to gain at first hand the knowledge which the

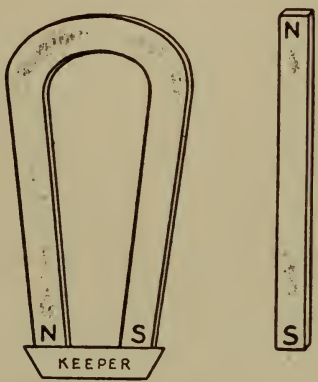


FIG. 3.—Horseshoe magnet and bar magnet.

discoverers were centuries in collecting. One of these can be bought at any toy store. For our purposes the bar magnet is better, as the poles are separated.

Fig. 4.—Magnetizing a needle.

Fig. 5.—Needle and iron filings.

Rub a large steel needle with one pole of the magnet; a knitting needle or darning needle will do. Rub only one end, and always stroke away from the center. After a dozen strokes or so bring the needle near to some iron filings. Two things are at once apparent: First, you have made a magnet attracting equally at both ends; second, the pull is much stronger at the tips or poles than anywhere else.

Now put this same needle through a cork, and let it float in a large china or glass dish of water. When it comes to rest it will point north or, rather, to the north magnetic pole. This is the early form of compass. The pole pointing north is the north-seeking pole, the opposite one the south-seeking pole.

Bring your magnet toward the needle, and the balance is at once disturbed. One end of the needle will follow the magnet. Reverse the magnet and the needle turns end for end. If the pole you brought toward the needle was the south pole, the needle's north pole was attracted. Unlike poles always attract; like poles repel. This was one of the greatest of the early electrical discoveries, and was mentioned by Dr. Gilbert, who was Queen Elizabeth's physician, and who made many electrical experiments.

Robert Norman's experiment showing magnetic dip may be easily performed just as done by its originator. Cut out a ball of cork as nearly round as possible, and large enough to float a darning needle. Run the needle through until it just balances. Then cut the cork down bit by bit until it just floats the needle. If too much is taken off add a teaspoonful of salt and it will float again. Now magnetize the needle by rubbing it with the magnet. The needle does not float evenly now; its north pole tips toward the earth's north magnetic pole.

This same floating needle will show the attraction of unlike poles, and the repulsion of like poles. A fish made from a cork, with the needle entirely hidden

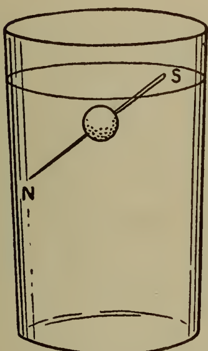


Fig. 6.—Robert Norman's experiment.

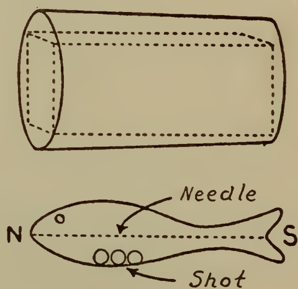


Fig. 7.—Fish cut from cork.

and a few shot to weight it down, seems almost as active as if it were alive.

Attraction becomes much stronger as the magnet is brought nearer to a piece of iron or steel. At 6 inches from the floating needle or magnetic fish the attraction would be slight. At 3 inches it would be four times as great, and at 1 inch thirty-six times as great.

Neither the glass nor the water makes the slightest difference in this attraction. To illustrate this in the Norman experiment, lay your bar magnet on a book about 2 inches away from the needle. The needle tips toward the magnet. Now place a piece of wood, glass, or paper between magnet and needle. There is no change in the inclination. Now put a piece of tin or iron in place of the other substance.

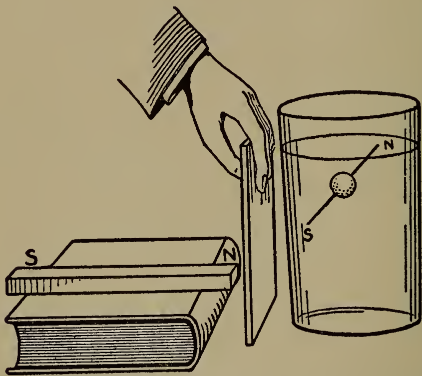


Fig. 8.—Showing how lines of force pass through glass.

At once the dip becomes less. The magnetism has been screened by the iron.

This screen effect is used in many ways. Watches carried in power stations are sometimes made with an inner case of soft iron. Instruments to which magnetism would be harmful are inclosed in iron boxes.

Attraction and repulsion can be well shown also by bringing a magnet near a suspended needle which has been magnetized.

By putting pieces of glass or books between magnet or needle you will see that the action is the same whether they are there or not.

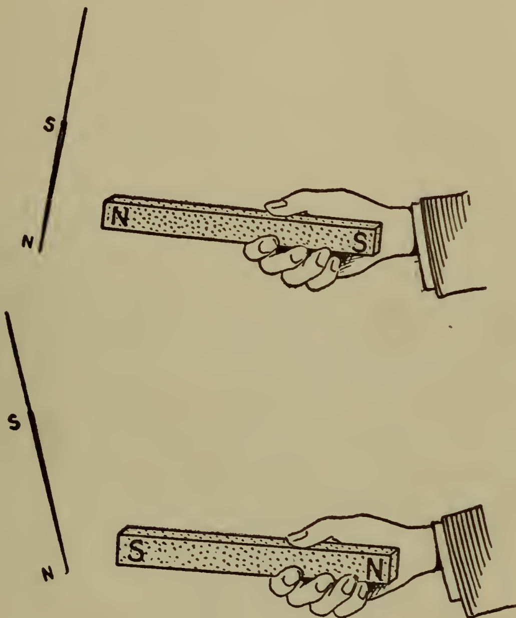


Fig. 9.—Attraction and repulsion.

MAGNETIC FIELD

As the magnet need not touch the needle to influence it, you can see that there must be something which reaches out and does pull or push the needle around. The strength of a magnet is said to be in the "field of force" that surrounds it. This field is made up of countless invisible lines of force.

Anyone can trace these lines easily with the help of a few pinches of fine iron filings.

To do this lay a clean piece of cardboard over the magnet, dust the filings on it, and then tap the cardboard gently with your finger. By trying this experiment with the magnet in several positions you can form an excellent idea of just the way the lines are arranged. These are the lines that attracted and repelled the

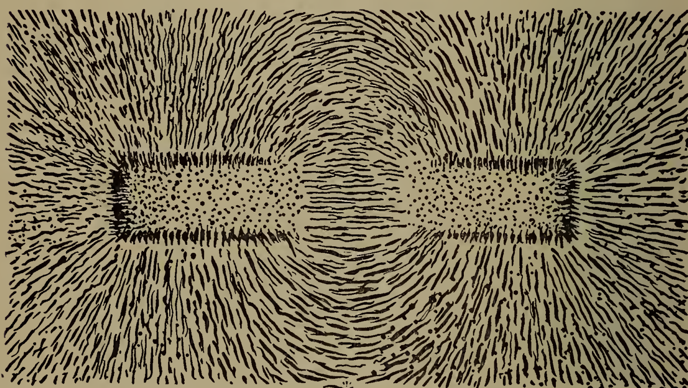


Fig. 10.—Magnetic field of bar magnet.

needle. They pass through wood, paper, lead, and practically every substance but nickel and iron as freely as rays of light go through a window-pane.

A sheet of iron placed near the magnet offers such an easy path to the lines that they do not reach beyond it at all. The sheet of iron, however, becomes slightly magnetized. This is called magnetism by induction. A good example of this sort of magnetism can be shown with a few small tacks. Arrange six or seven tacks end to end in a row, and the magnet will pick them all up. A temporary magnet has been

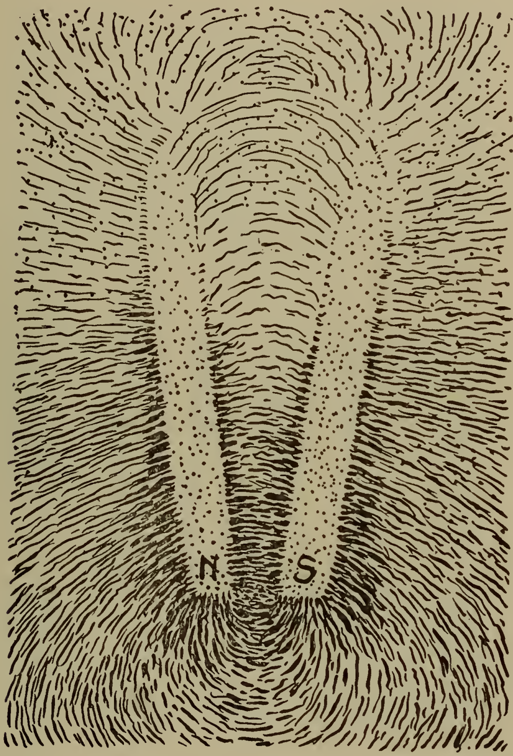


Fig. 11.—Magnetic field of horseshoe magnet.

made of each tack. It carries the lines of force to pick up the next in the chain.

A magnetized needle free to move in all directions always takes a position following the lines of force as closely as possible. This can be proved by laying a pocket compass on the piece of cardboard where the iron filings have been allowed to follow the lines. If

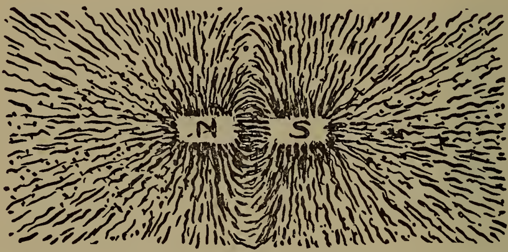


Fig. 12.—Field at poles of same horseshoe magnet.

the magnetized needle was very short and perfectly free to turn in any direction it would be possible to draw a map of the magnetic field of any magnet.

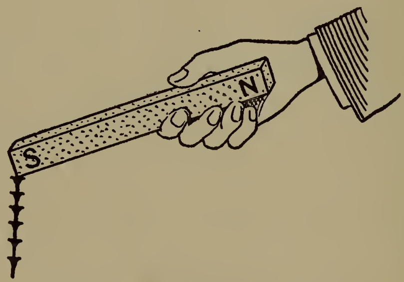


Fig. 13.—Magnetism by induction.

This would correspond quite closely with the one obtained by the filings.

It was through the action of iron filings that an Italian named Cabaeus first discovered the lines of force in 1629. He called them the "magnetic spectrum." The idea of lines came to him because the fine iron filings stood like hairs on the poles of the lodestone. He believed them to be straight, instead of curved from pole to pole as the cardboard experiment shows.

The earth itself is a big, but weak magnet. Its lines of force stretch 4000 miles unbroken, but have only enough strength to turn a delicately poised magnet or compass needle. Since opposite poles attract, it seems strange that the north pole of the needle points to the north magnetic pole. In reality, the proper naming of the north-pointing tip would be the south pole. But the tips were named before anything was known of the attraction of unlike poles. To avoid confusion, especially among sailors, the north-pointing pole has always been called the north pole.

MAGNETIC MATERIALS

Permanent magnets are all made of tempered steel. Something in its structure enables it to hold the magnetism. Soft iron will stay magnetized only a very short time.

Scientists explain this difference by a peculiarity of the molecules in the two metals. The molecules are the very small particles of which the metals are made up. For convenience we will imagine them large enough to be seen. In unmagnetized iron or steel they point in all directions.

Bring a magnet near to a bar of iron, and every molecule swings toward it as so many compass needles would. Each molecule has a north and south pole. Every one is magnetized by induction. The north

Fig. 14.—Effect of magnetism on iron or steel bar.

poles are all pointing in one direction and the south in the other. Take the magnet away and all the particles swing back helter-skelter. The bar lòses its magnetism quickly.

The molecules in a bar of hardened steel are stiffer. They turn with difficulty. If the steel is the right kind, and time is given to rubbing it with a magnet pole, the molecules are in place to stay, and will not swing back

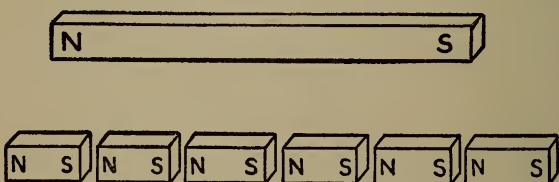


Fig. 15.—Many magnets could be made from one.

unless the bar is heated or jarred. These little molecules are so firmly fixed in a good bar magnet that it could be sawed in a dozen pieces, and each one would have a north and south pole, just as the unbroken bar did.

A simple comparison of materials may be made by rubbing first a piece of soft iron wire and then a steel knitting needle with one pole of a magnet. Be sure to rub always in one direction—away from the center, and with one end of the magnet. Now dip the iron wire in the filings and you will find that only a few cling to it; a good many more will be picked up by the steel needle. Half an hour later the iron wire will have lost all its magnetism, while the steel needle will be as good as ever for a long time.

Although steel makes the best magnets, it is not the only magnetic material. It offers a very easy path to the magnetic lines and is called Paramagnetic. Other Paramagnetic metals are nickel, cobalt, and manganese, but they are all so far below steel that no use is made of their magnetic quality. Metals offering resistance to the magnetic lines of force are called Diamagnetic. Phosphorus, bismuth, zinc, and antimony are all Diamagnetic.

To make a permanent magnet from a bar of steel first make sure that the bar is tempered to the proper hardness. This can be decided by testing it with a file. If the file cuts it easily the bar should be heated to a red heat and dropped into water. This will make it very hard. When cooled, lay the bar on a table and rub one end with the north pole of a strong magnet. The opposite end should then be rubbed with the south pole. Always rub in one direction—away from the center.

To preserve the magnetism in this or any magnet care should be taken to protect it against several things known to destroy magnetism. Never pound or hammer a magnet. To guard against rust the bar should be painted or shellacked within ½ inch of each end. It has been found that most of the magnetic effect is in the outer surface of the bar. When the surface is pitted with rust or eaten with acid most of the magnetism is lost.

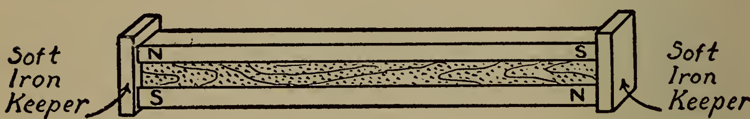


Fig. 16.—Pair of bar magnets with "keepers" in place.

Horseshoe magnets are usually furnished with a piece of soft iron called a keeper. This should always be kept in place when the magnet is not in use. It furnishes an easy path for the magnetic lines between the poles and in some way retains the strength of the magnet.

Bar magnets should be kept in pairs. They should be put side by side with a thin strip of wood between. The north pole of one should be near the south pole of the other. A keeper of soft iron put at each end of the pair of bars retains the magnetism just as the single keeper does in the case of the horseshoe magnet.

CHAPTER II

Static Electricity

"Static" is a word derived from Greek, meaning to stand, or remain motionless. Static electricity is really standing, or motionless electricity. It might well be called "universal" electricity, for it is everywhere. There is static electricity on the trees, the grass, the piece of paper you pick up, the book you are

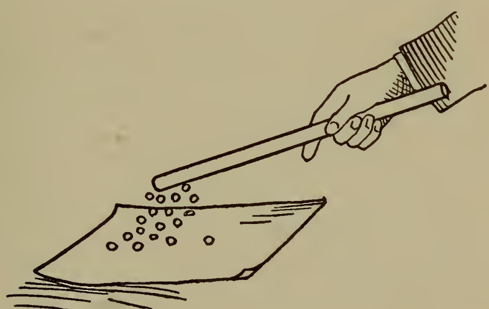


Fig. 17.—Attracting bits of paper with electrified sealing wax.

reading. This common form of electricity escapes our notice because the amount is usually so small. Some action is necessary to draw it to our attention.

An extra accumulation of electricity is easily caused by rubbing. Rub a hard rubber comb on your sleeve and you will find that it picks up bits of paper just as the magnet attracts pieces of iron. Every boy has noticed the sparks that come from rubbing a cat's fur when the cat is dry and warm. Here the accumulation of static electricity is marked both by an attractive effect, for the hairs rise to meet your hand, and by a slight crackling noise. If dark enough there is a third result. This is the appearance of small sparks.

It was from the simple attractive effect that the word electricity came. Elektron is the Greek word for amber, with which the strange attraction was first noticed. Amber is petrified resin, and is used now for pipe-stems, beads, and ornaments. It is found now mainly on the shores of the Baltic Sea.

Probably the electrical properties of amber were known long before lodestones were discovered. The Greeks loved jewelry, and the beautiful sunlike amber was used as a head ornament thousands of years ago.

In Syria women used amber spindles on their spinning wheels. They noted its attractive quality early. When their spindles turned they seemed not only to grasp bits of wool, but to hold them fast. From this property came the Syrian name for amber. They call it "harpaga" which means "the clutcher."

Static electricity has not a general use. Its great value has been in the promotion of experiments, and in creating interest in electrical matters. The many laws discovered are of use in helping us to make proper devices to protect machines and property, even life, against the effects of static electricity. The one great use of this form of electricity is in the operation of the Trans-Atlantic cables, which have become somewhat less important since the perfection of wireless telegraphy.

The little sparks seen on a dry day after one's feet are shuffled along the carpet are quite different from the ones visible at night when the trolley pole of a street car strikes a joint in the wire. They are both electricity, it is true, but one is the static form, while the other is always in motion. There is a relation between the two, but static only plays, while "current" electricity is the everyday worker.

At first the relation between magnetism and static electricity was thought to be very close. Experimenters held that both magnet and amber acted alike, except that the magnet received its power from the Arctic regions, while that of amber come from the Antarctic. It was not until Gilbert's time that electricity was found to be present in other materials. The idea before that was that amber alone would attract light materials when rubbed. Gilbert found that sulphur, glass, resin, diamond, and many other materials had the same property. This astonishing discovery was the first step toward the electrical science of to-day.

Gilbert's first instrument was a light pivoted needle. It showed the attraction of amber and the other substances by turning strongly when brought near to them. A needle of this sort can easily be made from a slip of paper folded and supported on the point of a needle. When a rubbed piece of glass or rubber is held near it, it behaves much as the compass needle did. This is a simple "paper electroscope."

Gilbert is often called the father of electricity. After his experiments, trials with rubbing glass and

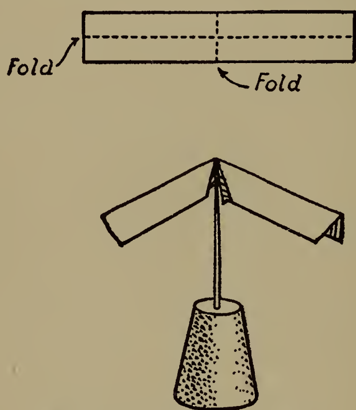


Fig. 18.—Paper electroscope.

drawing sparks became almost a craze in England, Europe, and even America. Nearly 140 years later the discovery was made in France by Dufay that there were really two kinds of static electricity. It was found that a rod of amber or resin hung from a string was pushed away when another piece of rubbed amber was brought near. When a piece of rubbed glass was brought near there was a strong attraction. One kind of electricity was called resinous; the other vitreous, or glassy.

With a glass rod made in something the same way as the little paper needle, the difference between these two electricities can easily be seen. The glass rod should be 6 or 8 inches long. First balance it carefully to find the center; then cut through one side with a small three-cornered file. Now the tube can be pivoted on a needle stuck in the cork of a dry bottle.

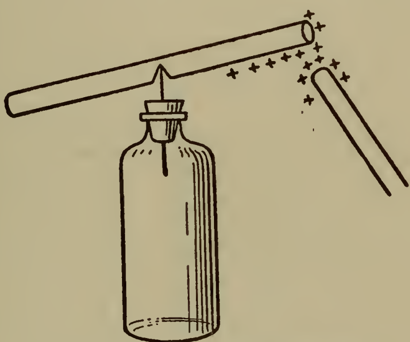


Fig. 19.—Repulsion of like charges.

When a piece of sealing wax is rubbed and brought near, the rod is attracted. If a glass tube is then rubbed and brought near, the pivoted tube swings away. In modern terms the glass rod is said to be "positively" electrified, while the wax is "negatively" electrified.

The balanced rod shows that like charges repel and unlike ones attract, in just the same way as the like and unlike poles of the magnet behaved.

The rod need not touch the needle to attract or repel it, and the needle is itself magnetized merely by the approach of the electrified body. This discovery was made by an Englishman named Gray in 1728. He found that an electrified body made another body electric by induction, and that all materials could be electrified in this way. Even red-hot coals behaved like amber. To be charged, however, the material must be supported or hung by an insulating material. Glass, mica, silk, paper, and such materials he found to be insulators or *non-conductors*, while all metals are *conductors*.

Gray's materials were at first even simpler than most boys can now have. Bits of twine, glass, resin, tin, and such material made up his whole "laboratory." They were enough to prove that a conductor actually carried electricity. He tried his experiment with a long piece of twine, which was a conductor, supported by silk thread, which is an insulator. Another experimenter in Germany tried to see how fast the charges traveled. He supported a long loop of string by silk threads and charged one while he watched the other. A few pieces of gold leaf put at the far end of the cord were to indicate when the charge had traveled the length of the string. After many tests he announced that the movement was instantaneous. Little wonder that Gray formed this opinion from his crude apparatus, for the charge travels with exactly the same speed as light. The exact figure is 186,213 miles per second. In a single second, then, a flash of electricity could go around the world seven times.

About thirty years after the discovery of the two kinds of electricity came one more wonderful still. Benjamin Franklin startled the world by proving that the sparks made in his laboratory were exactly the same as lightning. His experiment was as wonderful as it was dangerous. Several scientists had already ventured that lightning and electricity were the same, but none had thought of a way to prove the belief. The French came nearest with a tall iron rod which gave off sparks during thunder storms. Beyond doubt the rod became electrified during thunder storms, but as it did not reach even the lowest clouds there was no proof that the sparks they received were actually lightning.

Franklin had thought of this experiment even before it was tried in France. For his plan a high steeple was necessary; and there was not even a church steeple in all Philadelphia. An idea bolder than his first came to him. He could reach the very heart of the cloud with an ordinary kite. If lightning was electricity the cord would become charged.

The kite that Franklin flew was made of two light strips of cedar with a thin silk handkerchief stretched across and fastened at the corners. At the top of the upright was a sharp wire about a foot long. The cord was ordinary twine, but to this was fastened a piece of silk ribbon and a key. As silk is an insulator it would give some protection, while the conducting key would serve to draw sparks from—if sparks came.

With his only son, a young man of about twenty-two years of age, he went out into an open field in a gathering storm. The wind came in gusts, and the rain began to fall while they were preparing the kite for its trial. Lightning flashes from the dark low clouds came nearer and nearer. The kite was wet and rose sluggishly in the fitful wind. With thunder crashing around them. and drenched by the rain, Franklin and his son went under a shed for protection. The kite had disappeared in the cloud and the mist. The critical point of the test was near, and both watched cord and key. Suddenly they saw the little loose fibers of the string separate themselves from the kite cord and each stand erect. The time for the trial had come. Franklin put his knuckle near the key. As his hand came near the metal there came a crackling sound. A little spark jumped across the gap. It was the same little spark in every way that he had seen in his laboratory thousands of times. His experiment was successful and his name immortal. Lightning and electricity were the same.

This discovery was then considered the end of electrical knowledge, as the last secret had been solved. As we now know, it was only the beginning.

APPARATUS FOR EASY EXPERIMENTS

With the three pieces of apparatus described many experiments can be made. These are the Electrophorus, the Electroscope, and the Leyden Jar. The sparks secured will not be large, but will permit a study of static electricity.

THE ELECTROPHORUS

Melt enough resin and sealing wax, using two-thirds resin and one-third sealing wax, to fill a large pie tin. This mixture should be melted in a tin cup held in boiling water; if held over a flame it is apt to catch fire. When thoroughly melted and mixed pour it in the tin and allow it to cool slowly.

In the center of another pie tin about 2 inches smaller solder a flat-headed brass wood screw, which has first been screwed into a wooden plug as shown in the diagram. This plug should be whittled to fit tight in the neck of a bottle. An ordinary pint milk bottle will serve very well. If desired the plug can be coated with shellac and the bottle put on to dry in place. The electrophorus is now complete. You have made a simple machine for generating static electricity.

To use the electrophorus first rub the resin briskly with a piece of flannel. Then take the small tin by its glass handle and set it gently in place on the resin cake. Now touch the two tins at once with the thumb and finger of one hand. Lift the small tin again by its glass handle. On touching the pan a small spark is seen.

The action you have caused is this: First, the surface of the resin was charged negatively by rubbing, and the positive charge was driven into the metal pan. Second, the smaller pan was electrified by induction when placed on the resin cake. The tin does not rest evenly on the resin, but touches it at thou-

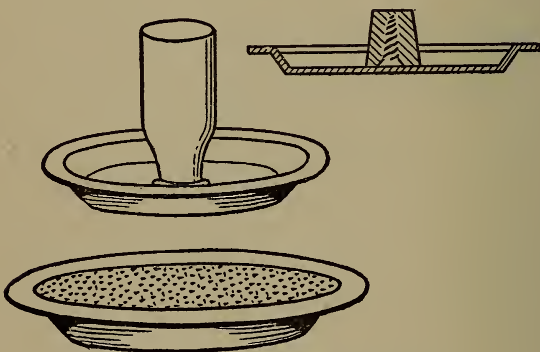


Fig. 20.—A "pie-tin" electrophorus.

sands of little points. This contact is so light that the negative charge does not escape to the upper tin. On the contrary, it induces a positive charge on the lower surface of it and drives the negative electricity to the upper surface. Touching the two tin plates with thumb and finger allows the negative charge to escape to the bottom tin and the earth. The positive charge is held, and cannot escape. When the plate is lifted it is positively charged.

This charging may be repeated many times without rubbing the resin again.

THE LEYDEN JAR

The only material needed to make a Leyden jar is an ordinary jar of good clear glass, some tin-foil, a piece of brass curtain rod, a small brass knob, and a piece

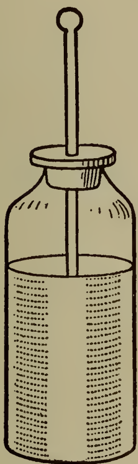


Fig. 21.—Leyden jar.

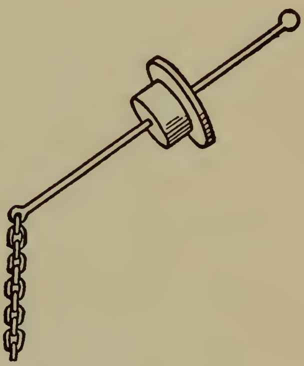


Fig. 22.—Cover of jar, showing rod with chain attached.

of chain. Before starting, the jar should be thoroughly washed and dried. The inside should then be coated with shellac. While this is drying the inside tin-foil can be put in place. This tin-foil lining should extend clear around, coming within 3 inches of the top, and lapping over the bottom ½ inch. The bottom piece of the lining should cover the bottom of the jar well.

Shellac and tin-foil can now be put on the outside in just the same way. The cover should be made from a well-dried piece of board, and must fit tight. Bore a hole in the center of the cover just big enough to force the rod in. At the top of the rod solder or screw the ball. At the bottom fix the chain, which should be long enough to rest on the tin-foil lining. Before putting the cover on dry out the jar thoroughly. Then see that the cover fits tight, shellac it well, and put it in place. The jar should be practically air tight.

You now have a device for storing static electricity in small amounts and for a short time.

DISCOVERY OF THE LEYDEN JAR

The Leyden jar is named for the town of Leyden, in Holland, where the discovery was first made that static electricity could be stored and held for a short time. Peter van Musschenbroeck accidentally hit upon it in 1746. His apparatus was a gun barrel suspended by silk threads, and included a piece of brass wire and a glass jar partly filled with water. The wire extended from the gun barrel into the water. The bottle was held in his hand. A static machine worked by two assistants supplied electricity to the gun barrel. Expecting to draw a small spark from the wire the experimenter touched it. The spark came, but was stronger than had ever been made before. The water in the jar acted as the tin-foil lining does, while the hand supplied the outer conductor, and the experimenter received the full force of the shock through his body. The spark that nearly knocked the experimenter senseless made the name of his town common in electrical science.

THE ELECTROSCOPE

Any instrument which shows the presence of static electricity is called an electroscope. The pivoted

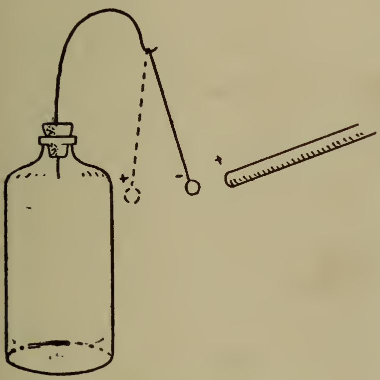


Fig. 23.—Pith-ball electroscope.

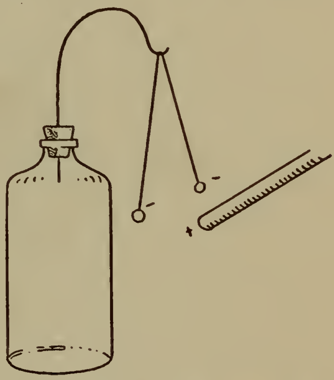


Fig. 24.—Electroscope with two pith balls.

paper needle was the simplest kind possible. A much better one can be made from a bottle and a ball of pith. The bottle should be clean and dry, and should have a cork. In the cork insert a wire bent as shown. From the tip hang a silk thread with the pith ball on the end.

With this many tests may be made. Bring the cover of the electrophorus near and the ball is attracted strongly. Let the ball touch it and it is repelled. This illustrates the attraction of unlike charges and the repulsion of like charges.

Now hang two pith balls by silk threads of the same length, charge the cover of the electrophorus and

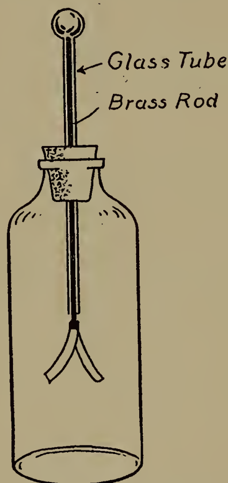


Fig. 25.—Gold-leaf electroscope.

bring it near. Both balls are charged negatively by induction. As they are charged alike they repel each other. On this principle the gold-leaf electroscope works, though it is much more delicate.

The gold-leaf electroscope can be made from any wide-mouthed bottle or fruit jar that can be provided with a tight-fitting cork. Besides the bottle the materials needed are: a brass tube or rod; a glass tube large enough to slip this through; a brass knob, and two pieces of gold or aluminum foil. The foil is simply very thinly beaten metal, and may be obtained from almost any sign painter.

First bore a hole through the cork with a small rat-tail file so that the glass tube will fit tight. The tube should extend an equal distance above and below the cork, and should come to within 3 inches from the bottom of the jar when the cork is in place. The tube can be cut by notching it with a three-cornered file and then hitting it a sharp tap. Solder or screw the brass knob to one end of the brass tube. Then slip the rod through the glass tube. It should be cut so that only ½ inch extends at the bottom. This end should be flattened by pounding. Now tip the tube up and pour shellac in so that the tube and rod will be held firmly together when it dries. After the drying is complete scrape the flattened end of the rod clean and fasten the two pieces of leaf in place.

As the electroscope must be kept dry to work properly, it is a good plan to heat the bottle before finally putting the cork in. To make a good piece of work the cork should also be well shellacked. A little calcium chloride dropped into the bottle will absorb any moisture that might remain or leak in. This must be fresh. Buy the calcium chloride the day you are going to finish your electroscope.

THE DISCHARGER

The Leyden jar should always be discharged by a metal instrument called a discharger. This can be made from a piece of heavy wire and a bottle. Twist the wire together for about 2 inches; then spread the ends out as shown. A brass knob or plate should be soldered to each tip. The twisted end can now be inserted in the neck of a bottle, and the discharger is

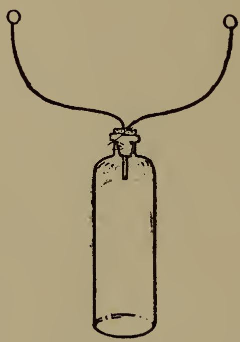


Fig. 26.—Discharger for Leyden jars.

complete. To discharge a jar, bring one of the tips in contact with the brass knob and touch the other to the tin-foil coating.

CYLINDER ELECTRIC MACHINE

Secure a good clear glass bottle about 4 inches in diameter and 8 or 10 inches long. See that it is round and that the sides are straight. Clean it carefully; then roughen the bottom at the center a little with a piece of emery paper. Find the exact center with a compass or by means of a circle marked on a piece of paper. With a glass-cutter make a hole in the bottom about $\frac{1}{4}$ inch in diameter. Smooth the edges with a file. In as near the exact center of the bottom as possible cement a large spool. Either bichromate

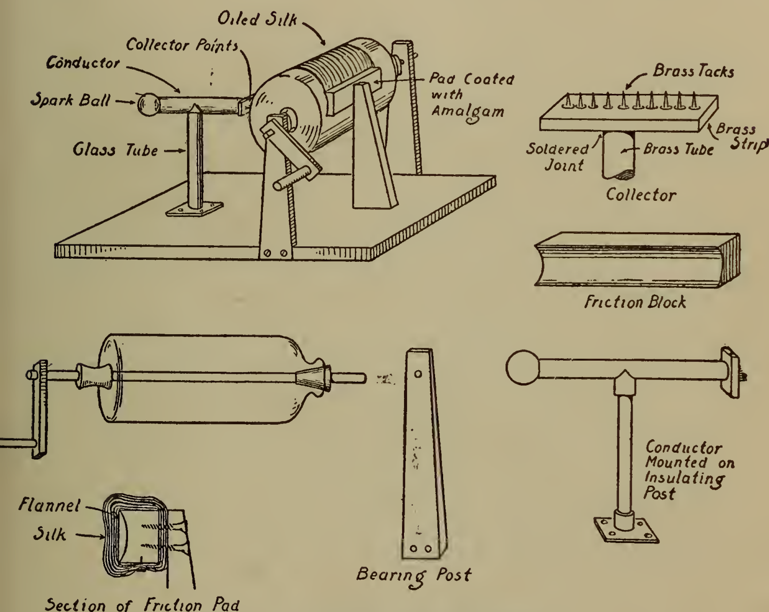


Fig. 27.—Cylinder electric machine.

glue or a good china cement can be used for this purpose. In the neck of the bottle fasten a spool of the same kind as the one in the bottom. This should be whittled or turned down carefully so that the hole will not be thrown out of center. The cylinder is now ready for the axle. For this a piece of hard wood can be used. It should fit tight in the spools, and can be cemented in place with shellac.

The bearing pillars should be of good dry, clear wood.

As the action of this machine depends on friction, the block which rubs the glass is especially important. This block should be made a little shorter than the bottle, and hollowed out to fit the curvature of the side. It is held in place by wood screws. Before being fastened to the standard, however, it should be wrapped with four layers of flannel and two of silk. These should be wrapped on tightly and fastened with small tacks.

On the opposite side of the bottle the electricity is collected from the glass by a set of small sharp points. From the points it is conducted to a brass ball, where the Leyden jar is charged or sparks may be drawn out.

In making the conducting part of the cylinder machine the ball, brass tube, and brass strip should first be soldered together. A $\frac{3}{4}$-inch tube is a convenient size to handle, and the strip can be of that width and any thickness available. The ball can be a little larger than the tube. In soldering these together be careful to clean them thoroughly, and tin the surfaces to be fastened together. The side to be nearest the cylinder should be tinned completely. Tinning is simply applying a thin coat of solder over the brass, and makes the soldering much easier.

After the ball, tube, and strip have been soldered firmly together, the collecting points should be soldered to the strip. These points may be made either from brass-headed tacks or small brass screws. If screws are used the threads should be smoothed down and the points sharpened. Then the flat head of each screw should be tinned. Solder them onto the strip one at a time, and as close together in line as their heads will permit. Be sure that each point in the row is of the same length.

The conductor is now ready for its glass tube support. This should be of about the same size as the tube, and long enough to bring the collecting points even with the center of the cylinder. A wooden plug curved to fit the brass may be cemented to it, and fixed in the top of the tube. Another plug fastened by a screw to the wood base makes a firm support for the tube. When in place the collecting points should not be more than $\frac{1}{16}$ inch away from the cylinder.

A shellacked or oiled-silk curtain should now be made, and tacked to the top of the rubbing block, so that it will lay on the top of the cylinder and extend to within $\frac{1}{2}$ inch of the collecting points.

Sparks secured with this machine are much stronger if the friction cushion is coated with mercury amalgam. This is made by mixing melted zinc and tin with mercury. The proportion is 2 parts of zinc, 1 of tin, and 6 of mercury. First melt the zinc, and to this add the tin. While cooling, pour in the mercury, being very careful not to breathe the fumes, as they are poisonous. Pour the mixture into a wooden box and shake until cool. The amalgam should be powdered and mixed with lard before being applied to the cloth cushion.

The machine should now be in working order and will produce a spark at the brass ball when the cylinder is rotated. A crank can be arranged for this purpose as shown in the illustration, although much longer sparks can be secured if a pulley can be fitted and a small motor used.

A FEW STATIC EXPERIMENTS

With the gold-leaf electroscope static charges may be detected in many unlooked-for places. The ways of exciting these little charges are almost endless. Sharpen a lead pencil and hold it near the ball of the electroscope. The delicate gold leaves will separate. Tearing a piece of paper, blowing powdered chalk from a pair of bellows, all have the same effect, showing that the rubbing or friction has caused an electrical disturbance. Pound a little dry brimstone in a mortar and let it fall on the brass ball. It is charged enough to cause separation of the leaves. Let another boy stand on a small board supported by four heavy glass tumblers, and then place his finger on the knob of the electroscope. No disturbance is visible. Flap him with a silk handkerchief and the leaves spread apart.

Care should be taken to guard the gold-leaf electroscope against heavily charged bodies, such as the electrophorus, as the force would tear apart the delicate gold leaves.

An experiment sometimes called the "electrified frog pond" is easily performed with the electrophorus. After the resin cake has been rubbed with a flannel cloth, place several bits of paper around the edge. Now touch the edge of the upper plate and lift it by the insulated handle. The bits of paper will jump from the edge of the pan in a very lifelike manner. Green paper cut in the shape of frogs can be used to make the action seem even more real. This experiment is another example of the repulsion of like charges. As soon as the pieces of paper become positively charged from the pan they are actually lifted off and pushed away.

A very well-made Leyden jar could be charged by the tiny spark of the electrophorus. With an ordinary jar the method is not practical, and the larger spark of the static electric machine must be used. To charge a jar with the machine described, bring the collecting knob near the brass knob of the machine, holding the jar by its tin-foil coating. When the glass cylinder is turned by its crank, a small crackling spark will be seen to jump across the gap. When this spark stops the jar is charged to its full capacity.

In this state the inside coating generally has a positive charge, while the outside is charged negatively by induction. The charges are equal and opposite. If the jar is placed on an insulating glass it will not charge, as the necessary negative charge cannot accumulate from the earth on the outer coating. The table or floor is a fairly good conductor. If the outer coating is connected to a water-pipe, a better charge than ever can be obtained.

For discharge a complete circuit is also necessary. The discharger should be used, touching one tip to the tin-foil coating and the other to the brass ball.

As the discharger tip comes near to the ball, a spark jumps across the gap. The charges have been equalized. Now recharge the jar, and place it on a clean pane of glass supported by four tumblers. When the ball is touched, a much smaller spark than before is seen. A similar spark can now be taken from the coating, another from the ball, and so on until the jar is discharged.

By connecting several jars together a much larger spark can be obtained. There are two kinds of connections possible. These are called the "series" connection, and the "parallel" connection. A combination of these can also be made.

The series arrangement as shown consists in connecting the tin-foil coating of one jar with the metal knob of the next. By this means the voltage is increased and a longer spark secured. All of the jars but the last one must be set on insulating stands.

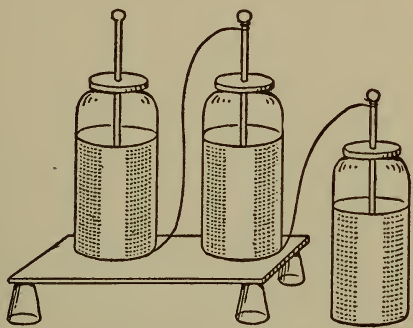


Fig. 28.—Series connection.

The parallel connection can be made by letting all the jars stand on a strip of tin-foil and connecting all

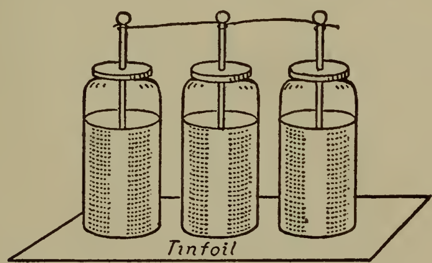


Fig. 29.—Parallel connection.

the knobs by a small wire. This arrangement increases the size of the spark, but not its length.

If desired, several jars can be wired in series groups and the groups wired in parallel.

Especial care should be taken with either of these arrangements not to let the jars discharge through the body. Do not play jokes with static electricity. The shock is not only unpleasant, but apt to be very harmful. In spite of the supposed value of electric treatment for nervousness, its helpfulness is very doubtful. Common sense demands the use of a discharger whenever a large jar or a series of any size is to be discharged.

Spark experiments done in a darkened room can be made to give a very brilliant display. Metal filings put in the path of the discharge from two or three jars make a long bright spark possible. These filings should be scattered over the surface of a glass plate which has been bound at two edges with tinfoil. One edge should touch the coating of the jar; one tip of the discharger should then be placed on the opposite edge, while the other tip is brought near to the brass ball. A bright zigzag spark will flash across, burning the filings in its path. Several kinds of metal can be tried. The color of the flash will be different for each.

Paper can be punctured with the spark from a Leyden jar by holding it across the path of the spark.

Although static electricity is not easily turned to power use, a small static motor can be made in a few minutes' time. All that is needed is a bottle and a piece of copper wire. Cut off two pieces of wire each 2 inches long and flatten them at the middle. Solder them neatly together in the form of a cross. Then file each end to a sharp point. Turn them back so that they all point in the same direction, and bend each down a little. Where the wires cross make a dent with a sharp punch. The wheel is now ready to balance on a needle stuck in the cork of an empty bottle. Connect the needle with the prime conductor of the static machine, and turn

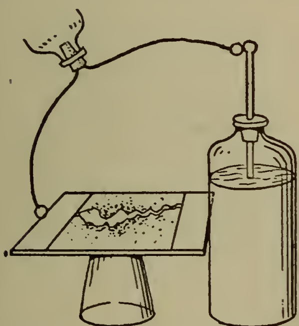


Fig. 30.—Burning metal filings.

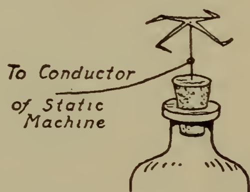


Fig. 31.—Static electric motor.

the crank. Static discharge from the sharp points of the wheel into the air will cause the wheel to turn.

The spark from a static machine can be broken up in a pretty display by means of a tin-foil spark pane. Take a pane of glass 3 by 4 inches in size, shellac one side and paste on a piece of tin-foil. When the shellac has dried, cut the foil in diamond-shaped or square sections with a sharp knife. Leave an edge $\frac{1}{2}$ inch wide at either side for contact to ground and conductor of the machine. A spark crossing the pane will be broken up in many bright little flashes.

On the same principle, a design glass with almost any simple picture can be prepared. For this a zigzag strip of tin-foil $\frac{1}{8}$-inch wide should connect the wider strips at each end. Where the strip is cut the sparks will jump, forming the design.

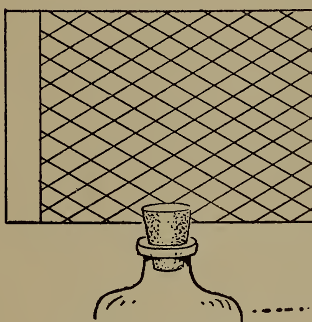


Fig. 32.—Spark pane.

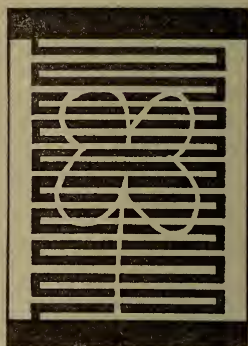


Fig. 33.—Electric spark design.

It is also possible to produce a fairly steady light from an ordinary lamp bulb and a static machine. The bulb should be one that is "burned out." It should be held by the glass part so that the brass tip is near the conductor, and the machine should be turned rapidly. The result is a glow that seems to fill the whole bulb. This can be seen only in a dark room.

Attraction and repulsion is the principle of the jumping dice experiment. For this a small glass cylinder with a metal top and bottom is necessary.

Put a number of cubes of pith in the cylinder and connect the upper plate with the conductor of the static machine. When electricity is generated the cubes jump as if they were being shaken. This is due to the fact that they are first attracted to the top plate and then repelled from it. By setting the two plates vertically and insulating the one connected to the conductor, paper butterflies hung by silk threads will flutter back and forth between the plates.

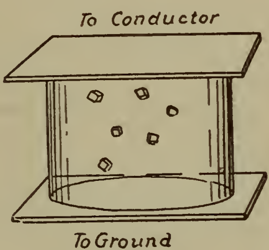


Fig. 34.—Shaking dice.

The mechanical force of a static discharge is illustrated by a mixture of sulphur and red lead shaken from a muslin bag on a charged piece of glass. The dust is electrified when shaken. Sulphur becomes positive and red lead negative, the two powders combining in symmetrical figures. The glass can be electrified with a point leading to an electric machine or by the spark from a Leyden jar. The figures that result are called Lichtenburg figures after their discoverer.

LIGHTNING

Heavy lightning discharges are caused in much the same way as those from a Leyden jar. There is no more mystery than in the experiments you can perform. The blinding flash and the thunder are merely enlargements of the crackling spark drawn from the cylinder machine.

The immense area of the clouds and the distance to the earth allow an almost unlimited voltage to mount up before the flash breaks across. It is estimated that a stroke of lightning has an average value of 50,000 volts per foot of length. An average figure for the actual energy spent is 250,000,000 horsepower. This enormous amount is used in an instant. The figure given by one authority is $\frac{5}{100,000}$ of a second.

One of the first intelligent ideas of lightning was that it is really caused by friction of the clouds. The later theory depends on the condensation of mist into raindrops. According to this, lightning is caused by rain. Each drop of mist is at first lightly charged by friction. Suppose we imagine that each particle has one charge. This is on the surface—not inside the drop. Striking together, a hundred of these might form one raindrop. There would be a hundred times as much water in a big drop as in each little particle, and also a hundred charges. There is not near as much as a hundred times the amount of surface to the big drop as to all the little ones. All the charge must crowd into a space only about ten times as great as all the original drops had. As the drops strike together and become larger the static voltage runs very high. The positively charged cloud produces an equal negative charge by induction on the ground, water, trees,

Fig. 35.—Field of static electricity around an unrodded house.

and whatever makes up the other plate of this natural Leyden jar. The spark jumps across the hundreds of feet that separate clouds and earth.

One of Franklin's most important discoveries about lightning was that the static discharge from sharp points equalized the charge gradually. The electrical condition of a lightning-rodded house, one without rods, and the readjustment when the spark occurs are shown in Figs. 35, 36, 37.

There are certain objects which do not seem to need protection and which seem to be free from all lightning

Fig. 36.—Field of static charge around a well-rodded house.

danger. Among these are: trains and locomotives, buildings with metal sides of frames, well-grounded steel windmill towers, steel battleships, and city business blocks. All of these objects allow so much leakage that the charges escape as fast as they form, and the voltage never reaches a high enough value to produce a flash of lightning.

Where lightning-rods are used great care should be taken to see that they are well grounded. If the

Fig. 37.—Charge equalized by lightning flash.

ground is imperfect the rod is worse than none at all. A good lightning-rod not only helps to prevent the lightning from striking, but conducts it to the ground without damage to the house when the charge is produced too suddenly to be prevented.

Fig. 38.—Lightning flashes are only heavy static sparks.

LIGHTNING-ROD EXPERIMENTS

The Thunder House.—This toy house shows the bad effects of a poorly grounded rod. The house can be built easily of boards from a cigar box, and put together as shown with small hinges. These should work easily. The lightning-rod should be tipped with a ball, and should reach to within $\frac{1}{2}$ inch from the tin-foil ground. The house is held together by

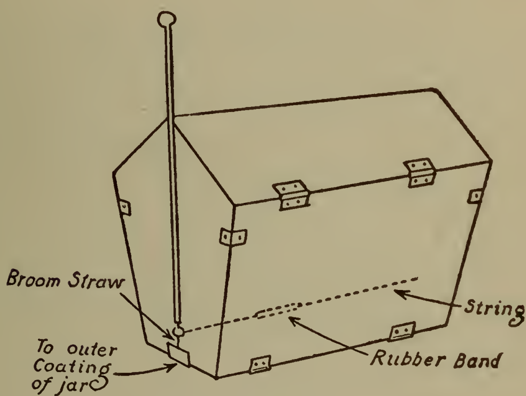


Fig. 39.—Thunder house.

a broom straw or splinter of wood, bridging the gap between rod and ground. This straw extending through a little ring holds the entire house together.

Bring a charged Leyden jar near the ball at the tip of the rod and a spark jumps across, flashes down the rod, and by breaking the straw releases the catch. The house falls apart of its own weight.

The *lightning ship* is an experiment very similar.

In this the straw holds the mast of a little boat. When the ship is struck the mast falls over on the deck. A large tin dish can be used to contain the water, and a metal plate suspended by silk threads

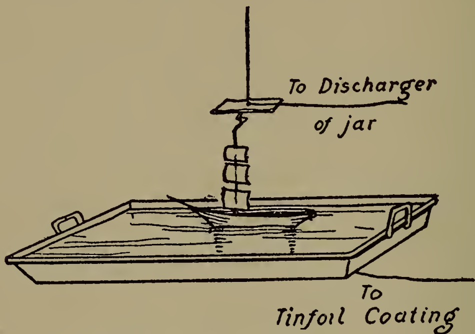


Fig. 40.—A shipwreck.

makes a good cloud. As the ship passes under this cloud, which is connected to a charged Leyden jar, the spark jumps to the tip of the mast, and causes a shipwreck.

CHAPTER III

Electric Batteries and Galvanic Electricity

The electric battery changes chemical energy into electricity. It is a common saying that electricity is generated, but this is not strictly true. We cannot make electricity any more than we could create wood or iron. We can only direct its production.

Electricity, light, heat, and chemical change are all forms of energy. They are interchangeable. Light is changed to heat when the sun's rays strike the earth; heat changes to light in a red-hot iron; electricity changes to heat in a flat-iron, and to light in a lamp; heat is changed to electricity at the generating station. In the battery a piece of zinc is consumed slowly, in much the same way as coal is burned under the boilers at the power-house.

Electricity from a battery is quite different from the static electricity of the electrophorus and cylinder machine. It flows as a steady current, will spark only a short distance, and is conducted only by metals and solutions of metal salts. In spite of the great difference in form, a static machine caused the discovery which led to the perfection of the chemical battery.

An Italian physician whose wife was sick, so the story goes, brought her a few frogs' legs for soup.

One of these legs was laying on a table near a large static machine which he used for treating patients. The woman accidentally gave the crank of the machine a turn. At the same moment she happened to touch the leg with a knife. There was a sudden twitch of the muscles; the frog's leg moved. When she told the doctor he was interested and determined to find the cause. After many experiments he discovered that the same twitching could be produced without the static machine if he touched one end of the frog's leg with a piece of zinc and the other with a piece of copper, and then touched the free ends of the metals together. This was the very first electric battery. The physician was Galvani, and from his name came the terms "Galvanic battery" and "Galvanic electricity," although he called it animal electricity and believed it came from the muscles and nerves of the frog's legs.

The theory of animal electricity did not satisfy every one. Volta believed that the metals played a very important part. To prove this he built up a pile of zinc and copper plates, with flannel soaked in acid between each pair. It produced small currents, and proved that he was right. This arrangement of plates is called a "Voltaic pile," after the inventor, from whose name the word "Volt" is also taken.

A simple electric cell is made up of two metals, and a solution which acts upon one of the metals. The other metal is not affected and may be replaced by carbon. These two metals, or metal and carbon, are called the electrodes. Carbon and zinc are the most commonly used. The zinc is the positive electrode, or anode, and the carbon the negative, or cathode. Both of these words are from the Greek. The solution of the cell is called the electrolyte. One pair of electrodes and their electrolyte should be spoken of as a *cell*, and not as a *battery*. The term "battery" indicates a number of cells all connected together.

A cell having all the necessary elements may be made in a few minutes from a plate of zinc and one of copper immersed in a glass of dilute sulphuric acid. Place the lower ends of the strips as far apart as possible and let the tops lean together. Each of the elements of the cell is now in contact with two others. Copper is touching zinc and acid, zinc is touching copper and acid, and the acid immerses the lower part of both metals. The same effect is secured if the electrodes are straightened up and connected by a wire. Current flows from the zinc through the acid to the copper and back along the wire. As the current *outside* the cell flows from copper to zinc the terminal on the copper is called the *positive* terminal and that on the zinc the *negative* terminal. This

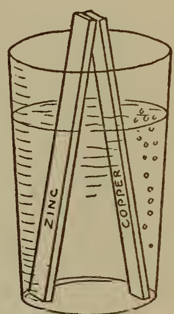


Fig. 41.—A simple zinc-copper cell.

current is too weak to make a spark, but can be felt by touching both wires to the end of the tongue. This slight excitation affects the delicate nerves and produces a noticeably salty taste.

The force by which current is sent through the wires is called the electromotive force and is abbreviated into E. M. F. Other common terms for this force are "voltage" and "potential."

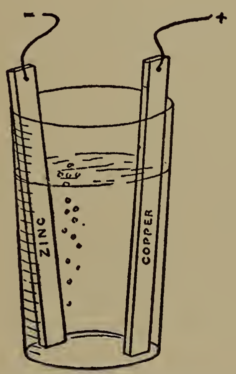


Fig. 42.—Cell when current is not flowing.

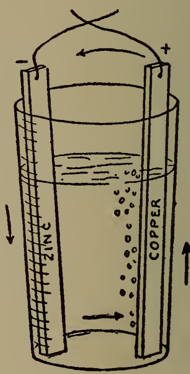


Fig. 43.—Cell when current is flowing.

When the electrodes are put into the zinc-copper cell described you will notice that small bubbles rise from the zinc. Leave the cell connected for several days, and the zinc will be entirely eaten away, while the copper is not affected at all. This bubbling and corrosion are the only way in which you can see the change that is being made from chemical energy to electrical energy.

All the time the cell is working the zinc is being consumed and hydrogen gas is forming in little bubbles at the copper electrode. This hydrogen which comes from the solution is a great hindrance to the proper working of the cell. It surrounds the electrode and protects it from the solution. This action is called "polarization." To prevent it a material known as a "depolarizer" is used. Any substance that absorbs free hydrogen easily is a depolarizer, and will keep the cell at its normal strength, even when the circuit is closed for some time.

In an ordinary zinc-copper cell with acid solution the zinc would be eaten away nearly as soon with the circuit open as with it closed. This chemical change takes place only because of the impurities in the metal. It is known as "local action." As this is very wasteful and not at all necessary, it is avoided in nearly all zinc cells by coating the metal with mercury amalgam. This prevents the waste in a great measure. To apply the amalgam the zinc must be cleaned with acid and then rubbed with pure mercury until it takes on a silvery appearance.

FORMS OF CELLS

On account of polarization it is useless to make an ordinary zinc-copper cell, using acid electrolyte, with the hope of getting enough current to run a motor or operate induction or spark coils for any length of time. With a carbon electrode instead of the copper, a better result can be secured, and this arrangement is used in a cell known as the "carbon cylinder" type. The carbon electrode is in the form of a cylinder, in the middle of which the zinc is suspended. An electrolyte made up of sal ammoniac and water is used.

A still further improvement can be made by providing a depolarizer to combine with the free hydrogen.

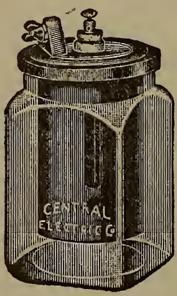


Fig. 44.—Carbon cylinder cell.

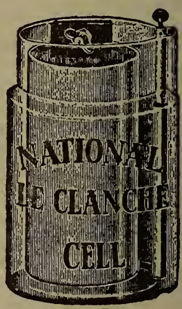


Fig. 45.—Leclanche cell.

Manganese dioxide held in a porous cup around the carbon electrode produces the desired effect. With this addition the cell will deliver current and keep its voltage for a much longer time than before. This depolarized cell with sal ammoniac electrolyte is known as the Leclanche cell.

The Daniell cell, and the gravity cell which is a variation of the Daniell type, are the most popular for uses that require steady current. In one form the outside container is a copper cylinder. This forms the negative electrode. The positive or zinc electrode is inserted in a cup of unglazed porcelain. This container allows the current to pass, while the liquid inside the cup and outside of it cannot mix.

To set this cell at work the copper container is filled with copper sulphate solution. Copper sulphate is "blue vitriol," or "bluestone."

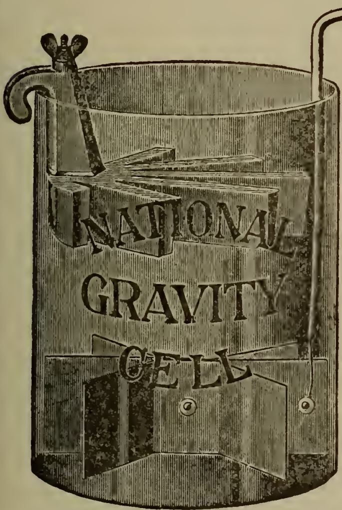


Fig. 46.—Gravity cell.

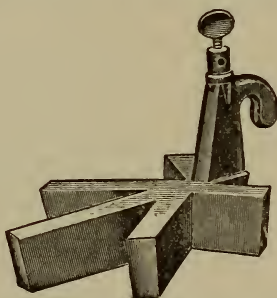


Fig. 47.—Zinc "crow's foot" of gravity cell.

Plenty of this must be supplied to keep the solution saturated. A handful of crystals are generally left right in the solution.

In the porous cup a solution of 1 part sulphuric acid to 20 parts of water is poured.

Polarization cannot take place in such a cell because the hydrogen that comes from the zinc is seized and held just as it leaves the porous cup. Copper from the solution takes its place and is deposited on the copper container.

In the gravity cell the electrodes are the same, but no porous container is used. Both electrodes are contained in a glass jar. The zinc is at the top in the shape called a crow's foot, and the copper at the bottom. A saturated solution of copper sulphate with a little sulphuric acid added is poured around the copper electrode, and on top of this a weak zinc sulphate solution is added. When in action the zinc sulphate surrounds the zinc electrode at the top, while the copper sulphate remains at the bottom of the cell. This cell has to be kept at work. If the circuit is opened for any length of time the liquids mix and the strength of the cell is lost.

Fig. 48.—Dry cell.

The dry batteries which are ordinarily used for bell ringing, automobile engine ignition, and so on, are a form of the Leclanche cell. These convenient cells have not enough moisture to spill, and in that sense are dry, but they depend on an electrolyte for their action. There must always be enough moisture inside to make the chemical change. One common form of "dry" cell is shown in the sectional view (Fig. 49). The "mix" which surrounds the carbon electrode is made of manganese dioxide, ground coke, and graphite. The electrolyte, which is sal ammoniac, is contained in this mix and also in the pulp-

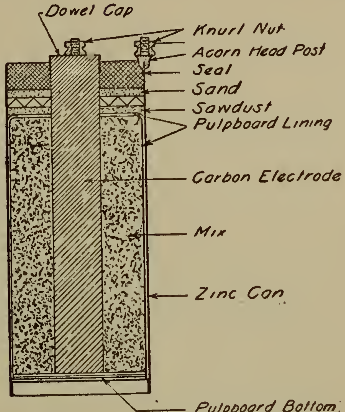


Fig. 49.—Inside of dry cell.

board lining of the cell. Zinc chloride is sometimes added to reduce local action and lengthen the life of the cell.

MAKING CELLS

There is no economy in making batteries; a good cell can be bought for about the price of the raw materials. In spite of this it is a good thing to build some cells, as in doing the work yourself you secure a better idea of the action and construction than anyone could possibly give you. The chemicals needed are common and can be had at any drug store. Old dry cells will supply both zinc, carbons, and connectors.

A Leclanche cell may be made easily by using a glazed milk crock for the outside container and a porous flower-pot for the inner. These materials are selected because they can be secured anywhere. The flower-pot chosen should be new and clean and of sufficient height to stand a little above the edge of the crock. While the illustrations show a crock with sloping sides, the straight-sided kind is even more desirable.

The carbon and zinc electrodes needed for this cell can both be taken from an old dry battery. Cut

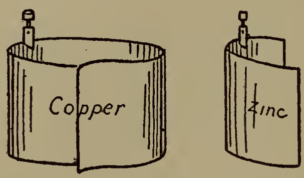


Fig. 50.—Copper electrode for Daniell cell and zinc for Leclanche cell.

down the side at the joint with a cold chisel and take off the bottom. Then trim off evenly so that the zinc left will stand a little shorter than the flower-pot. Clean the zinc thoroughly with hot washing soda. The plate is ready to be amalgamated. Both sides should be rubbed with mercury until they are silvery in appearance. An old tooth-brush is a good thing to use for rubbing on the amalgam.

In preparing the flower-pot as a porous cup, first dip an inch of the top in a bath of melted paraffin, letting it stay until it is well waxed. A plug of wood also soaked in paraffin should be used to stop up the hole in the bottom. Now spread a layer of manganese dioxide and powdered carbon, mixed in equal quantities, in the bottom of the pot. Stand the carbon upright in the center. Pack in more of the carbon and manganese dioxide around it, and the porous

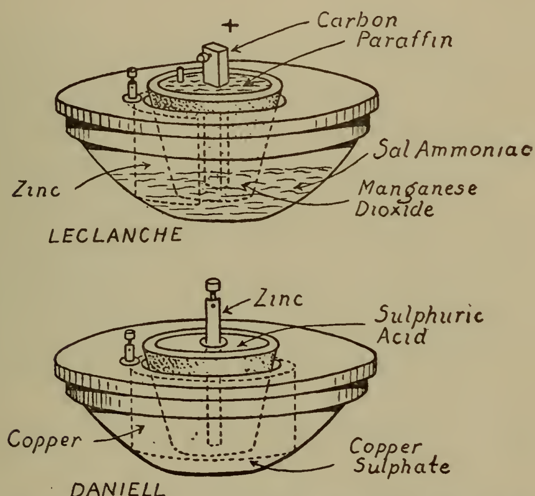


Fig. 51.—Leclanche and Daniell type "milk crock" cells.

cup is complete. When this is in place in the crock, and the sal ammoniac solution poured in and around it, the cell is ready for action. A well-paraffined wood cover can be added to give a little more finished appearance. Four ounces of sal ammoniac is about the right quantity for this cell. When the solution becomes weak after use it will appear milky. More sal ammoniac should then be added. The zinc will also need to be renewed.

With exactly the same arrangement of electrodes a cell can be made with chloride of lime and common salt. The chloride of lime is packed around the carbon rod in place of the manganese dioxide and carbon. A strong solution of common salt replaces the sal ammoniac solution.

With a change in electrodes the milk crock and flower-pot can be used to make up a Daniell cell. In this the copper should be cut in a sheet long enough to make a cylinder that will go clear around the flower-pot. The zinc can be an amalgamated rod or a dry-cell casing. Two electrolytes are used. Dilute sulphuric acid should be poured around the zinc, and a copper sulphate solution in the large crock. A bag of "bluestone" should be suspended over the edge of the crock or a shelf made of copper to hold the crystals.

Another simple form of cell can be made from an empty tomato can. This should be provided with a porous earthenware container of about the same height, but 2 inches smaller. If a porous jar is not available a container can be made from blotting-paper. With the help of pasteboard made in the form of two cylinders a very good plaster-of-Paris container may be made for this or the other fluid cells. The plaster should be thoroughly dried by standing it in the sun for several days, or baking it a few hours before use.

Iron filings and turnings packed in the bottom of the can and around the porous cup make up the negative electrode. As borings and turnings from a machine shop are usually greasy, they should be boiled for a few minutes in a strong solution of washing soda and rinsed in clear water before use. The positive electrode is a piece of zinc suspended inside the cylinder.

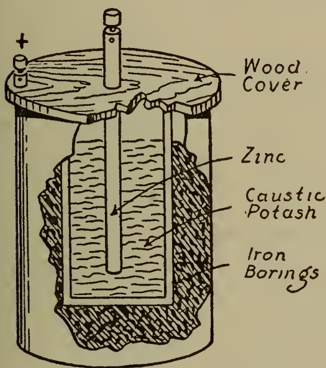


Fig. 52.—Tin-can cell.

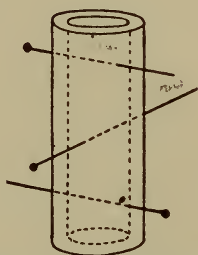


Fig. 53.—Pasteboard cylinders held in place by hatpins for casting porous containers.

To prepare for use, a solution of caustic potash is poured over the turnings and around the porous cup.

MAKING A DRY CELL

The dry cell is called "dry" only because there is not enough liquid in it to spill. It is really a form of Leclanche cell as generally made. The electrolyte is a sal ammoniac solution. It is held in the porous lining and in the depolarizer.

To build a dry cell you will first need a zinc can about the size of a standard dry-cell container. Solder the edges carefully and be sure the joints are all right. Cut a lining of blotting-paper to fit closely in the bottom and at the sides, reaching nearly to the top. Secure a carbon from an old cell. The connector should be in good condition for use.

Make up this mixture for the electrolyte and depolarizer:

Manganese dioxide.........	100 parts.
Graphite..................	20 parts.
Sal ammoniac	20 parts.
Zinc chloride	20 parts.

Add enough water to make the mixture into a thick paste. Put a $\frac{1}{2}$-inch layer of this in the bottom of the can, pack it firmly, and place the carbon upright in the center. Then fill in the rest of the electrolyte to within $\frac{1}{2}$ inch of the top of the can. Pour a mixture of beeswax and resin over the top, leaving a small vent for the escape of gas.

SINGLE-FLUID CELLS

All the cells described have been double-fluid cells. In other words, the depolarizer was held in a porous cup with the negative electrode. In the single-fluid cell it is dissolved in the electrolyte. The single-fluid cell is easy to build, but needs a good deal of care. The chromic acid compound sold as depolarizer or "electropoian" fluid eats the zinc very rapidly. When the cell is not in use the positive or zinc electrode must be lifted from the solution and washed.

Either zinc and carbon or zinc and copper electrodes may be used with the single-fluid cell. A large fruit jar or straight-sided crock makes a very good container. No cover is needed. If two flat zinc and copper plates

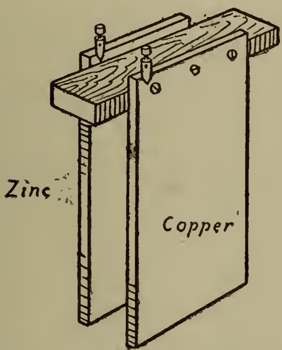


Fig. 54.—Mounting plate metal electrodes.

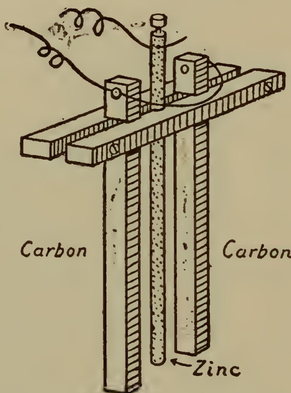


Fig. 55.—Mounting for carbons and zinc rod.

are used they may be screwed to each side of a wood strip long enough to extend over the sides of the jar. This strip should be well boiled in paraffin. Care should be taken that the screws holding one plate do not touch the screws in the opposite one. Each plate should extend a little above the strip to leave room for binding-screws. Carbon can, of course, be used in place of copper. Carbons taken from old dry cells answer very well, but great care must be taken in boring the screw holes, as the strips are hard and quite brittle.

Where round electrodes instead of plates are used, a better support can be built by arranging two small square sticks as clamps and screwing them together with the electrodes between. Each stick should be

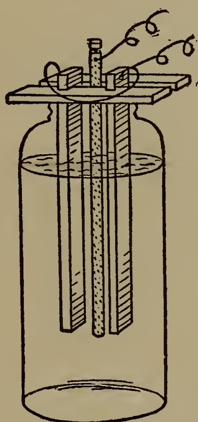


Fig. 56.—Complete fruit jar cell.

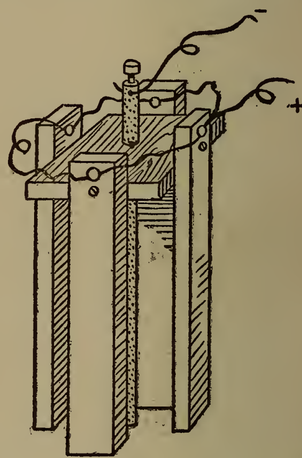


Fig. 57.—Mounting for four carbons and one zinc electrode.

notched to receive a zinc rod in the middle and a carbon rod on each side. The strips should be long enough to extend over the sides of the crock, and should be well soaked in melted paraffin. A long screw through each end of the sticks holds all three electrodes in place.

A very good arrangement of electrodes which gives a large surface of carbon is secured by screwing four carbons to a square piece of wood and putting down a rod of zinc in the center. All the carbons should be connected together by a piece of wire.

To get good results with any of these pairs of electrodes the special depolarizing solution should be used. A very good one is:

Chromic acid	20 parts.
Water	80 parts.
Sulphuric acid	10 parts.
Chlorate of potash	1 part.

Remember that this solution consumes the zinc very rapidly. The electrodes should always be taken out and washed when the cell is not in use.

HANDLING CHEMICALS

The workroom is the only place for handling chemicals. Sulphuric acid will quickly ruin rugs or carpets if allowed to spatter on them. Other necessary chemicals will leave a bad burn on the skin if not washed off quickly. Sulphuric acid is neutralized by ammonia. A bottle of strong ammonia solution should be kept close at hand when working with acids. A few drops of it put on a cloth burned by sulphuric acid will sometimes bring back the color and save the cloth. Caustic potash gives at first a soapy feeling to the fingers, but quickly eats through the flesh and leaves a very bad burn. It should never be touched with the fingers. In case it is accidentally touched, wash the spot quickly with a weak acid solution, and then hold the hand in a stream of running water.

Neither of these remedies take the place of careful handling of chemicals. Always wear old clothes when working with batteries. In addition, try not to spill or spatter the acids or caustic solutions. Unless proper precautions are taken it is better not to experiment with cell making at all.

A point always to be remembered in mixing acid and water is to add the *acid* to the *water*, and not the water to the acid. Acid should always be poured in *slowly* and the mixture *stirred gently*.

BATTERY CONNECTIONS

The E. M. F. or voltage of each one of the batteries described has an unchanging value. In the Daniell cell the E. M. F. is 1.08 volts; in the Leclanche, 1.48 volts; in the tin-pot cell, 1.14 volts, and so on. If these were made as small as a thimble or as big as a wash-tub the voltage would not change. The big ones would only deliver more current.

Either voltage or current may be increased by connecting a number of cells together. For increasing the E. M. F. the connection must be in series. The series connection consists in wiring the carbon of each cell to the zinc of the next. The E. M. F.'s are thus added. With the parallel connection the E. M. F. is not increased, but the cells will deliver a much heavier current. Either of these arrangements is called a battery.

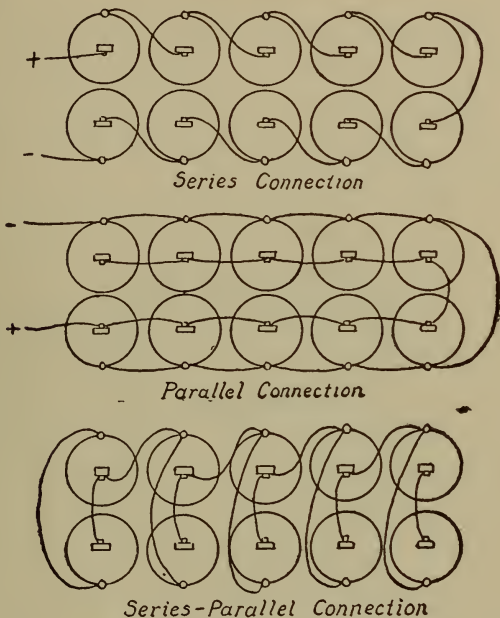


Fig. 58.—Connections for dry cells.

STORAGE CELLS

Where a considerable battery current is wanted for some time, even the Daniell cell is not entirely satisfactory. For running electric automobiles, electric launches; for electric lighting and starting of automobiles the storage battery or secondary battery is used.

"Secondary battery" is a more correct name than "storage battery," for although electricity seems to be stored in the jars, it is not. The current used to charge the cells really forces a chemical change in the metal electrodes. Changing back to their original form, they generate an E. M. F., and will deliver current until the change is complete. The chemical change takes place only when the electric current is being used. Using current from the cell is spoken of as "discharging" the cell.

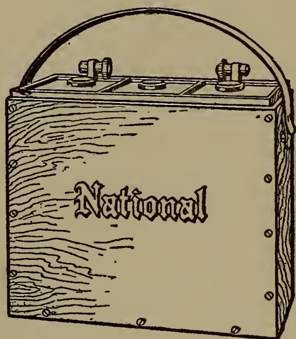


Fig. 59.—Storage battery.

As in the primary cell, the active parts here are a negative plate, a positive plate, and an electrolyte. The plates are called grids because of their peculiar shape.

Instead of using two metals, both grids of the secondary cell are usually made of lead. This is cast quite thick, and is filled on both sides with little pockets to contain the active material. The latter is really responsible for the work of the cell, and the lead plates only act as supports and conductors.

In the most common form of secondary cell the active material of the positive plate or anode is lead peroxide. At the negative plate the material is a spongy form of metallic lead. Sulphuric acid is the electrolyte.

Other metals and other electrolytes can be used to good advantage in building storage cells. In the Edison cell the metals are nickel and iron, with a caustic potash electrolyte. This cell is very light and strong.

HOW TO MAKE A STORAGE CELL

Secure enough sheet lead $\frac{1}{4}$ of an inch thick for three plates of a size to fit any square glass or glazed crockery jar available. These should be rectangular, with a lug at one corner, and all the same size. Roughen two of them on one side with a sharp chisel, always cutting downward. Roughen the third in the same way on both sides. When through the plates should be full of little points all turned upward.

On a piece of clean glass mix a paste of red lead and sulphuric acid. The acid should be diluted with an equal quantity of water. Use a flat paddle to make the mixture uniform. Coat all the plates thinly on one side with this, taking care to press it into the little dents.

Let the paste harden for a few hours. Coat the roughened side of the third plate. Now cut thin pieces of wood of the same width as the plates, but a little longer. These are called separators. One should be placed on each side of the plate to go in the middle, and the three plates laid together. The coated sides of the outer plates should rest against the separators.

To set up the cell, bolt the two outer plates together, passing the bolt through the hole in the projecting lugs. To keep the plates a proper distance apart lead washers cut from sheet lead should be used. After

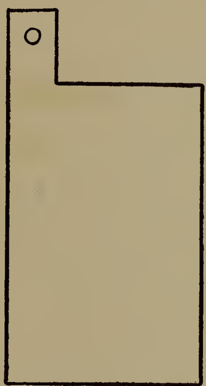


Fig. 60.—Lead sheet for battery plate.

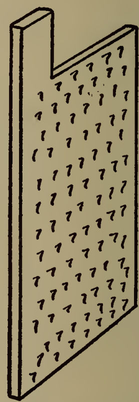


Fig. 61.—Plate prepared for red lead paste.

the bolt is drawn up and the wood separators are in place between the plates, stout rubber bands should be put around all three plates at top and bottom.

The electrolyte used should be made up of 5 parts of water to 1 of sulphuric acid. The acid should be poured slowly into the water. On account of the heat that is generated by the combination the mixture should be stirred constantly with a carbon rod. A glazed earthenware jar is a better container for mixing than a glass jar. Acid of proper strength for a storage battery has a specific gravity 1.2 times as great as water. Battery men call this "1200 acid." If there is a garage handy where electric automobile batteries are charged, 1200 acid can be bought already mixed.

Place the plates in the jar, and add enough acid to cover the coating of active material. They are now

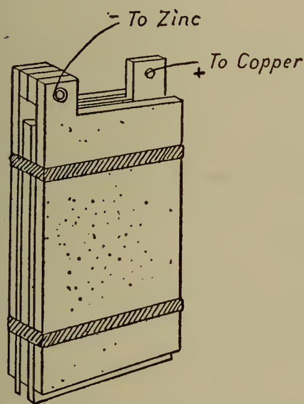


Fig. 62.—Lead plates completed, with separators between.

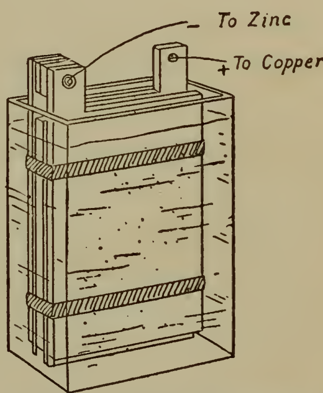


Fig. 63.—Storage cell assembled.

ready for the first, or forming charge. The middle or positive plate should be connected to the positive (copper) pole of a primary battery. One of the outside plates should be connected to the negative zinc pole. The battery supplying the current should be made up of three Daniell or chromic-acid cells connected in series. Current should be allowed to flow for a couple of days. After the first charge much less time is needed.

CHOOSING THE RIGHT CELL

Each cell has features that make it especially desirable for certain kinds of work. Some have a much higher E. M. F. and longer life than others. Some will work well only when current is flowing most of the time, and others must be allowed to rest after being used. The first class is known as the closed-circuit cell, and the second as the open-circuit cell.

The "tin-pot" cell, the dry batteries, and the Leclanche cell are all well suited for bell ringing, telephone work, and other service where current is only needed a small part of the time.

The commercial dry battery as made today is so well depolarized and has such remarkable recuperation that the short period of rest between sparks in an automobile engine are as much as it needs to get rid of the free hydrogen.

When the circuit is really to be closed for weeks at a time, the best cell is the Daniell, of the gravity type. This is used in telegraph work. It is an excellent cell to use for the chicken thief or burglar alarms. The gravity cell must be kept at work all the time or it will soon get out of order. A long piece of insulated wire coiled up and connected between the two poles answers the purpose very well. This keeps up the chemical action by allowing a small current to flow, and keeps the zinc sulphate at the top and the copper sulphate at the bottom, where they belong.

Where heavier currents are needed the storage cell is better than a primary cell. Care should be taken, however, not to use too great a current, or the active material drops off the plates and will quickly ruin the cell.

CHAPTER IV

Electric Circuits

When the zinc and copper plates of the simple voltaic battery were allowed to come together, current flowed from the zinc to the copper, up the copper, down the zinc, and so on. Adding a piece of copper wire between the terminals made no difference except to lengthen the path. In either case the current followed a metal away from one electrode and back again to the other. This path is called an electric circuit. The circuit is closed when current is allowed to flow from one side of the cell or battery back to the other. When either side of the battery is disconnected the circuit is open.

Current cannot flow unless the "circuit" is closed. The E. M. F. is generated whether the circuit is closed or open.

Voltage and current can be compared to pressure and flow of water. Imagine two water barrels half-filled and connected at the bottom by a short piece of pipe. The pipe can be closed with a valve. If the two barrels are filled to the same level there is no flow from one to the other even if the valve is open. There is no "voltage" and no "current." Now suppose the

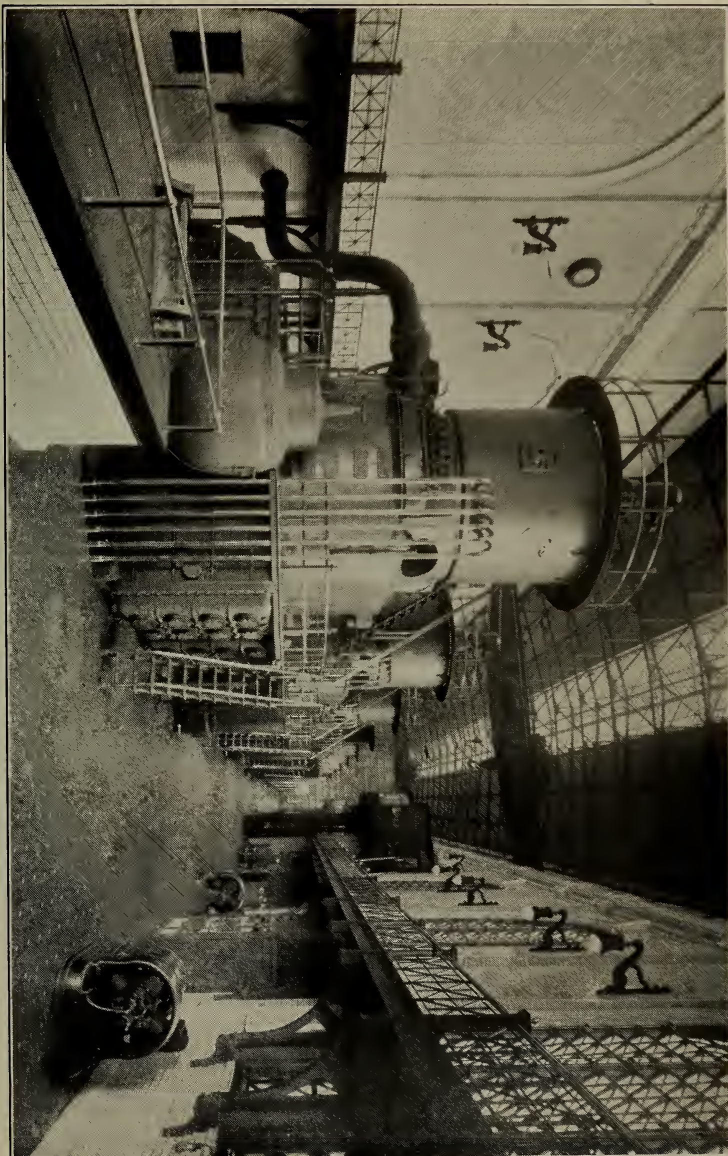


Fig. 64.—Fisk Street Station of Commonwealth Edison Co., Chicago.
(Courtesy of "Electric City" Magazine.)

valve is closed and all the water pumped from one barrel to the other. The full barrel exerts a pressure, but cannot force water into the other. The condition is similar to an open circuit. Opening the valve has the same effect as connecting the two poles of an electric battery with a piece of wire. Water flows through the connecting pipe until the two levels are equal.

If water is continually pumped from one barrel into the other and allowed to flow back through the pipe

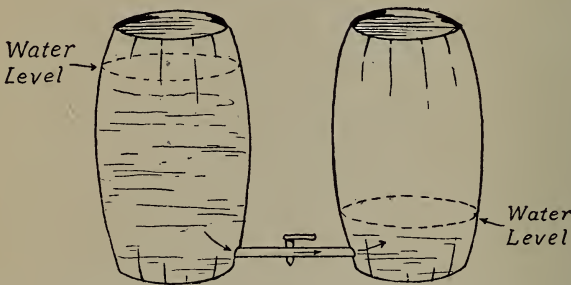


Fig. 65.—These water barrels can be compared to an electric circuit.

at the bottom, we have a condition that can be likened to a complete electric circuit. We apply the E. M. F. by pumping. The "circuit" is from one barrel through the pump into the other barrel and back through the pipe.

All the principles of the electric circuit are the same for batteries as for electric railroads, great power systems, and long transmission lines. Current must always go out from the power plant, do its work, and come back. The current is not used, but simply forced around the circuit by the electromotive force, or E. M. F.

In transmission lines the circuit is all carried underground or out of reach on poles or towers. In a railway system it goes out on the trolley wire, comes down through the metal circuit in the car, turns the motor, and returns to the power-house. The E. M. F. is supplied by steam or water power, but the result

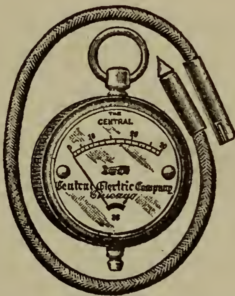


Fig. 66.—Voltmeter for testing batteries.

would be just the same if large batteries of storage cells were used.

E. M. F. is measured in Volts, just as water pressure is measured in pounds. In the primary cell the E. M. F. is always somewhat less than 2 volts, and in some it is under 1 volt. Incandescent electric lights are commonly used at pressures of 110, 125, or 250 volts. Street car lines use 550 volts in the city, and often much higher on suburban lines. In long electric transmission lines the voltages in use are as high as 50,000 volts, and sometimes even more than 100,000. Any E. M. F. higher than 125 volts should be considered as dangerous.

Current is measured in Amperes. When an ordinary incandescent lamp is turned on a current of about $\frac{1}{2}$ ampere is flowing. This current leaves the station flowing at a speed of more than 186,000 miles per second; the same velocity as a ray of light. Flashing to the furthest ends of the system, it enters homes to be turned to light in the delicate filaments of the electric lamp, or to heat in the flat-iron. This current all goes back to the station. In big stations the flow of current is often enormous. If a lamp could be made large enough to take all the current supplied by a single one of the machines at Fisk Street Station in Chicago it would shine with a brilliancy of about 30,000,000 candlepower. The copper conductors that take current to and from two of the Chicago stations contain nearly 70 tons of metal. If drawn out into wire $\frac{1}{16}$ inch in diameter, this would be more than enough to build a telephone line from Chicago to Panama.

As mentioned before, current has to be forced to flow, even over a copper wire. Something about the wire actually opposes the flow of current. This opposition is called "resistance." The harder the current is to force along the substance, the greater its resistance is said to be.

Substances with low electrical resistance are called conductors. Carbon, all metals, and salt solutions are conductors.

Substances with very high electrical resistance are called insulators. Air, glass, hard rubber, and fiber are all good insulators. Current can be made to flow along even the best insulator, but the E. M. F. must be very high to move even a small current.

A wire carrying current is "insulated" when it is separated from the earth or other conductors by insulating substances. Telegraph, telephone, and electric light wires are insulated by their glass or porcelain supporting knobs, and sometimes by a rubber covering. Where the E. M. F. is very high a type of insulator known as the "petticoat" insulator is used. The petticoats act as little umbrellas to keep the under side of the insulator dry.

When two sides of a circuit are allowed to come together with no resistance between, the line is short circuited. If one side of the circuit touches the ground the line is said to be grounded.

The size and length of the wire determines its resistance. Just as water flows easier through a large short pipe than a small long one, so current flows easier through the short thick wire.

Resistance is measured in Ohms. The Ohm, Ampere, and Volt were all named after scientists. As electrical units they are very closely united to each other. The relation is simple. An E. M. F. of *one volt* is required to force a current of *one ampere* through a resistance of *one ohm*. Putting this in another form, the resistance of a circuit multiplied by the current flowing always equals the voltage. This can be expressed:

$$E = CR$$

E represents the E. M. F. or voltage, C is the current, and R is the resistance. This is called Ohm's law. It is generally written:

$$C = \frac{E}{R},$$

which means that the current is equal to the E. M. F. of the circuit divided by the resistance.

If, for instance, a current of 5 amperes flowed in a circuit, with an E. M. F. of 10 volts, the resistance of the circuit would be

$$R = \frac{E}{C} \text{ or Resistance} = \frac{10}{5} = 2 \text{ ohms.}$$

The Watt is the unit of work. It is named in honor of the celebrated James Watt, who fixed the "horse-power" unit at the amount of power needed to lift 33,000 pounds at the rate of a foot a minute. The number of watts changed to work or heat in any circuit is the E. M. F. in volts times the current in amperes. Thus the power expended in an incandescent lamp might be 110 volts $\times \frac{1}{2}$ ampere, or 55 watts. Lamps are now generally spoken of in terms of watts, and are commonly made in 25-, 50-, 60-, 100-watt, and many other sizes.

In speaking of larger quantities of power the word "Kilowatt" is used. A kilowatt is 1000 watts. It is equal to about 1⅓ horsepower. Electric power is bought and sold not by kilowatts, but by kilowatt hours. A kilowatt hour might be a kilowatt used for an hour, or one watt used for a thousand hours, or

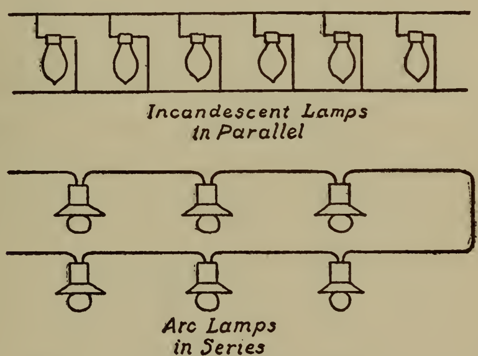


Fig. 67.—Series and parallel lighting circuits.

200 watts used for five hours. Average power multiplied by time in hours gives kilowatt hours. It is abbreviated "kw. hrs." In some of the larger stations power is sold for as low as 2 cents per kw. hr. Ordinarily the price is from 10 to 15 cents for electric light users.

Circuits from a generating plant may be either in parallel or series, much the same as the batteries were connected. Incandescent lamps are usually wired in parallel. With this arrangement the current goes out over one wire, then divides, part of it going through each lamp and returning on the other wire. The voltage is practically the same whether one lamp or many are used, but the current increases with the addition of each lamp.

The series connection is used for some types of arc and incandescent lamps. With this arrangement all of the current has to pass through every lamp. A high E. M. F. is needed to force current through the combined resistance. As lamps are added the current does not increase, but the voltage does. For this reason the voltage of a line supplying current to series lamps is quite high, making the line somewhat dangerous.

CHAPTER V

Electromagnets

When current flows in a circuit the wire is heated, and there is another even more important effect. The flow of current actually turns the wire into a temporary magnet. The material of the wire has nothing to do with the magnetic effect except to conduct the cur-

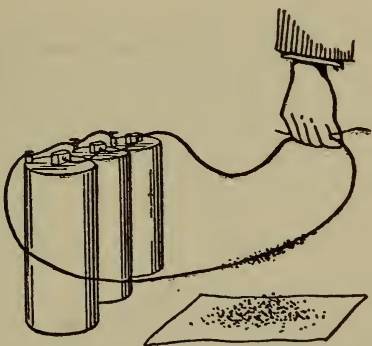


Fig. 68.—Current in a wire attracts iron filings.

rent. The magnetism can be shown quite plainly with two or three good primary cells connected in multiple. Run a piece of wire from a negative to the positive side through a little pile of iron filings. Lift the wire up and quite a bunch of filings will stick. Disconnect either end from the battery and they all fall off. There is not a trace of magnetism left in the wire.

The same effect is shown by a single cell and an ordinary pocket compass. Pass the wire over the top of

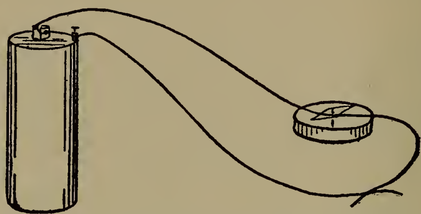


Fig. 69.—Current directs a magnet needle.

the compass parallel to the needle, and you will immediately notice a little vibration. When the delicately balanced needle comes to rest it will not be parallel to the wire, but pointing at an angle. Wind half a dozen turns of wire around the compass box, and

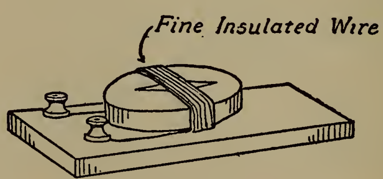


Fig. 70.—Small currents can be detected with a compass fixed this way.

the deflection will be still greater. By placing the compass on a neat board base, and winding the wire on it carefully, an instrument can be made that will detect very weak currents.

These and many other experiments were first tried by Oersted in 1819. The facts discovered laid the way for the dynamo, motor, and much of the other electrical machinery and apparatus in use today.

Oersted discovered that the magnetic field set up by an electric current is in every way like the field around a magnet. The lines of force even arrange themselves in the same way. Run a wire carrying current through a clean piece of cardboard on which iron filings have been dusted. Tap the card gently; the iron filings will group themselves in little circles around the wire.

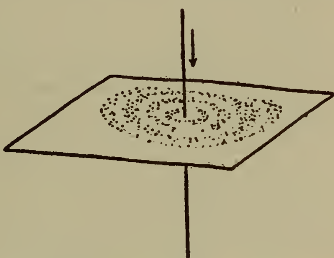


Fig. 71.—Lines of force around a wire carrying current.

The lines of force they indicate surround every electric line carrying current, no matter how long it may be. As the field surrounds all the length of the wire many feet of it can be collected by simply winding the wire in a coil. It can be still further increased by putting a piece of soft iron inside the coil. Lines of magnetic force seem to find an easier path through iron, and crowd into it wherever possible.

Without the iron core the coil of wire is called a solenoid; with the core it becomes an electromagnet.

A glance at Fig. 72 will show how the lines of force wander outside the solenoid, and are collected by the iron core of the electromagnet.

The north and south poles of solenoids and electromagnets are determined by the direction of flow of the current. Remember that current flows from carbon electrode to zinc electrode in the circuit to which a battery is connected. A good way to remember polarity is to imagine a boy swimming with this current, facing toward the inside of the coil. In this position

Fig. 72.—Coil without and with an iron core.

his left hand would be toward the north pole and his right hand toward the south pole.

A simple solenoid can be made by winding 50 or 75 turns of fine wire around a small paper tube, and connecting the two ends to the terminals of a primary cell. This will attract iron filings much better than a single wire, and will affect the compass needle quite strongly. If carefully balanced at the end of a long strand of silk thread, and connected by long wires to the cell, it swings to the north.

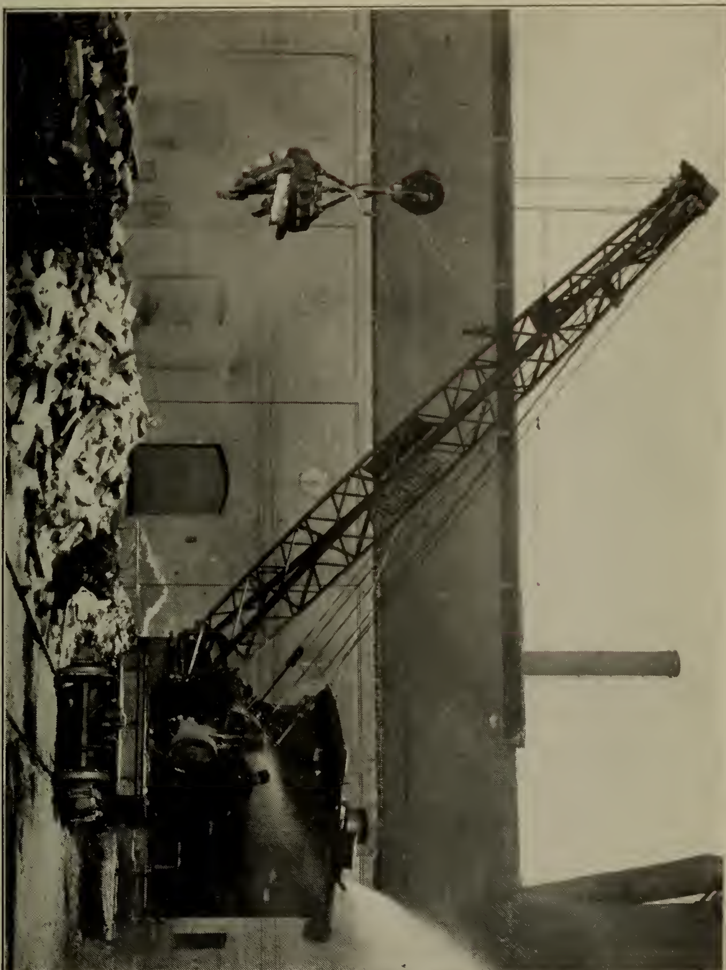


Fig. 73.—This magnet lifts scrap iron to load or unload it.

Insert a nail part way in this tube and it will be drawn clear in. The solenoid has been made into an electromagnet. It is considerably stronger than the bar magnet, and behaves like it in every way but one. When the current stops, the magnetism disappears.

If more turns are added and a piece of steel substituted for the soft iron core, the steel will retain part of its magnetism for a long time. Very good permanent magnets may be made with the use of strong solenoids.

Solenoids are used a great deal in electrical apparatus for opening and closing small switches; the circuit is opened or closed by a solenoid "core" which is drawn into the coil when current is flowing. They also are used to regulate the carbon of arc lamps.

Electromagnets are by far the most widely used piece of electrical apparatus. Telegraph, telephones, motors, generators, and wireless all depend to a certain extent on the action of the electromagnet. Magnets purely for attracting iron are made in a great many forms. Some with especially shaped poles have been built to take bits of steel from workmen's eyes. At the immense steel mills near Chicago iron is broken up by lifting a big iron ball with a magnet, and then letting it drop by cutting off the current. These magnets, and magnets for carrying iron scrap or sheets, are made quite flat. This brings all the windings close to the poles, where the magnetism can be used to best advantage.

ELECTRIC BELLS

The electric bell furnishes a good example of an everyday use of the electromagnet. The circuit of a bell includes the coil, a contact which opens and closes the circuit, the batteries, and the push-button. All of these parts are wired in series; that is, when current flows it goes through every part. When you press the button of an electric bell the circuit is closed through the magnet coil. The coils attract an armature of soft iron fastened to a spring. When the armature is attracted

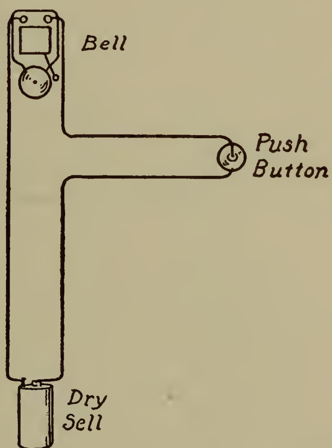


Fig. 74.—Simple electric bell circuit.

it is pulled away from the contact point. The circuit is opened and the coils are at once demagnetized. As there is no magnetic pull to hold the armature against the magnet, it flies back and the spring again touches the contact point. This completes the circuit once more. The armature is pulled by the magnet and the circuit again broken. Thus the hammer of the bell vibrates back and forth as long as the button is pressed.

A good bell may be bought for about half a dollar. The experience gained in building a bell of your own make could not be bought at any price. In making a bell it is a good plan to lay out a base on a piece of $\frac{1}{4}$-inch wood to fit whatever gong you may have. If this is done before the wood is cut there is a chance to make changes as you go along. For the bell planned here a

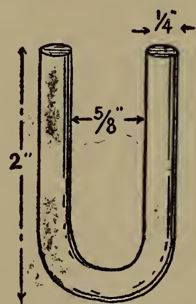


Fig. 75.—Magnet core for bell.

$2\frac{1}{2}$-inch gong is used. If a gong of nearly that size is secured the dimensions laid down on the plan in Fig. 80 can be followed.

For the magnet core have a blacksmith bend a piece of $\frac{1}{4}$-inch iron rod into a U shape; when bent this should be 2 inches in length and $\frac{5}{8}$ inch between the poles. This core should not be plunged into water, but should be allowed to cool slowly. When cool the whole surface should be filed smooth, and the ends filed or sawed off flat and true. At least $1\frac{1}{2}$ inch of each pole should be straight. The next step is to make two paper tubes that will just slide over the poles. These can be made by wrapping two or three turns of heavy paper around a stick whittled to the right size, and

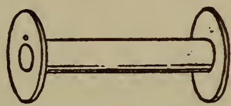


Fig. 76.—Spool for wire coil.

gluing the turns together. Cut each tube $1\frac{3}{8}$ inch long, but leave them both on the stick. When the tubes have dried cut out two wooden ends for each. These can be made from cigar box wood planed to

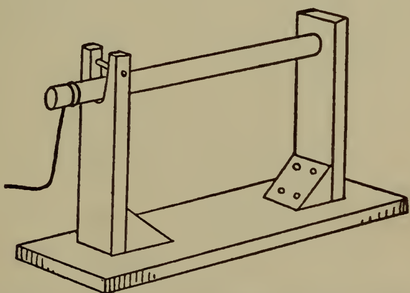


Fig. 77.—Windlass for winding wire on spools.

about half-thickness. They should each be $\frac{3}{4}$ inch in diameter, and should be carefully bored out so that they fit tight on the ends of the paper tubes. A little glue will hold them firmly in place.

The two spools, or bobbins, can be left in place on the stick for winding. At this point a little extra work will pay very well. Winding will be much easier if a small winding stand like the one shown in Fig. 77 is made. A piece of wire will do for the crank.

For winding use No. 22 cotton-covered magnet wire. About 4 ounces will be needed. Before putting on the

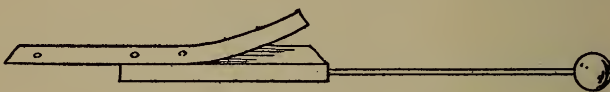


Fig. 78.—Armature, spring, and tapper.

first layer drill a small hole in the spool at the paper core and pull about 6 inches of wire through for connections. Wind evenly. A sheet of tissue-paper between layers will help in keeping the coils even. The last coils should be fastened by passing the wire under and pulling it tight.

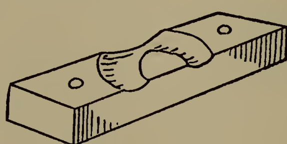


Fig. 79.—Block for holding magnet.

The armature should be made of a piece of soft iron riveted to a clock spring. The wire on which the iron hammer is attached can be screwed in or riveted to the armature. In order to straighten the spring and bore the holes it must first be annealed. This is done by heating it to red heat and then letting it cool off very slowly in hot ashes or hot sand. After it has been drilled and bent to the proper shape it can be tempered by heating again and dropping in water.

For mounting the magnet on the base make two wood strips exactly alike and each about 2 inches long, $\frac{1}{2}$ inch wide, and $\frac{1}{4}$ inch thick. Chisel out a **U**-shaped groove in each one to receive the bend of the magnet. When screwed to the wood base these strips will hold the magnet firmly in place.

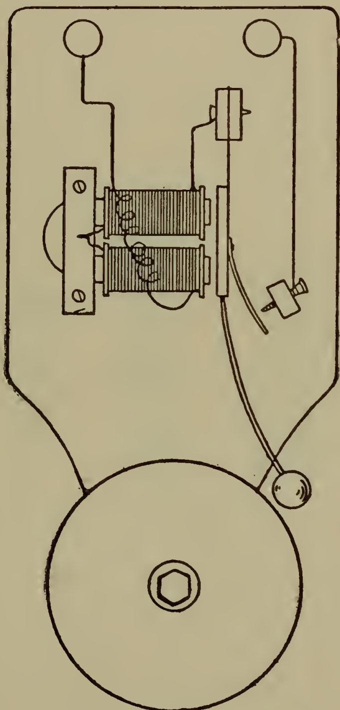


Fig. 80.—Inside of electric bell.

The spring can be tightly held by a small block of wood in which a fine saw cut has been made. For additional tightening a small screw can be run through the block. See that the block is placed so that the soft iron armature is held about $\frac{1}{16}$ inch away from the pole tips and parallel to them. In this position the end of the spring should just touch the contact screw.

An ordinary brass screw held by a small block fastened to base serves very well as a contact. This screw can be turned until the bell works best.

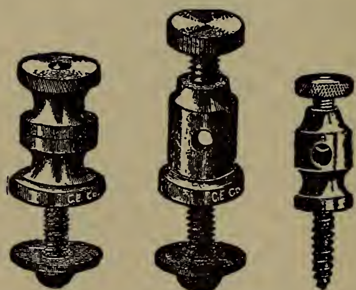


Fig. 81.—Common forms of binding-posts.

All wiring connections are shown in Fig. 80. Current comes in through the coil to the spring and out through the brass screw. When the magnet pulls the armature the circuit is broken at the screw and the spring flies back, completing the circuit again.

Binding-posts for the outside connections can be had in many shapes. For the bell, those with wood screws are convenient. Two are needed, and should be evenly spaced at the top of the board base. To one connector attach the fine wire running from the armature end of the magnet. Then connect the two wires left at the beginning of the coil. These should each be coiled

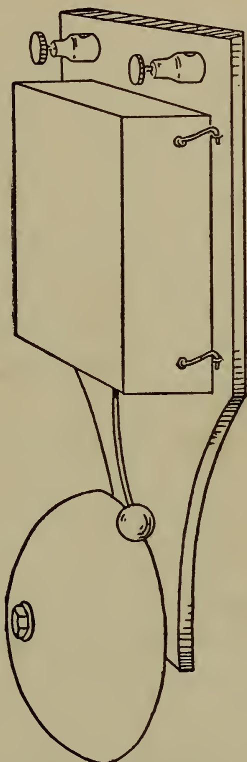


Fig. 82.—Finished bell.

tightly around a pencil to make a neat piece of work. The remaining wire should be run to the base of the spring, and fastened by a small screw. From the brass contact screw a piece of wire is connected to the other binding-post. Connections to the binding-posts should be soldered, as this reduces the resistance of the joint. The connection at the contact screw should be left loose until the screw is regulated. It can then be soldered.

A cover to protect the bell and give it a finished appearance should be made from cigar box wood. It should be just large enough to allow free working of the armature. A slot at the bottom will allow for movement of the hammer. Four small brass hooks and screw eyes can be added to hold the cover firmly in place.

Finally, the base and box should be well smoothed with sandpaper and given two coats of shellac.

WIRING THE BELL

When the location of the bell has been decided, measure the circuit carefully, being sure to include the distance to the battery. No. 16 insulated wire is a convenient size to use for the circuit. It can be bought in any length needed. The best place to run this wiring to a door is through the basement. If this is not practicable, it should either be carried along the base board or over the picture molding. Fasten it in place with small insulated staples. Keep it out of sight as much as possible and make the turns square and neat.

Especial care should be taken with wire joints, as one hastily made may introduce a high resistance and cause considerable trouble. Figure 83 shows the right and wrong way of making joints. The Western Union joint is both neat and easily made. While soldering is not absolutely necessary, it makes a much better joint. Either resin or one of the compounds sold for the purpose may be used as a flux.

Push-buttons are so simple and cheap that it hardly pays to make one, though this is easily done. The only materials are a piece of brass spring, a brass

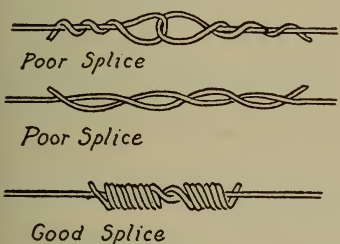


Fig. 83.—Wrong and right way of making splice.

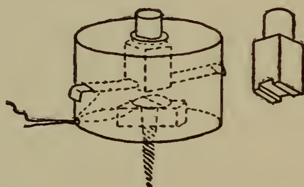


Fig. 84.—A push-button made from a pill box.

screw, and a small wooden box. The screw serves both as a contact and a fastener for the bell. Cut a little slot through each side of the box, so that the spring can be pushed in place. There should be about $\frac{1}{16}$ inch space between the brass strip and the screw head, but this can be regulated according to the strength of the spring. For the push-button whittle a round end on a piece of wood the proper length and about $\frac{1}{4}$ inch square. The round part should work freely in a hole through the box lid.

For connections, bend a piece of wire under the screw head and solder another to the spring. Insulated bell wire should be used, with the ends scraped off clean where connections are made. Both wires can be brought out together through a hole in the side of the box.

Batteries can be located near the bell or in the basement. The diagram in Fig. 74 shows the simplest arrangement of a bell circuit.

If the bell is to be rung from any one of several points other push-buttons may be wired in parallel. The circuit is then closed through the battery and bell, no matter which is pushed.

A BURGLAR ALARM

A burglar or chicken thief alarm can be arranged with the addition of a relay. Such a relay need have only

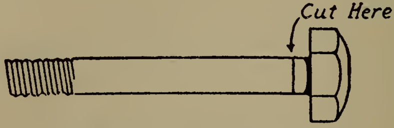


Fig. 85.—Bolt for magnet core.

one coil, and is not hard to make. Its only purpose is to keep the bell circuit open as long as everything is all right, but to close it when a door or window is opened.

For the relay magnet core an ordinary $\frac{5}{16}$-inch bolt cut off to $1\frac{1}{2}$ inch in length can be used. It should be screwed in a strip of soft pine and fitted to the end of a sawed down cigar box, as shown in Fig. 86. A $\frac{3}{4}$-inch spool of No. 22 wire should be wound on a bobbin to fit, just as for the electric bell. No spring is needed. The armature should be hinged at one end, so that it will be held up as long as the magnet is energized. A clip should be bent from a piece of brass, so that when the armature drops it will be caught and a good con-

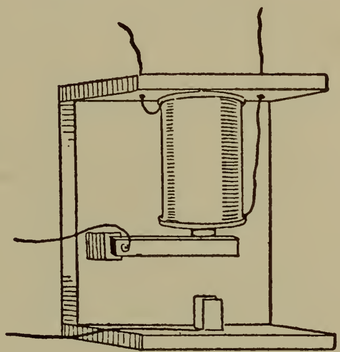


Fig. 86.—How alarm relay is wired.

tact made. Two binding-posts should be attached above for the magnet circuit and two below for the bell circuit. To the upper posts the two ends of the coil are attached. From one of the lower ones a wire runs to the brass clip, and from the other one to the armature near the point where it is hinged.

Suppose a chicken-house door is to be guarded. A thin strip of brass should be screwed to the top of the door, and another in the door casing, so that they rub together when the door is shut. To each of these a piece of insulated wire should be run. These should

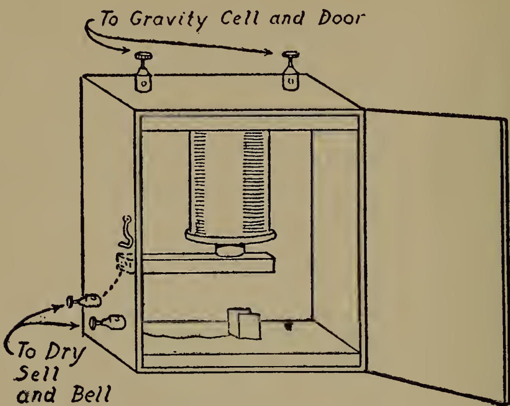


Fig. 87.—Complete relay.

be carried on insulators to the house, where connection is made with the relay coil and battery in series.

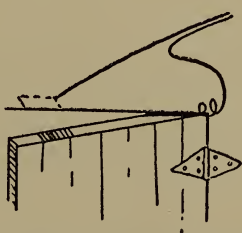


Fig. 88.—Wiring for a chicken-house door.

This is a good place for a Daniell gravity cell to be used, as the circuit is closed most of the time.

The electric bell can then be connected to a couple of dry batteries in a separate circuit. One wire from the bell and one from the battery should be connected to the lower binding-posts of the relay. It is well to put a little switch in this circuit, so that it can be opened in the daytime. If this is not done the bell will make itself a nuisance by ringing every time anyone goes into the chicken-house.

One advantage of such a system is that the thief cannot stop the bell after it has once started ringing. If he finds the wires and cuts them the circuit will be

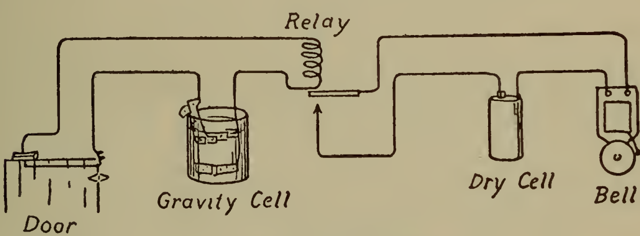


Fig. 89.—Wiring for burglar alarm.

opened and the alarm sounded just as if the door had been opened. The main disadvantage is that the alarm must be set by putting the armature in place every night.

A THREE-CALL ANNUNCIATOR

An annunciator is only a little harder to make than the burglar alarm. Much the same kind of materials are needed. It is necessary to wind three magnets instead of one. They can be of the same size as those for the alarm, and wound with No. 22 wire. Mount them on a ½-inch board to which another board has been

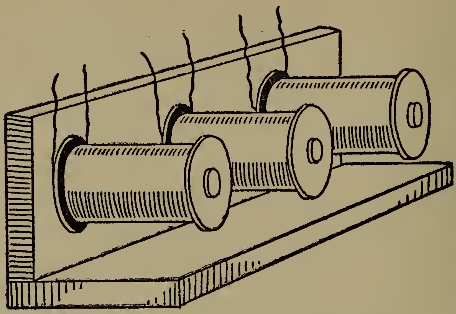


Fig. 90.—Magnets for annunciator.

attached at right angles. In front of each one screw a piece of clock spring to which a soft iron armature

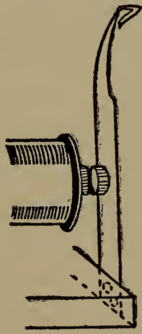


Fig. 91.—Catch for annunciator drop.

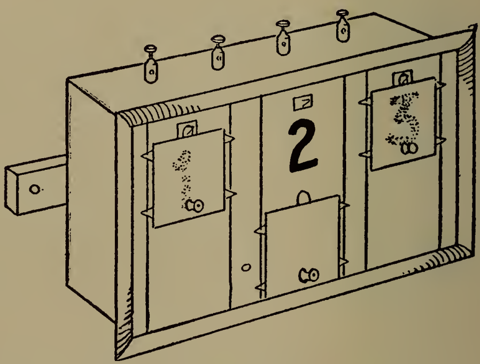


Fig. 92.—Three-call annunciator.

has been riveted. The armatures may be made of ⅛-inch sections sawed from the ends of the bolts which were used as cores. The springs should be long enough to almost touch the top of the containing box after they have been bent in the shape shown. A little hole for each should be cut near the top of the box, so that all will project through when not attracted by the magnets.

Three little sliding doors or drops are now needed. These can also be made from cigar box wood. They should be about half the height of the box, and each less than one-third its width.

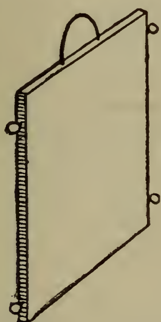


Fig. 93.—Annunciator drop.

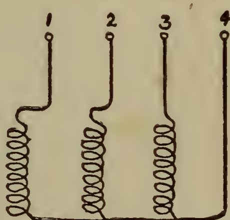


Fig. 94.—Annunciator connections.

Both for finish and to provide slides for the drops a piece of picture frame can be cut just to fit the box. Before this is put in place it can be fitted with three pairs of vertical wires; one for each drop. Tiny screw eyes or staples at top and bottom of the drops make excellent guides.

Right under each spring tip a numbered card can be placed. When the drops are up all these numbers will be covered. When one of the drops falls the number behind is shown. Each magnet is made to work from a different push-button, and all the push-buttons are connected in circuit with the electric bell.

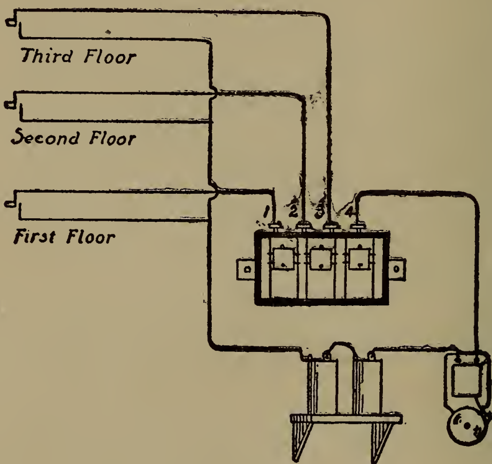


Fig. 95.—Annunciator circuit.

Only four binding-posts are needed for this annunciator. The connection is shown in Fig. 94. Connections to both bell and annunciator are indicated in Fig. 95.

INDUCTION

The circular lines of force that surround a wire when current is flowing in it are really tubes of force, since they extend the entire length of the conductor. The instant you connect the wire to the terminals of a battery these tubes begin to form. They grow from the wire to their full strength much as the rings of waves grow when a stone is tossed into a pond. When the current is stopped the process is reversed. Both movements are very rapid.

If a second wire is put near the wire in which current is allowed to flow regularly, the lines or tubes of force will pass by it. When this happens an E. M. F. is induced in the second wire. It will be induced every

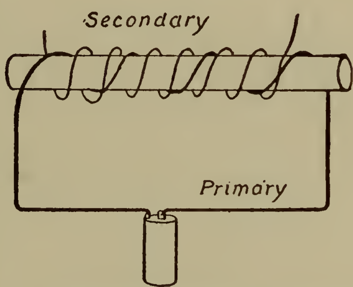


Fig. 96.—Connections of an induction-coil.

time the first wire is connected to or disconnected from the battery.

This principle is used in the induction-coil. The wire is wound on a core of soft iron to make the best use of the magnetism. Current is interrupted almost instantaneously.

While spoken of as a single coil, the induction-coil is really two separate coils of different sized wire. They are called the "primary" and "secondary" coils. The primary coil is the one connected to the battery which supplies the E. M. F. The secondary coil is the one which produces the spark.

Just as with the two parallel wires, current from the battery has produced a varying magnetic field, the rapid changes of the field have generated an E. M. F. in the other wire.

The E. M. F. of the secondary coil depends on the E. M. F. supplied to the coil, and on the number of turns of wire in each winding. If both coils are alike, the E. M. F. in primary and secondary will be the same. If the primary has a hundred turns and the secondary 10,000, the secondary voltage would be 100 times that of the primary. With a battery of, say, six cells in series and ten volts applied to the primary, the secondary E. M. F. would be 1000 volts. In an induction-coil the attraction of the primary core for a soft iron armature breaks the circuit, and a spring immediately closes it again. This is just what was done in the electric bell. The action here is much more rapid.

MAKING AN INDUCTION-COIL

A good induction-coil is not an easy thing to build. Considerable care must be taken with each step, or the builder is apt to find that all his work has gone for nothing, and his coil is worthless. The wire used is thinly insulated and is very fine and easily broken. Any breaks must be very carefully repaired. One break would, of course, ruin the coil.

The induction-coil described here will give a spark 1 inch long. This is large enough to make possible many interesting experiments, and can be used later for wireless telegraphy, where the distance is short.

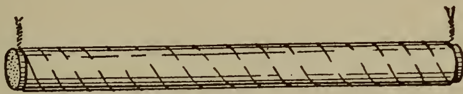


Fig. 97.—Core of induction-coil.

Requirements in the way of wire are a half-pound of No. 12 single cotton covered, and two pounds of No. 32 single silk covered. For the core a bundle of No. 20 annealed iron wire is used instead of the single rod needed for the bell and relay. These wires can be

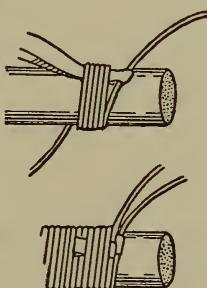


Fig. 98.—How wire is held in place.

bought at any electrical store. About one pound will be needed. Have them cut 8 inches in length.

To begin the coil make up a bundle of these iron wires ¾ inch in diameter, binding both ends tightly with wire. Then wrap from one end to the other with two layers of insulating tape. Now set the coil on end and pour shellac in between the wires. Allow this to dry before going any further.

The primary, consisting of two layers of No. 12 wire, can now be wound on. This should be put on tightly and evenly. The beginning of this coil should be held in place by little loops of cloth as shown in Fig. 98. The winding should extend to $\frac{5}{8}$ inch from one end of the core and to $\frac{3}{4}$ inch from the other. Finish by wrapping the coil with ten layers of paraffined paper.

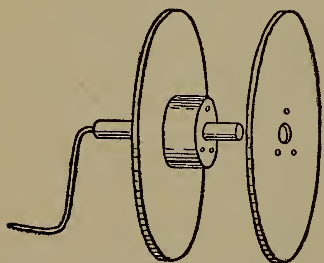


Fig. 99.—Section winder for induction-coil.

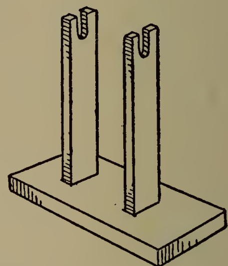


Fig. 100.—Winding stand.

While the secondary could be wound on the primary just as the bell magnet was wound, and insulated by layers of paraffined paper at every second turn, better results are obtained by winding the wire in sections. That is, the coil is made up of 12 sections slipped on over the primary winding. One big advantage of this is that every section can be tested as you go along.

For easy winding a section winder should be made.

This is simply a flat spool with one end removable. The ends can be made from cigar box wood, and should be cut to about 3 inches in diameter. The center part on which the wire is wound should be $1\frac{1}{8}$ inch in diameter and $\frac{1}{2}$ inch thick. This should be turned on a lathe, but can be whittled out if proper care is taken.

One end can be nailed fast to the center piece, but the other should be fastened by three screws, as it has to be slipped off after each section of wire is wound.

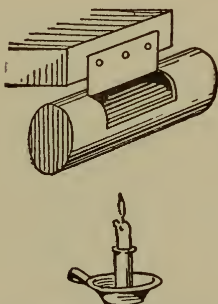


Fig. 101.—How can and candle are fixed for winding sections of coil.

A small wood shaft fitting tightly through the block provides the axle. A winding stand similar to the one made for the magnet coils is, of course, necessary.

A second piece of apparatus will be needed for winding the coil; this is a bath of melted paraffine. A square cake tin or a tin can big enough to hold the spool of wire will answer. If a tin can is used the lid must be soldered on and a hole cut in the side big enough to slip the spool of wire in. Both edges should be turned back to avoid scraping the insulation. The top edge can be used as a support.

Enough paraffine should be put in the can to soak the coil, and it should be kept melted by a small candle set underneath. Be very careful not to get the paraffine bath too hot, it is liable to catch on fire, and besides the heat injures its insulating properties.

To start the first coil of fine wire, pull the end of the paraffined wire through the small hole in the spool end.

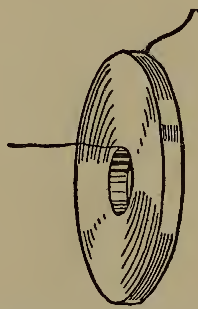


Fig. 102.—Coil section.

Now turn the winding spool so that the wire will wind in the same direction as the turns on the primary. As the insulation is well soaked with wax, the coil will be quite solid when finished. The removable end of the spool can then be taken off and the coil pried out gently by inserting a knife between the windings and the wood end. In this way 12 coils should be made. Wind them all in the same direction. Three half-pound spools of wire should be enough to wind eight, though this depends on the evenness of the winding. As each is finished it can be tested by putting the ends to the terminals of a dry battery. If a little spark can be made by rubbing the terminals the coil is all right. A test can also be made with a compass needle.

After the 12 coils are finished, cut about 75 sheets of writing paper the same size as the coils and with a hole in the middle large enough to slip over the primary winding. Now make two square wood end pieces, boring a hole in the center of each large enough to fit the iron core and hold it tightly. Force the core into one of these wood ends, standing it upright. This is the first step in assembling the windings. Then slip on 4 or 5 sheets of the paraffined paper. Next comes the coil, put on so that its winding runs the same way as that of the primary.

The next step is the most delicate and important of all. It is the connection of two coils. For convenience it is best to connect the inner end of the first coil to the inner end of the second. To do this the second coil must be put on so that its windings run *opposite* to those of the first. This allows the current to flow in the same direction in both coils. The two ends to be joined must be unwrapped and scraped very carefully. Then they should be united with a drop of solder and wound again with a fine silk thread. Before the coils are finally laid together slip four of the paraffined paper disks between them.

The third coil is put on like the first. Its outer end is connected to the outer end of the second. Remember that the first, third, fifth, seventh, ninth, and eleventh coils are put on with windings running

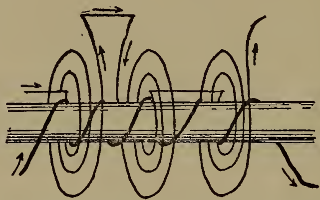


Fig. 103.—Diagram showing direction of coil windings.

the same way as those in the primary. The second, fourth, sixth, eighth, tenth, and twelfth run in the opposite directions. Fig. 103 will give you an idea of the windings. Each coil should be insulated from

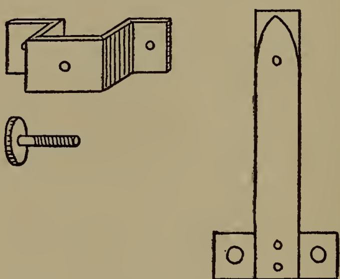


Fig. 104.—Interrupter parts.

the next by at least four layers of paraffined paper. After the twelfth coil has been connected add enough paper sheets at the ends to fill the core within $\frac{1}{2}$ inch of the end. When the wood end is in place the core should come through it about $\frac{1}{16}$ inch.

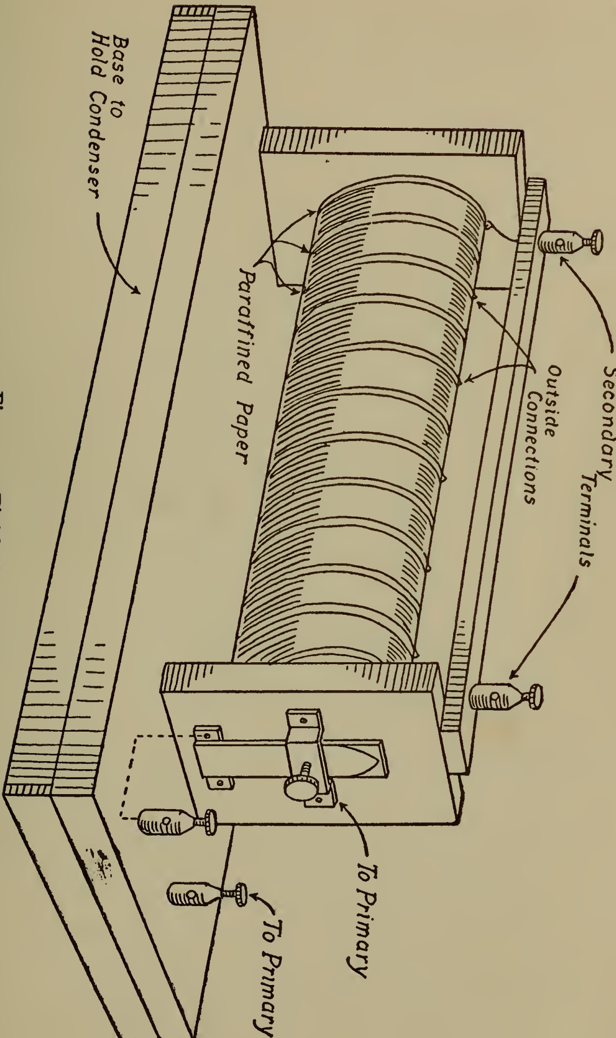


Fig. 105.—Finished spark coil.

You are now ready to add the interrupter. It is hard to make a good interrupter, so this part of the coil had better be bought. It can be secured from an electrical supply house. To connect it in after attaching it to the end piece with short screws, run one of the primary terminals to the vibrating part, and connect the contact screw to one of the binding-

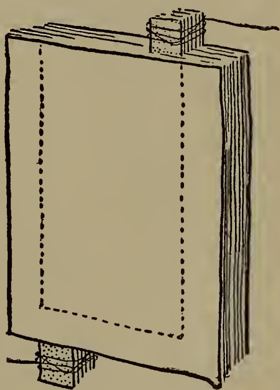


Fig. 106.—Tin-foil condenser.

posts set in the coil base. The other primary terminal goes direct to the second binding-post.

The secondary terminals are connected to another pair of binding-posts set on the end pieces of the coil.

A spark could be secured from the coil just as it is now, but it would not be very long or very regular. There would also be a sparking at the interrupter point that would soon wear out the contact. To prevent sparking at the contact, and to give a longer, better secondary spark, a condenser must be added.

For a condenser of suitable size, 100 sheets of tinfoil, each cut to 5 by 7 inches and left with a short

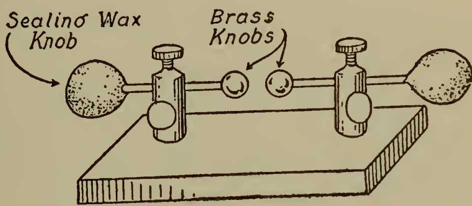


Fig. 107.—Spark gap.

tab at one corner, will be needed. An equal number of sheets of good bond writing paper should be cut 6 by 9 inches. In putting these together the tin-

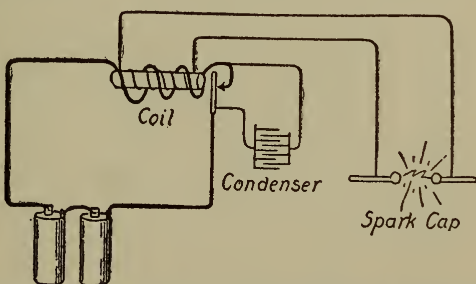


Fig. 108.—Connections for induction-coil and spark gap.

foil sheets should all be separated by the sheets of paraffined paper. Half of the little tabs should project from one corner of the package and the other half from the other corner. When finished bind each set together with a piece of fine wire. The two wires make the terminals of the condenser. To connect it run one of the wires to the interrupter spring and the other to the bridge that holds the regulating screw.

To hold the condenser a shallow box should be built under the base of the coil. A spark gap for use with this coil can be built from brass rods as illustrated. Figure 108 indicates the connection for coil, condenser, and spark gap.

WIRE TABLE

American or B. & S. Gauge

The resistance given in the table is that of pure copper wire; ordinary commercial copper has a resistance from 3% to 5% greater.

Gauge No.	Diam. in Mils	Area in Circular Mils.	Weight in lbs. per 1000 feet	Feet per Pound	Resistance of Pure Copper in International Ohms at 20°C. or 68°F.		
					Ohms per Ft.	Feet per Ohm	Ohms per lb.
0000	460.0	211600.	640 5	1.56	.0000489	20440.	.00007639
000	409 6	167800.	508.0	1.97	.0000617	16210.	.0001213
00	364.8	133100.	402.8	2.49	.0000778	12850.	.0001931
0	324 9	105600.	319.5	3.13	.0000981	10190.	.0003071
1	289.3	83690.	253.3	3.95	.0001237	8083.	.0004883
2	257.6	66370.	200.9	4.98	.0001560	6410.	.0007763
3	229 4	52630.	159.3	6 28	.0001967	5084.	.001235
4	204 3	41740.	126 4	7.91	.0002480	4031.	.001963
5	181.9	33100.	100.2	9.98	.0003128	3197.	.003122
6	162.0	26250.	79.46	12.58	.0003944	2535.	.004963
7	144.3	20820.	63.02	15 87	.0004973	2011.	.007892
8	128.5	16510.	49.98	20.01	.0006271	1595.	.01255
9	114.4	13090.	39.63	25.23	.0007908	1265.	.01995
10	101.9	10380.	31.43	31.85	.0009972	1003.	.03173
11	90.74	8234.	24.93	40 12	.001257	795.5	.05045
12	80 81	6530.	19.77	50.58	.001586	630.5	.08022
13	71.96	5178.	15.68	63.78	.001999	500.1	.1276
14	64.08	4107	12.43	80.45	.002521	396.6	.2028
15	57.07	3257.	9.86	101.4	.003179	314.5	.3225
16	50 82	2583.	7.82	127.9	.004009	249.4	.5128
17	45.26	2048.	6.20	161.3	.005055	197.8	.8153
18	40.30	1624.	4 92	203.4	.006374	156 9	1.296
19	35.89	1288.	3 90	256.5	.008038	124.4	2.061
20	31.96	1022.	3 09	323.4	.01014	98.62	3.278
21	28.46	810.1	2 45	407.8	.01278	78.24	5.212
22	25.35	642 6	1.95	514.2	.01612	62 05	8.287
23	22 57	509.5	1.54	648 4	.02032	49.21	13.18
24	20.10	404 0	1.22	817.6	.02563	39.02	20.95
25	17.90	320.4	.97	1031.	.03231	30.95	33.32
26	15.94	254.1	.77	1300.	.04075	24.54	52.97
27	14.20	201.5	.61	1639.	.05138	19.46	84.23
28	12.64	159 8	.48	2067.	.06479	15.43	133.9
29	11.26	126.7	.38	2607.	.08170	12.24	213.0
30	10.03	100.5	.30	3287.	.1030	9.707	338.6
31	8.928	79 71	.24	4145.	.1299	7.698	538.4
32	7.950	63.20	.19	5227.	.1638	6.105	856.2
33	7.080	50.13	.15	6591.	.2066	4 841	1361.
34	6.305	39.75	.12	8311.	.2605	3.839	2165.
35	5.615	31.52	.10	10480.	.3284	3 045	3441.
36	5.000	25.00	.08	13210.	.4142	2.414	5473.
37	4.453	19 83	.06	16660.	.5222	1.915	8702.
38	3.965	15.72	.05	21010.	.6585	1.519	13870.
39	3.531	12.47	.04	26500.	.8304	1.204	22000.
40	3.145	9.89	.03	33410.	1.047	.955	34980.

EXPERIMENTS WITH THE SPARK COIL

With a well-made coil all the static spark experiments described in the second chapter can be performed. Many new ones are possible. When doing these always keep in mind that the voltage of the secondary is very high. A shock from it is not only very unpleasant, but actually dangerous.

Experiments with the spark pane and filings burned by the spark make pretty exhibitions in a darkened

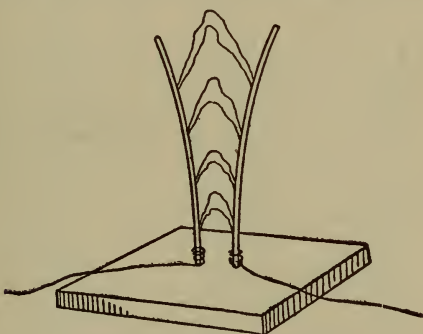


Fig. 109.—A spark "ladder."

room. To these the experiment with the climbing spark can also be added. The only additional apparatus needed is a small board provided with two binding-screws, and two pieces of fairly heavy copper wire. The bottom of these wires should be within sparking distance of each other, and the tops bent apart. When this spark gap is connected to the secondary of a coil sparks will continually jump across the bottom, climb to the top, and disappear.

With the glass bulbs known as Geissler tubes the induction-coil can be made to give a faintly flickering but beautiful light. These tubes are filled with rarified gases of different kinds and are made in a number of shapes. The plain ones are not expensive and can be bought from any electrical supply house.

When the two metal ends of a Geissler tube are connected to the secondary terminals of a spark coil

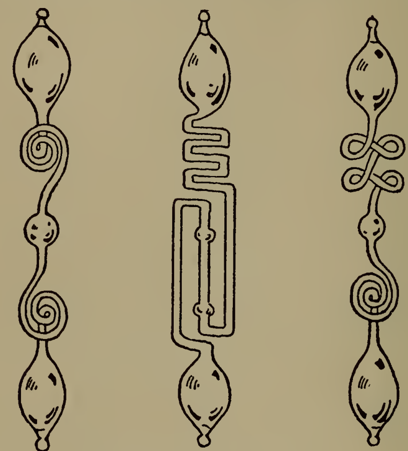


Fig. 110.—Geissler tubes.

it lights up in a very weird fashion. The color of light depends on the gas in the tube. Half a dozen different kinds hung around the wall and connected in series with the coil make a pretty decorative display in a darkened room.

A somewhat similar effect can be secured with a burned-out incandescent lamp bulb. One in which

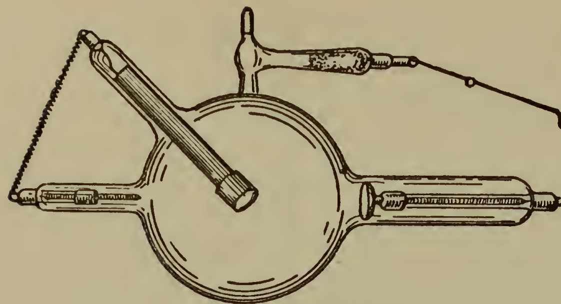


Fig. 111.—X-ray tube.

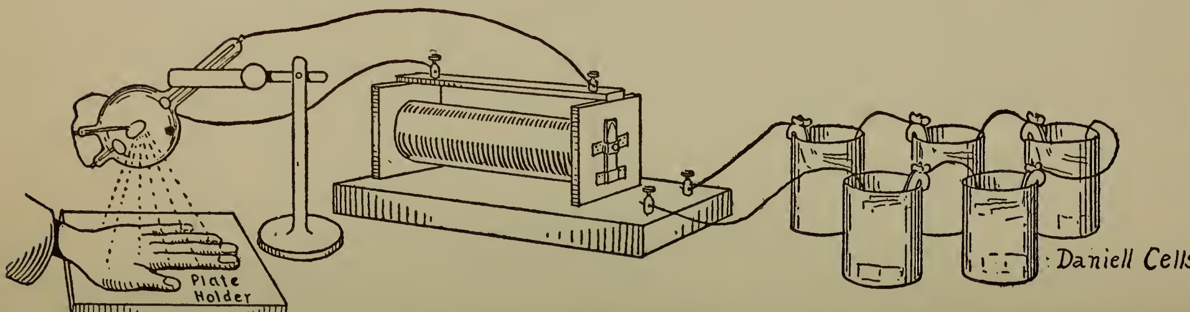


Fig. 112.—How an X-ray tube is connected.

the filament is broken gives the best results. By taking hold of the bulb and touching the brass plug to one of the secondary terminals the bulb is made to glow a faint ghostlike light. This can be seen only in a dark room.

With a coil giving a longer spark experiments with X-rays may be performed. The X-ray tubes ordinarily cost in the neighborhood of from $5.00 up. They are simply tubes from which the air has been exhausted after platinum electrodes have been sealed in at the ends. The one in the small end is called the cathode, and the two in the bulb are the anodes. Rays from the cathode strike the diagonal anode and are reflected as shown in Fig. 112. These rays pass easily through flesh, but not so easily through bone. They will affect a photographic plate just the same as ordinary rays of light.

If the anode is turned down a few inches above a plate holder containing a dry plate, and the rays allowed to strike it for a few minutes the plate is spoiled just as if it had been exposed to the light. If your hand is laid over the plate before the current is turned on you will get a shadow picture of the bones. The flesh seems to be transparent.

This "shadow-picture" is not visible to the eye. A fluoroscope is needed to see the X-ray effect. The fluoroscope is simply a box covered at one end by a cloth coated with a platinum-barium-cyanide compound. When the rays strike against this screen, it is all set in a faint glow. This can be seen by looking in the open end of the box. A hand held between the X-ray tube and the screen makes a bone shadow just like the one photographed on the plate.

With a little practice very good photographs can be taken of hands, coins in purses, nails in wood, and a variety of other objects.

In working with an X-ray tube it must be remembered that there is a right and wrong way of connecting it to the coil. This can be determined with the fluoroscope. If the connections are right the box will be filled with a greenish glow; if wrong, no effect is visible. Before changing the connection be careful to disconnect the batteries.

CHAPTER VI

Electric Heat

A wire carrying a current of electricity always becomes heated. No matter how small the current is, some of the electrical energy is changed into heat. It is commonly said that this heat is generated in overcoming the resistance of the wire. A better way of imagining it is that when the little particles, or molecules, of the wire are set in such rapid motion by the current, they strike against one another until all become hot. There seems to be a mechanical action in the wire just such as you could apply on the outside of a rod by hitting it rapidly with a hammer.

When a wire is carrying current the heat is radiated and carried away by the air. If all of this heat could be kept right around the wire so much would accumulate that the metal would melt. The time required for this would, of course, depend on the current flowing.

Each metal behaves differently as to heating when put in an electric circuit, just as it acts differently in other ways. Some have high resistance and melt easily, others have a low resistance and are quite hard to melt. Others have a high resistance and can be kept red hot for hours without a sign of softening.

Copper has a low resistance, is fairly cheap, and has a high melting-point, so it is used to carry current. Alloys of tin and lead have a higher resistance and a much lower melting-point. Of these alloys "fuses" are made. Still other alloys have a high resistance and a very high melting-point. They are used to make electric toasters, flat-irons, and other heating appliances.

Electricity is very easily changed to heat, but these resistance wires change it in such a way that it can be put at the useful work of ironing, toasting your bread at breakfast, boiling the coffee, and supplying heat any time for all sorts of uses. In all these heating appliances you see the last step in changing sunlight back to heat.

The coal at the power-house contains energy stored by the sun centuries ago. Unfortunately, the best engines and boilers made can only turn about one-tenth of that stored-up energy into electrical energy. Changing back is much easier, and every bit of electrical energy can be turned into heat.

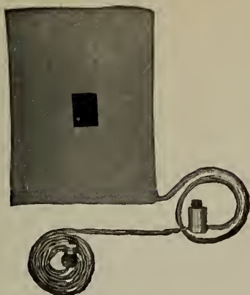
Whether the power you use comes from a waterfall or from a coal-burning plant, about the only difference between the electric heat it gives you and the natural kind sunlight furnishes is one of time. Sunlight is really stored up in the water and in the coal. Where heat is obtained from coal many centuries passed by since it was stored up in the tropical plants; with water power the energy turned into heat today may have been spent only a few days before in evaporating water from ocean or lake. The water falls as rain, adds to the current that turns the turbine, and provides electricity to make your morning toast.

All the electric heat we use today comes directly from sunlight in these two ways. Batteries for this purpose are too expensive and clumsy to be practical. To equal your electric heating circuit even for a short time at least a hundred primary cells would be needed.

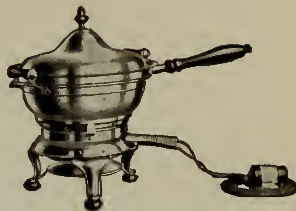
At ordinary prices for electricity, electric appliances are really economical. The heat can be applied just where it is needed and can be regulated perfectly. The demand has been so great that there are hundreds of these appliances on the market. A few are illustrated in Fig. 113.

In each of these the "heating element" is the important part. This is simply a piece of high resistance wire connected in the circuit so that it will be heated by the current. By arranging its shape and size to suit, it can be made to provide just the sort of heat needed for each device.

For the flat-iron the heating element must be flat and shaped to fit the bottom of the iron. In a toaster



Heating pad.

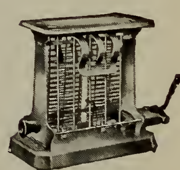


Chafing dish.

Coffee percolator.

Flat-iron.

Radiant heaters.



Electric toaster.

Fig. 113.—A few electric appliances.

the heat is radiated out to the bread instead of being held in by metal, so the wire is generally run in zig-zag coils. A still different arrangement is necessary for the heating pad which takes the place of the hot-water bottle. In this the wires must be very long and very easily bent in all directions. They are encased with asbestos, which is both flexible and fireproof, and the whole is covered with felt or flannel.

With all these electric heating appliances electricity becomes as good a servant in the house as it is workman in the factory.

THE ELECTRIC FLAT-IRON

An ordinary electric flat-iron furnishes a good example for the explanation of electric heating. Two

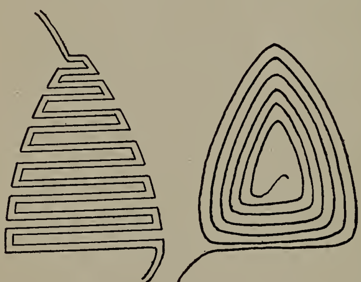


Fig. 114.—Heating elements for flat-irons.

insulated wires connect the power company's lines to the two brass prongs which usually stick out at the back of the iron. One of these prongs is connected to each end of the heating element. Both of them are insulated from the metal covering of the flat-iron.

Flat-iron heating elements are made in many styles, though all of them are flat and shaped to fit the bottom of the iron. Some zigzag back and forth, others are like a flat coil. In any case they are insulated from the rest of the iron by mica and asbestos. To give the iron weight and make it hold the heat there is a piece of iron also above the heating element.

There is not much that can happen to a heating element. Sandwiched between two pieces of iron

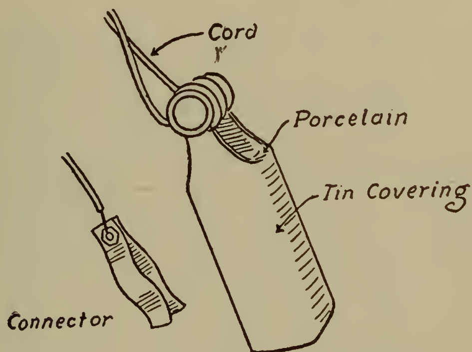


Fig. 115.—One style of flat-iron connector.

and protected by good insulation it will last for years under ordinary circumstances. If the iron should fail to heat for any reason, first make sure that the cord is all right by connecting it to some other heating appliance. Each connection through the cord and iron must be perfect, as the current flows down one of the insulated wires through the heating element, and back again through the other wire to the powerhouse.

If the cord seems to be all right, look for a break either in the flat wire that makes up the element or in the little wires that run to it from the posts. A more common place for failure in some irons is the plug that is used to connect the iron to the circuit. Sometimes the copper terminals become pitted by sparking or the porcelain is broken. Repairs can be bought for either part.

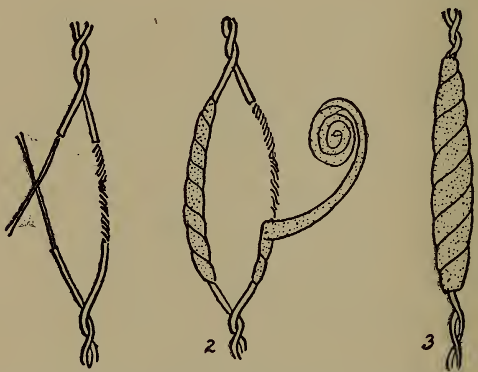


Fig. 116.—Three steps in making splice of flat-iron cord.

When the cord wears out in a spot it should be fixed at once by splicing and winding each wire separately with insulating tape. Figure 116 indicates three steps in making such a splice.

Never do any work on an iron when it is connected to the circuit. Carelessness in this is apt to result in a bad burn, or at least in blowing a fuse and cutting off your current.

A very common practice in using a flat-iron is to connect it right to a lamp socket. Sometimes the little key is used to turn off the current just as you would turn a lamp on and off. This is a very bad habit. If kept up the parts of the socket will soon be worn out by sparking, and a new lamp socket will be needed. A plug at the iron is provided to turn current on and off and ought always to be used. An addi-

Fig. 117.—Push socket and plug.

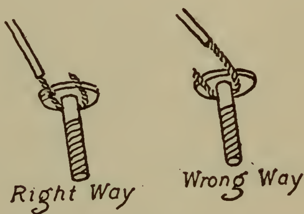


Fig. 118.—Right and wrong way of connecting wires.

tional socket and plug at the other end of the cord is also a great convenience.

Sometimes the wires become separated from the terminals in the plug or broken near it. When this happens, cut both wires off the same length, and then scrape off about $\frac{1}{2}$ inch of insulation. Fasten the wires firmly under the little screws and see that none of the fine wires stick out. When the flexible wire is wound around the screw under the flat head, remember to wind it in the direction the screw turns when put in place. If this is not done the wire is apt to come out when the screw is tightened, or at least make a poor job.

MAKING AN ELECTRIC TOASTER

A plain but very useful electric toaster can be made from ordinary cement, using a simple mold made from a cigar box and two boards. The only parts of this toaster that need to be bought at the electrical store are a porcelain plug connector, about 6 feet of flexible cord, and 12 feet of resistance wire. After all the materials have been secured the first step is to cut the top of the box off so that the part left will be 2 inches high all around. Then cut the cover down so that it is ½ inch narrower than the inside of the box and 1 inch shorter. For the next piece a bit of ¼-inch board is needed. This should be cut ¼ inch smaller all around than the cover was. With a sharp bitt put six equally spaced holes in one end of the board and seven in the other.

To finish the mold a piece of board cut just to fit the top of the box is needed. Cut each of the corners off as shown in Fig. 119. Nail two strips across to prevent it from falling clear into the box when placed on it.

In assembling the mold nail the piece of cigar box cover and the board with the holes together. The space should be the same all around the edge of the thicker board. When fastening these two boards in the bottom of the box the holes should be up and the space at the sides even. Leave about twice as much space at the end with the seven holes as at the other. In this space the porcelain connecting plug will be held. Two holes in the middle of the box end will be

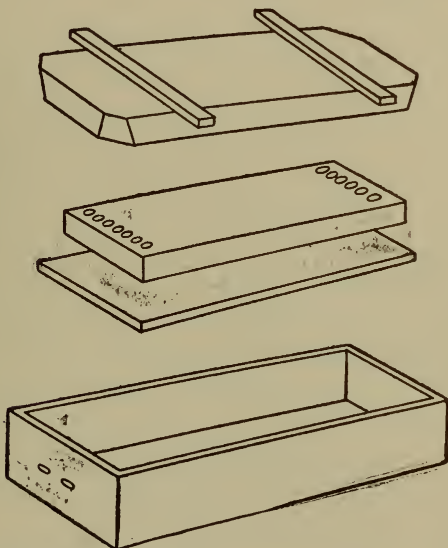


Fig. 119.—Mold for casting cement toaster base.

needed for the brass prongs of the connector to stick through. The fit should be good enough to hold the connector straight in place.

The mold is now ready for the cement. If very carefully made there will be no trouble in getting the cement casting out of it. If each of the edges is beveled a little and the whole inside of the mold treated with paraffine wax, a number of castings can be made if desired.

Get good cement and mix it thoroughly. Before pouring, it is well to have 13 little pieces of cardboard ready, each the width of the small holes and one-half as deep. Set one of these on edge in the bottom of each hole. In pouring cement into the holes be careful not to disturb the position of these strips. The remaining quantity should be added slowly so that there are no air bubbles. The cement should be like a very thick paste. When the cement filling is within $\frac{1}{2}$ inch of the top press the top board down until the little strips nailed across it rest on the sides of the box. Some cement will squeeze up into the four triangular spaces left by the sawed off corners. If this is not enough to fill them level with the top of the box, add a little more cement and smooth off. This cement filling should be allowed to set for at least three days.

To take the cement toaster base from the wooden form it will be necessary to pry the corners of the box apart a little. In removing the board with the holes a little more care is necessary. In each hole a small post is formed, and carelessness here might cause some of these to be broken. The small pieces of cardboard will be embedded in the ends of the posts, and when these are picked out little slots will be left.

The toaster is now ready for the heating element. This should be made from $9\frac{1}{2}$ feet of No. 26 "Nichrome" wire if the lighting circuit is 110 volts. If it is 125 volts use 10 feet. Coil this wire tightly

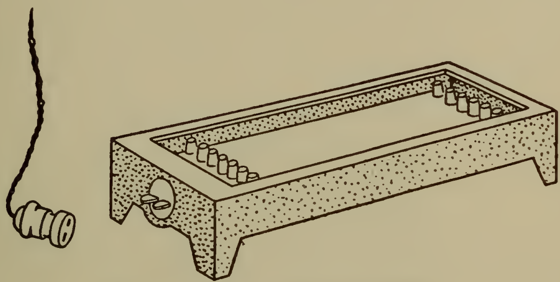


Fig. 120.—Cement base for toaster.

around a small round bar (a small drill will do nicely) so that it is like a long spiral spring. Leave 3 inches straight at each end. Now pull it out evenly until the coiled part measures 6 feet. Connect one end to

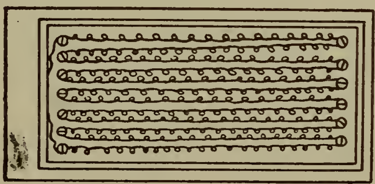


Fig. 121.—How the toaster is wired.

one of the screws in the porcelain plug base in the cement, and run the wire in zigzag fashion from post to post. Connect the other end to the remaining screw of the terminal. The little slots that hold the resistance wire in the posts may now be filled with cement if desired to hold the wire more firmly in place.

A piece of screening should now be cut to hold the toast. This should be of a size to just fit in the top of the toaster. By sandpapering and shellacking the outside of the toaster it can be given as nice a finish

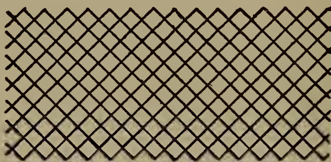


Fig. 122.—Screen for holding bread.

as desired. It is very convenient and will allow you to toast your slices of bread in just a few minutes.

OTHER USES OF ELECTRIC HEAT

In addition to the household uses of electric heat there are many applications in factory work. The electric soldering iron saves the use of the blow torch and keeps a steady even heat as long as it is needed. The electric glue pot is largely used in furniture factories. Electric ironing machinery in laundries and electric welders in iron working shops are quite common.

In the electric welder the two pieces of iron to be united form the conductor. Current is allowed to flow in them until they reach the intense heat necessary for welding, they are then pressed or pounded together until they unite to form one solid piece. Rail joints of electric railway lines are often welded in this fashion, so that the whole line is one solid piece of iron instead of being broken by joints.

Where an even more intense heat is needed the electric arc is used. This arc is the flame that is seen when the circuit carrying a heavy current is opened. Two carbons connected in a circuit and then pulled apart a little distance offer such a resistance the instant they are separated that some of the carbon is actually evaporated. This evaporated carbon carries the current, but has enough resistance to be kept at white heat and continually evaporates more of the carbon. The flame is white hot carbon vapor and air.

The heat from this electric arc is so very intense that it will melt any metal known, and even makes possible the manufacture of tiny artificial diamonds. The electric furnace is used to make the grinding material called "Carborundum." This is almost as hard as a diamond, yet is made out of the simple materials salt, sand, and sawdust by the application of electric heat. The materials are all mixed together and placed in a big electric furnace. After heat has been applied for some time the three common materials have been changed to one of an entirely different nature.

In a little different way the electric arc is used to cut steel in buildings or bridges which are being torn down. For this work one of the electric terminals is firmly attached to the piece of steel and the other to a carbon tip furnished with a handle. Wherever the workman touches the tip of the carbon an arc will be formed and the iron quickly melted. Huge beams can be cut in a short time by this process. The job is not easy for the workman, as he has to wear heavy asbestos gloves to protect his hands, and double smoked glasses to keep the intense glare from blinding him.

A small electric arc may be made with three or four primary cells and a couple of lead pencils. The ends, of course, must be notched so that the current from the batteries can reach the leads which are conductors. This experiment should be tried only with batteries and not with a lighting circuit.

CHAPTER VII

Electric Light

A FEW FACTS ABOUT LIGHT

Heat and light are a good deal alike. Both are caused by vibrations of molecules. At the temperature called absolute zero, which is far colder than anything we know, all the molecules are supposed to be at rest. As soon as the material is heated at all the motion of these little particles begins, and becomes faster and faster as the temperature rises. Current passing through a resistance wire causes a motion so fast that the wire soon becomes too hot to touch. Then it takes on a glowing red color; it is beginning to give out some energy in the form of light. Increase the current and the color becomes brighter. Finally, there is a bright flash; the wire has actually melted.

All the time the vibrating molecules are sending out waves of energy. At first these are felt only as heat. Next they affect the delicate nerves of the eye and we speak of them as light. The only way that we know these waves as light and heat is by their effect on our nerves of touch and sight.

The nerves of the eye are so sensitive that they can even tell a difference between the length of waves that are set in motion by the vibrating molecules. The different lengths give a sensation of different colors. Daylight shining on a piece of white paper or on clean snow has no color at all. It is really a combination of all colors. With a glass prism you could split these rays up into a rainbow, just as the light is divided naturally into a real rainbow.

The light of a heated body is called direct light. When such light becomes bright it is painful to the eyes, which are intended for reflected light. The white rays from the sun strike on an object that we say is colored, and certain rays from that surface reflect into the eye, giving the sensation of sight. From a certain piece of paper all but the red rays are absorbed; the red is reflected. We say then that the paper is red. From another piece only the blue is reflected, and so on.

An artificial light, to be pleasing, must have all the different colors in it. Then it is reflected the same as sunlight, and colors appear in their natural value.

Nearly every one can tell colors easily. Brightness is much harder to judge. When you sit reading by an open window at sundown you hardly know that the light is getting dimmer and dimmer until, finally, you are unable to see at all. This is because the eye accommodates itself so very readily to differences in brightness.

Guessing at brightness is a very poor way to tell whether a light is suited for reading or not. Manufacturers, therefore, adopted a definite measure for it: This is the candle-power. A candle-power is the light given by a special kind of lamp burning a certain oil. Ordinarily carbon lamps were first made in 16- and 32-candle-power sizes, as these were about right for reading and general lighting. Larger and smaller ones were soon added. The 16-candle-power lamp used about 50 watts of electrical energy and the others used more or less according to their size. At present the "rating" of a lamp is usually given in watts instead of candle-power. A 20-watt lamp, for instance, gives about 16 candle-power; a 60-watt lamp gives about 50 candle-power.

THE ARC LAMP

Before the incandescent electric lamp was perfected the only available electric light was the arc light, which was not so very different from the arc lamp of today. In simple form the arc lamp consists of two pieces of carbon which are first touched together and then pulled apart so that current flows across the gap against a high resistance. One of the carbons in such a lamp is attached to each side of the circuit, so that current is forced through the carbon the instant their tips touch together. Heat is generated immediately. The spot where the carbons touch becomes white hot. When the tips are pulled apart a little current continues to flow because connection is still made by the gaseous carbon and small particles of white-hot solid material that fill the gap. The temperature of the arc is so high (about 2000° F.) that the carbons are actually burned up. The intense light comes principally from the white-hot tips.

The first man to really strike on the principle of the arc lamp was Sir Humphrey Davy. He turned

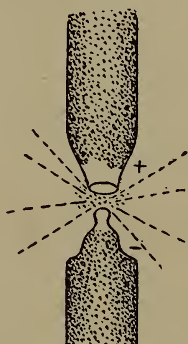


Fig. 123.—Direct current arc.

night into day in his laboratory, in 1812, with one of the most expensive arc lamps that has ever been built. For current he employed a battery of 2000 primary cells. His electrodes were two rods of charcoal, which he touched together and then pulled apart. The lamp was without regulating machinery and was simply fed by hand. Startling as this invention was, nearly sixty years passed before anybody really put the idea to work. Then a man named Jablochkoff created a sensation in Paris by lighting several streets with what he called an "electric candle," but which was only an improved arc light.

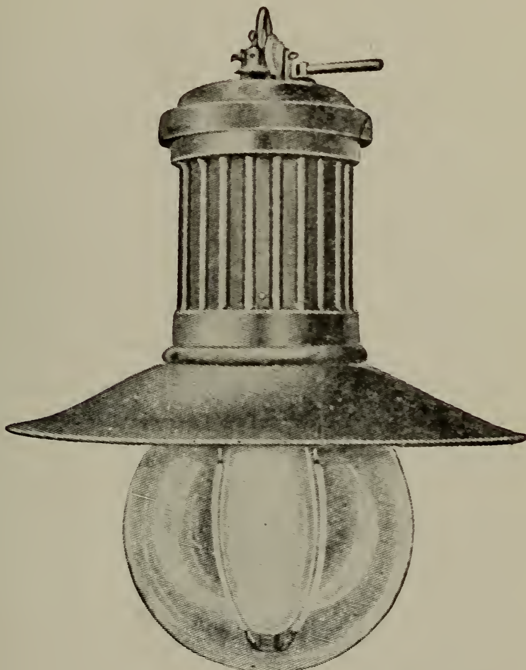


Fig. 124.—A modern arc lamp.

Jablochkoff's lights were bright, but would not burn long. Besides, they needed the services of a repairman to start them every time the current was interrupted. Improvements were needed and came rapidly. Clockwork was employed to feed the carbons together as they burned, and thus keep an arc of the best length for proper lighting.

Even this elaborate scheme was not very successful, and the solution, as often happens, was found in a simple method that is still used. A little clutch is operated by a solenoid so that the carbons are dropped together and pulled apart in just the right way to make up for the carbon burning away. When

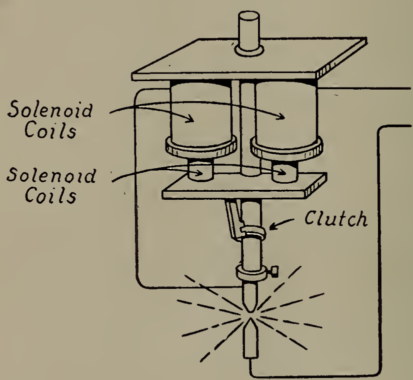


Fig. 125.—Principle of arc lamp.

the circuit is actually broken, the light goes out for an instant. The solenoid immediately lets go of its clutch and the tip of the upper carbon drops to the tip of the lower one. Then current flows again; the magnetism of the solenoid pulls up a plunger that works the clutch; the carbons are separated, and the current continues to flow again in the white-hot gas. When the gap becomes too long the clutch lets go and the carbon drops again. This principle with variations is used in many lamps.

As soon as it was perfected the arc lamp began to find a wide use. It supplied light to city streets, factories, warehouses, docks, mills, and wherever an abundance of bright light was needed. Its powerful rays were well suited to the needs of search-lights on land and sea. Today it is used the world over

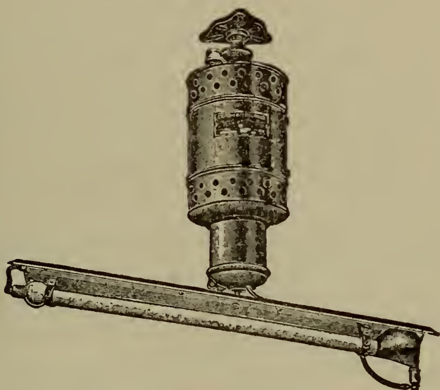


Fig. 126.—Mercury-vapor lamp.

in the thousands of moving picture machines, although in these installations the regulation is done entirely by hand.

Another form of lamp somewhat similar to the arc lamp is the mercury-vapor lamp. In this the current is carried by mercury vapor instead of carbon vapor, the mercury being enclosed in a long vacuum tube. This lamp gives an excellent light for factories and printing plants, but its color is not entirely pleasant. As the red rays are lacking from it, a greenish light is cast, which is disagreeable to some people. It is said to be very easy on the eyes in spite of its strange color, and is quite economical.

THE INCANDESCENT LAMP

Even if current had been cheap and common, there were several objections to the arc lamp. In the first place, it was entirely an outdoor light. Its brightness was too great for any such use as reading or house lighting. Another objection was that it used up carbons very rapidly and for that reason was quite expensive.

When Edison began his experiments the important subject was called "dividing" the electric light. By this was meant dividing the great brilliancy of one electric arc into many little lights that could be used for reading and had about the same intensity or illumination as the gas flame or kerosene lamp which was then so generally used. Many scientists said the task was impossible and the search useless. One electrical authority claimed that the lighting of houses by electricity was "a mere dream," and that, therefore, all efforts in that direction were doomed to necessary and final failure.

In the face of these discouragements Edison kept on experimenting. Every experimenter of those early days knew that platinum wire could be heated electrically until it gave out light. Edison's first trials were made with this wire. Platinum, however, was expensive and the light was very dim. Something better was needed.

A story is told of the discovery of this improved material by Edison working one night in his laboratory. Happening to roll between his fingers a bit of tar and lampblack, then used in his telephone, he was struck by the thought that this very substance might give a suitable light. Edison-like, he tried it. The result was surprising. It was not all that could be desired, but was much better than platinum. If carbon was good, why not try a carbonized thread? Putting a thread in an iron mold, he placed it in a furnace. This thread was placed in a glass globe. The air was removed so that the carbon would not burn. When current was sent through this slender thread the result was even better than before. The light produced was bright, yet soft and beautiful. The "division" of electric light had been accomplished.

Other materials were tried. Experiments were made with paper, straws, cardboard, and hundreds of other substances. As delicate as the charred paper was, it seemed to give best results. Of this material the filaments were made which supplied light to Edison's grounds at Menlo Park more than thirty years ago.

With the same thin horseshoe of carbonized paper the very first independent electric lighting plant was equipped. This was on an ocean steamer, the "Columbia," which was built to run between San Francisco and Portland, Oregon. This little plant was put in operation in May, 1880, when the boat left New York for its long trip to the Pacific coast. Current was supplied by a generator built at Edison's factory. In spite of rough weather 'round the Horn, the delicate nature of the lamp filaments, and the newness of the whole thing, the plant on the steamer gave wonderful satisfaction.

Subdivided electric light was now an assured fact. Developments came rapidly. Two years later, at Appleton, Wis., a small plant was built to generate electric power for distribution and sale. This was the first central generating station in the world, and quite a different affair from the enormous, powerful plants that supply electricity today. Its little Edison generator was turned by a water-wheel.

Even the paper filaments which had been discovered after so much work did not satisfy the inventor. He experimented continually and searched the world for a better substance. Over 6000 materials were tried. Soon it was discovered that carbonized bamboo gave even a better light and lasted longer than paper. Filaments of other styles followed, each one better than the last. Today you read by a light that is the

Fig. 127.—The first central station in the world.

result of all these years of search and work. It is called the "Mazda" lamp. While the word "Mazda" was chosen by a number of manufacturers to indicate the best lamp for all time, the Mazda lamp of today has a filament of tungsten, and is sometimes called a

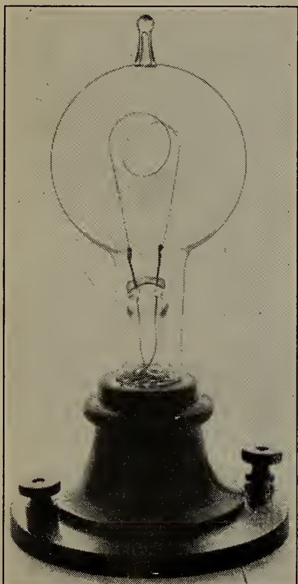


Fig. 128.—Edison's first electric lamp.

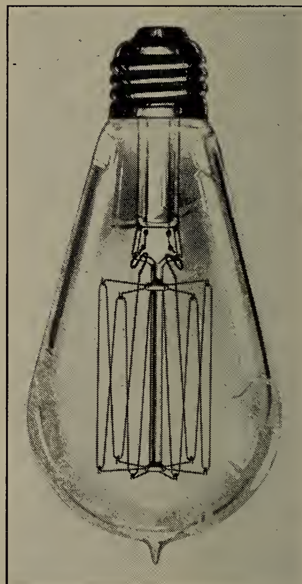


Fig. 129.—A Mazda lamp.

tungsten lamp. Tungsten is a metal. It is very heavy, hard, and difficult to melt.

Tungsten has a much lower resistance than carbon. For this reason quite a long filament is necessary. To provide for this extra length the wire has to be strung back and forth between supports in much the same way as the wire of the toaster already described. The glass rod in the middle merely supports the filament.

There is one feature of these latest lamps that has remained just the same as it was in Edison's first paper filament lamp. This is in the way of bringing the wires from the outside through the glass. As explained, all the air is pumped from the lamp bulb before it is finished. The lamp has to be made so that all the air is kept out. In other words, the joint between the glass and the little leading-in wires must be absolutely perfect. Platinum has been found to be the only suitable material for this purpose. The reason for this is that it expands with heat exactly the same as the glass itself. If this was not true a little crack would soon develop where the wires pass through the glass, and the lamp would be ruined. Every year hundreds of pounds of platinum are used in the United States alone for the tiny wires that pass through the glass of incandescent lamps.

Today the electric light has been "divided" further than even Edison thought possible. The electric flash-light, the electric lantern, and many applications of incandescent lamps in smaller sizes can be made with the comparatively weak current of a primary cell.

MINIATURE LAMPS

As comparatively high voltage is necessary for the larger lamps described, it is not wise to try any experiments with them. The smaller lamps mentioned will provide means of making a number of useful things.

These lamps are made with carbon filaments and with tungsten wire filaments. The tungsten or Mazda lamps are better for all purposes, as they are both

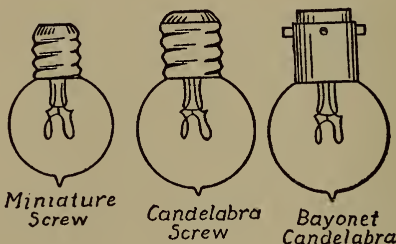


Fig. 130.—Miniature lamps.

stronger and more efficient than the carbon type. Such lamps can be secured in all sizes from $\frac{1}{2}$ to 20 candle-power, and for voltages between $1\frac{1}{2}$ to 20 volts. For use with one dry cell the $1\frac{1}{2}$-volt lamp should be used. Where more light is needed the 6-volt lamp operated by four dry cells in series is best.

The smaller lamps are made with only one style of base, called the miniature screw base. The 6-volt lamps are commonly supplied with either the miniature base, the candelabra base, which is larger, or the bayonet candelabra base. For any of these a socket to match is needed.

An electric lantern is easily made with a $1\frac{1}{2}$-volt lamp and a single dry cell. This will give enough light to work around the barn or make trips to the cellar, and will be a great convenience. The first

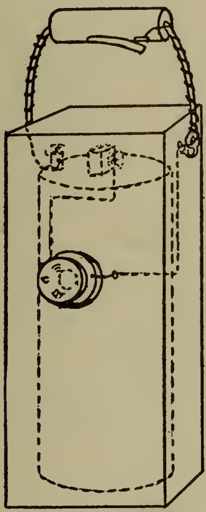


Fig. 131.—Electric lantern.

Fig. 132.—Switch for handle of lantern.

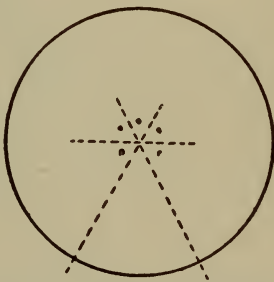


Fig. 133.—Pattern for reflector.

thing needed is a box just big enough to hold a single dry cell. Put a hinged door at the back and provide a little catch to hold it shut. On the front screw a porcelain receptacle for a miniature base. From one of the contact screws run a wire direct to one battery terminal. The other wire should run right up the wire handle which is put on to carry the lantern.

The wooden grip of this handle should be wedged on so that it will not turn, and a spring switch fixed on the under side. From one side of the switch a wire runs to the battery, and from the other a connection is made direct to one lamp terminal. Ordinarily, the switch is open. In picking the lantern up you press the spring ends together and the lamp lights. This lamp is easy to carry and can be lighted and put out with one hand. There is no danger of setting things afire when you make trips to the woodshed or barn with such a lantern as this. A small tin reflector will

Fig. 134.—Finished reflector for lantern.

add to its efficiency, but, of course, is not absolutely necessary.

A very nice present for a friend who is sick is an electric clock light. This can be made either with the one cell and a $1\frac{1}{2}$-volt lamp or four cells in series and a 6-volt lamp. The 6-volt lamp gives a much better light and permits longer use of batteries. The dry cells can be laid side by side in a box built to fit, and the miniature receptacle mounted near one end of the cover. One of the battery terminals and one of the socket terminals should be connected together.

To the other battery terminal and the remaining socket terminal connect the ends of a piece of flexible lamp cord. This can be of any length desired, and should have a pear push-button at the other end. A

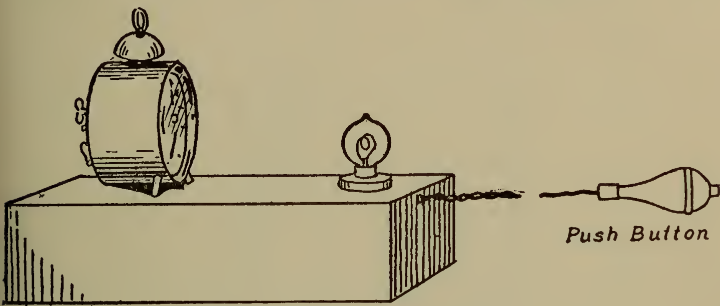


Fig. 135.—Night light for clock.

reflector cut from a piece of tin and mounted back of the lamp adds to the appearance and effectiveness of the device. When a clock is set on one end of the box and the button pressed the dial is so brightly

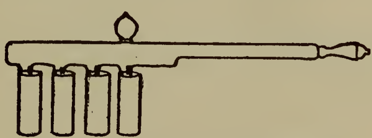


Fig. 136.—Wiring for night light.

lighted that the figures can be read at quite a distance. It can be made as ornamental as it is useful by carefully staining or shellacking it to suit the furniture of the room where it is to be used.

Much the same scheme can be used to make a ruby lamp for use in a dark room. In this, however, the lamp should be mounted at the back of the box, while the front is made up of a well-fitted piece of ruby glass. In this a switch which can be left on for some little time should be used. A very good switch for the

Fig. 137.—Reflector for night light.

purpose can be made from a piece of spring brass and two round-headed brass machine screws with nuts and washers to fit. Such a switch is illustrated in Fig. 138.

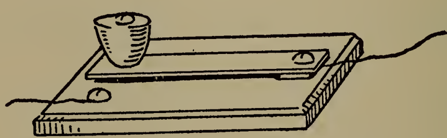


Fig. 138.—Switch for dark-room lamp.

Many other lighting appliances can be devised with a little thought by any boy who is handy with tools. Even tie pins can be whittled from bone and set with a little light inside. A little ingenuity makes extremely pretty decorations possible for Hallowe'en parties, Christmas trees, and the like. The many colors of the lights and their absolute safety makes them much better than candles for such a use.

A table of some sizes in which miniature lamps may be bought follows:

Diameter of Bulb.	Watts.	Candle-power.	Volts.
$\frac{7}{16}$ inch........	.6	$\frac{1}{2}$	1.5
	.75	1	2.8
	1.05	$1\frac{1}{2}$	3.8
$\frac{9}{16}$ inch........	1.05	$1\frac{1}{2}$	3.8
	1.65	2	6.2
$\frac{3}{4}$ inch........	2.5	2	2
	1.25	1	3
	2.5	2	4
	1.8, 2.5, and 3.7	1.5, 2, and 3	6
	5	4	4
	5	4	6

CHAPTER VIII

Electric Generators

Before any great steps could be taken in electric power or electric lighting it was necessary to find a means of providing electric power in large quantities and at low cost. The primary cell was all right as far as it went, and even provided electric light—at a cost of $4.00 or more for burning one dim lamp an hour. Chemical energy could be converted into electricity in almost any quantity, but the process was too expensive to be used. The problem was solved when it was found that the power of an engine could be changed to electric power. In this way the energy was secured from the coal, and changed to electricity through a steam engine and electric generator.

Practically all of the power used today is secured from electric generators. Some of them run by steam, others by water power, but all are turning the heat of the sun back into electrical energy, so that it can again be used as power, light, or heat.

In the electric generator swiftly moving wires passing through strong magnetic fields produce the E. M. F. that propels the street cars, lights our streets, and runs the factory machinery. This simple combination of a moving wire and a magnet is at the basis of the generation of all electricity today. The principle was discovered back in 1831 by Michael Faraday.

Faraday long suspected that electricity could be produced from magnetism. He knew magnetism could be obtained from a battery current. For nine years he experimented, without result. He even

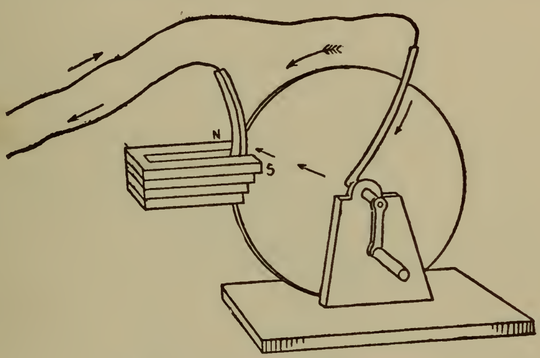


Fig. 139.—Faraday's first generator.

carried a little electromagnet in his pocket to help him think of his problem in spare moments. At last he succeeded in producing a slight effect by rapidly passing a loop of wire between the poles of a powerful electromagnet. Substituting a disk of copper for the wire loop, the inventor made a generator which he could turn with a crank. Current was taken off by two brushes—one at the outer edge and one at the axle. This was the first generator ever made.

From this crude generator to one wound with many coils of wire was only a short step. Improvements have been mostly of a mechanical nature.

An electric generator in the very simplest form can be made by placing a horseshoe magnet near the edge of a table and passing a piece of wire back and forth between the poles. The E. M. F. is too weak to be easily detected, but it is there all the same.

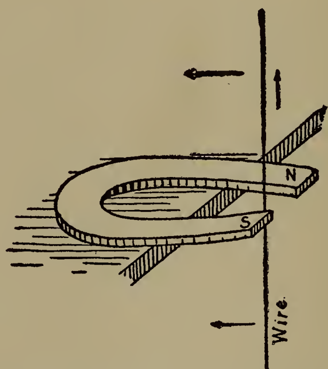


Fig. 140.—How a weak E. M. F. may be generated in a wire.

The invisible lines of magnetic force that pass from the North to the South Pole are actually divided or cut by the moving wire. The effect of this is to produce the E. M. F. in the wire. Why this is so is a mystery; we simply have to accept it.

There is no mystery about the direction of current or the voltage in any case. Both can be determined definitely. The E. M. F. depends on only two things:

the speed with which the wire is moved and the strength of the magnetic field. The calculation is rather complicated and cannot be gone into here. The matter of determining the direction is quite simple.

The method is known as Fleming's right-hand rule. According to this rule the right hand is held so that the thumb and first two fingers point as shown

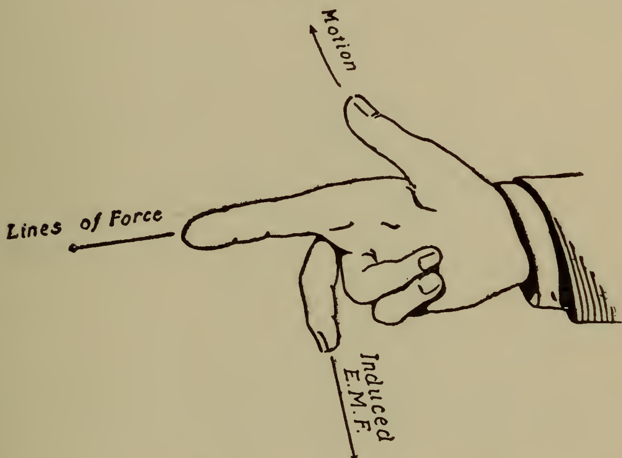


Fig. 141.—Fleming's right-hand rule shows direction of E. M. F.

in Fig. 141. If the first finger is pointing from the North to the South Pole, and the wire is moved in the direction indicated by the thumb, the E. M. F. will be in a direction pointed out by the second finger. With this rule the direction of E. M. F. is always very easily found.

If a closed loop of wire is passed between the poles of a horseshoe magnet, a small current will flow in the direction indicated by Fleming's rule just as long as the wire is moving through the field. Pull the loop out again, and current flows in the opposite direction. This reversal of current is just what would happen if a dynamo was made from a loop of wire and two bar magnets as shown in Fig. 142. If this loop was turned round and round the E. M. F. would be first

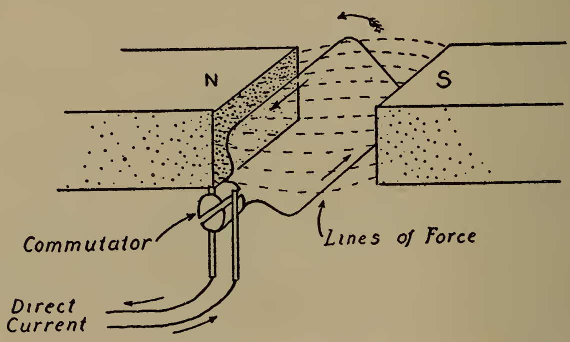


Fig. 142.—A simple commutator. Every half-turn the current is reversed in the loop, but in the outside wires it is always in the same direction.

in one direction and then the other, changing faster as the loop was turned with greater speed. This current would be very feeble, but otherwise practically the same as the alternating current that operates street lights and motors. It could be collected by a ring running to each wire.

Although the alternating current generator is very simple, it was not popular at first because experimenters believed that only direct current could be used to advantage. Their problem was to convert the seemingly useless alternating current to valuable direct current. This was done by using a simple device called the "commutator." Instead of having a ring connected to each end of the wire loop, a single ring was divided into two parts, and one-half connected to each end. This simple arrangement is shown in Fig. 142. The current still reverses in the wire loop with every half-turn, but it always

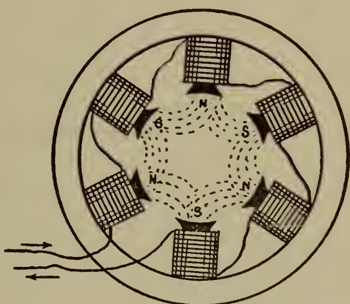


Fig. 143.—Six-pole field winding showing magnetic circuits.

flows in the same direction through the outside circuit, which is the important thing.

When these first dynamos were made permanent magnets were used to secure the necessary field. As a next step electromagnets were substituted. These were magnetized from a smaller dynamo made with permanent magnets. Then the discovery was made that a small part of the current generated could be sent through the coils to keep them magnetized. This principle is used in the shunt-wound generator today. Of course, some magnetism is needed to begin with, or the generator would not produce any E. M. F. at all. There is usually enough magnetism left in the iron poles to produce a slight E. M. F. when the armature is turning at full speed. This is called "residual magnetism." The small current flowing through the field coils

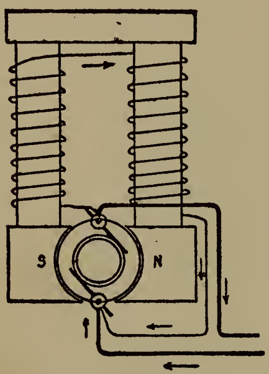


Fig. 144.—Shunt-wound generator.

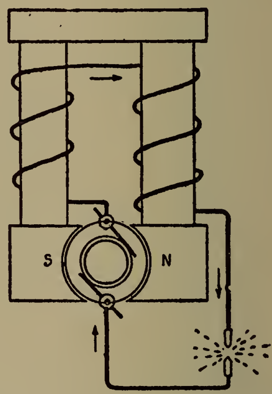


Fig. 145.—Series-wound generator.

adds to the magnetism. This makes the field stronger, and a still higher E. M. F. is produced. Naturally, the E. M. F. is increased by this building-up process until the proper voltage of the machine is reached.

Although the moving loop of wire and the magnetic field are the important parts in a dynamo, there is a good deal more in an ordinary commercial machine. To begin with, there may be almost any even number of poles; suppose there are six. All of these are wound with fine insulated wire, so that when current is sent through the whole winding there is a North, South, North, South, and so on, clear around. The armature, which is turned so rapidly in the space between the poles, has a double purpose: the first is to carry the many coils of wire which pass through the magnetic field; the

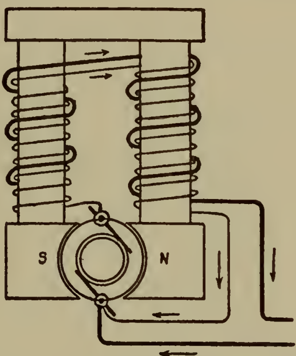


Fig. 146.—Compound-wound generator.

second, to provide an easy path for the magnetic circuits. The magnetic fields all stay perfectly still, but the wires held by slots cut in the iron armature are forced rapidly through one after the other of them. If the generator is a direct current machine the wire coils are fastened to the many separate copper bars of the commutator. Current then flows through the bars to the carbon brushes which press on them, and out in the circuit to do its work.

A very small part of the current generated is used to excite the fields and provide the necessary magnetism. This current can be provided in several ways, depending on how the coils are wound and connected. Shunt-winding is the simplest possible arrangement. In this the fields are in a separate circuit. Series generators have fields which are wound with only a comparatively small number of

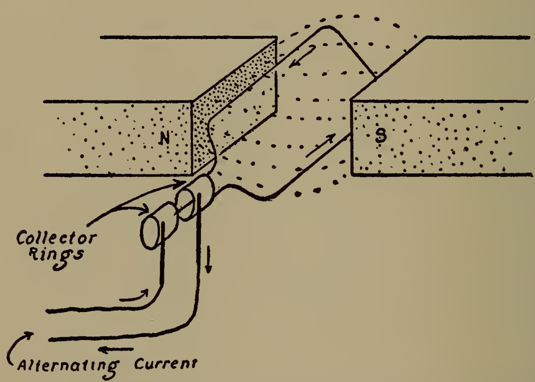


Fig. 147.—Simple loop with collector rings in place of commutator.

turns. These fields are connected so that all of the current in the outside circuit flows through them. This is shown in Fig. 145.

A third variety of winding is used in the compound generator. In this there are two sets of fields: one made of many turns of fine wire, and the other of a few turns of coarse wire or copper strip. This is the variety of winding which is most commonly used.

In an alternating current machine the main difference is that simple iron rings take the place of the commutator. These are called "collector rings." As reversals of current taken from these rings depends on the speed of the armature, the number of poles, and the winding of the machine, the frequency is usually spoken of when the voltage is given. By frequency

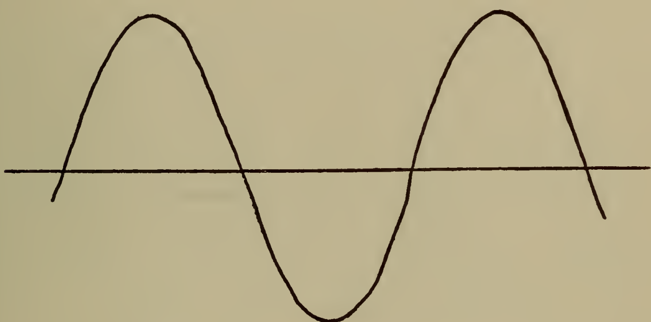


Fig. 148.—An alternating current wave.

is meant the number of complete reversals of direction in a second.

By twenty-five cycles we mean that the direction of the E. M. F. and the current has been completely turned around twenty-five times in a second. Sixty cycles means sixty complete reversals. Even twenty-five in a second sounds quite fast, but it is not fast enough for an incandescent light. The delicate filament cools off so much between reversals that the light seems to flicker and is consequently unpleasant to the eyes. With sixty-cycle current no flickering can be noticed.

Alternating current is becoming more and more popular for very good reasons. In the first place the machinery is much simpler than for direct current. A still greater advantage is that the power can be sent, or transmitted, over long distances much easier than direct current.

To understand this big advantage it must be remembered that the power equals the voltage times the current. For instance, 10 volts × 100 amperes = 1000 watts. This is just the same as 1 ampere at 1000 volts. There is this difference: the single ampere at 1000 volts could be carried over a very small wire, while the 100 amperes at 10 volts would require a much larger one.

With direct current there is no simple way of raising the voltage. If power is generated at 110 volts, it is transmitted over the circuit at 110 volts or even less. Alternating current, on the other hand, can be very easily raised or lowered to any value with a simple transformer. These transformers are contained in the iron boxes which may be seen on poles around a power-house or outside a factory. They work on much the same principle as the induction-coil, although there is no mechanical motion or breaking of the circuit.

A transformer consists simply of two coils of insulated wire wound on an iron core. One of these coils is connected to the generator, and is called the "primary." The other is connected to the light or power line and is called the "secondary."

When the primary coil is connected to a generator supplying an alternating E. M. F. the iron core is magnetized. The magnetism is not steady; it grows and dies down many times in a second. With every change of strength the lines of magnetic force move. In their movement they are divided or cut by the

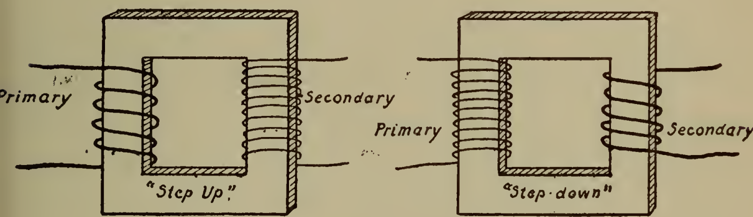


Fig. 149.—How transformers are wound.

wires of the secondary coil. Thus an E. M. F. is generated just as it would be if moving wires cut through a stationary magnetic field. If the number of turns on both primary and secondary were equal, the two voltages would be equal. If the secondary had ten times as many turns as the primary, the secondary voltage would be ten times the primary. If there were one-tenth as many turns on the second-ary as on the primary the secondary voltage would be one-tenth of the primary.

A transformer that is used to increase voltage is called a "step-up" transformer; a transformer used to decrease voltage is called a "step-down" transformer.

MAKING A DYNAMO

The work of building a successful dynamo or generator requires quite a little thought and a great deal of accurate work. Some lathe work, careful drilling and threading of holes, and at least one casting are necessary. It is useless to attempt the work of building a dynamo unless the machine work on it is accurately done. In starting work on a generator the first thing to be made is the field structure. This can be made from two $\frac{1}{2}$-inch iron rods, a cross-piece of $\frac{1}{4}$-inch iron strip, and two pole pieces of wrought iron bar. The rods should be turned down to $\frac{3}{8}$ inch at one end and threaded. They can then be passed through the holes in the iron strip and fastened by nuts. The pole pieces should screw onto the threaded bottom end of the rod and should be exactly parallel. The rods must stand at right angles to the cross-piece. The completed field structure should then be put in a lathe, and the pole faces turned until a cylinder 1 inch in diameter will just fit in.

A little wooden armature should now be made just as shown in Fig. 150. This should be made very carefully, turned on a wood lathe, sandpapered, and then shellacked. It should be just a little too large

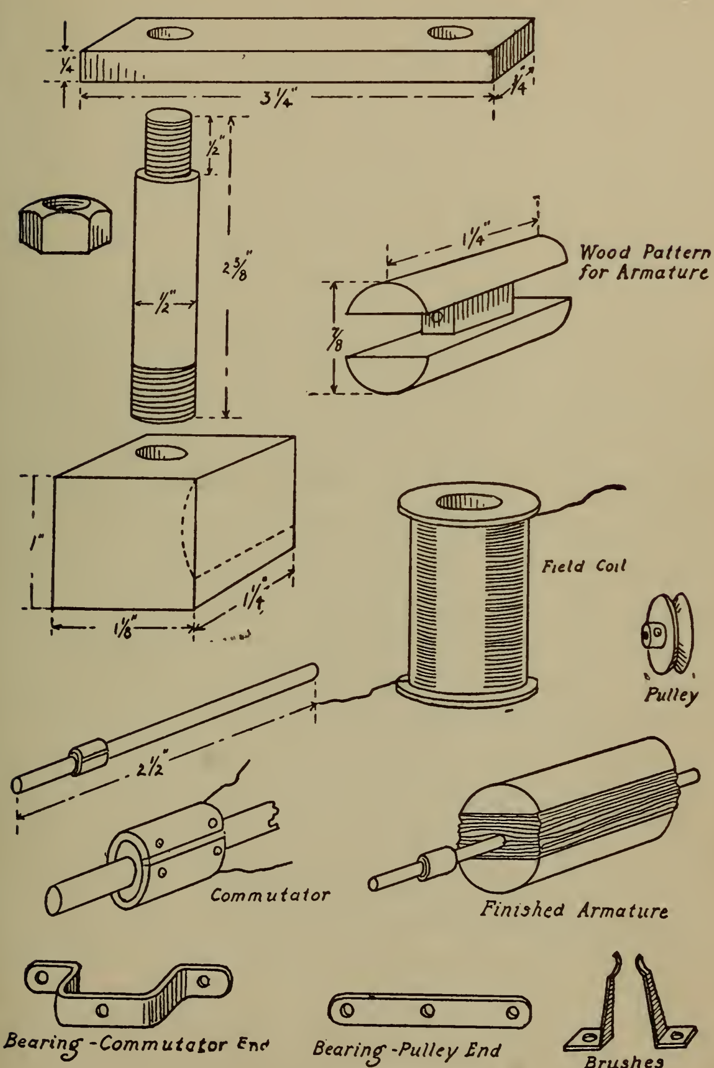


Fig. 150.—Parts of dynamo.

to fit in the turned space. The pattern should be taken to a foundry where small castings are made, and a duplicate of the wooden form cast in iron. This should be turned down until it just fits loosely in the space at the bottom of the field structure. A hole should also be drilled to take the shaft. The shaft should be a straight steel rod and should fit so tight that it has to be driven in place.

The next step is to bore a hole through a piece of fibre rod and force it onto the axle. The outside of this rod should be carefully turned down so that a piece of brass tubing can just be forced on over it. Fasten the tubing to the fibre by eight small screws carefully countersunk into the brass. Be sure that these screws do not go through the fibre and touch the shaft. The brass tube should now be sawed in two places. The fine saw cuts should go clear through the brass and a little way into the fibre. The armature is now ready to be wound. The winding is simple and consists only of putting on enough turns of No. 20 cotton-covered magnet wire to fill the space left for it. Care should be taken not to put on so much that it will strike the magnet poles when the armature turns. Both ends should be brought out to the commutator, and one attached to each half with a drop of solder.

For the field windings two spools are necessary, these being made to slip easily over the ½-inch iron rods. The ends should be made of cigar box wood or fibre, and should be about 1 inch in diameter. Wind these with No. 20 cotton-covered magnet wire, being sure to wind both in the same direction. After slipping the coils in place and bolting the yoke down, be careful that the field poles are exactly parallel, as they were when bored.

Holes should now be bored and threaded in the ends of the two pole pieces, and two strips sawed out of sheet brass for bearings. One of these little strips can go straight across; the other should be bent to make room for the commutator. Especial care should be taken to see that the armature is centered perfectly, and does not scrape anywhere when it is turned.

The dynamo is now ready to be mounted on a wood base. This should be about $3\frac{1}{2}$ by $5\frac{1}{2}$ inches for the dynamo described. All that remains now is to add the brushes and make the necessary connections. The two brushes can be cut from sheet brass, and best as shown in Fig. 150. They should then be screwed down to the base so that one touches each side of the commutator. Now connect the two outside terminals of the field coils together, and connect one inner one to each of the brushes. Also run a piece of wire from each post to a binding-post. The wires can be run underneath the wooden base to give the work a neater appearance.

The dynamo is now mechanically complete, but not ready to generate. It must first be connected up to two or three dry batteries in series and run as a

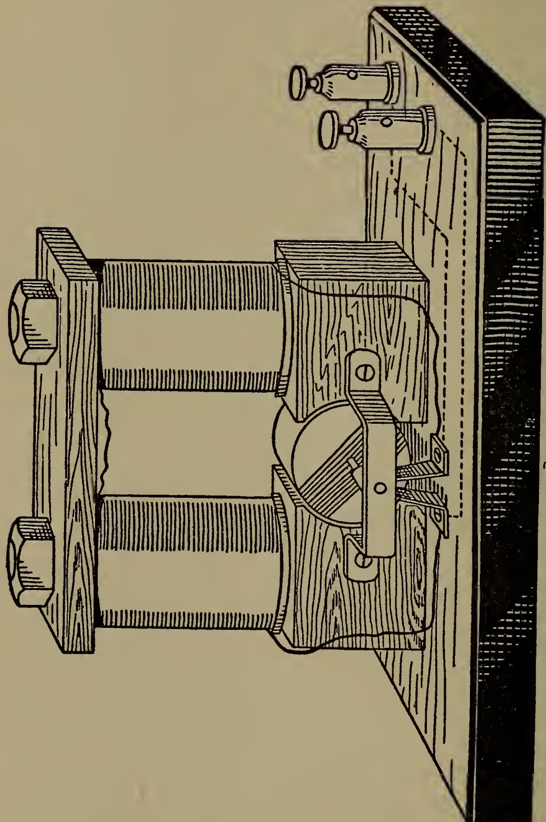


Fig. 151.—Completed dynamo.

motor. This magnetizes the fields and leaves a little magnetism in the iron. It must be remembered that this generator will only operate in one direction. To work as a dynamo it must be turned in the same direction as it ran when used as a motor.

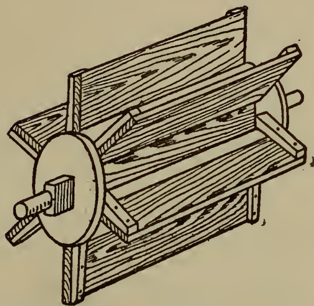


Fig. 152.—Wheel of windmill.

To produce a high enough E. M. F. to light a small light the generator must be turned at a high speed.

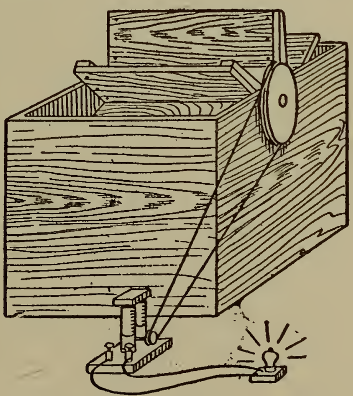


Fig. 153.—A wind-power dynamo.

This can be secured by belting it to a large hand wheel, an old sewing machine wheel, or a little water motor. If a fairly steady breeze is available a small windmill of the "Jumbo" type can be used to supply power. This can be made from a drygoods box, and is much the same as an old-fashioned water-wheel except that wind instead of water forces the blades around. The size of the pulley wheel can be regulated so that the best results are obtained. Of course, such light will not be very steady, but it makes a novel wind-power electric light plant.

BUILDING A TOY TRANSFORMER

It is neither wise nor safe to try any experiments with an electric lighting circuit, or to attempt to run toys from it. Practically all toys are made to operate at lower voltages and would be immediately ruined beyond hope of repair if an attempt was made to connect them to the 110-volt lighting circuit. If alternating current is available the voltage can be reduced with a small transformer. Then the motors and toys designed for use with alternating current can be used with entire safety. With such a transformer miniature lamps can also be lighted.

For a toy transformer large enough to run electric trains and motors the principal materials are a number of sheets of thin sheet-iron, about 1½ lb. of No. 22 single cotton-covered wire, and 1½ lb. of No. 12 double cotton-covered wire.

The first step in construction is to cut out enough squares of the sheet-iron to make a pile 1 inch high. These should be 4 by 5 inches in size. Then cut out

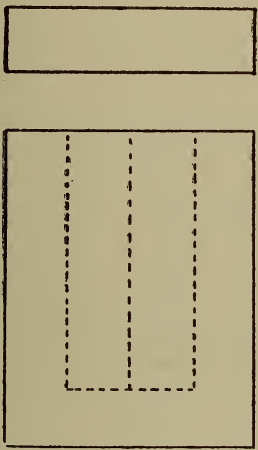


Fig. 154.—How sheet is cut for transformer.

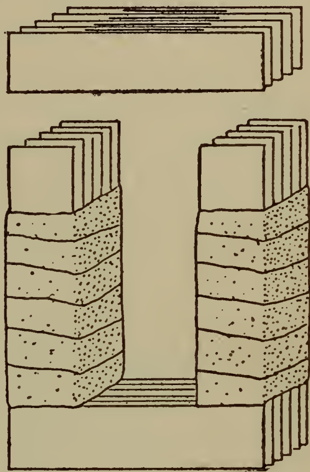


Fig. 155.—Transformer core.

the middle of each sheet so that 1 inch of iron is left on each of three sides. By cutting a strip from each of the center pieces that are left a set of strips can

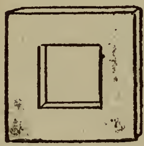


Fig. 156.—Spool end.

be secured for the fourth side. Half of these should be cut to 3 inches and the remainder left the full

4 inches; 1 inch should also be trimmed off every alternate U-shaped piece in the pile.

Now bind the two legs of the U-shaped set of pieces tightly with insulating tape, putting on two layers. They are now ready for the winding. Owing to the small number of turns it is hardly necessary to make separate spools, though this can be done if desired. In any case, four spool ends are necessary.

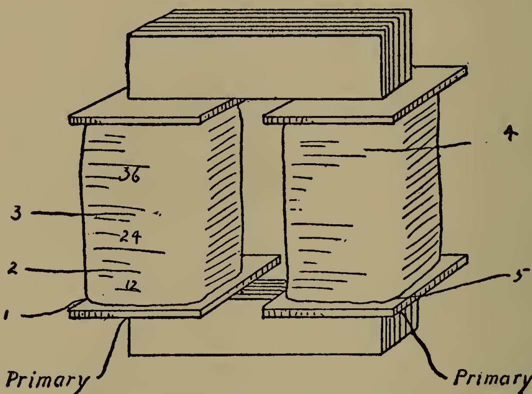


Fig. 157.—Transformer assembled.

These may be made from fibre or cigar box wood that has been well shellacked. The four pieces should measure 2 inches square outside, and should fit tight on the legs of the transformer core. For the primary, 600 turns of No. 22 cotton-covered wire should be wound on each leg. Both coils must be wound in the same direction. Bring the inside pair of terminals out through the small holes in the spool ends.

The other ends should be connected together and the joint carefully wound with insulating tape.

Over these coils should be wound two layers of good writing paper which has been well soaked in shellac. Let this dry before going ahead with the secondary. For the proper ratio the secondary winding should consist of 60 turns of the No. 12 wire on each leg. Wind the wire in the same direction as the primary. These coils should at first be put on somewhat loosely.

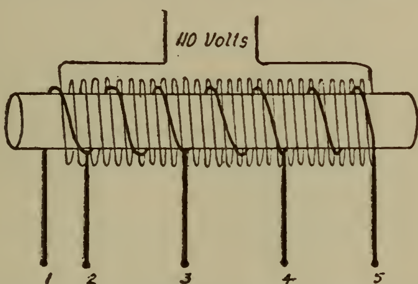


Fig. 158.—How various voltages are obtained with toy transformer.

A little slack will be necessary to add the taps properly. It is from these taps that current is taken at different low voltages desired.

For the taps cut four pieces of flexible lamp-cord each about 6 inches long. For the first one, count 12 turns from either end of the secondary. From the bottom of this turn scrape off a little insulation. Then wind about ½ inch of the bare end of one piece of wire around the uninsulated part. A better job will be made if a little solder is used.

For the second tap count 24 more turns and connect another piece of the flexible wire; count 36 more and add a third. All of the joints should now be well covered with insulating tape, and the turns of the secondary wound tightly to finish the job. The end turns of both primary and secondary should be held in as described in Chapter IV. For protection and finish the coils may be wrapped in heavy black cloth which has previously been soaked in shellac.

The only remaining work now is to make the base and arrange binding-posts and connections. The base need not be any certain size, but large enough to hold coils and core, leaving room at the end for the binding-posts. It should be made from good clear grained wood about $\frac{5}{8}$ inch thick.

For the primary side no binding posts are necessary. Connections can be made by bringing the two small wires down through the base and into grooves cut to receive them. Then bore a $\frac{1}{4}$-inch hole straight into the end of the base, and a $\frac{3}{8}$-inch hole up from the bottom to meet it. Then pass the end of a piece of lamp cord through the small hole and tie a knot in it 1 inch from the end. Now solder the two coil terminals to the two wires of the cord, insulating the joints with tape, and laying the wires in little grooves cut for the purpose in the base. Put melted sealing wax in the grooves around the wire and around the knot in the cord. In this way all the strain is taken

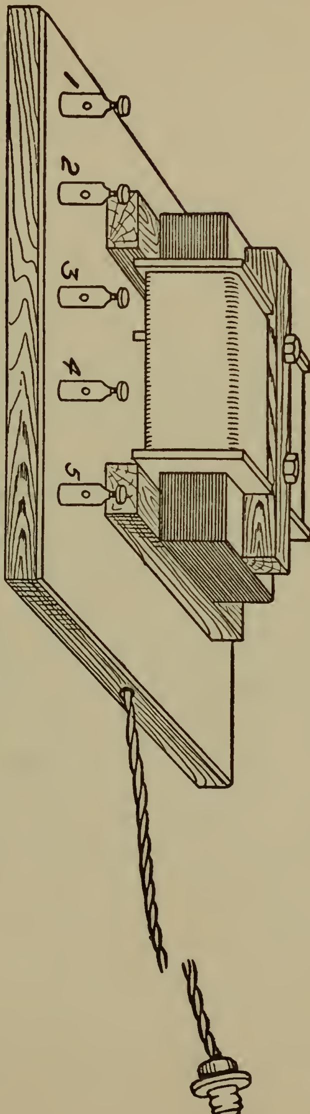


Fig. 159.—Toy transformer mounted on base.

from the transformer leads. Cut the cord to any convenient length and connect a standard screw plug so that current can be taken from any lamp socket.

The secondary connections are somewhat more complicated. These too can be brought through to the bottom of the base if desired.

Five binding-posts are needed, and should be equally spaced across the end of the base opposite to the primary terminal. To the two outside posts connect the two secondary terminals. To the three middle ones connect the flexible leads in order.

Fig. 160.—Bottom connections for transformer.

Three wooden strips are now needed to fix the transformer firmly on the base. These should be placed as shown in Fig. 159, the short pieces supporting the core ends and the long cross-piece being held down firmly by two long bolts.

With the finished transformer carefully made as described you will be able to secure current at five different voltages from a 110-volt 60-cycle alternating current line. These will be approximately as follows: Between terminals 1 and 2, 1 volt; between 2 and 3, 2 volts; between 3 and 4, 3 volts; between 4 and 5, 4 volts; between 2 and 4, 5 volts; between 1 and 4, 6 volts; between 3 and 5, 7 volts; between 2 and 5, 9 volts; between 1 and 5, 10 volts.

With this range toy trains and motors can be run and miniature lamps of various voltages lighted. It

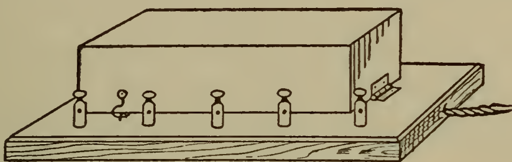


Fig. 161.—Toy transformer with cover in place.

should be remembered that the transformer is not intended to be left connected to the line. Disconnect it as soon as you have finished. Remember also it must not be connected to a direct current line. The direct current cannot be reduced to a lower voltage in this way, and the transformer would probably be ruined in the bargain.

CHAPTER IX

Electric Motors

"It's a poor rule," we say, "that doesn't work both ways." It would be strange indeed if heat could be turned into electricity and electricity could not be changed to heat. Since electric power can be secured from falling water, it is only reasonable to suppose that the state of affairs can be turned about, and water raised by electric power. Such changes of energy are everyday occurrences. Energy in one form is made to appear as another—and then changed back to its first form. The mechanical power of water falling over a cliff may generate electricity, and the electric power, carried to a farming district miles away, is put to work at the irrigation of orchards and farms. Of course, there is always a loss, but the convenience more than makes up for it.

To generate this electricity the many wires of an armature winding are forced rapidly through a magnetic field. The opposite way of the rule is that a wire carrying electric current will actually be pulled through a magnetic field.

The truth of this is very easy to get at. All the apparatus needed, in fact, is a bar magnet, a couple of dry batteries, and a piece of copper wire. Set the cells a couple of feet apart and connect the north pole of one to the south pole of the other. The wire should be fine, uninsulated, and long enough to hang rather loosely. Now stand a bar or horseshoe magnet upright under the wire and as close as it can be set without touching. With a second piece of wire touch the other two poles to complete the circuit. When current is allowed to flow there is an immediate

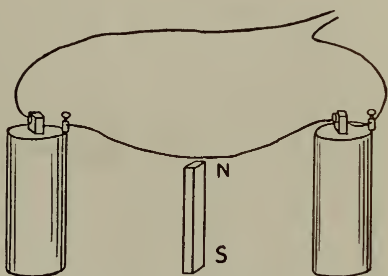


Fig. 162.—This will show the principle of an electric motor.

movement of the wire. It is pushed across the field even by the small current flowing.

This action of a magnetic field on a wire carrying current was one of the discoveries made by Oersted in 1819. Its importance is apparent, for every trolley car is propelled by this force, every motor of the millions that supply power to factories and shops is turned by the action of a magnetic field on a wire carrying current.

When electric power was first used the simplicity of this principle was not realized. Inventors went the long way around. Devices called electric engines were built to operate on a magnetic or a solenoid principle. One experimenter even tried to run a boat with an engine of that sort. This strange craft ran on the river Neva in Russia and carried 14 passengers. Current from 320 Daniell cells propelled it at a speed

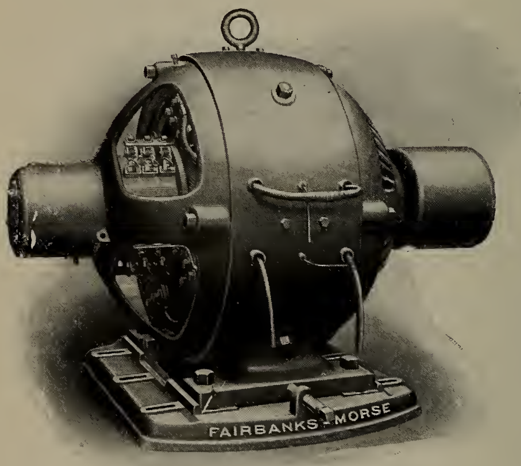


Fig. 163.—Direct current motor.

of three miles an hour—about the same speed as you ordinarily walk.

Electric power uses were at this stage in 1861, when an Italian named Paconnoti discovered that an electric generator could be used very well and without any changes as an electric motor. He reasoned that since the dynamo *produced* electricity when rapidly turned, it should turn rapidly when *supplied* with electric power. This Italian was really the first

Fig. 164.—Parts of direct current motor.

to see that if an ordinary shunt dynamo was connected to a circuit of proper voltage it would work perfectly as a motor and change electrical power into mechanical power.

For most people the motor is harder to understand than the generator. It seems quite natural that the mass of metal whirled by an engine should produce electricity or something equally wonderful. The hard thing to understand about the motor is where the powerful pull comes from, and how it can be so strong when the only points of contact between stationary and moving parts are at the carbon brushes. About the easiest way to imagine a motor is in the form of a single loop of wire turning between the north pole of one bar magnet and the south pole of another. Each end of the loop is fastened to half a metal ring. The two rings must not touch. This split ring is a simple commutator just as in the case of the dynamo.

For bringing current through the loop two wires from the poles of a dry cell should touch the opposite sides of the ring. Current from the battery now flows up one wire, through one half of the ring, around the loop, and out through the other half of the ring to the dry cell again. When current flows through the coil it acts against the magnetic field and actually pulls one side of the loop up and pushes the other down. If the battery wires were spliced right on to the ends of the coil the loop would only turn a little way; then it would stop. It could not go on any more than water will run up hill. If the wires were reversed it would go on another half turn and then stop again. With the simple commutator shown, the current is actually reversed every half turn of the wire loop. There is really an alternating current in the revolving coil. But the result of it all is that the coil turns round and round if it moves fast enough to pass over the "dead center" each time.

A very simple little motor which will make the principle clear may be built from a couple of hairpins, a needle, a good cork, and a few feet of fine insulated wire.

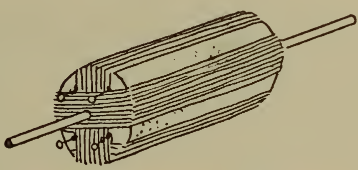


Fig. 165.—Cork armature of motor.

The cork should be even on the sides or should be trimmed so with a sharp knife. The knitting needle should be carefully forced through the exact center. Two entirely separate coils should then be wound on, both in the same direction, and with the same number of turns. At the end of the cork and in the spaces between the turns stick four straight pins. Each one must be the same distance from the knitting-needle axle. Scrape a little insulation from the end of each wire and connect the two ends of each coil to opposite pins. The "armature" is now finished. For bearings, twist a little loop in each of two hairpins, sticking the ends in corks to act as supports.

Now set the armature in its bearings between two magnets as shown in Fig. 166. It should spin around quite easily. To run it as a motor connect two fine wires to a dry cell, and hold the ends against opposite pins of the commutator. It may be necessary to help

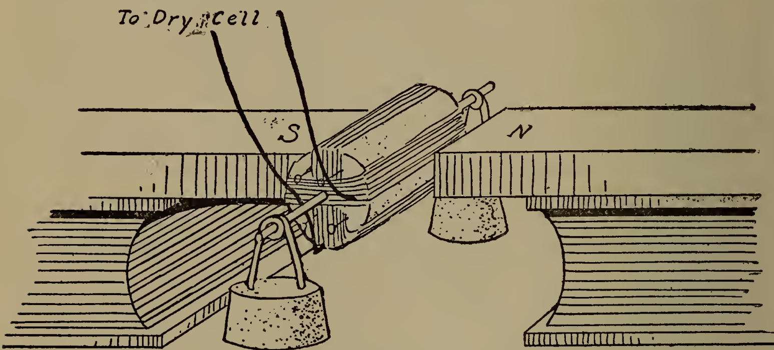


Fig. 166.—Complete "cork" motor.

the motor along a little at first, but once started it will spin along at a great rate.

Of course, all large motors use electromagnets, and these are connected in the circuit in different ways, as they are for the shunt, series, and compound dynamo.

In the series motor all of the current goes through the heavy copper field winding. In the shunt motor the coils are fine and there are many more turns, so that only a very small part of the energy goes to magnetize the field. In the compound motor the greater part of the winding is shunt, but a few coils are wound on in series.

The armature or revolving parts of all three kinds are practically alike. The wire is heavy and has very little resistance. If a big shunt motor was suddenly put in circuit there would be such a rush of current that its winding would be injured or perhaps ruined. When a motor is turning the movement of the wires takes the place of resistance and prevents this rush of current. So in starting, a motor field has first to be connected. Then a little current is allowed to flow in the armature through a starting resistance. As the motor speeds up the resistance is made less and less, until it is all out and the motor has the full voltage across it.

It is now using very little current. Let it turn a pump, compressor, or any machine using power and enough current is taken from the generator to do the work. This current becomes heavier and heavier as work is added for the motor to do. In spite of all this load a shunt-wound motor keeps on running at very nearly the same speed. For this reason the shunt motor is best for pumping or turning lines of shafting where a regular, even speed is needed. To change this speed you would have to make the field weaker or stronger. A stronger field would make the motor run slower, a weaker field, faster. If the field connections were broken suddenly the motor would run so fast that the coils would fly out of place and the machine would be ruined.

In the series motor the speed is always changing. About the only use of this sort of motor is in hoisting work and on street cars. All street car motors are series motors.

When a motorman starts his car he lets current flow from the trolley wire through his controller, through a resistance, then through the motor, and back to the power-house along the rails and ground. All of this current goes through the field coils of the motor as well as the armature. The field is enormously strong; the current in the armature is heavy. A strong slow pull is the result, and the car starts. Just as soon as it moves the current decreases. The field becomes weaker. The weaker field makes the car move faster. The motorman takes more and more resistance out so that soon the motor is getting all the voltage of the system. All the time the field is becoming weaker and the car is soon whizzing along. Even a moving car is hard to push, so there is soon a limit to the speed of the motor. Then it settles steadily to its work. If anything happened to the shaft—if the gears that drive the car should strip off—the motor would soon be going so fast that it would be ruined. Owing to this tendency to "run away" a series motor can never be run unless it has work to do to keep it at the proper speed.

Very often a few turns of series winding are added to the shunt winding. These turns are put on opposite to the main field, so that the field will be weakened as the motor is loaded. This balances the natural tendency of a load to slow down the motor, and helps keep it at an even speed.

While simpler from a mechanical point of view, the alternating current motor is more complicated electrically. The most common variety of alternating current motor is the induction motor. In this, current is induced in the armature coils by current in the stationary or stator windings. There are no field windings in the sense that there are on the direct current motor.

MAKING A MOTOR

A good motor can be made on exactly the design given for the generator in the preceding chapter. With even less work a simpler design can be made that will run along quite steadily, but with very little power.

For the frame of this motor a piece of soft sheet-iron $\frac{1}{16}$-inch thick will do very well. It should be cut 1 inch wide and 7 inches long.

Then mark it with a file, or scratch it as shown in Fig. 167. These marks will serve as a guide in bending. At *A* and *B* the strip should be bent at right angles. Then form the rounded part by bending carefully over a $\frac{3}{4}$-inch rod, and bend back the two feet so that the frame is shaped to the form shown in Fig. 172.

The field magnets may now be wound. For this purpose two layers of No. 22 cotton-covered wire will be sufficient. Before putting this wire on, each leg

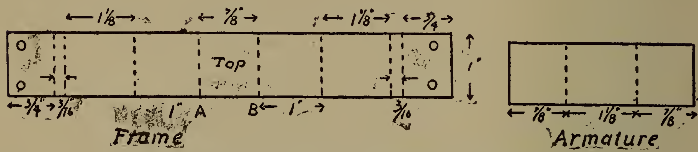


Fig. 167.—Strips for frame and armature of toy motor.

of the strip should be wound with a layer of insulating tape. After the magnets have been wound it is well

Fig. 168.—Shaft of motor.

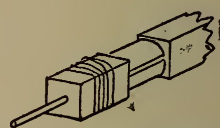


Fig. 169.—Commutator.

to test them by connecting the two free ends of the wire to the poles of a dry cell. A compass or an ordi-

Fig. 170.—Commutator parts.

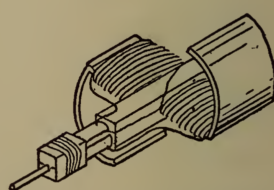


Fig. 171.—Complete armature.

nary sewing needle will tell whether the winding is all right or not. If so, the needle will turn sharply when current is flowing, or the sewing needle will be held across the two poles by the attraction. If the winding tests all right in this way it can be shellacked, which will protect it.

Next comes the armature. This may be made from a strip of the same sheet iron that was used for the fields. Cut this also 1 inch wide and $2\frac{7}{8}$ inches long. Mark off $\frac{7}{8}$ inch from each end and turn the tips back as shown in Fig. 171. The two tips then point in opposite directions. Wind the straight parts with one layer of insulating tape. For the winding put on two layers of No. 22 cotton-covered magnet wire, the same as used for the fields. In putting this wire on it is a good plan to first mark the center of the strip by tying a white thread around it. Then begin the winding about $\frac{1}{8}$ inch away and wind to the bent part; then back to the start. Carry the wire over to $\frac{1}{8}$ inch on the other side of the thread, and continue the winding in the same direction. On reaching the bent part wind back to the start. Be sure to leave a couple of inches of wire at each end for connection to the commutator. The winding can now be tested with a battery and the coils shellacked.

For a shaft cut out two pieces of wood 2 inches long and trimmed down to $\frac{1}{8}$ x $\frac{1}{16}$ inch. Cut a shallow mortise in each one so that the armature will be held tightly between them. Then set the armature in place even and true with a strip on each side, and tie the strips together with strong linen thread or fine wire.

A commutator may be easily made by bending two thin pieces of spring brass in half-round shape, leaving the ends turned in so that they will grip the wood. The shaft will need to be carefully rounded to receive them. A thin strip of wood forced between each pair of ends will keep the two parts separate, at the same time helping to hold them in place.

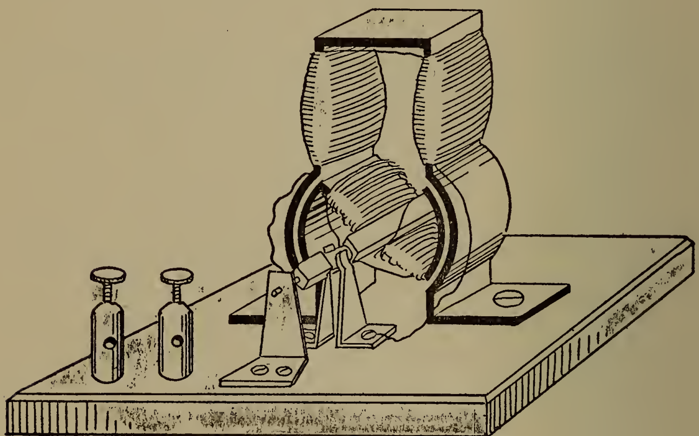


Fig. 172.—Finished motor.

When one wire of the armature is soldered to each of the sections the moving part of the motor is completed. A needle forced into each of the ends of the wooden shaft makes bearings that have very little friction.

Two bearing-posts can be very simply made from iron strips in which holes have been bored at the right height to hold the armature between the fields. These should be set in place temporarily to make sure that the armature is held at the right height, and does not strike on the field structure when rotating. The brushes still remain to be made. These can be cut from sheet brass and bent at the ends to touch the commutator.

All parts are now in shape to be fastened with small screws to a wood base. The only connections necessary are made by bringing the two terminals of the field to the base of the brass brushes, and running a pair of wires from that point to a couple of binding-posts fixed to the base.

This motor will always need a little assistance at starting, since it has only two poles and a very light armature. Some adjustment of the brushes may also be necessary. Even with these failings the little machine serves to illustrate the principle of the electric motor, and will spin along at a good speed if properly made on the current from a single dry cell.

CHAPTER X

The Telegraph

In these days of wireless telegraphy we often lose sight of the importance of the older wire telegraphy. Experimenters have rushed to the extreme in building wireless stations, when often more satisfaction could be had among three or four friends connected by wire. The expense is much less and the chance to learn the proper use of the instruments much greater. As the simplest things should always be the first learned, it will pay any experimenter who is planning a wireless plant to first learn telegraphy with a Morse outfit.

Although it is old compared to wireless, the Morse system is hardly old enough to be spoken of as "old fashioned," though some look at it that way now. Like the motor and generator, it had its beginning in the mind of Oersted in 1819, but the idea of sending messages by the clicks of a magnetic armature was too big a stretch even for the imagination of those days.

The possibility of sending messages did not even appear to Joseph Henry, who was the first to discover that an electromagnet could be controlled perfectly at a distance. Here was the germ of the telegraph, for by closing the battery circuit a long way off the magnet was energized and would attract an iron armature. When the circuit was opened the armature would be released. The modern telegraph is really a growth of this idea that was worked out by the school-teacher, Joseph Henry, in his spare time.

Henry's experiments interested Samuel B. Morse. Mr. Morse was a portrait painter. He had studied abroad under Benjamin West, and had become quite prominent. One of his characteristics was a good imagination. In his mind he saw that with Henry's idea signals might be sent like a flash of light for hundreds of miles, and perhaps, clear around the world.

Professor Morse thought that the instrument ought to record the message in black and white, so he built his receiving instrument for that purpose. A strip of paper was moved along by clockwork, and each message was a string of straight marks, some long and others very short. When a message was finished the dots and dashes were translated into words.

Morse's sending key was a heavy brass affair nearly two feet long. The relay magnets used were heavy enough to be a good load for two men. Compare all this with the neat little instruments that click out their messages in a modern telegraph office, and the wonderful improvements are quite apparent.

Morse's first station, with these clumsy instruments, was not a great success. One end of the line was at

Washington, D. C., the other at Baltimore. When completed in 1844 very few had faith in it. People bothered the operators with foolish questions and would not even send messages free of charge. Many jokes were told of the queer ideas many had about sending "letters by electricity." So few were sent that the total receipts of the Washington office on one day were only 60 cents and on another day $1.04. From that first line with its small business to the enormous systems of today is a mighty jump for the few years that have passed.

About the first big improvement made was that operators began to take messages by sound instead of figuring the letters out from a tape. At first the little clicks were so feeble that it was hardly possible to hear them. Then the relay was devised, so that the sound could be made as loud as necessary at any distance. With one of these relays and a sounder in a little box near his ear the expert telegrapher can typewrite a message as fast as it comes in.

PARTS OF A TELEGRAPH SET

In an ordinary telegraph circuit for moderate distances there need only be four parts; these are the key with which the message is sent, the sounder with which it is received, a battery to supply the current, and a line to carry it.

The key is simply a contact switch that is held open by a small spring. When the knob on the switch lever is pressed down, two little platinum points touch together, and the circuit is completed through the battery and wires to the other station. When the lever is allowed to come up again the points separate and the current stops. If the lever is held down for a very short time it makes what is called a dot. A longer space of

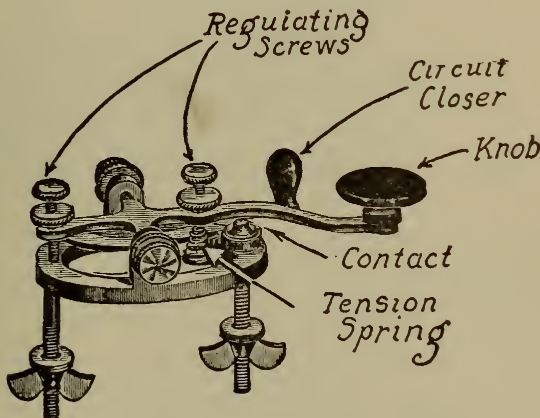


Fig. 173.—Standard type of key.

time makes a dash. As the circuit has to be closed when the sender is not in use, there is a little switch attached for this purpose. Screws are provided so that the key can be adjusted to just the stroke that the operator finds easiest for him.

A sounder is a little more complicated. Its most important parts are the pair of electromagnets and the soft iron armature that they attract. These magnets are wound with many turns of fine wire. The armature is held by a little spring at a short distance

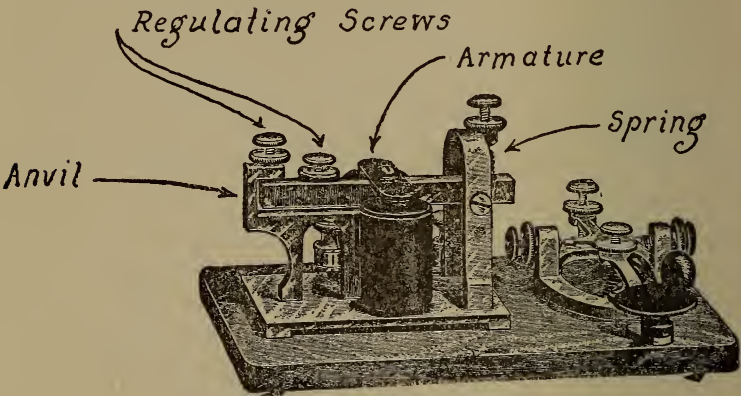


Fig. 174.—Combined key and sounder.

above the poles. When current flows through the coils this armature is pulled down. When current is

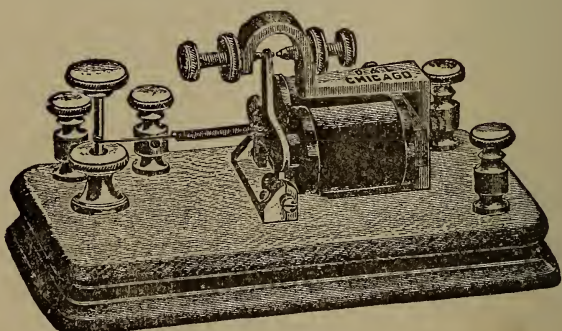


Fig. 175.—Relay.

interrupted the spring pulls the armature away again. So every time the current flows there is a click—every-time the circuit is opened there is another. The click is made by a pivoted lever attached to the armature. Sometimes this lever is brass, in other makes it is aluminum. The two screws that it strikes can be regulated to suit the operator.

A good key can be bought for about $2.00 and a sounder for a little more. Very neat sets with key and sounder both mounted on a base can be had for $4.00 up. These are good for lines up to 15 miles in length. On larger ones a relay must be added.

BATTERIES AND LINES

For telegraph work the Daniell cell is the very best. On the other hand, it is somewhat wasteful, since zinc is being consumed all the time, as the circuit must be closed when the key is not in use. Where the line is very short and not used a great deal dry cells will do very well. If these are used the circuit must be left open; otherwise the cells would soon be worn out. For telegraph wire ordinary galvanized iron wire will do. This should be supported along the way by glass insulators so that the current will not escape to the ground. Only one wire is needed, which makes quite a saving if the line is a long one, as the ground or water pipes can be made to serve as a return.

The simplest sort of a telegraph circuit is shown in Fig. 176. Connections are made so that the sending key at one end controls the motion of the sounder at the other. Every time the key is pushed down at one end the circuit is completed and the sounder at the other end is pulled down. Each time the key is released the sounder gives a second click. It is the time between the clicks that makes the dots and dashes. A quick pair of clicks is a dot. Clicks with a little more time

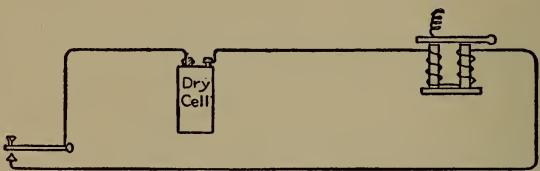


Fig. 176.—How key and sounder are wired.

between them make a dash. The letters made by combinations of these dots and dashes are easily read after a little practice.

A SIMPLE TELEGRAPH SET

For a beginning it is a good idea to build a simple set of instruments, to telegraph from room to room, or perhaps from house to house, if another boy who is interested lives nearby.

For such a set two keys and two sounders will be needed. The keys are quite easily made. A piece of board about 3 x 5 inches will serve very well as a base. On this mount a piece of spring brass, fastening it down by means of screws through two holes in the end. Just below the free tip set in a brass round-headed screw. A piece of tin bent in a U shape and screwed over the brass spring should also be added. A hole may be punched through this and a small screw put in. Two small binding-posts should be attached to the base, and a wire run from one to the lower contact screw. The other connects to the base of the spring. This key can only be used with dry cells or other open circuit cells.

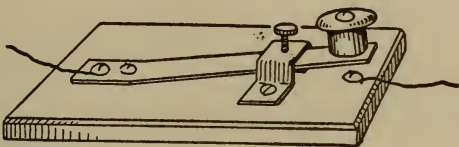


Fig. 177.—A simple sending key.

A sounder is somewhat harder to build. This instrument is made up of two electromagnets mounted on a wood base, and placed so that an iron armature

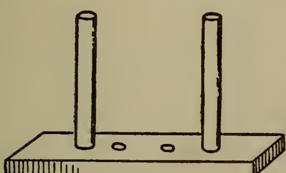


Fig. 178.—Field structure for telegraph sounder.

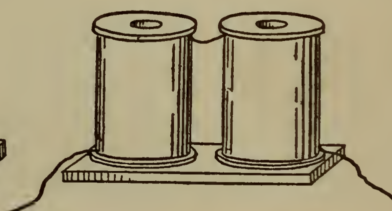


Fig. 179.—Coils of sounder in place.

will be attracted whenever current flows through the magnet windings. The coils can be wound with No. 22 cotton-covered wire. A couple of $\frac{1}{4}$-inch bolts will do very well as cores. The threaded ends should be screwed into a yoke and the heads cut off. Bobbins should be made just as in winding coils for bells. The four ends necessary can either be made from thin wood or from fibre board. After both coils are wound the magnet should be mounted vertically on the board base with a couple of screws placed through two holes in the yoke. Be sure that the magnet stands straight and true, and that the ends of the two cores are even.

The armature can now be made. It should be cut in the shape of a cross from sheet-iron as thick as can be conveniently cut. Bore two holes in the long end of the

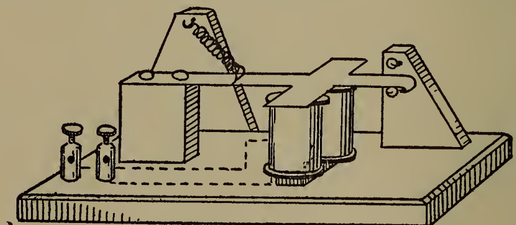


Fig. 180.—Complete sounder.

strip and fasten with screws to a block the same height as the electromagnet. If light sheet-iron is used a little of the tip should be rolled back or a little weight added to the tip. To balance this weight the armature should be supported by a rubber band or a light spiral spring.

For the sounder points two screws should be set in a board at the proper height and the board screwed to the wood base. A little experimenting will show just where the points have to be placed to get best results. These points cause the clicks that produce the dot and dash alphabet.

To complete the sounder place two binding-screws at the end of the board and make the electrical connections. The two bottom leads of the magnet wind-

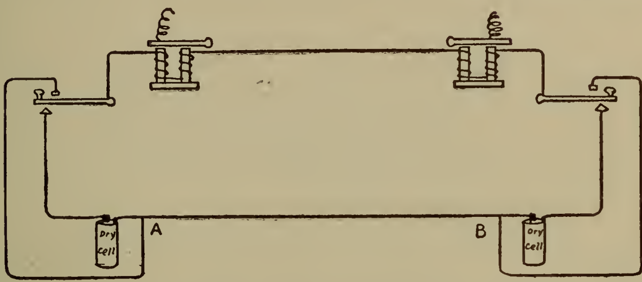


Fig. 181.—Circuit with two keys and two sounders.

ing should be connected together, and the two top ones should go to the binding-posts.

With two sets built as described you can telegraph to your chum in the next room or the next house, using

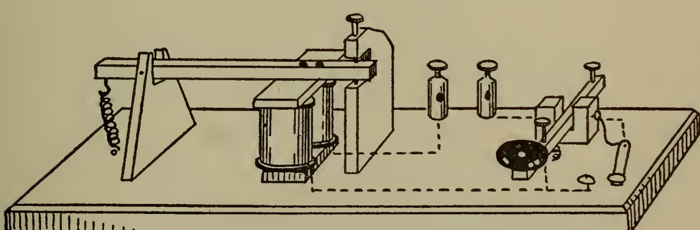


Fig. 182.—Combined key and sounder.

the standard Morse telegraph code. The set illustrates the principle of the telegraph and is built without much labor and at a very slight expense. An additional saving on wire can also be made by connecting the points *A* and *B*, indicated in Fig. 181, to water or gas pipes, or to metal plates sunk in the ground. If ground plates are used they should be at least 2 feet square and should be sunk in ground that is always a little

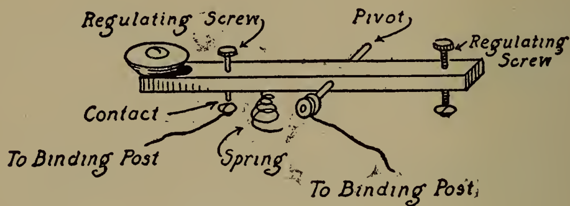


Fig. 183.—Detail of key.

damp. The damp ground or the metal pipes will carry the current quite as well as the wire.

A combination key and sounder of a little more substantial design is well worth while if much telegraphing

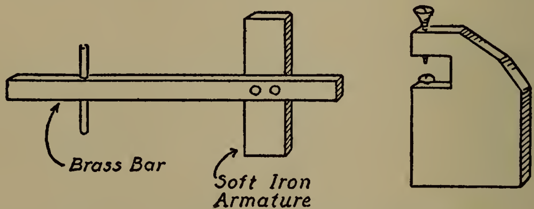


Fig. 184.—Armature and anvil of complete set.

is to be done. For this, a pair of magnets built the same as for the lighter set may be used. The heavier armature and sounder and the design of the key in detail are all shown in Fig. 182. It will be noted that a switch is provided in this outfit to close the circuit when the key is not in use. The circuit on one set must always be closed to receive messages from the station at the other end of the line. A little different wiring is also necessary with this set. The general scheme is shown in Fig. 185. As arranged here the intention is to use dry batteries, and for that reason a small two-way switch should be connected in at each end of the line. One of these switches can be made or

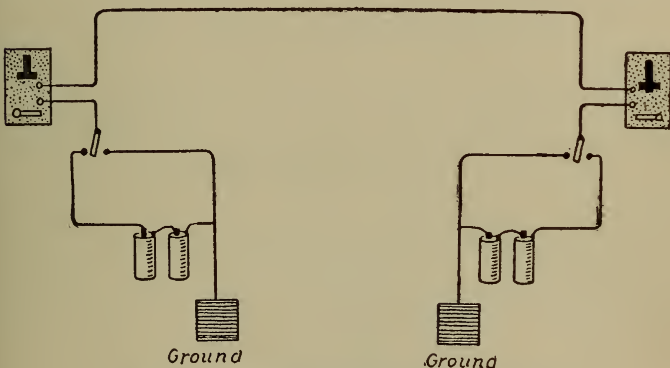


Fig. 185.—Circuit for two key and sounder sets.

bought at a very low price. When the sets are not in use these switches should be thrown so as to disconnect the cells, but keep the telegraph circuit closed. In this way the line is always kept ready for use without running down the dry cells. If gravity cells are used this little switch is not necessary, as the cells are intended for closed circuit work, and should be left connected in the circuit when not in use. If you and one chum are the only ones using your telegraph line, the instruments described, with batteries, are all you need. With a larger line, and five or six instruments, you would be fortunate in hearing the messages at all. This is where you would need a relay. One can be built in

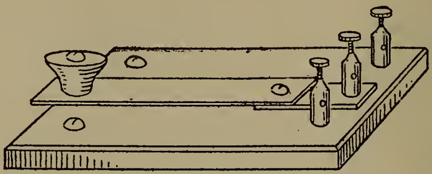


Fig. 186.—Two-way switch.

your own workshop and is not much harder to make than a sounder. It is considerably more delicate and works with a very small current. The wire used for winding is very fine and there are many more turns than on the sounder. The armature is light, moves easily,

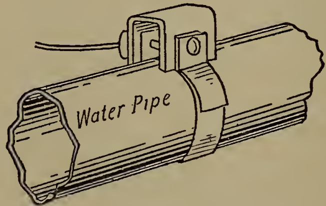


Fig. 187.—A convenient ground clamp for water pipes.

and is pulled through a very short distance. Each time it is attracted it closes a "local" circuit through a set of batteries and the sounder. The sounder then gives the usual loud click, while the relay is not heard at all. Wiring arrangement can be seen in Fig. 191.

Winding for the magnets is the same as in a sounder except that No. 32 cotton-covered or enameled wire should be used.

The armature is made from a piece of $\frac{1}{32}$-inch sheet-

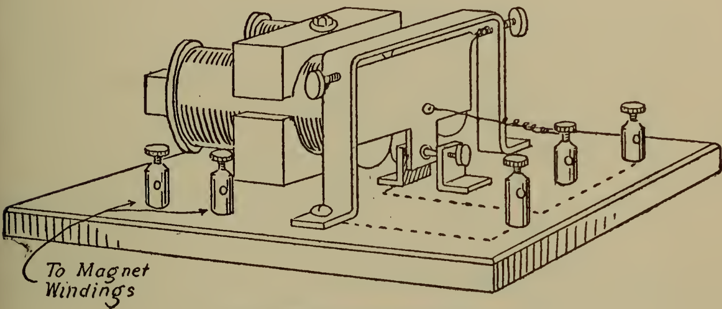


Fig. 188.—Telegraph relay.

iron. This swings in a frame made by bending a piece of sheet brass in a U shape. The two supporting screws can be ordinary machine screws with a little

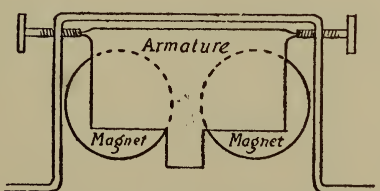


Fig. 189.—How relay armature is pivoted.

socket drilled in the end of each. Two little L-shaped pieces of the same brass strip hold the screws that regulate the motion of the armature. (See Fig. 190.)

A glance at Fig. 188 will show how the whole piece of apparatus is mounted on a little wood base, and how the connections are made. The middle binding-post

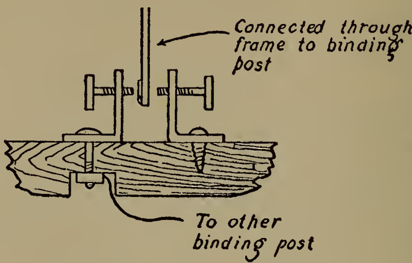


Fig. 190.—Relay contacts.

is used only to fasten the spring or rubber band that pulls the armature away from the magnets.

With two sets of keys and sounders two boys who

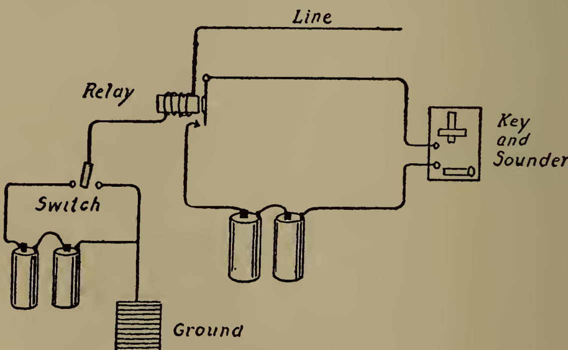


Fig. 191.—Connection for receiving with relay.

have plenty of enthusiasm can learn to telegraph in a short time. Care should be taken to begin properly, as bad habits in sending are easily acquired. They are much harder to get rid of and will limit the careless operator's speed. To begin with, the key must be held properly. The grip on it should be firm, but not stiff. One of the most widely used is known as the "Catlin" grip. In this the hand is held somewhat as in writing. The two forefingers are simply rested on the top of the knob, and it is not held at all. Some operators grip it lightly between the thumb and the second finger.

For best results the key should be fixed solidly to the table, about 18 inches from the edge. This allows the

Fig. 192.—The "Catlin" grip.

free wrist movement which is necessary. The forearm should rest on the table. There should be no side movement of the key in sending. For this practice a key sounder such as shown in Fig. 182 should be connected in circuit with a battery so that the beginner can hear the sound of his own letters.

As a beginning the dots and dashes of the alphabet should be memorized with the help of the key. In practising the letters, it is well to learn the "dot" letters first, then the "dot and space" letters, and then the "dot and dash" letters.

A single dot is made by a quick pressure on the key, so that it gives two clicks very close together. For a dash the lever is held down a little longer. A dash should take as much time as four dots. For a long

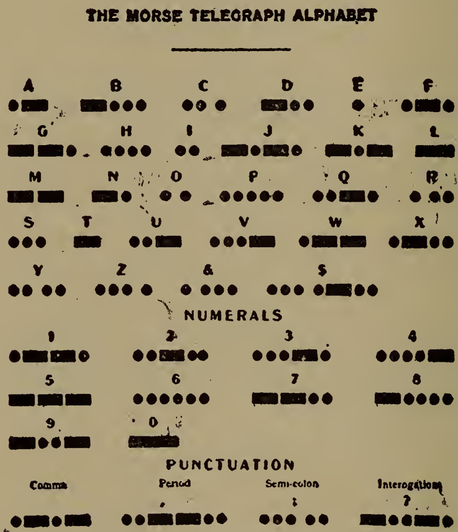


Fig. 193.—Morse alphabet.

dash, such as is used for the letter "L," the key should be held down for the space of six dots.

For practice it is a good thing to make long strings of dots one after the other and all equally spaced. Then the dots in groups of 2, 3, 4, 5, and 6. These are the letters I, S, H, P, and the numeral 6. These should be perfected before going any further.

DOT LETTERS

E	.	H	. . . .
I	. .	P	. . . . .
S	. . .	6	. . . . . .

In sending these letters practice until the sounder clicks so rapidly that the "up-stroke" or "back-stroke" of the sounder is not heard. In the letter "P," for instance, the only back-stroke you could hear would be after the fifth dot.

The dash letters are made by holding the key down for a part of a second before letting it up. The dashes in the letters should all be of the same length except in the letter "L." The dash for this letter must be noticeably longer than the others.

DASH LETTERS

L	——	T	—
M	— —	5	— — —

DOT AND DASH LETTERS

N	— .
D	— . .
B	— . . .
8	— . . . .

The above are the only letters which are made by starting with a single dash and then following with one or more dots. There should be no "back-stroke" heard until the end of each letter. A little thought will show why the dots should follow quickly. If the letter "N" was being sent, and a pause was left between the dash and dot, it would be read at the other end as "T I" instead of "N." A similar pause in sending "B" would change it to "T S." So the pauses mean just as much and are just as important as the dots and dashes. It is excellent practice to compare N and T E, D and T I, B and T S until you are entirely familiar with the sound of each.

Further practice should be applied to the dot and space letters. These are as follows:

DOT AND SPACE LETTERS

C . . .	O . .
R . . .	Y . . . .
Z	

The space is made in each case by pausing a very short time between dots. There should be just enough pause to be noticeable. It is made by letting the key stay up for a fraction of a second, and recognized by the sound of the "back-stroke." That is, the "back-stroke" will be heard after the second click of the "C" and after the first of the "R." As these spaced letters are considered the most difficult of all, they should be practised even more than the others. Compare the sound with that of the evenly spaced dots until you are perfectly familiar with each combination.

After the alphabet has been learned, select a number of common words with the same endings or the same beginnings, and practice sending and receiving them until you are familiar with the sound of the whole word. It is best to have your friend far enough away so that there will be no temptation to call out to him to find out what he says or tell him what you are sending.

A number of words and thoughts are very commonly abbreviated, and make telegraphing much easier when they are learned. A few of these follow:

Min.	Wait a minute.
5	Have you a message for me?
7	I have a message for you.
8	Wait, I am busy.
13	Understand?
30	Good-bye.
Ga.	Go ahead.
Hr.	Here is a message.

In calling your chum at the other end of the line it is convenient to use the first letter of his name. His first name being George, you would send G several times until he answered. When his attention was attracted he would answer by sending the letter I several times, and then signing or sending his initial G. You would then send the letters "Hr" and go on with your message.

CHAPTER XI

The Telephone

Receiving telegrams by sound instead of printed dots and dashes became popular just as soon as the instruments were perfected. Then men thinking along electrical lines began to wonder why other sounds could not be reproduced by wire in something the same way as the clicks are. All sounds are caused by vibrations or waves of some kind. The sound may be a click, a bang, a scraping noise, or a musical note; each one causes its own sort of motion in materials nearby. The wood sounding-board of a piano and the metal bell of a horn actually move when the instrument is being played. This movement can be plainly felt. It is very small and very rapid, but enough to make the air all around it vibrate strongly. The waves of air then strike on the ear-drum and give us the sensation we call sound.

If the vibrations of the cornet bell could be duplicated electrically or in any other way the notes of the cornet would be reproduced.

The movement of the telegraph key was recognized as a slow vibration. It was exactly reproduced at the other end of the line. If the key could be moved fast enough and the armature of the sounder was light enough to follow each movement, the result would be a humming sound at the sending end and receiving end. Both sounds would be exactly alike. For such a note to be produced at all the key would have to be moved about 34 times a second. If it vibrated faster the note would be clearer and sharper. It would go right up the musical scale until it reached nearly 40,000 movements a second. Then it would be too high to affect the nerves of an ordinary ear.

It occurred to a poor German named Philip Reis that a musical note might be sent by making vibrations open and close a magnetic circuit. He was without money, and his materials were beer barrel bungs, a sausage skin, and such bits of brass and wire as he could gather together. The skin was stretched over a hole and a bit of brass attached to it touched a needle. When a note was sung or played near the membrane there was a vibration which rapidly made and broke contact between brass and needle. This contact was connected in a circuit just as a telegraph key is. At the other end of his line was simply a battery and a small electromagnet with a knitting-needle for a core. The magnet was mounted on a sounding-board. There was no armature, but the vibration of the needle core was enough to produce a sound.

When middle C, which is always 517 vibrations per second, was sung or played near the receiver of Reis' telephone it caused the circuit to be completed and broken 517 times a second, and the little magnet to be magnetized just as rapidly. The result was that the receiver gave out a faint note of the same pitch. But it made no difference whether the note was sung, played on flute, violin or cornet, the effect on the transmitter was the same. A listener could not tell which was being played. Still, any note played near the transmitter reproduced the same note in the receiver.

Sometimes a word could even be understood, but Reis' telephone was apparently not much of a success.

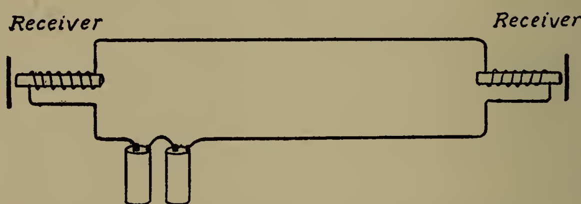


Fig. 194.—How Bell's first telephone was wired.

It remained for Professor Alexander Graham Bell to make the discovery that resulted in the wonderful systems of today. Bell had for many years been a teacher of the deaf. He knew the construction of the ear perfectly. He realized that the sound of the human voice was too complicated to be reproduced by such a make and break arrangement. His solution was to place a little iron diaphragm very close to an electro-magnet to transmit the sound and another one just like it to receive it at the other end. Then the vibrations in one diaphragm caused very delicate currents to be generated in the electric circuit. The other diaphragm was affected so that it vibrated exactly with it, and sent out sound-waves that were almost identical with those at the other end. Not only musical notes, but singing, talking, or any sort of sound could be heard.

Of course, the little currents generated by the vibrating diaphragm were weak. The telephones were only good for short distances. Then Professor Hughes and,

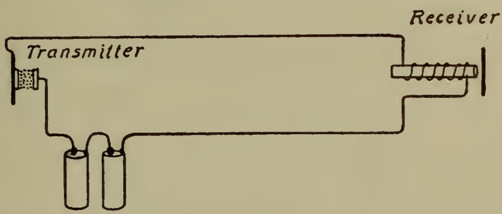


Fig. 195.—Simple circuit with microphone transmitter.

independently, Edison discovered the carbon transmitter that is used today.

This depends on an altogether different principle. It is based on a device called the Microphone. Professor Hughes found that if two pieces of carbon touched lightly together a very slight pressure made a great difference in the resistance at the point of contact. With two such sharpened pieces of carbon touching and each supported by a spring attached to a sounding-board very small noises could be heard. The footsteps of a fly heard through an ordinary telephone receiver connected in the circuit would sound like a horse galloping on a hard road. Even the very light steps of the fly are enough to affect the contact and change the resistance, so that the diaphragm of the telephone receiver is vibrated a corresponding degree.

The explanation is that the slight pressure forces the molecules of the carbon tips together, and allows more room for the current to pass, with a consequently decreasing resistance.

In the modern telephone transmitter the material used is carbon broken into little grains, so that there are many delicate contacts in place of one, and a consequently greater effect.

Here are the things that happen when you speak in the transmitter of a telephone: First, your voice striking against the iron diaphragm of the transmitter sets it into vibration, corresponding to every tone and change of the voice. With these vibrations a lot of little carbon granules are pressed together. Their resistance changes with the slightest movement of the diaphragm. As they are connected in the circuit the current flowing also changes rapidly. Thus every tone of your voice is faithfully followed by the changing current in the circuit.

In the receiver at the other end this current flows through the fine coils of an electromagnet that is wound on the end of a permanent magnet. The tip of the magnet almost touches a soft iron diaphragm. All the little current changes affect the magnetism of the little bar and, consequently, its attraction for the diaphragm. The result is that the diaphragm of the receiver vibrates exactly like the diaphragm in the transmitter. We hear—not the same vibration, that went into the transmitter—but brand new ones exactly like them. There is a great difference between this and Reis' scheme, for

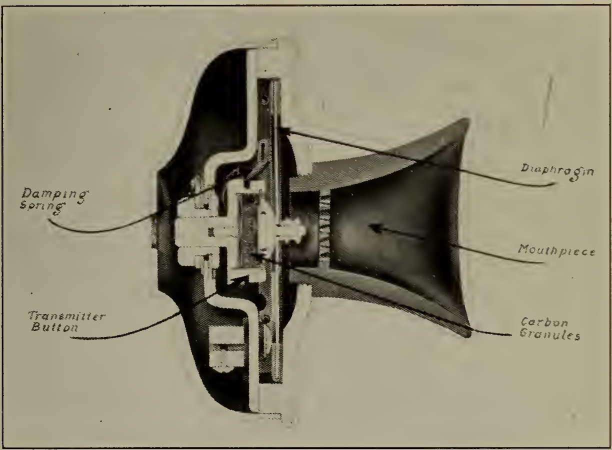


Fig. 196.—Parts of modern telephone transmitter.

the circuit is never entirely broken, and the tones reproduced are practically perfect. In the first telephone a middle C on all instruments sounded the same. With the modern telephone it is quite easy to recognize each one.

The actual construction of a receiver and transmitter may be seen from the two sectional views (Figs. 196 and

197). In the transmitter the main parts are the diaphragm and the carbon contact arrangement. The grains of carbon are very hard and are especially prepared for the purpose. They are held between two highly polished plates of carbon. This transmitter is the result of great study and many improvements. The

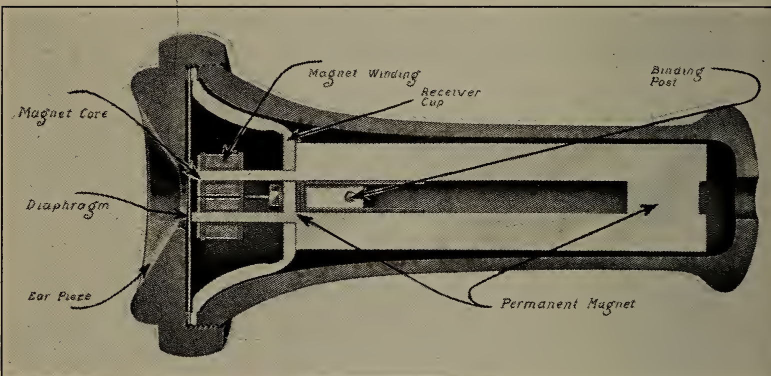


Fig. 197.—Parts of telephone receiver.

receiver is practically in the same form as originally invented by Bell.

HOW TO MAKE A TELEPHONE

A telephone receiver is not hard to make, though it does require care in detail, and is very apt to be a failure unless the working parts are made accurately and correctly. The cost of making the receiver will be small, as the only materials to be bought are a small bar magnet, a hundred feet of No. 36 silk-covered wire, and a piece of ferrotype plate such as is sold by photographic dealers. The magnet should be about 6 inches long and not more than $\frac{1}{4}$ inch in diameter.

The first step is to make a little spool for winding the fine wire. For this two discs cut from thin wood will be needed. They should be 1 inch in diameter and should fit snug on the end of the magnet. For the middle part of the spool wind a thin piece of cardboard or several turns of stiff paper tightly around the bar, and slip the two wood ends on over it. The ends should

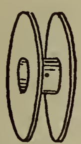


Fig. 198.—Spool for magnet winding.

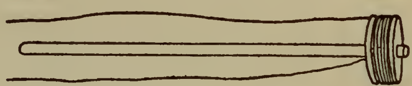


Fig. 199.—Magnet and core for receiver.

then be glued to the paper center, so that $\frac{1}{4}$ inch space will be left for winding the wire. When the glue is dry wind on the wire; leave 6 inches at each end for connections. To make the winding a little more solid it may be slipped off the magnet, dipped in a bath of melted paraffin, and slipped back again.

This bar magnet and a little electromagnet, with a diaphragm of this iron held before it to produce the sound, are all the working parts of even the best telephone receivers. The rest is simply a case added for convenience and protection. A very good case to hold the magnet may be whittled from two pieces of wood, or, if a lathe is available, may be turned from a single piece. If two pieces are used they should each be whittled in the half-round shape shown in Fig. 200.

If the wood is a straight-grained piece there will be no trouble in cutting the grooves for the magnet, wire, and air chamber *A*. The groove in which the magnet is held should be small enough to grip the steel

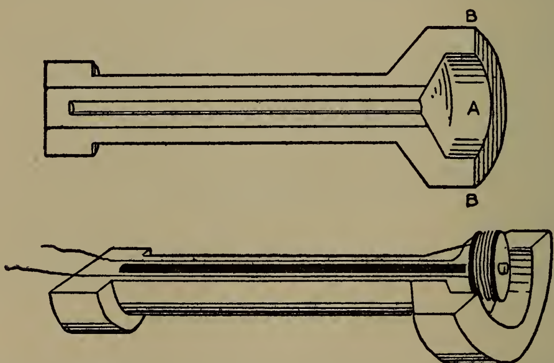


Fig. 200.—Two halves of receiver case with magnet in position.

bar tightly when the two halves are glued together. It should just be held with enough firmness so that a slight tap is required to move it.

After both halves have been finished and fit together properly the magnet, with the coil in place, should be layed in the groove of one half and placed so that it lacks about $\frac{1}{32}$ inch or even less of being even with the edge *B–B*. Then the two halves may be glued together and set in a vise or clamp to dry.

Two small binding-posts should now be set in the end, and one of the fine wires carefully soldered to each.

The thin diaphragm should now be cut. One thing that must be especially remembered in doing this part of the work is to make sure that the part cut is perfectly smooth. There must be no dents in the diaphragm. It can be cut round with an old pair of shears, but the circle should not be marked on it with compasses. A better way is to mark and cut a piece of paper $1\frac{3}{4}$ inch

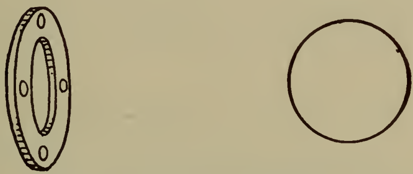


Fig. 201.—Ear-piece and diaphragm.

in diameter and then use this as a pattern for cutting the iron sheet. This avoids the little dent at the center.

For a cap to hold the diaphragm in place a piece of $\frac{1}{4}$-inch wood can be used. A hole should be cut in it as shown in Fig. 201, and the bottom cut away slightly so as not to interfere with the free movements of the sheet iron, which is held all around the edge between the two pieces of wood. It should not be touched by the small wood screws which hold the cap in place.

A little adjustment may be necessary to secure the best results. If the magnet is too far from the diaphragm the sound will be weak, and if it actually touches there will be no sound at all. The best point is where it just misses the magnet tip. With cap and diaphragm removed you should be able to see light between the magnet and a straight-edge held across the edges of the sound chamber. When this adjustment has been made and the cap fastened back in place the telephone receiver is complete. For the sake of appearance it is a good scheme to paint it with lampblack or black paint and give it one or two coats of shellac.

This receiver can also be used as a transmitter; thus a complete telephone line could be made with two trans-

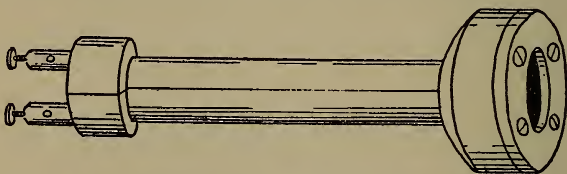


Fig. 202.—Complete receiver.

mitters and a couple of dry cells connected in series between them. Such a line will not work well over long distances, but will enable you to talk between house and workshop or to your chum in the next block.

Much better results can be secured with the carbon or microphone transmitter, which is now used in all telephones. As explained, this is not magnetic in action, but depends on changes of resistance caused when the sound-waves strike it. As a first step in building a carbon transmitter cut out two pieces of carbon each $\frac{5}{16}$-inch thick and $\frac{3}{4}$ inch in diameter, then bore a $\frac{1}{8}$-inch hole very carefully through the middle of each. Cut a circular diaphragm $1\frac{3}{4}$ inch in diameter from thin iron. This should have a hole in the middle and another at the edge. These carbon discs and the diaphragm make up the principal parts of the transmitter. To fasten a disc on the diaphragm cut threads on

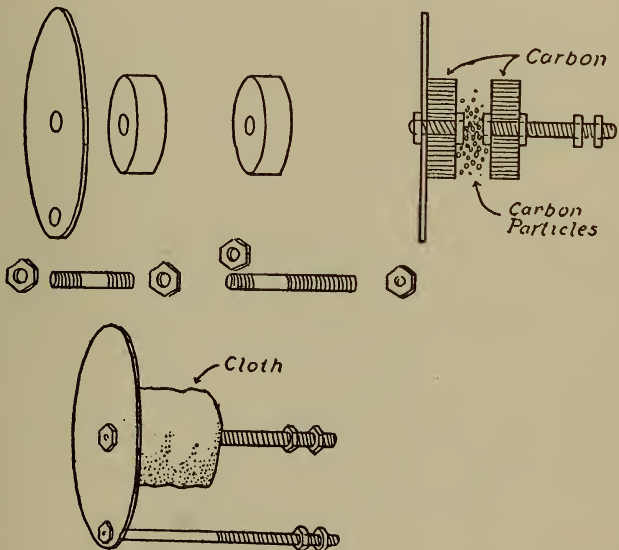


Fig. 203.—Parts and method of constructing telephone transmitter.

pieces of $\frac{1}{8}$-inch wire and make nuts to fit, or buy small bolts sawed to the proper length. The next step is to break up some coke in pieces the size of a pinhead or, better still, secure from an electrical dealer about a saltspoonful of the polished carbon particles used in the standard telephone transmitters.

Cut a piece of cloth large enough to go around the carbon discs and lap over a little. Paste this two-thirds of the way around the two discs, leaving $\frac{1}{4}$ inch between them. Then drop in enough of the bits of carbon to fill the space about two-thirds full. Finally, paste the cloth the rest of the way around. This makes up the working part of the transmitter.

For the case, secure a piece of clear-grained wood 1 inch thick and saw out a block $2\frac{1}{4}$ inches square. In

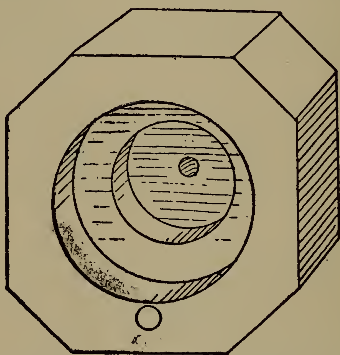


Fig. 204.—Back half of transmitter case.

this bore a hole about $\frac{5}{16}$ inch deep and just a little smaller than the iron diaphragm; bore a smaller hole deep enough to contain the carbon discs with their cloth wrapping, and a third $\frac{1}{8}$ inch in diameter clear through the block. For the cover a piece of wood $\frac{1}{2}$ inch thick will do. This also should have two sized holes cut in it; a $1\frac{1}{2}$-inch hole $\frac{1}{8}$ inch deep and a 1-inch hole the rest of the way through. Four holes for screws should be bored through the cover. The corners of both blocks may be trimmed as shown in

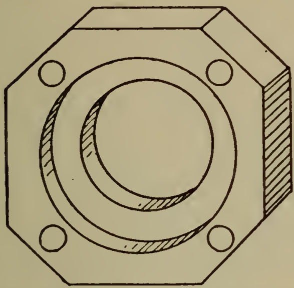


Fig. 205.—Front half of transmitter case.

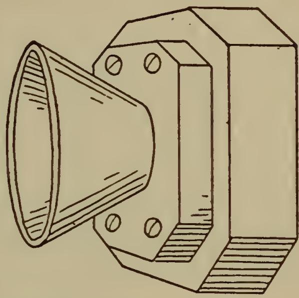


Fig. 206.—Finished transmitter.

Figs. 204 and 205. A small mouthpiece to collect the sound may be made from stiff pasteboard or tin, and the case assembled with the microphone inside.

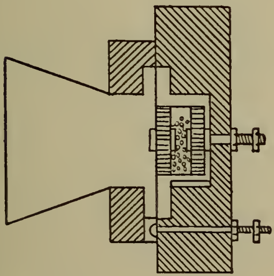


Fig. 207.—Section through assembled transmitter.

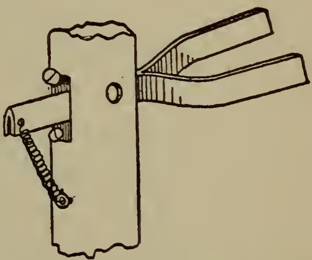


Fig. 208.—Detail of hook and connection.

The finished transmitter may now be made up either as a wall set or a desk set. For the desk set secure a piece of wood $8\frac{1}{2}$ inches long and about 1 inch in diameter. A piece of broom handle will answer very well. Cut a $\frac{1}{2}$-inch shoulder at one end for the transmitter, and cut a mortise through about 1 inch below to receive the hook. This hook can be made from a single piece of brass as shown in Fig. 209.

Two round-headed brass wood screws will serve as the two contacts, and a spring strong enough to nearly balance the weight of the receiver must be added. A piece of thin spring brass and a brass plate attached at

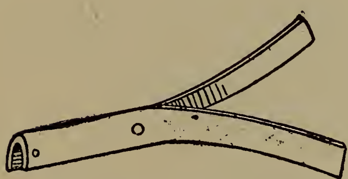


Fig. 209.—How hook is cut from one piece of sheet brass.

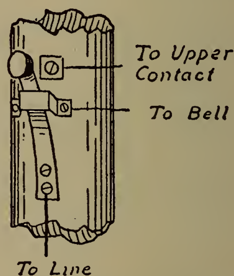


Fig. 210.—Detail of bell-ringing switch.

a convenient point on the standard make up a switch which closes the bell circuit of the other party and calls him to the line. In ringing up the other party with this telephone you first have to take the receiver off the hook and then press the little contact switch. Then the circuit will be completed through the hook, the lower contact of the hook, the batteries, and the line. Your chum's bell rings; he takes his receiver off the hook, and then both bells are disconnected—the batteries are in the circuit and you are ready to use the line. An ordinary electric bell with this battery arrangement will do all right as a signal for short lines.

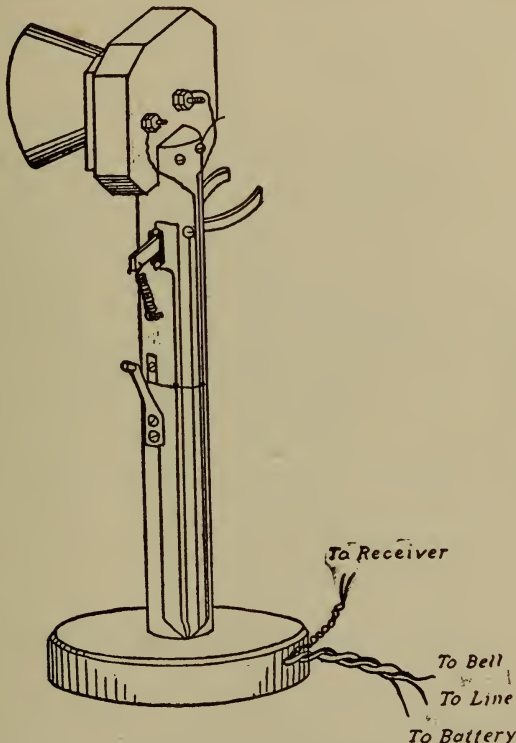


Fig. 211.—Desk telephone.

For long ones a magneto is necessary to give a strong ring.

In wiring the set built as described and illustrated by Fig. 211, it is well to bind all the wires together after connections have been made, and lay them in a groove cut in the telephone standard. This groove can then be filled with sealing wax. This little extra work adds both to the permanence and appearance of the set; when painted black it will have quite a workmanlike look if carefully made.

THE MICROPHONE

Many experiments have proved that an actual mechanical movement of the diaphragm is at the

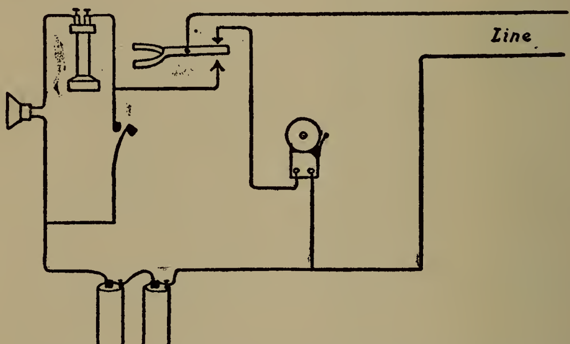


Fig. 212.—One station of telephone circuit. Other station is exactly the same.

bottom of telephony. The voice moves the diaphragm of the telephone to compress the particles of carbon in the transmitter. The sound-waves go from the mouth through air and strike the diaphragm, making it vibrate.

In the instrument known as the microphone the sound comes through solid material instead of air, and is greatly magnified. This is the instrument which was discovered by Mr. Hughes, and independently by Edison. With it the experimenters were able to hear a fly walking about, and hear the buzz of his wings until it sounded like an express train.

The microphone depends entirely on a very delicate contact between two or more conductors. They may be almost any conducting material, but carbon works

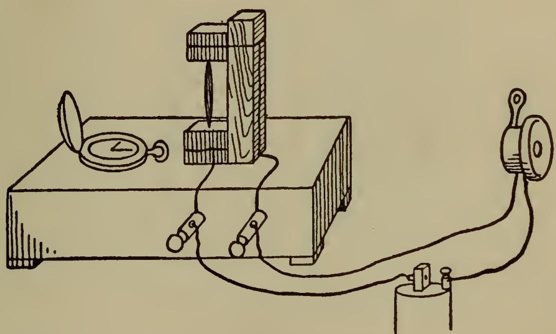


Fig. 213.—A simple microphone.

about the best. A very common form, illustrated in Fig. 213, is made with two bits of coke cut to about the size of dice and a sharpened pencil of carbon. In each carbon block bore a hole about $\frac{1}{16}$-inch deep with a sharp knife. A groove also will have to be cut in the lower block so that the carbon can be slipped in place. The little carbon strip can be made by taking the lead from a pencil and sharpening both ends to a fine point. Both the carbons can be glued to a little wooden standard, and attached to a box made from thin boards. Much better results are secured if the box is glued instead of being nailed at the corners. A pair of small binding-posts should be added for convenience.

With this microphone connected in a circuit with a couple of dry cells and an ordinary watch-case receiver

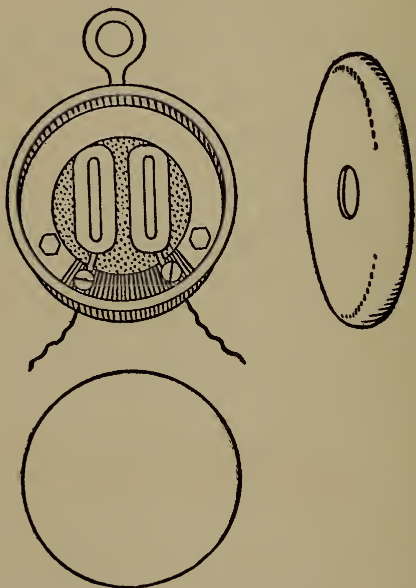


Fig. 214.—Parts of watch-case receiver.

you can hear the ticking of a watch very plainly at any distance you want to take the receiver. With a carefully made instrument you can understand speech, hear music by setting it on a piano or graphophone, or do practically anything that can be done with a telephone transmitter. Adjustment to some extent can be made by tipping up one end of the box, which makes the carbon pencil lean heavier against the upper carbon block.

With even less work a microphone can be made from a couple of safety razor blades mounted on a box. They

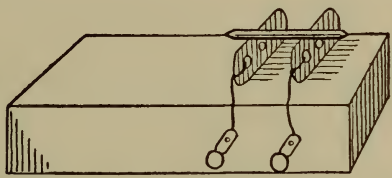


Fig. 215.—Microphone made from safety razor blades.

can be fastened on with a bit of sealing wax. When a piece of pencil lead is laid over the two sharp edges the instrument is ready for use. For convenience and to keep the lead from rolling off continually a piece of

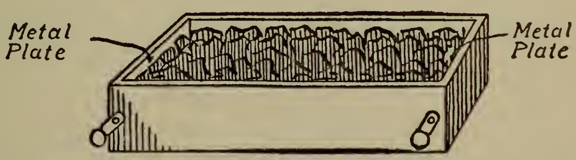


Fig. 216.—Multiple contact microphone made with broken coke.

thin cardboard with a little slot cut in it to hold the pencil may be mounted upright between the two blades. The experience of the writer has been that this works the best of any easily constructed form of microphone. It transmits very nearly as well as a telephone.

Another form which is easy to make, but not so delicate, is shown in Fig. 216. This is nothing more than a box of broken bits of coke. Current passes through it from a plate at one end to a plate at the other. It is really a multiple contact microphone of the sort used in a standard telephone transmitter.

TELEPHONE INDUCTION-COIL

All of these telephone and microphone arrangements transmit sound, but not always as steadily or clearly

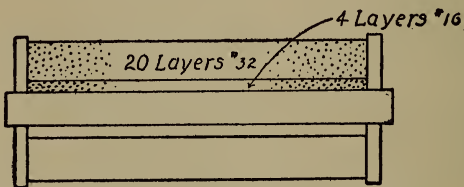


Fig. 217.—Induction-coil for microphone or telephone.

as we would like. Some tones will be very good—others noisy or hard to hear. All are improved by a

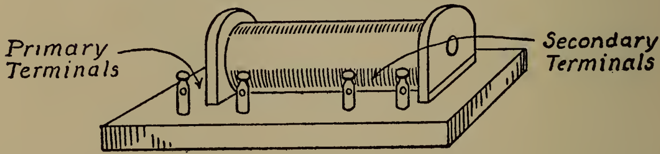


Fig. 218.—Finished induction-coil.

very simple induction-coil. This consists of a $\frac{1}{4}$-inch iron rod 3 inches long wound with four layers of No. 16 wire and twenty layers of No. 32 wire. The leads should be brought out to two pairs of binding-posts and the whole mounted firmly on a neat base.

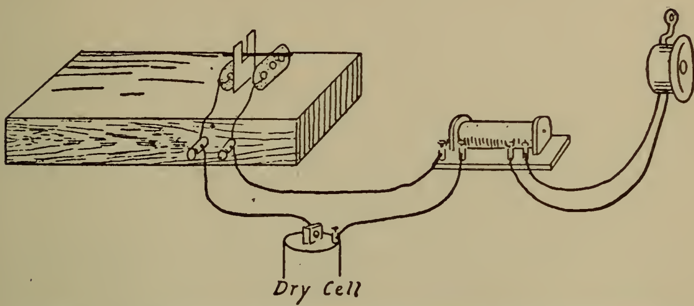


Fig. 219.—Connections of razor-blade microphone with induction-coil.

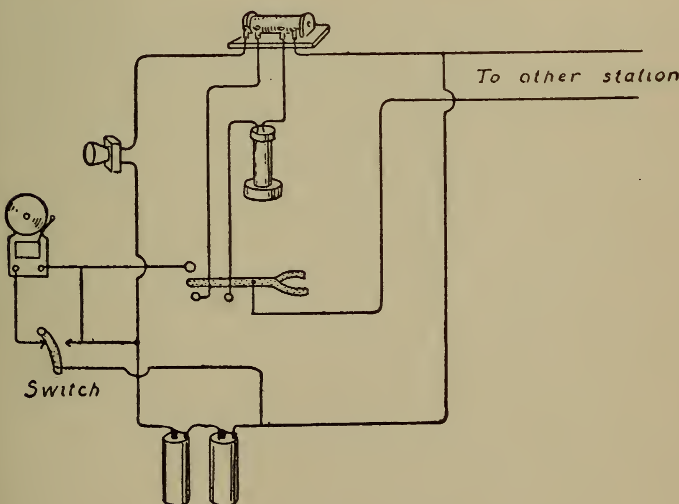


Fig. 220.—Telephone circuit with induction-coil.

When the primary of this coil is connected in series with battery and transmitter each change in current makes a change in the magnetic field. Every one of these changes induces a current of much higher voltage in the many fine windings of the secondary. Consequently, each little change is magnified many times. When the receiver is connected in the secondary there is a great gain in loudness and clearness of tone. The small work of making this little coil is well paid for by greatly improved results.

The wiring for an induction-coil in a microphone circuit is shown in Fig. 219, and for a telephone circuit in Fig. 220.

CHAPTER XII

Wireless Telegraphy

When you sit in a quiet room and watch some one blowing smoke rings you have about the best visible example of the way wireless messages travel. The ring starts in a little puff of smoke and whirls in a wider and wider circle. The next ring follows—then another and another. If they were timed in dots and dashes a message could actually be sent across the room in smoke. In wireless, a series of waves or disturbances are similarly started by a heavy spark; they spread out and out through a substance called "ether" which fills all space. Ether is an actual substance, yet colorless, odorless, and almost without weight. It is so very light that a mathematician has estimated the weight of a sphere the size of our earth at only 250 pounds. The word "ether" is said to be derived from a Greek word which means the same as our term "perpetual motion." The ether is supposed to be in constant motion.

Vibrations set up in this substance by the sun's energy appear on the earth as light and heat. Light is brought to us by it at the speed of an electric current —186,000 miles a second. At the same speed and in much the same way the disturbances or waves used for wireless are carried through it. These are called electromagnetic waves, or "Hertzian" waves, after their discoverer.

All wireless messages are sent with Hertzian waves. These travel from the spark in much the same way as the smoke rings did, or the tiny ripples that move from the center of a tub of water when a pebble is dropped in it. In Fig. 221 the spark is represented by the

Fig. 221.—Ripples on water resemble electromagnetic waves.

pebble and the ether by the water. Messages could be arranged just by timing the ripples and making them into dots and dashes with spaces between. Just as the ripples go in all ways from the center of the tub, the electromagnetic waves move in every direction from the spark which starts them. A message sent from Detroit to Chicago, for instance, would reach Mackinac on the north, Rochester on the east, and Cincinnati on the south all at exactly the same instant and with equal strength.

As so little of the energy ever reaches any receiving station, a strong spark is quite necessary for sending. This might be produced with a static machine, an induction-coil, or a transformer. The first is never used for the purpcse on account of unreliability and other features which are not desirable. For small sets an induction-coil such as is described in Chapter V does very well.

A sending set of the simplest kind would consist of such a coil with a telegraph key and batteries connected in the primary, and a spark gap in the secondary. One side of this spark gap is connected to an aërial, consisting of several wires strung at some height from the ground; the other is firmly connected either to a ground plate or to a water pipe.

This is the way such a set works: The moment the key is closed the E. M. F. of several thousand volts is generated in the secondary. The aërial and ground are instantly charged. As soon as this happens a spark jumps across the gap, and the electromagnetic waves start off at lightning speed in all directions. A touch of the key sends out the few waves that make a dot in the code, and holding it down a second makes a dash. Either the Morse or Continental code could be used. For reasons to be given later this simple "hook-up" is forbidden by the United States wireless laws.

When the swiftly moving electric waves pass a wire a current is generated. If this wire is near the starting-point there will even be enough induced to make quite a heavy spark. At a distance of several miles the waves have spread so that the effect becomes very weak. There must be quite a long wire to catch enough for a signal. The aërial wires that indicate the houses

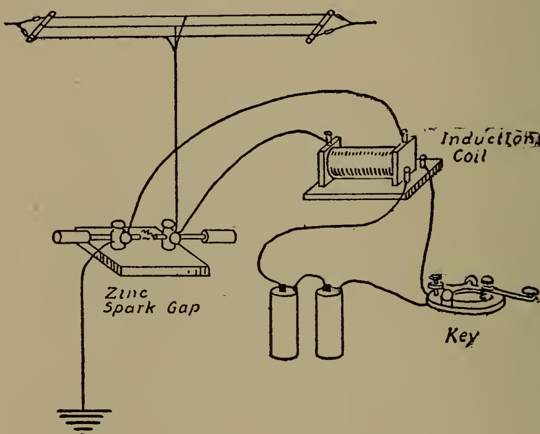


Fig. 222.—Simple transmitting set.

and workshops of so many wireless experimenters are as important for receiving as they are for sending.

Even with these long wires raised high in the air the effect of the transmitted waves is very feeble. If the distance between the two stations is many miles, only a very small part of the original energy ever reaches even the longest of aërials. The rest is wasted as far as the receiving station is concerned. The problem is to read dots and dashes from such a very small disturbance. For this a telephone receiver is generally used, and, as delicate as it is, it cannot do the work alone. In addition, a detector is needed. The object of this is to change the very small oscillating currents that come from the aërial into direct current. It then affects the telephone receiver so that a sound is produced. There are several metals and ores from which detectors

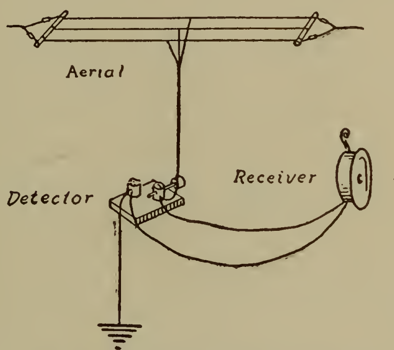


Fig. 223.—Simple receiving station.

can be made. Among these are silicon, galena, and iron pyrites. Both galena and fused silicon give excellent results and are commonly used in very easily made detectors.

The simplest arrangement of a receiving station is shown in Fig. 223. It consists merely of a detector connected in the line that runs from the aërial to the ground, and a telephone receiver connected across the detector.

When electromagnetic waves from any source pass by the aërial they generate slight oscillating currents. This flows to the ground through the detector, is rectified by it, and heard as a faint "buzz" in the receiver. There are no clicks of the sort heard with the Morse telegraph sounder.

In theory the simple sending and receiving set described would send messages over short distances fairly well. In practice their use would be impossible, as the untuned transmitter is stricly forbidden by United States wireless law. A simple tuning arrangement not only complies with the law, but enables you to transmit messages over much greater distance. By "tuning" is meant a regulation of the oscillating discharge of the system so that the electromagnetic waves are greatly increased in strength and only one length of wave is sent. The action of a tuned transmitting set resembles that of a bottle made into a whistle by blowing over its edge. You may blow hard, soft, at any angle, but the tone is always loud and clear on some particular note. The sound-waves of this note are added in the bottle in such a way that its loudness is greatly increased.

An idea of a single wireless wave may be gained from a simple experiment with a rope or heavy cord. Tie one end to a post and shake the other in a way sailors call "Surging." Wave after wave can be made to run along to the post. The line moves only up and down; the wave travels lengthwise. As the line is shaken more rapidly the waves become shorter. Moved more slowly,

Fig. 224.—Wave motion is easily shown with a long piece of rope.

they become longer. By wave length is meant the distance from the top of one wave to the top of the next.

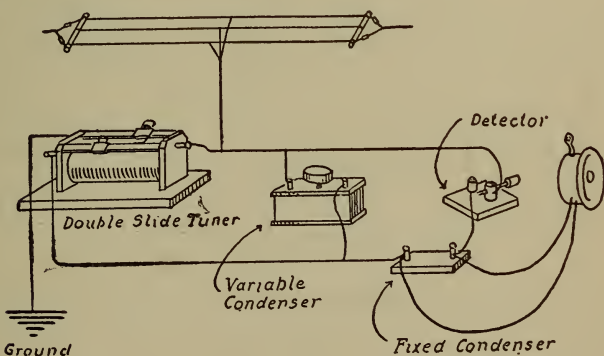


Fig. 225.—Receiving station arranged for tuning.

Wireless waves traveling in ether may be almost any length. Those starting from a flash of lightning may be as long as 10,000 miles. At the other extreme waves have been produced which must be measured in tenmillionth parts of an inch. By reason of the United States wireless law now in force amateur stations are not allowed to use waves longer than 200 meters. A meter is a little more than a yard.

With a receiving station also tuned to catch the reinforced waves of the sending station great distances are possible. The circuit is only sensitive to one length

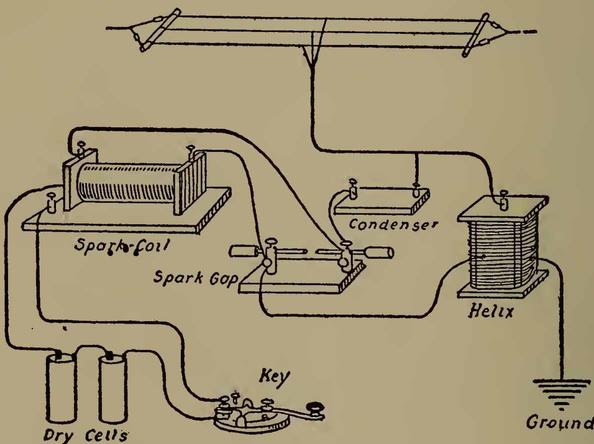


Fig. 226.—Tuned transmitting set, close coupled.

of wave, and so disturbance from other stations is avoided.

A sending station is tuned by putting a "helix" and condenser in the circuit. This helix is simply a coil of wire mounted in a frame and provided with contact clips for ground and coil. It is connected between the aërial and ground as shown in Fig. 226. The condenser is connected between the spark gap and helix.

With these additions the outfit becomes a simple tuned transmitting set. It is "close coupled," which means that the secondary of the induction-coil is actually connected in the aërial circuit. Adjustment or "tuning" is secured by changing the position of the two clips *A* and *B* which make contact with the metal of the helix.

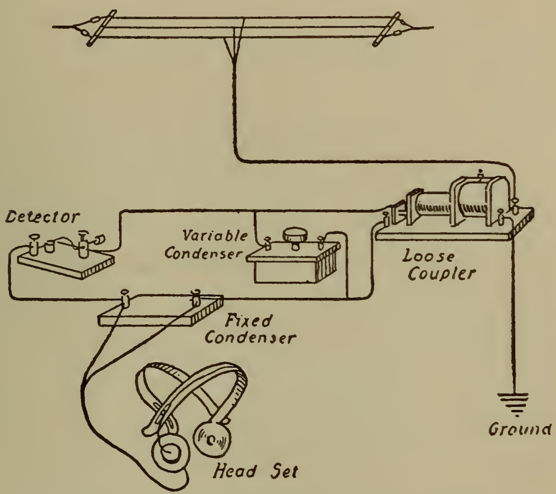


Fig. 227.—Tuned receiving set, loose coupled.

Even better results in transmitting can be secured with an oscillation transformer put in place of the helix. The arrangement in Fig. 228, with power taken from an alternating current line, and stepped-up through a small transformer, gives much stronger transmission than is possible with batteries and a coil. The spark gap is connected across the secondary of the transformer, just as in a simple set. In series with

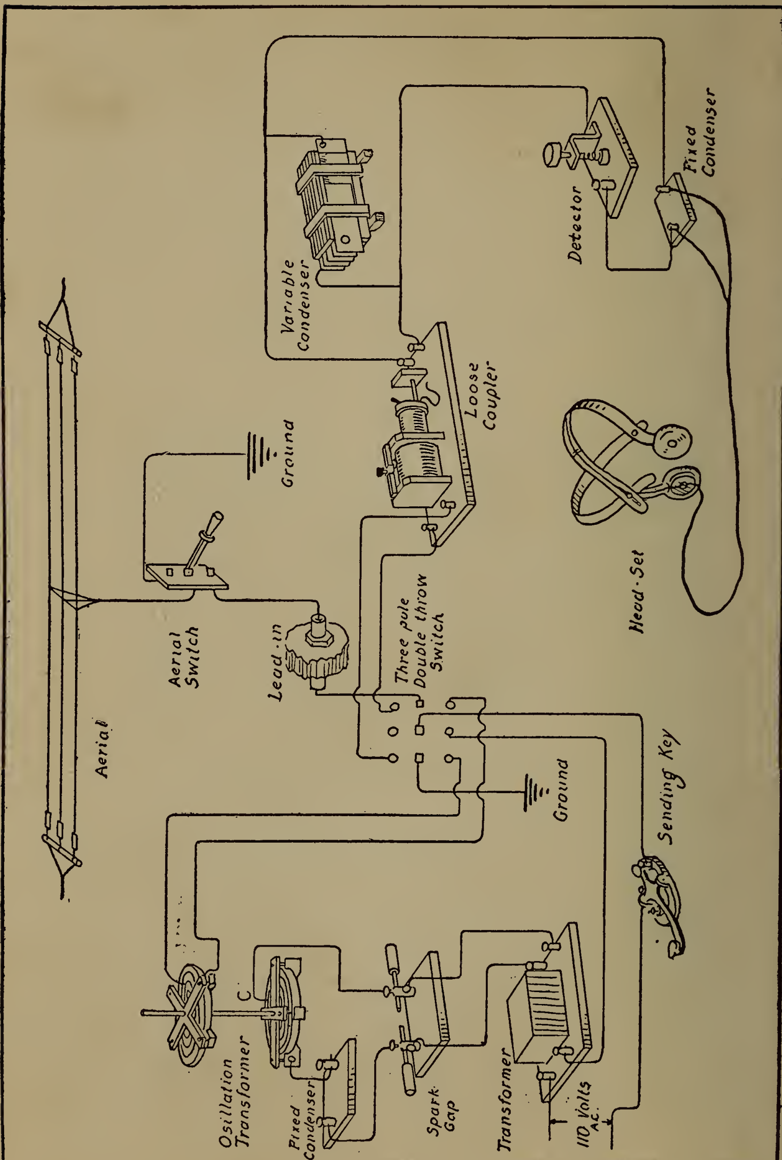


Fig. 228.—Connections for complete transmitting and receiving set.

coil and spark gap is a condenser and one side of the oscillation transformer. The other side is connected between the aërial and ground. For best results the clips *C* and *D* are moved until the strongest waves are secured.

For a tuned receiving station it is necessary to add an ordinary fixed condenser, a variable condenser, and a double slide tuner to the simple circuit shown. The fixed condenser is made of thin metal plates separated by insulating material or by air. The variable condenser must have a movable set of plates which can be moved in and out between the opposite plates, giving whatever capacity is needed. The tuner is simply a coil of wire arranged with two sliding contacts, so that any part of the coil desired may be included in the circuit. Proper adjustment of the tuner slides and the variable condenser enables you to hear plainly messages which could not be detected at all without the tuner. Like the transmitting apparatus, the receiving circuit may either be close coupled or loose coupled.

MAKING WIRELESS APPARATUS—THE AËRIAL

Every wireless station needs an aërial, or set of wires strung at a height above the station. They are doubly important, since they are used both for sending and receiving messages. It is quite necessary that they be clear of surrounding trees and buildings. By noting what a few other boys in your neighborhood are using you will see that there are several styles. This naturally raises a question as to which is the best for your use.

It cannot be said that any one is best in all cases. The kind to put up depends entirely on conditions. A few of the most popular kinds are illustrated in Fig.

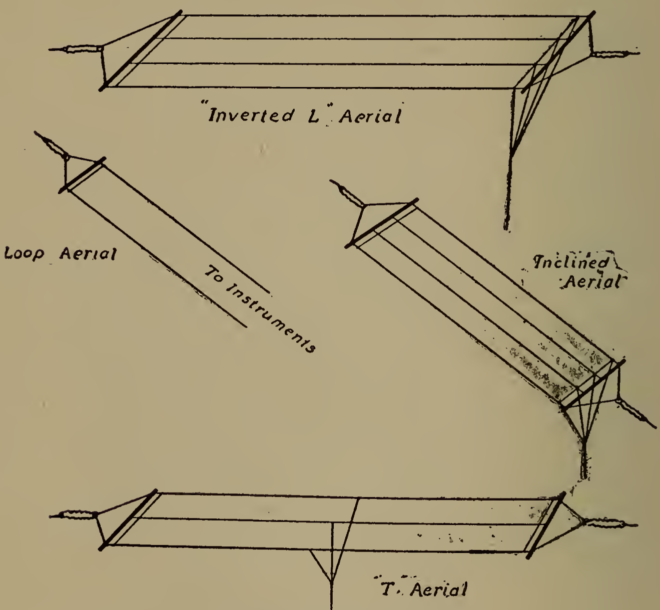


Fig. 229.—Types of aërials.

229, and each one has its special advantages. If only one support is available, either the loop or the inclined type should be used. For all-round work where two supports are to be had the "T" type is generally preferred. Under the same conditions some prefer the inverted "L" type.

As to the materials for aërial conductors; most amateurs prefer bare copper wire. In size this should not be smaller than No. 14 B. & S. gage. Aluminum wire can also be used and has the special advantage of very light weight combined with great strength. Iron wire is not good for the purpose as it greatly decreases the sensitiveness of the set.

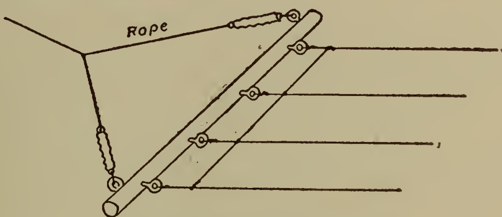


Fig. 230.—Aërial spreader.

In picking a site for the aërial and buying wire it is well to provide for a span of at least 50 feet. Even longer is preferable. The location is governed entirely by circumstances. Two convenient roofs are often used. Some boys string the wires in an attic. Where

Fig. 231.—Aërial strain insulator.

room can be spared in a back yard or vacant lot it is a good plan to set up two strong wooden or iron masts properly stayed. Iron is about as cheap and much easier to handle than wood, since the different sizes can be screwed together with reducers to make a pole any length and size you want.

At each end of the aërial wires there must be a wooden "spreader." These spreaders can be made of wood $1\frac{1}{2}$ inch thick, each piece being cut 3 to 4 feet long. Near each end of the spreaders put in a heavy screw-eye. Opposite to these and spaced equally put in four slightly lighter. The two heavy screw-eyes receive the supporting ropes; the lighter ones support the aërial wires. Strain insulators can be attached either to the ropes that hold the spreaders or between the spreaders and the aërial wires. The latter is usually preferred. In this case eight strain insulators will be needed. They can be bought at a cost of from fifteen cents up.

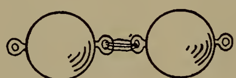


Fig. 232.—"Golf-ball" strain insulator.

If you like you can make very good insulators from old golf balls. In using these the first thing to do is to clean all the paint off, since it is a fairly good conductor. Next screw in two short heavy screw-eyes opposite each other. Care must be taken that they do not meet in the middle. Then wire or heavy cord can be passed through the screw-eyes to fasten the balls together. An insulator of this kind is shown in Fig. 232.

Assuming that the aërial is to be of the "T" type, the conductor which goes to the detector and spark gap will be fastened across the middle of all three wires. There are several ways of making the connector, which is called a "rat-tail." A very good scheme is to saw out a triangular piece of board $\frac{1}{4}$ inch thick and attach five good-sized binding-posts to it. Such an arrangement is illustrated in Fig. 233. The four top posts go to the wires of the aërial, and the bottom one to the transmitting and receiving station. All five posts should be connected with copper strips, which should be screwed tightly under the posts.

Having attached the rat-tail to the wires and the strain insulators and rope to the spars, they can be

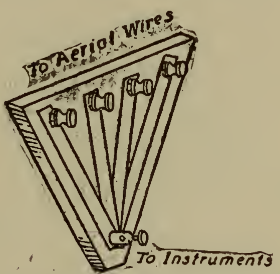


Fig. 233.—An efficient rat-tail.

raised and the aërial stretched. No matter what type of aërial is used, pulleys should be provided for raising it in place. Do not make the mistake some boys do of tying the aërial fast to the poles and then raising them, as it may be necessary at any time to let down the wires for repairs. A "kink" which will save time and temper is to put a large screw-eye bolt below each pulley. This will guide the rope and keep it from jumping out of place and catching while the wires are being raised or lowered.

The aërial conductors should always be kept quite taut and stretched evenly. The leading-in wire which extends from the rat-tail to the spark gap should be well insulated and should pass through a heavy porcelain tube where it enters the house or workshop. Of course, such insulators can be bought, but you can make a very good one with little trouble or expense. First secure a fibre tube at least an inch in diameter and 6 inches long. Then get a brass or copper rod 4 inches longer and fasten a binding-post on each end.

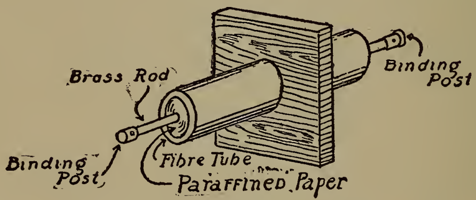


Fig. 234.—This lead-in is substantial and easily made.

Around this rod wrap paraffined paper until you can just squeeze the roll in the tube. Then heat the whole thing; add a little more paraffin if necessary, and the insulator is complete. For convenience it can be mounted on a board as shown in Fig. 234. One binding-post then is connected to the aërial outside the house, and the other to the set in the house.

As to the location for your transmitting and receiving apparatus; it will be hard to find a better place than a good dry basement. Here a fine ground on the water pipe is nearly always handy, you are out of the way, and you can have your workshop handy. A good ground connection on a convenient pipe may be made as illustrated on page 220.

HOW TO FIGURE THE NATURAL WAVE LENGTH OF YOUR AËRIAL

The waves sent out and received to advantage by the aërial you put up will depend to some extent on the length of the wires and their height from the ground. Every aërial has naturally a particular length of wave. This is called its "natural" wave length. In a simple system it is very nearly four and one-half times the length of the aërial plus the distance to the ground. With tuners and condensers the natural wave length becomes longer—it is then nearly 4.7 times the sum of the two lengths given.

As an example, suppose that your aërial is 50 feet long and raised 40 feet in the air. The natural wave length would then be

$$(50 + 40) \times 4.7 = 90 \times 4.7 = 423 \text{ feet.}$$

To change feet into meters divide by 3.28.

$$423 \div 3.28 = 128.9 \text{ or, practically, } 129 \text{ meters.}$$

This is for figuring an inverted "L" aërial or an inclined aërial, where the rat-tail is at the end of the wires. In a "T" aërial, with the rat-tail in the center, add in only half the length of the stretched wires.

The natural wave length of any type is made considerably longer in the tuning process by use of the double slide tuner or loose coupler in receiving, and the helix or oscillation transformer in transmitting. It will be well to remember that the wave length cannot be increased very much in sending. Present United States wireless laws are quite strict, and will not allow

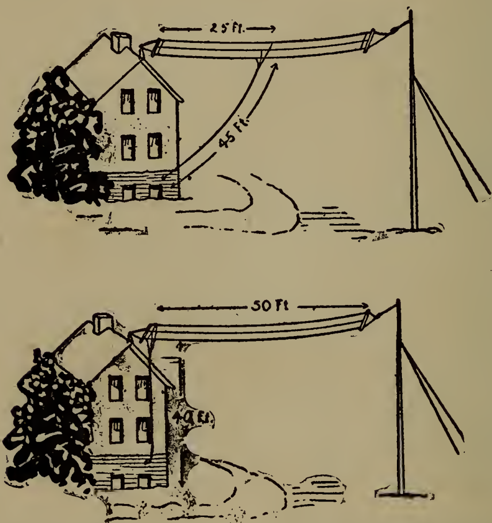


Fig. 235.—Measuring "inverted L" and "T" aërials for natural wave length.

you to send waves over 200 meters long, although you can, of course, receive waves practically any length.

A SIMPLE DETECTOR

The first piece of wireless apparatus made should be your detector. The fact that it is so simple makes it a good piece to start on. The main things needed are a short piece of $\frac{1}{4}$-inch brass tubing, a piece of galena, two binding-posts, and a rubber knob of the sort used on a typewriter carriage. In the knob fix a piece of brass wire about 1 inch long and small enough to pass through a hole in the binding-post. Mount this post at the edge of a board base $2\frac{1}{2}$ inches square. Break a chip of galena off and fit it in the little brass tube. Then fasten the tube upright at the opposite edge of the base. A piece of wire should be soldered to the

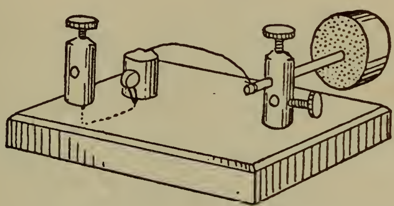


Fig. 236.—"Cat whisker" detector.

tube and brought to a second binding-post for convenience as shown in Fig. 236.

The "cat whisker" that gives this detector its name should now be fixed. As the word indicates, the wire of a "cat whisker" is very fine. It should be phosphor-bronze either No. 30 or No. 32. Solder one end of it with a small drop of solder to the end of the brass rod. Then bend the other end until it strikes about the middle of the crystal of galena. The pressure of this wire on the crystal can now be regulated by turning the rubber knob. When the best point is reached the adjustment is held by tightening the little brass screw in the top of the post.

The important thing in the detector is to have a very delicate contact. This may be secured in a number of ways with many different materials. A detector from which good results may be had can even be built from two safety razor blades with a piece of lead from a pencil, or, better still, several pieces of carbon filament

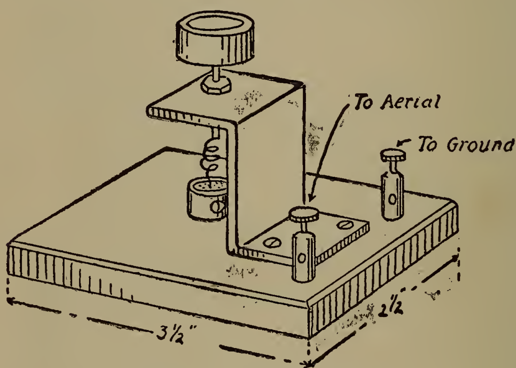


Fig. 237.—Silicon detector.

from an incandescent lamp stretched between them. This is a simple form of the microphone which has already been described.

A very common and substantial detector may be made by bending a piece of strap brass in the shape illustrated by Fig. 237, and mounting this with a suitable screw adjustor and a piece of fused silicon. Here the fine wire is coiled in a delicate little spring. The regulation is very close; also the tip of the wire strikes points all over the top of the mineral, so that the most sensitive point can be picked out. In making this detector the brass cup should be filled with melted

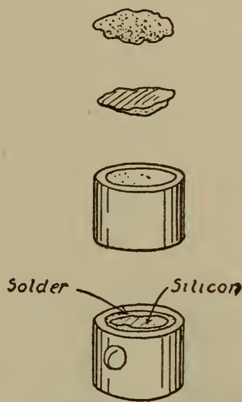


Fig. 238.—Cup of silicon detector.

solder, and a thin piece of silicon ground flat and pressed down in the hot solder. The appearance of both parts finished up are shown in Fig. 238.

DOUBLE-SLIDE TUNER

When you add a double-slide tuner to your aërial, detector, and telephone receiver you have all the apparatus that is absolutely necessary for receiving messages. The tuner not only increases the loudness of the signals, but allows you to get rid of some disturbances from waves you do not want to hear.

To make this tuner, first secure two brass rods each $\frac{1}{4}$ inch square and 8 inches long. Through both ends of each should be bored a $\frac{1}{16}$-inch hole for a wood screw. About 200 feet of No. 22 enamel-covered wire will also be needed for the winding.

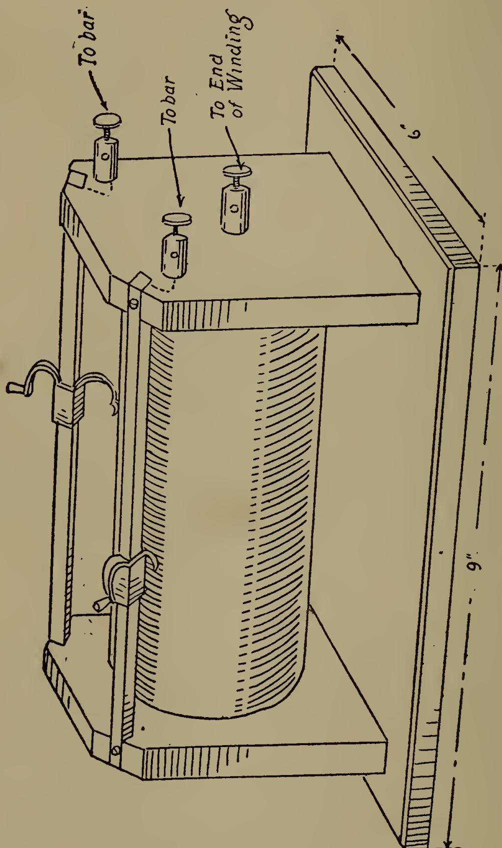


Fig. 239.—Double-slide tuner.

From a piece of bristol board or several layers of heavy paper coated with good glue roll a tube 3 inches in diameter and 7 inches long. This should be made quite stiff. When the glue is dry, paint it with two coats of shellac, letting it dry thoroughly; then bake it for several hours in a fairly warm oven. This will prevent shrinking and loose coils later. Now wind the wire on evenly and smoothly, fastening each end by

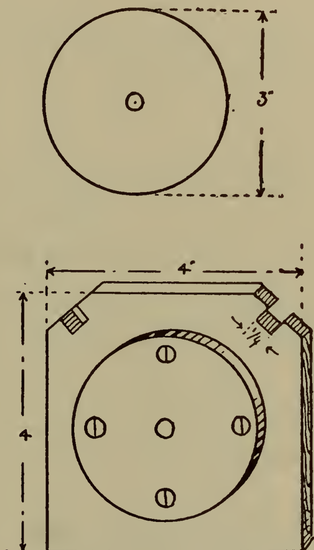


Fig. 240.—Ends for tuner.

passing it several times through the cardboard center. It is well to shellac the finished winding once more.

Winding and bars can now be mounted on a base. For this part cut a board 5 by 9 inches. Cut two ends each 4 by 4 inches. Trim off the corners and mortise to hold the slider bars. Two additional circular pieces will be needed for attaching the cylinder. These must just fit inside the tube and are to be screwed inside the end pieces. The tube can be fastened in place later with small tacks. Only one fixed connection with the wire is made. One of the ends of the wire coil should be attached to a binding-post set in the middle of one end piece. The two other binding-posts may be placed on either end piece near the mortises which are to hold the bars.

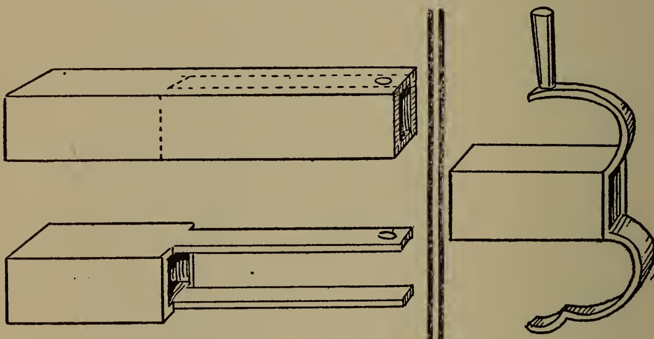


Fig. 241.—A slider that is easy to make.

For the two sliders a piece of square tubing that will just fit nicely over the $\frac{1}{4}$-inch rod will be needed. A piece 3 inches long will make both sliders. The common trouble of fitting handles is avoided if the scheme indicated in Fig. 241 is followed out. Any little wooden or rubber handle can then be used and easily screwed or riveted in place without interfering with the smooth movement of the slider.

Before screwing the bars in place note where the sliding contact will touch the wire. Then along these two lines scrape clear paths in the insulation. Be very careful not to cut or dent the wire or to take away the insulation from between the turns.

With the bars in place one of the binding-posts should be connected to each by a stout piece of wire or copper strip. This completes the instrument. For finish, two coats of shellac should be applied to the wood work.

A LOOSE COUPLER THAT YOU CAN BUILD

If you have been receiving with a double-slide tuner in the circuit, you will be surprised to see how much better results a loose coupler like the one in Fig. 242 will give you. For this eight pieces of wood cut to size will be needed. The dimensions of the base are indicated in the drawing. Instead of one stiff paper or bristol-board cylinder two will be needed. One of these should be 4 inches long and $2\frac{1}{4}$ inches in diameter; the other $3\frac{3}{4}$ inches long and 2 inches in diameter. The larger tube should be fixed in place between the two end pieces. To do this fit one end with a disc of thin wood and tack the cardboard to it. Then fasten the wood with screws to the thicker end piece. For the other end cut a circular hole in the second end piece and fit the cardboard tube inside it. Gluing this end is easier than tacking and answers as well. Now wind the tube from end to end with a layer of No. 22 single silk-covered or enameled wire. One end of this at-

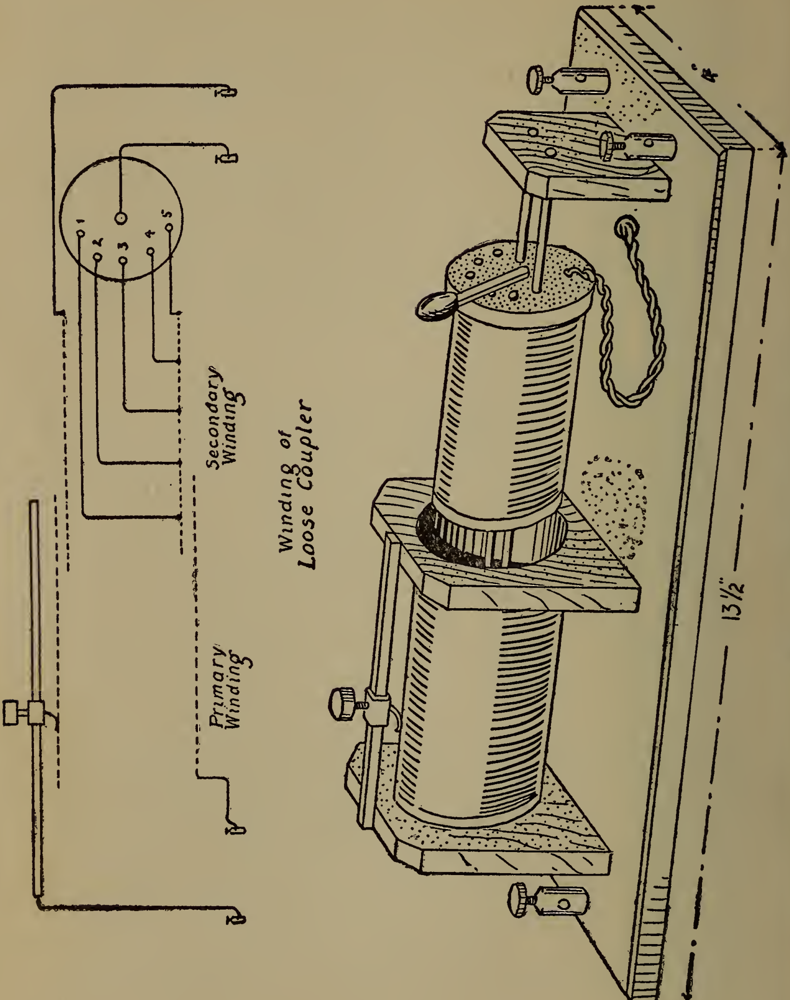


Fig. 242.—Finished loose coupler.

taches to one binding-post. The outer end is simply fastened by passing it through pinholes in the cardboard. The remaining post is, of course, attached to the end of the single-slide bar. For the secondary No. 26 wire will be needed. Before winding this on, it will be necessary to fix the five switch points in the round wooden piece that makes the head. Five of the points will be needed. They can be made from flat-headed brass machine screws. The switch can be made from a flat strip of brass and provided with a hard wood or rubber handle. The inside connections for this sliding secondary are shown plainly in Fig. 242. After the coil is finished and the connections made, a round wooden piece must be inserted in the other end of the tube to act as a guide. Two holes in this piece and the piece holding the five-point switch permit the brass rods to pass through so that the coil is easily slid in and out of the larger fixed coil without touching anywhere. A piece of lamp cord connected to the two secondary binding-posts and passing through a hole in the wooden coil head connects to the switch and one end of the coil.

In using this tuner the number of turns in the primary is regulated by working the little brass slider. Current in these turns induces current in the turns of the smaller secondary. The secondary can be slid in and out, and the number of turns changed with the five-point switch. Very fine regulation is possible, as the switch and the double slide arrangement allows you to change the inductance to practically any value.

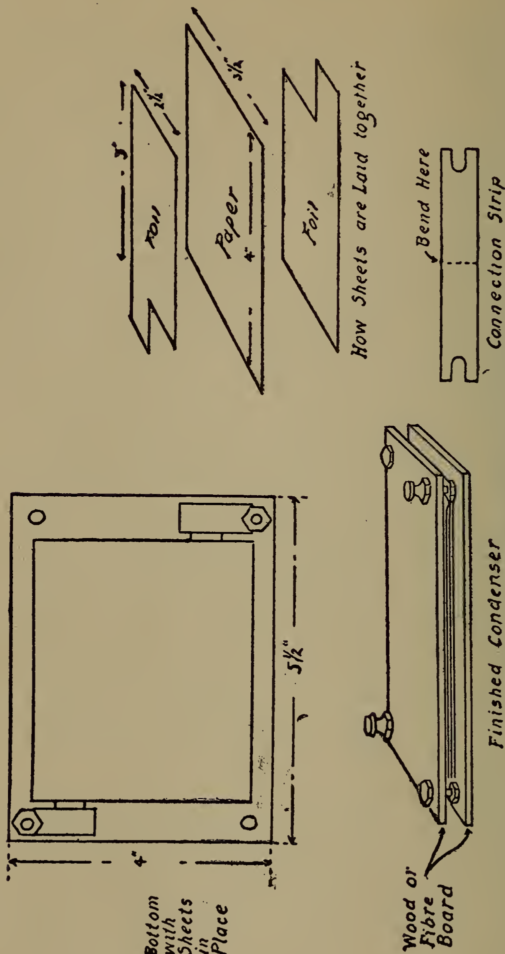


Fig. 243.—Fixed condenser for receiving set.

FIXED CONDENSER FOR RECEIVING

You can build a good condenser for this purpose from paraffined paper and tin-foil sheets. Twenty sheets of paper will be needed, each cut to 4 by $5\frac{1}{2}$ inches. Nineteen sheets of tin-foil each $2\frac{1}{2}$ by 3 inches make up the metal part. Between each tin-foil sheet is a sheet of waxed paper, and half of the tin-foil leaves stick out a distance of $\frac{1}{2}$ inch at each end. For top and bottom cover secure two pieces of hard rubber, wood, or fibre board 4 by $5\frac{1}{2}$ inches. Bore a $\frac{1}{8}$-inch hole near each corner. These are for connectors and also to hold the condenser together. Two connecting strips should be cut from thin sheet brass or copper. They should be bent over the tin-foil ears and held under the connecting screws. Small binding-posts, such as are used on dry batteries, will answer for connections and for holding the plates together. The connecting strips are clamped under the washers at two corners, making firm connections with the sets of tin-foil sheets. When the condenser is mounted tie a piece of tape around the edge. Cut one hole for pouring and another to let the air out, and fill with melted paraffin. About the same result is secured if the sheets are rolled instead of being laid flat and the whole thing bound with rubber bands and inserted in a fibre tube. Wooden plugs at each end close the tube tightly and also allow the binding-posts to be fastened on.

VARIABLE CONDENSER

This is not an absolute necessity and is omitted from many good receiving sets. Still it is not hard to make and will sometimes help considerably in getting satisfactory tuning. It can be made from six ordinary 5 by 7 inch photographic plates and two sets of metal

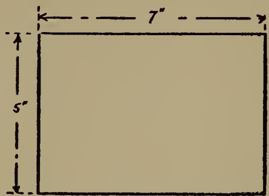


Fig. 244.—Glass plate for condenser.

plates, all held in a plainly made wood frame. The first thing to do is to clean the plates well and fasten them all together with little wood spacers between. These spacers may be held in place by a good china

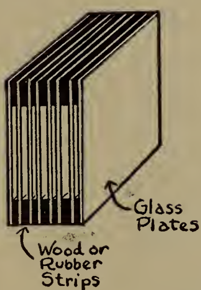


Fig. 245.—Glass plates assembled with separating strips between.

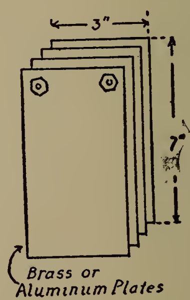


Fig. 246.—Set of metal plates.

cement. Half of them should be very thin, and the other half of the number a little thicker, as shown in Fig. 245, but all should be the same length and width.

The stationary plates will then be held in the narrow spaces, and the sliding plates in the wider ones. If both plates are to slide, all the spacers can be made exactly alike.

The next thing is to make up two sets of plates from thin brass or aluminum, each plate being cut to about

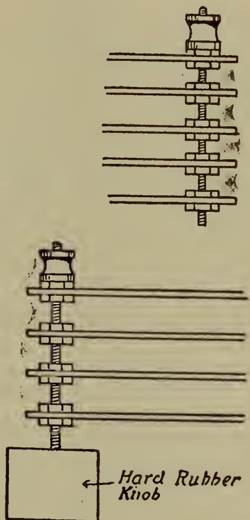


Fig. 247.—How plates are assembled.

3 by 7 inches so that it will slide in between a pair of the glass plates. For this condenser nine plates should be cut, all alike. Four plates go to make up the sliding set and five to make up the stationary set or vice versa. The plates in a set should be held together at two corners only by long threaded bolts, with each plate gripped between two nuts. This scheme of fastening is indi-

cated in Fig. 247. The frame is built plainly as shown in Fig. 248.

The metal plates are slipped in place between the glass separators from the two ends. A sheet of glass is now between each plate of one set and the nearest

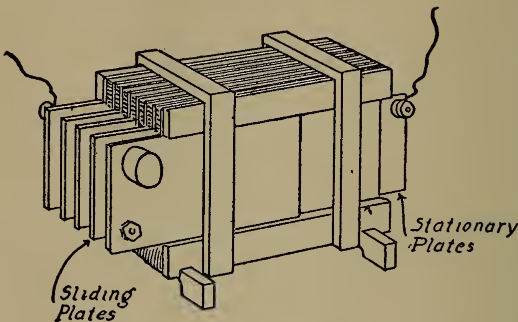


Fig. 248.—Variable condenser.

plate of the other set. By sliding the movable set of plates in and out by means of a rubber handle which can be easily attached you have practically any capacity you need for tuning.

TELEPHONE HEAD SET

The sensitive receivers needed can hardly be made by the amateur. They can be purchased one at a time and later connected together, or the whole set can be bought complete. While the 75-ohm sets are a good deal cheaper than the 1000-ohm receivers, they are not by any means as delicate. The greater sensi-

Fig. 249.—Wireless head set.

tiveness of the higher resistance is worth a good deal in increased clearness of signals.

INSTRUMENTS FOR TRANSMITTING—INDUCTION-COIL

The thin spark of the ordinary induction-coil does not give as good a range as those made especially for the purpose. The spark of these special wireless coils is much "fatter." Heavier wire is generally used in the winding of the secondary coil.

One authority gives this general rule for building wireless spark coils: Use $1\frac{1}{2}$ pound of No. 32 wire on the secondary for each inch of spark up to 6 inches; then allow 2 pounds to the inch. For the primary use two layers of wire according to the following table:

TABLE FOR INDUCTION-COILS

Core diameter. (Inches.)	Core length. (Inches.)	Spark length. (Inches.)	Primary wire.
½	6	½ to 1	No. 16
¾	8	1 to 2	No. 15
⅞	9	2 to 4	No. 14
1	10	4 to 8	No. 13
1⅛	12	8 to 12	No. 12

While it is really an economy to buy a good wireless coil if one is to be used, this table is given for boys who want to try their hand in making up their own.

TRANSMITTING KEY

The ordinary telegraph key does very well with a small set. When you send to your chum four or five miles or even further away you will need something better able to stand sparking. Special wireless keys are

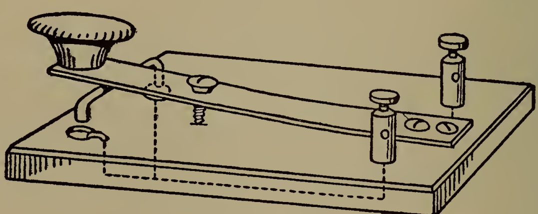


Fig. 250.—Sending key for heavy current.

made, but you can easily build a serviceable one yourself. Take a strip of spring brass like the one shown in Fig. 250 and solder a wide U-shaped piece of copper or brass wire to one end. Drill four holes in the strip; two at one end, for the screws that hold it to the base; one at the other for the knob, and the fourth about in the middle for a screw which limits the up-stroke of the key. A bit of $\frac{3}{8}$-inch hard wood 3 by 4 inches will answer for the base. Before finally putting the spring in place find exactly where the wire tips will come when the spring is down. Bore a $\frac{1}{4}$-inch hole about half-way through the base at each of these points. Run a copper wire from a single binding-post to both of the holes. Connect the second post to the base of the spring. Place a drop of mercury in each hole and the key is complete. Contact between the mercury and wire is always good, and the mercury is easily renewed.

THE HELIX

Here is the simplest device for tuning a transmitting set. It consists of a heavy copper or aluminum wire wound on a four-post wooden frame, as shown in Fig. 226. One end is brought up to a binding-post; the other is simply made fast to the frame. The binding-post can then be connected to the aërial. The other connection is made by means of a metal clip which can be fastened to the coil at any point. This coil puts inductance in the circuit and increases the wave length. When sending, the helix clip is adjusted until the best radiation is secured. Ordinarily this point is found with a little instrument called the "hot-wire ammeter." Sometimes good results can be secured with a little incandescent lamp connected in series with the aërial. When the lamp burns brightest the radiation is most powerful.

A somewhat more compact helix than the kind described above can be made by winding a coil of copper strip in a flat frame. Such a frame can be made

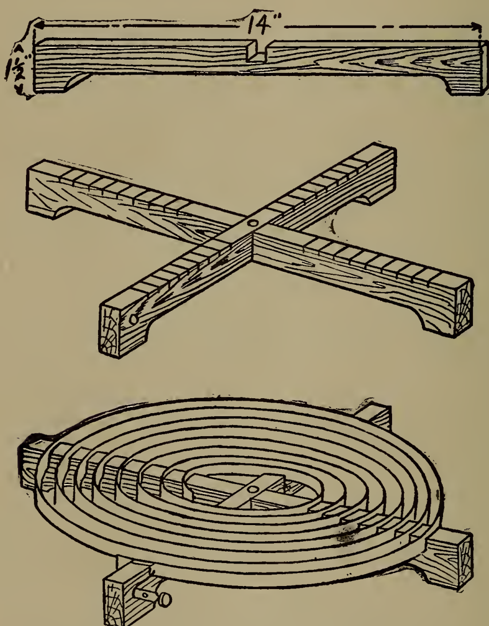


Fig. 251.—Helix for tuning transmitting set.

from two ½-inch boards each 14 inches long. These serve both as a base and a support for the coil. The metal ribbon is held in slots cut with a fine saw. In cutting these begin 2 inches from the center and space the cuts ½ inch apart. About 50 feet of the strip will be needed. Put one end of it in a slot nearest the center and wind out, keeping the turns well rounded. A helix with crooked bends makes a poor looking job. As you go along pound each turn down into the slots

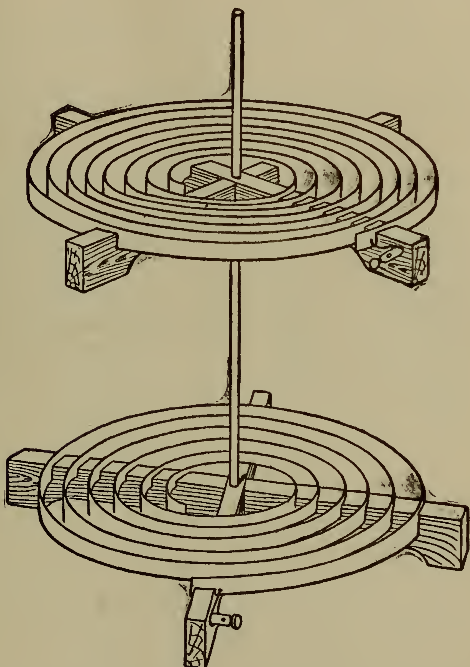


Fig. 252.—Oscillation transformer for closer tuning.

with a wooden mallet. At the end of one of the arms of the base set in a binding-post. Solder a connecting strip to it and the end of the helix. It is ready to work, but you can make a really fine looking job of it by painting the woodwork over with a coat of lampblack and then shellacking and polishing it. This will give a finish like hard rubber.

Still better tuning is possible with an oscillation transformer. This is simply two helix coils that can be set at any distance from one another. The brass rod which supports the upper coil should be a fairly tight fit in it. Then the coil will slide back and forth, but will stay where you put it.

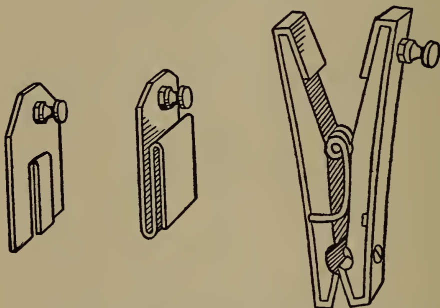


Fig. 253.—Easily made helix clips.

Helix clips for connecting the aërial and spark-gap leads to the coil are easily made. A brass strip can be bent to grip the metal strip tightly, or a spring clothes-pin can be fitted with a copper grip and a binding-post for connection. A few forms of clip are illustrated in Fig. 253.

A GLASS PLATE CONDENSER

A good condenser makes a wonderful difference in the quality of your work. One can be made from a few

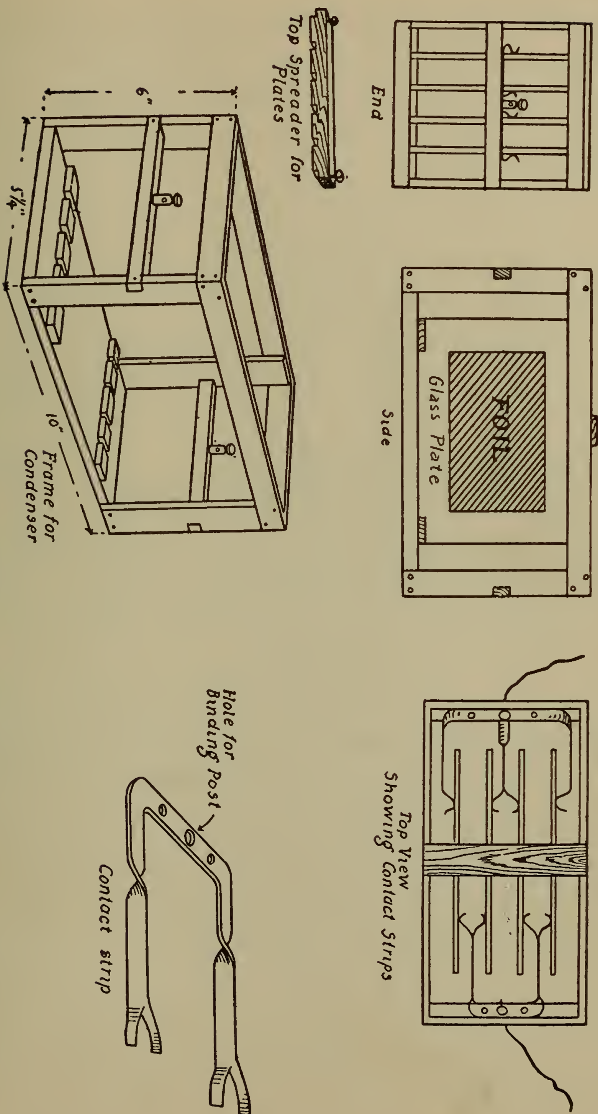


Fig. 254.—Condenser for transmitting set.

photographic plates and some tin-foil that will answer all purposes. Old plates can be secured from any photographer. Clean the gelatin off thoroughly. Then shellac one side of all four plates and carefully put a square of tin-foil 2 by 4 inches exactly in the center of each. Let it dry in place. When thoroughly hard, put tin-foil squares on the opposite side in the same way.

Now build a frame as open as possible, but substantial. Fix two slotted pieces in the bottom to hold the plates an inch apart, and a third one to space them at

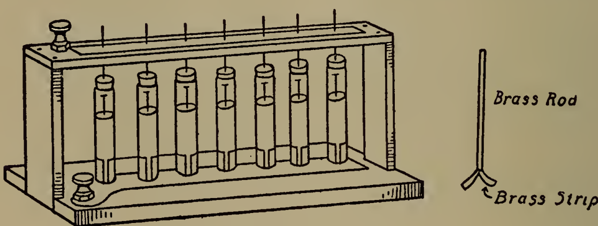


Fig. 255.—Test-tube condenser.

the top. Both of these should be well paraffined. On the cross-pieces at the ends fix the two binding-posts. Brass strips bent to shape and held under these make the contact with the tin-foil. The post at one end should connect with the inside foil of the two middle plates and the outside of the two outer ones. The other post then connects with the inside of the outer plates and the outside of the middle ones. More plates or less can be used according to the character of aërial and spark.

Another form of condenser may be made from test-tubes. One of this sort is shown in Fig. 255.

The *transformer* is a little beyond the scope of the amateur. It is better to buy a standard make of wireless transformer if one is to be used. Such a transformer is shown in Fig. 256.

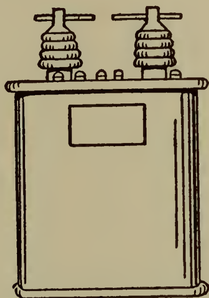


Fig. 256.—Transformer used for wireless.

SPARK-GAP

After a little experience with good and bad spark-gaps you will find this little piece of apparatus quite important. For one of the simplest types, and one that gives good results, zinc rods are used. A zinc spark-gap is quite easy to make. All that is needed is two zinc rods and two large brass binding-posts in which the rods can be clamped firmly. If desired, sealing-wax handles can be added. When the posts are solidly mounted on a little wooden base the gap is ready for use. The length of spark can be easily adjusted so that it gives best results.

When you connect your set, try to see how neatly and not how quickly you can place the different pieces

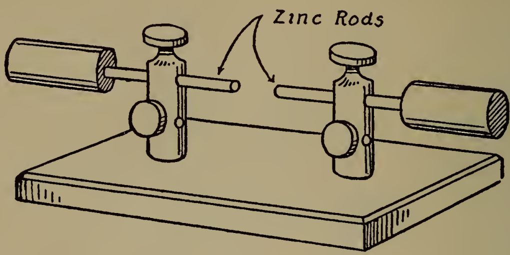


Fig. 257.—Zinc spark-gap.

of apparatus. Here are a few tips for connecting the transmitting set. Use copper strips for connections

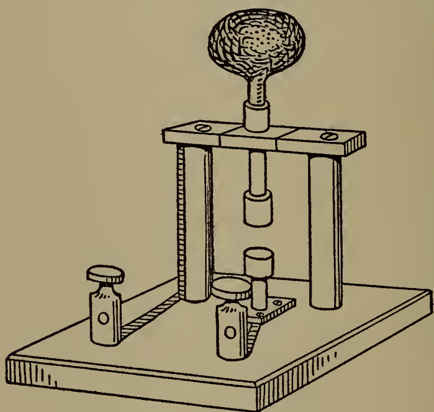


Fig. 258.—Vertical spark-gap.

instead of bell wire; run the conductors parallel and as far apart as possible; make all joints at right angles and solder every joint carefully.

Every boy who is going to put in a set should first find out about the "Radio" club in his neighborhood. Pointers from other boys with a little experience often saves trouble and embarrassment later. The United States Radio inspectors are quite particular about badly tuned waves, especially as they approach the 200-meter limit. In order that all amateurs may enjoy the use of their sets it is necessary that each one should avoid disturbance, fake distress calls, and so on.

THE BUZZER TEST

The buzzer test is not hard to arrange, and it gives you a sure indication that your detector is properly adjusted. All the additional material that you need is a dry cell or two, a small buzzer, and the necessary wire. The buzzer has to be wired in so that it works when you press a key or push-button. Of course, you could send messages to yourself with this buzzer arrangement just as you could with a Morse key and sounder, except that the clicks would be replaced by buzzes. With the test the point is to fix the buzzer so that you cannot hear it except through the telephone receiver. This can be done either by putting the buzzer away in some other room, or by mounting it in a little box with cotton wrapped around it.

The buzzer is connected in according to Fig. 259. Two or three loops in the buzzer circuit wire go inside a single loop in the ground wire of the receiving set.

The detector is connected as usual. For the test you simply send signals with the buzzer button or key and listen through the telephone receiver. The oscillations started by the buzzer induce slight currents in the

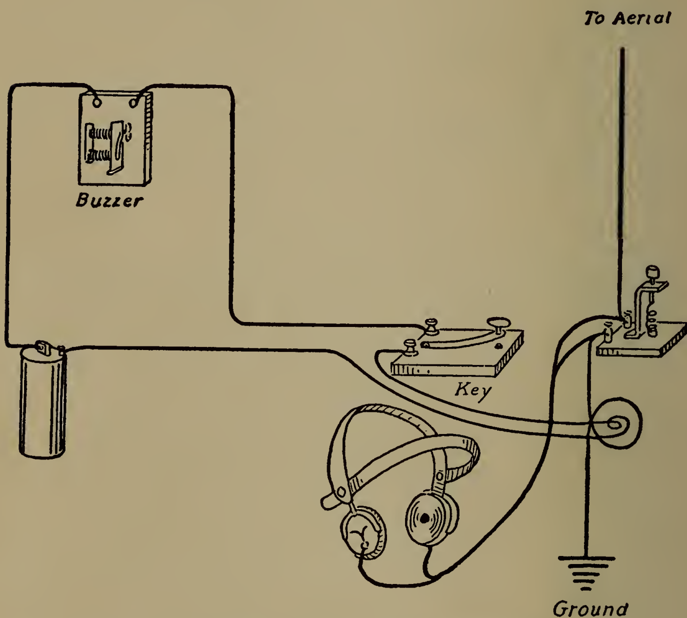


Fig. 259.—Buzzer connected to test detector adjustment.

aërial circuit. When the signals are heard plainly you may know that your detector is properly adjusted.

When good results are secured you are ready to receive. For this the next step is to set the loose coupler or double-slide tuner to a point where some

INTERNATIONAL MORSE CODE

1. **A dash is equal to three dots.**
2. **The space between parts of the same letter is equal to one dot.**
3. **The space between two letters is equal to three dots.**
4. **The space between two words is equal to five dots.**

A	• —	**S**	• • •
B	— • • •	**T**	—
C	— • — •	**U**	• • —
D	— • •	**V**	• • • —
E	•	**W**	• — —
F	• • — •	**X**	— • • —
G	— — •	**Y**	— • — —
H	• • • •	**Z**	— — • •
I	• •	**1**	• — — — —
J	• — — —	**2**	• • — — —
K	— • —	**3**	• • • — —
L	• — • •	**4**	• • • • —
M	— —	**5**	• • • • •
N	— •	**6**	— • • • •
O	— — —	**7**	— — • • •
P	• — — •	**8**	— — — • •
Q	— — • —	**9**	— — — — •
R	• — •	**0**	— — — — —

Fig. 260.—International Morse code.

message is heard plainly. Then finer adjustment is secured by regulating the variable condenser.

A FEW WIRELESS STUNTS

Although the common method of receiving wireless messages is with the telephone head-set, another method is possible. For this a device called the "coherer" is needed. It is used with a relay and an ordinary telegraph sounder. Both are described in Chapter X.

The coherer was the first instrument to receive messages. It is so simple that you can easily make one.

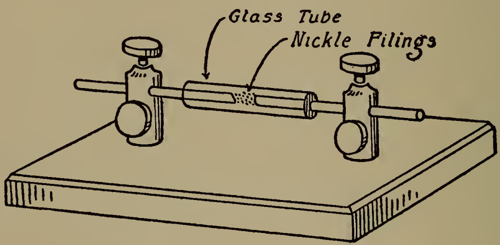


Fig. 261.—Coherer.

All there is to it is a pinch of nickel filings and a much smaller amount of silver filings. These are enclosed in a tube of glass or any good insulating material. The little pile of filings is held in the tube between two brass rods which fit the tube quite closely.

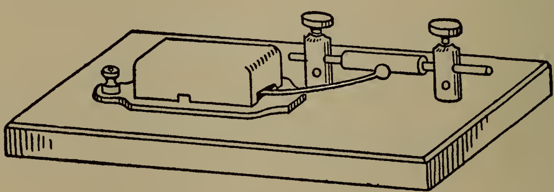


Fig. 262.—Coherer and tapper.

Filings in such a loose heap hardly conduct electricity at all under ordinary conditions. Just as soon as an electromagnetic wave comes along through the ether

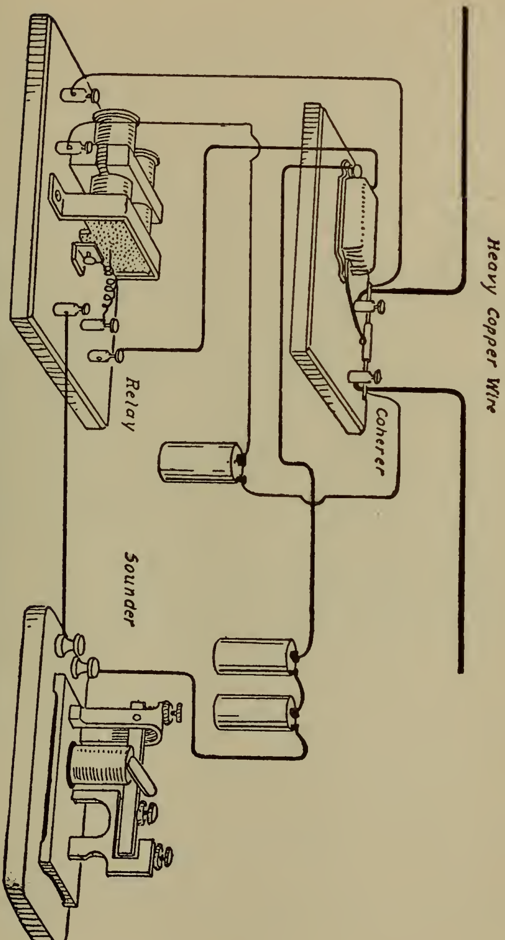


Fig. 263.—Connections for coherer, relay, and sounder.

there is a big difference. The filings at once become good conductors. If they fell apart again for the next wave the coherer would be very simple; but they do not act that way. After the wave passes they continue to stick together. An actual shock is needed to separate them. The little knock of an electric bell tapper does the business in good shape. The gong is removed and the bell connected so that there is a tap every time the filings cohere. The action is this: a wave passing allows a little current to work the relay; then the telegraph sounder is operated by the heavier local current. The same current works the tapper, so that the filings are jarred. With this arrangement you get about the same clicks as in an crdinary metallic telegraph circuit.

There are a lot of things you can do with a coherer. You can fire off a charge of flashlight powder in another room, ring a bell, light a lamp, or arrange connections for other stunts. A lot of ingenuity can be exercised in arranging electromagnets, switches, and batteries to do whatever you like by wireless control.

CHAPTER XIII

House Wiring

There is as much room for a display of skill in wiring a house for electric light as there is in building and operating a wireless set or a telephone line. Of course, wired houses are so common these days that few of us stop to think about how the wires were put in or just where they lie back of the wall. As simple as the wiring of a small house may look to you, it is likely that considerable thought was given to the wiring so that lights and switches would be just where they were wanted and the wire put in with the least possible material and labor. Any house that is to be wired deserves this consideration. Outlets for fixtures, floor lamps, flat-irons, and so on should be planned very carefully. Much credit is due to the boy who can not only plan the wiring of a house, but can also make a good job of running the wires.

After all it is not so hard to bring current from the electric line to your house if you plan and study the work carefully. Neither is it beyond a boy handy with tools to distribute the current so that it can be available where needed and safely controlled. If you live in the city you may not be allowed to do the work, but you can plan it anyway and see how your ideas work

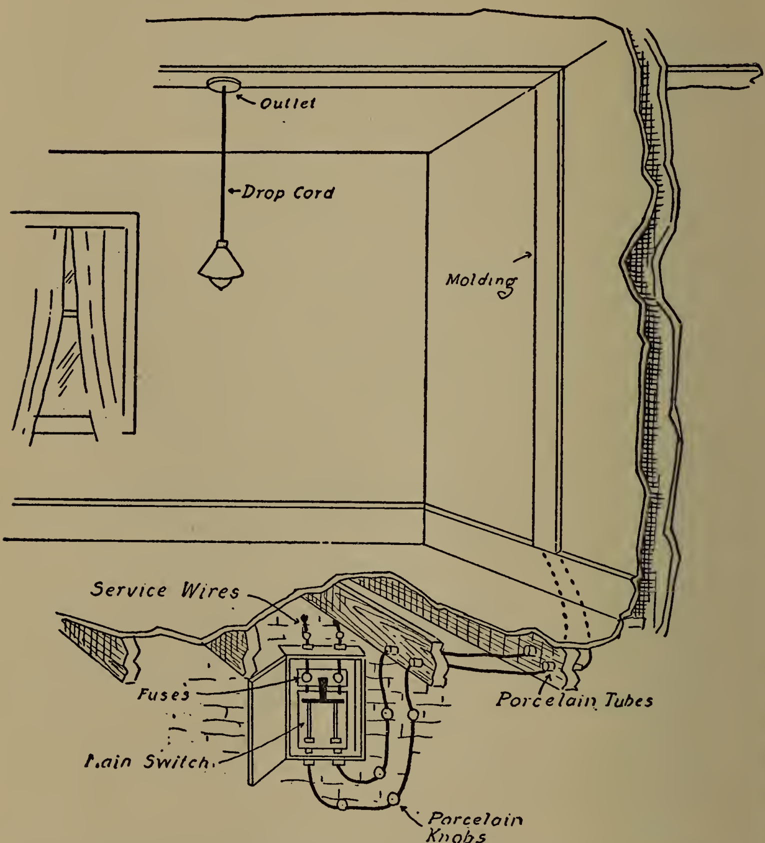


Fig. 264.—Room wired with molding. Floor broken away to show service switch.

out. If your home is in the country there is nothing to keep you from doing all the work yourself.

If you take the work into your own hands, there are two schemes for you to choose from. The first and easiest is to run the wiring in wooden molding along walls and ceilings, using porcelain tubes to carry wires through walls and floors. The other is to run the wiring between the ceiling and the floor above, carrying it back of the plaster on the walls. In this way you can do a better, more professional looking job than is possible with the wooden molding.

WIRING IN MOLDING

The wood molding used for this work is made in long flat strips of wood, each with a double groove running the full length. These strips fasten with long nails right to ceiling or wall. The wires are laid after the strips are in place and held in by a thin strip which acts as a cover. Particular attention must be given to getting molding on perfectly square and straight, as carelessness always shows up very plainly in a molding job.

Before starting on any wiring job it is well to find out just how much wire you are going to need and how much molding. To do this it is well to draw up a little plan of the house, and decide just where the circuits are to be run and the lights located. As an example, take a five-room cottage with two bedrooms, sitting-room, dining-room, and kitchen. There will be at least six outlets; that is, one for each room and one for the hall.

By "outlet" is meant the place where the current is brought out for use, whether it is to lamps, washing-machine, flat-iron, or anything else. All of the outlets in Fig. 265 are for lamps. The position of each one is indicated by a cross. After all outlets have been decided on, figure carefully all the runs of wire, up

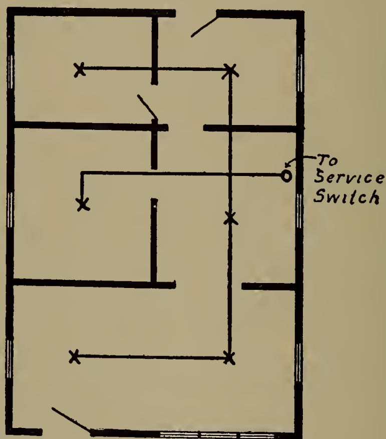


Fig. 265.—Plan of house with molding indicated by lines, and outlets by crosses.

walls, across ceilings, through floors, and so on; then add about 20 per cent. to your estimate.

Almost any kind of fixtures may be used with this style of wiring, but the ordinary drop light is by far the commonest. With the drop light a wood or porcelain rosette is usually fastened to the ceiling or on the molding where light is wanted, and the lamp simply hung by a flexible cord. Especial care must be taken where branch circuits are run, and all joints must be well soldered and taped. Switches can be put in where wanted and wired according to the scheme indicated in Fig. 273.

For running the circuits rubber-covered wire at least as large as No. 12 B. & S. gage should be used. All of

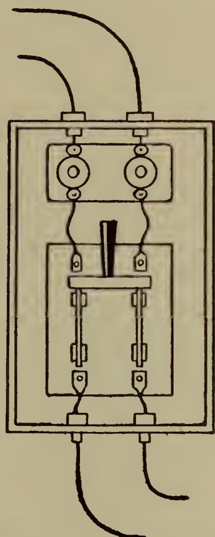


Fig. 266.—Service switch.

the circuits in the house must in some way be connected in multiple with the wires which run to the service box in the basement. This box can either be bought or made. It is simply a fire-proof case containing a double pole switch and fuses. If home-made it can be built by lining a good wooden box with asbestos. Such an arrangement is indicated in Fig. 266.

Remember these two points before you wire up your service box: first the wires from the power line should come to the fuses and not to the switch itself; second, the switch should be placed so that the handle is pulled down to open it. This is done to prevent the switch from accidentally "falling" shut. The two fuses simply protect the circuit. If too heavy a current flows for

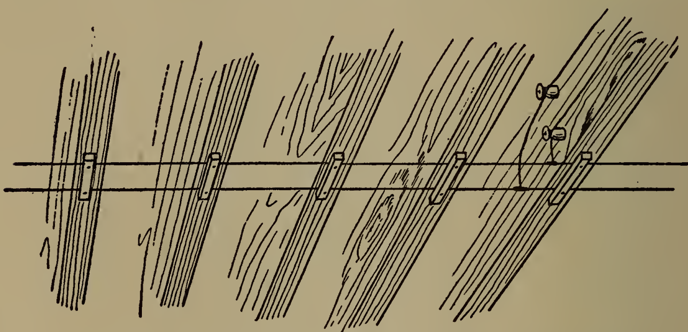


Fig. 267.—How cleats are attached to rafters in wiring barn.

any reason they will burn out instead of melting the wires.

Porcelain cleats provide even a simpler method of wiring, but are only used for barns, workshops, and so on. With this style of wiring practically the entire circuit is in view at all times, so that a fault can be very easily discovered.

CONCEALED KNOB AND TUBE WORK

A few boards will have to be taken up if you do concealed knob and tube wiring, but the workmanlike result that is secured more than pays for the extra trouble. For wiring the first floor a little sawing and cutting will have to be done on the floor boards of the second story. Parts of the baseboard will also need to be taken out. Wires for the second story can usually be put in the attic with very little work.

As the wires in knob and tube work run in the space between ceiling and floor they have to be carried along the floor joists on knobs, or passed through them in porcelain insulating tubes. In Fig. 268 a run of wires

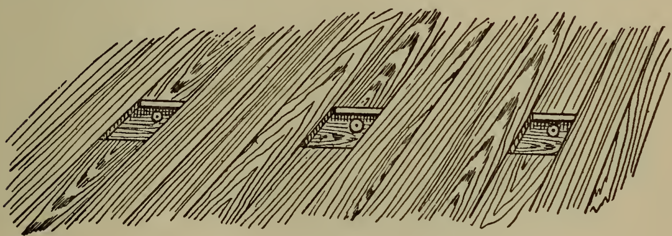


Fig. 268.—Knob work with pockets cut.

on knobs is illustrated, and in Fig. 269 the method is shown of carrying them in tubes. The knobs are usually held in place by wire nails. The tubes are simply forced into the holes that are drilled in the joists to receive them.

After the wiring has been planned in a general way the first step in running knob and tube work is to mark the plaster or wall-paper of each room for outlets and switches. Be careful to get the lighting outlets exactly in the middle of the room, or spaced evenly from the sides if there is to be more than one drop light or chandelier. After the outlet mark is made on the ceiling, bore from below with a long thin bit clear up through the floor of the room above. This will indicate where the first pocket is to be cut. By "pocket" is meant the cutting of a board to allow knobs to be put in place and the wires fished through. If the wires run along between two rafters it will not be necessary to take whole boards up, but only to cut a number of

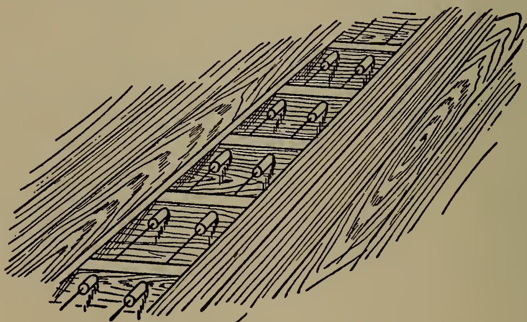


Fig. 269.—Floor removed to show tube wiring.

such pockets about $4\frac{1}{2}$ feet apart along the line. These pockets are illustrated in Fig. 268. In making them the floor boards should be sawed just as close to the rafters as possible. The position of the rafter should first be located as closely as possible by tapping on the floor. Then by boring a small hole and feeling with a piece of wire you can with a little practice tell exactly where the joint is. Use a thin keyhole saw for making the cuts. Nail the knobs about 2 inches below the floor.

When running tubes, holes should be bored through each rafter about 4 inches apart and just large enough to make a snug fit on the tube. Of course, each one will slant down a little, but the only effect of this will be to make the wire a little harder to pull. Some branches of the circuit will always have to run crosswise of the rafters in tubes, and along this path the whole board, or perhaps two, will need to be taken up, and each rafter bored in two places.

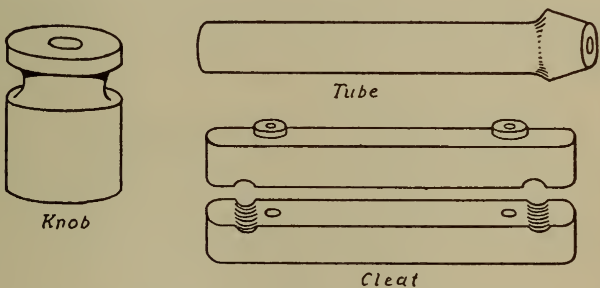


Fig. 270.—Insulators for knob and tube and cleat wiring.

After all the knobs and tubes are in place you are ready to go ahead with the actual wiring. The best way to start this is to lay your two coils of insulated wire on the floor near the point where the wires will run down to the service box. Take an end from each coil and run the two ends under the floor from pocket to pocket and through the tubes until the end of the circuit is reached. If there is to be an outlet at this point leave a few inches extra to connect on later.

Every one of the knobs must now be fastened onto the wire it is to carry. About the best way of doing this is with a hitch. To make the hitch simply tie a piece of insulated wire about 14 inches long around the knob and the main wire, twisting the ends around the wire as shown in Fig. 271.

With all wires properly joined and tied to the insulators, the ends of the coils that remain should be cut to about the proper length to reach the service box. These ends should then be protected by pulling them through lengths of circular loom or "Flexduct." This

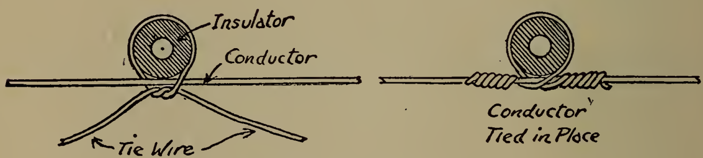


Fig. 271.—How to tie wire to knobs.

supplies the extra insulation that is needed on account of lack of insulators. A weight can then be tied to the wires and the ends dropped down behind the plaster to the service box.

In every job of wiring it is necessary to run branch circuits, which involves both splicing and soldering. All splices should be made very carefully, and the joints finished with good solder and a non-corrosive flux. This soldering should be done with a little blow torch or an alcohol lamp. Solder is most convenient in the form of solder "wire." While the joint is still hot from soldering it should be wrapped with rubber tape and then with friction tape. This makes the insulation practically the same as at the other points. Remember that neither the insulation nor the joint gets any better than it is right at first; it always gets worse as time goes on if not done thoroughly. When such a splice is made be careful that the two wires do not cross in such a way that the insulation may rub and cause a short circuit. It is always best to protect such a crossing with porcelain tubes strung along where necessary.

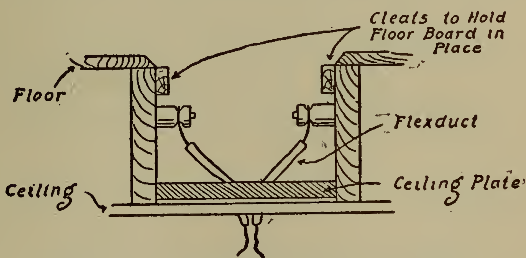


Fig. 272.—Ceiling plate in place at outlet.

At each outlet for properly installing fixtures later a piece of board at least $\frac{3}{4}$-inch thick should be set in between the rafters just above the plaster. This will provide a firm hold for the screws that support the lighting fixture. Care must be taken that the nails used to fasten this board in place do not slant downward too much and crack the plaster on the ceiling.

All of the suggestions given are for wiring a small home. In buildings of this kind it is usually considered that one outlet for a chandelier or drop light in the middle of each room is sufficient. If desired, however, a reading lamp can be added in the library, and other lights for decorative purposes can be supplied from baseboard outlets. In the dining-room floor outlets can be placed conveniently so that the electric toaster, electric coffee percolator, or chafing dish can be used on the table. For the kitchen the electric iron is a great

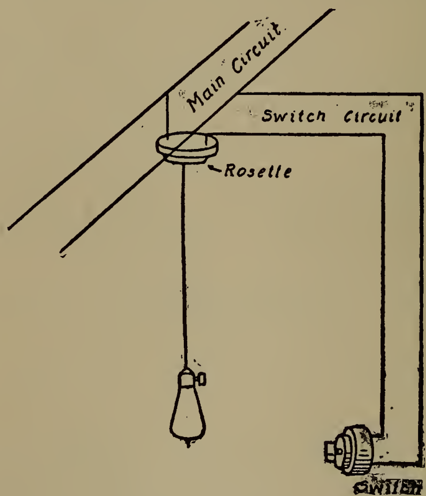


Fig. 273.—Connections for lamp and wall switch.

convenience. This device should take current from a wall or baseboard outlet, and not from the drop light cord. In the laundry two extra outlets, one for a flat-iron and the other for the washing-machine, are great helps.

In closets and pantry drop cords are generally used. Many fires are started by people who use matches in hunting for clothes, so you will be helping to make your home a great deal safer by adding electric lights in all the closets.

SWITCHES

In the library, dining room, and hall, at least, wall switches are quite a convenience. A snap switch or

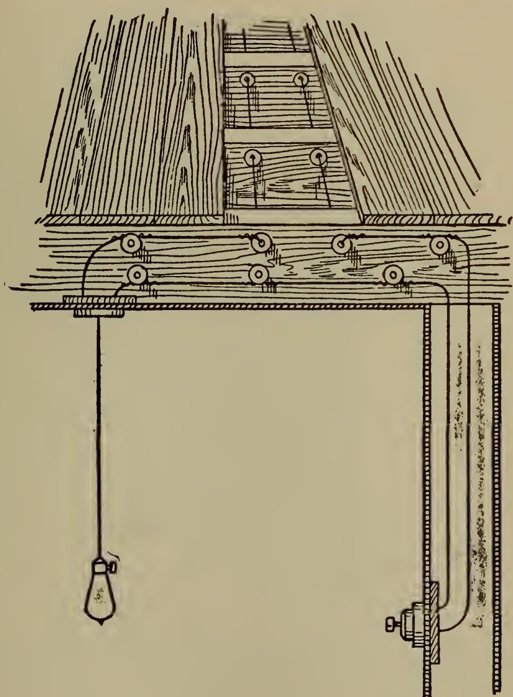


Fig. 274.—Lamp and wall switch installed.

push-button switch will save a lot of fumbling in the dark, and perhaps upsetting furniture while hunting for the light. Each of these switches means an extra run of wire from the fixture down the wall to the switch terminals. The method of connection is shown in Figs. 273 and 274.

Three-way switches are a little more complicated, but are fine for a front hall. With one of these switches

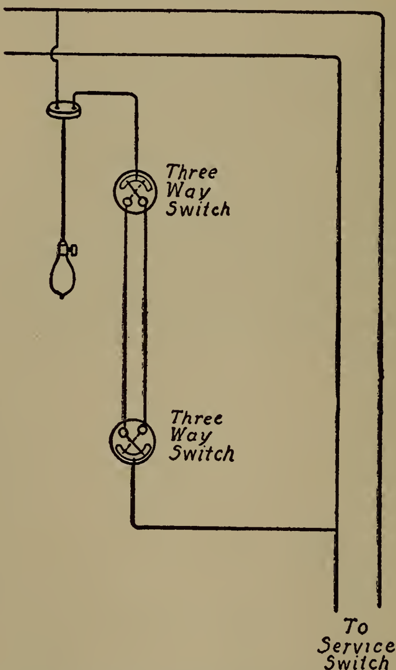


Fig. 275.—A light wired with two three-way switches can be turned on and off from either one.

wired in at the top of the stairs and another at the bottom you can turn the hall light on and off from either of the two switches. The wiring used is shown in Fig. 275. The switches are really wired in series, but are connected by two wires instead of one. When the light is off both of the wires are connected to the circuit, but there is not a complete circuit, since one wire is discon-

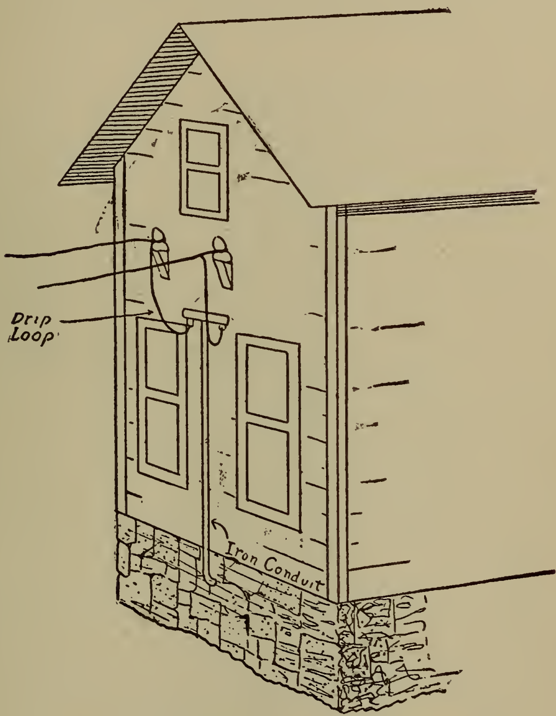


Fig. 276.—How wires are brought into house.

nected at one end and the other at the other end. Move either switch and one or the other of the wires is immediately disconnected, while the other completes the circuit and current flows through the lamp.

SERVICE WIRES

In bringing service wires from an electric line an iron conduit is generally used. This is attached to the side of the house as shown in Fig. 276. Insulators take the

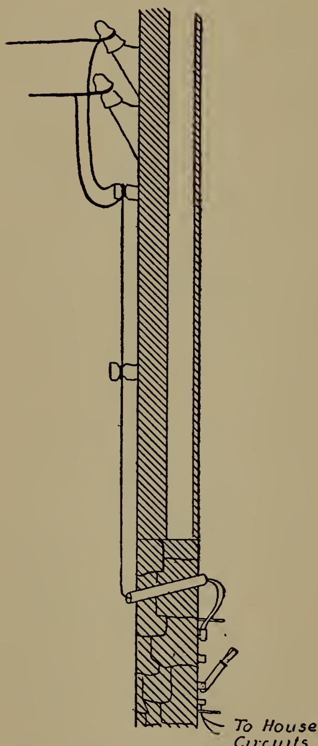


Fig. 277.—Wires brought through wall in porcelain insulating tube.

strain from the pipe. A loop in each wire where it enters the top of the pipe gives the necessary "slack" and at the same time prevents the rain from following the wire down the tube and damaging the insulation. These loops in the wire are called "drip loops." Wires can also be brought in through porcelain insulating tube if this is preferred to using the conduit.

WIRING LARGER HOUSES

Nearly all of the wiring in cities is done either in flexible or rigid metal conduit. The flexible kind is generally used where old buildings are to be wired, as it can be quite easily run under floors and back of walls.

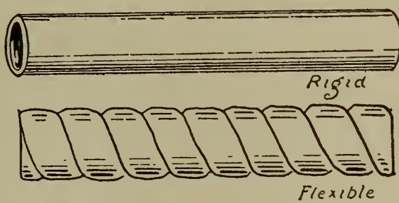


Fig. 278.—Rigid and flexible conduit.

The rigid style is put in when the wiring is done during construction of the building. The idea with both kinds is to furnish a complete metal path for the wires to run through. Then there is really nothing that can rub, crush, or damage the protecting insulation. Wherever branch circuits are to be brought out or switches are to be placed, iron "knock-out" boxes or outlet boxes are provided. The wire is then pulled through the conduit from one box to the next. With both flexible and rigid conduit special tools are required that put the work a little out of reach of the average amateur.

Several uses of electricity and electric light are indicated in the full-page diagram, Fig. 279. For simplicity each of the circuits is shown by one wire instead of two. Note that here the service wires run first to the meter, and then divide into six separate circuits. Each circuit is provided with fuses, and the whole lot with a single large fuse placed in the main line. The panel shown is usually enclosed in a box of sheet steel. Briefly, the six circuits run as follows:

To iron and washer in laundry.

To floor outlet, chandelier, and ceiling lamp in dining-room, and to lamp in pantry.

To baseboard outlet in dining-room.

To chandelier in library, to fixture in attic billiard-room, and to sleeping porch.

To lamps in parlor and bedroom.

To baseboard outlets and porch lights.

Of course, it would be possible to have all these lights on one circuit, but this is against the rules of the insurance companies. By dividing the circuits the job is not only made more workmanlike and convenient, but is actually safer. Each circuit on any job should be planned so that it will never carry more than 660 watts. Eleven 60-watt lamps would, in other terms, be allowed to each. There are many other rules made by the fire underwriters, and if any of them are violated the in-

ILLUSTRATED

1 Four-Light Fixture on Two Wall Switches.
2 Baseboard Connection for Electric Percolator, Fan, Etc., on Sideboard.
3 Detachable Electric Toaster on Dining Table with Outlets Connected to Floor Box.
4 Baseboard Outlet on Porch.
5 Baseboard Outlet for Piano Lamp.
6 Bracket Lights at Sides of Dresser.
7 Separate Switches for Ceiling Lights and Chandelier.
8 Separate Switches for Pairs of Lights on Shower Fixture.
9 Connections for Electric Washer and Electric Iron. Cord Support.
10 Small Reading Lamp on Screened Porch.
11 Picture Lighting Fixture Controlled by Switch.

NOT ILLUSTRATED

Three-way switch wiring for hall lights and lights for basement and attic stairs; also, in kitchen, a light near the range and above the sink; also electric heating circuit.
Closet lights.

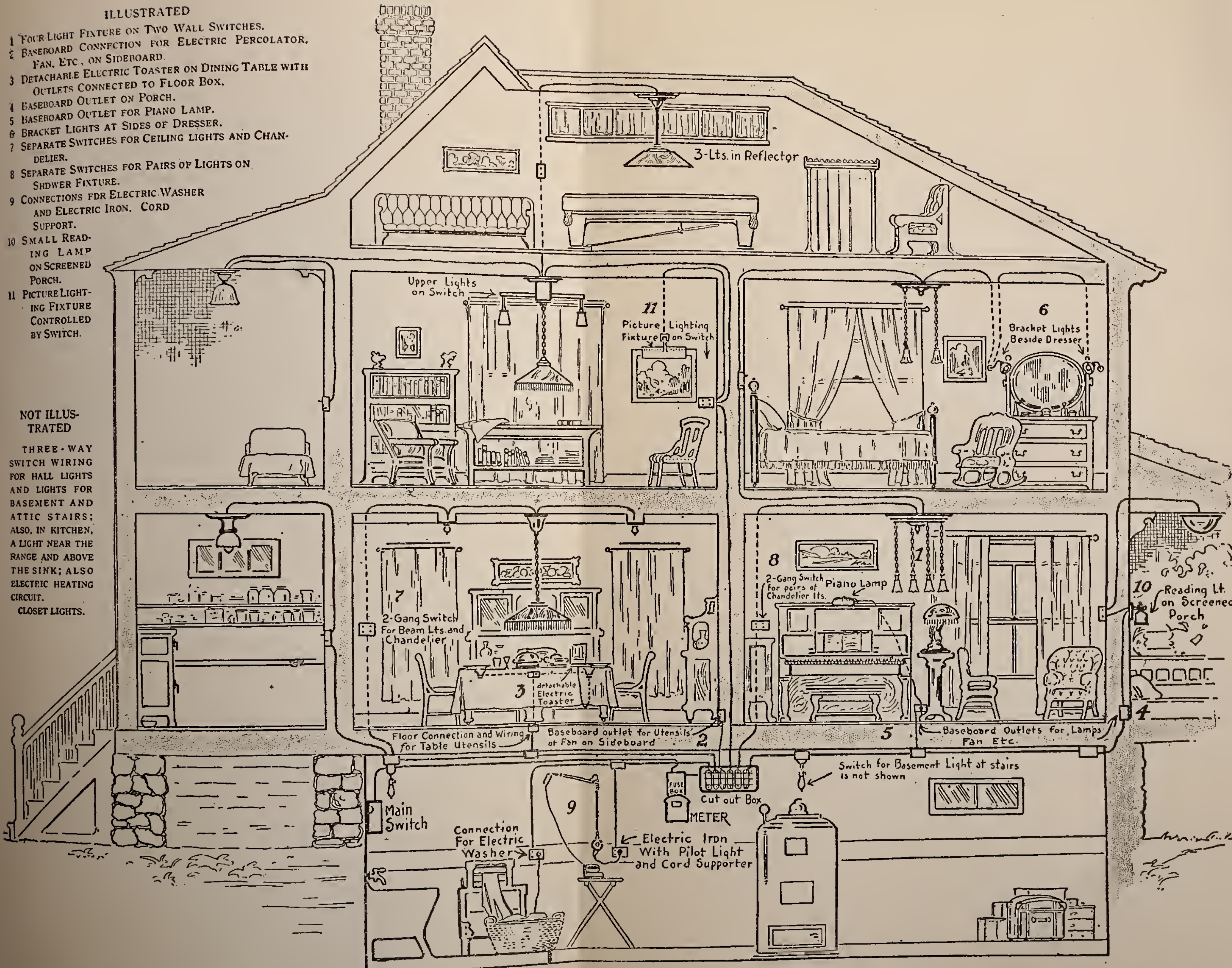


Fig. 279.—Circuits for electric lighted residence.

Courtesy of Electric City Magazine.

Facing page 316

surance on the house is canceled. If a fire started for any reason in a house with defective wiring the insurance companies could refuse to pay the loss and would probably do so. On this account it pays to do the work carefully, and have the job inspected before the wiring is concealed or the current turned on. In order to learn just what all the rulings on wiring are it is advisable to read carefully a copy of the latest edition of the Underwriters' Rules. These can be secured from your insurance agent or the Underwriters' Laboratory, Chicago. Everybody who is going to do wiring around any sort of building should be familiar with these rules.

CHAPTER XIV

Private Electric Plants

Every farm boy has the advantage of fresh country air, ample sunlight, and many other things that the shut-in city boy misses. He is doubly lucky in this electrical age because he can add many of the city advantages to his more healthful country home. Almost any farm or suburban home can have electric lights now. The convenient plants sold all ready to run are just as independent and give the same service as the big generating stations. The handy little gasoline engine does, on a small scale, the same work as the immense turbines or big engines of the city plant, and provides power to light anywhere from twenty lights up to as many as the largest dwelling would need.

A really complete plant in the basement of your home brings the convenience of the city right in your door. Light from the dynamo is just as steady and reliable as you could secure anywhere. With a set of this sort mother can enjoy her electric flat-iron; her hard work of washing will be driven away by electricity; and everybody can enjoy the toaster, coffee percolator, and electric fan.

The diagram in Fig. 279 indicated how the circuits ran in a big city house, and showed some of the uses of electricity in it. There are even more in a country home. A circuit run to the barn allows light for milking, and prevents that chance of fire which always used to exist when you took a lantern near a kicking cow. A motor in the barn or workshop can turn a line shaft to which the feed mill, grindstone, lathe, or other machinery can be belted. If there is a forge and machine shop the motor will be especially convenient. Remember that a motor of this kind is not to be run

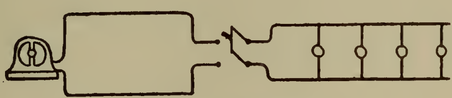


Fig. 280.—Simple plant.

from the storage batteries. Always start the engine up, as the load is apt to be too heavy. The engine should also be used whenever a flat-iron is connected, or the battery would be ruined in short order.

Of course, the engine and electric generator are the big parts of such a plant, and would supply current for lighting without either switchboard or battery if connected according to the simple arrangement in Fig. 280. These alone would not be very satisfactory, since the lights would go out just as soon as the engine stopped. If you came in late at night you would need matches and a kerosene lamp just as much as ever, and if electric light was wanted you would have to go and start the engine. Even when the plant was running there would be a little flicker due to the slight changes of speed of the engine.

An arrangement that avoids some of these troubles is made up of an engine and storage battery wired so that the lights are always run from the storage battery, and the battery is charged in the daytime from the generator. While this gives steady light at any time, there is the inconvenience of charging the battery a

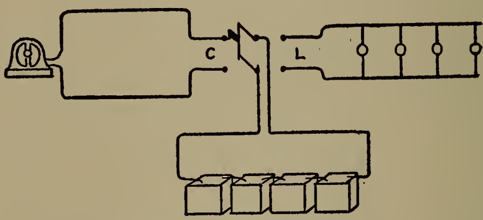


Fig. 281.—Battery plant.

couple of times a week. Figure 281 shows how such a set would be wired. The storage battery would have to be big enough in such a plant to supply current for at least three or four nights.

A third scheme combines battery and engine, and this is the best of any. In it the lights may be supplied with current direct from the generator, from the battery, or, what is better still, from the dynamo and battery combined. The battery then is said to be "floating" on the line. It is always ready to help out if needed, or to be charged if its charge happens to be low. A glance at Fig. 282 will tell you just how the different connections are made.

With the ordinary plant the parts that you ought to be familiar with are: First, the engine; second, the generator; third, the battery; and fourth, the switchboard.

The engine of a set that is to supply you with first-class light must be very steady running. This holds even if you have connections made so that the battery floats on the line. An engine would naturally try to

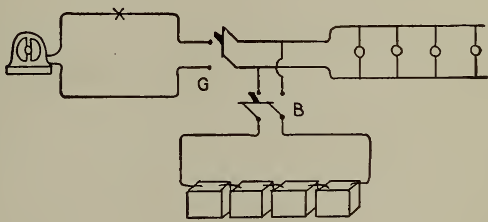


Fig. 282.—Plant to give power from battery, engine, or both.

slow down when a lot of extra work is put on it, and speed up when this is taken off. This change is ruinous to good light; so here is where the governor comes in. Its duty is to help the engine along a little when it wants to slow down, and to hold it back when it tries to speed up. With the governor set just right the change in load affects the engine very little.

As to methods of keeping the speed steady, there are two schemes that are quite commonly used: the "hit-and-miss" system and the "throttling governor."

In the first the speed is regulated by missing explosions; that is, when the engine is loaded down there is a charge taken in and ignited at every stroke. When

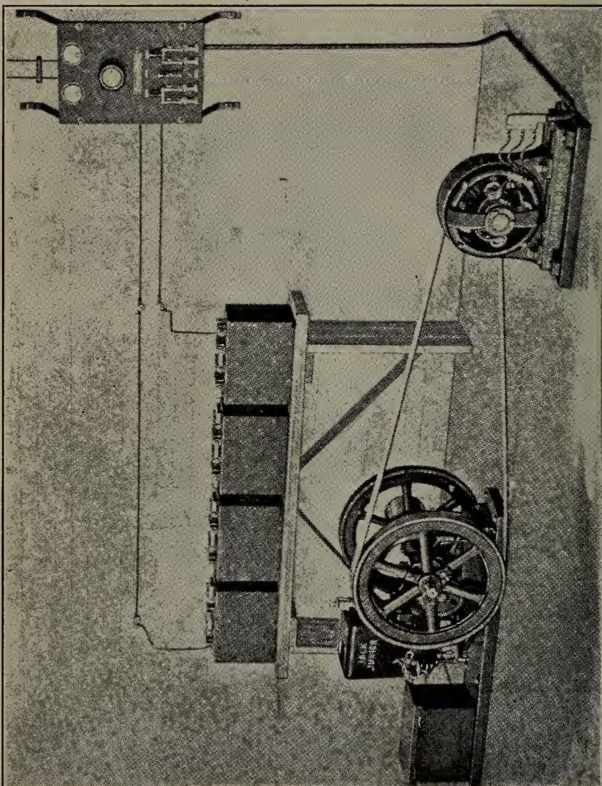


Fig. 283.—A belted plant that will give light whether engine is running or not.

the speed runs a little higher the engine misses explosions and naturally slows down. With the throttling governor there are no explosions missed at all. When the engine is working hard it gets a full supply of

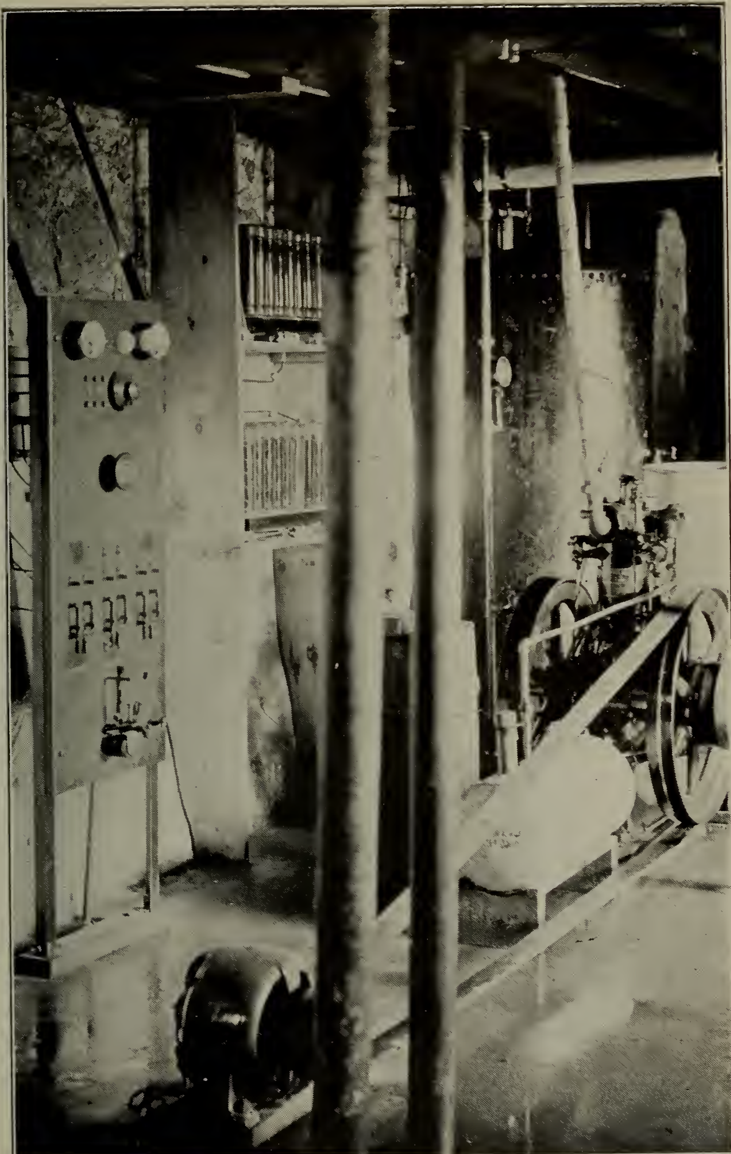


Fig. 284.—A private electric plant.

gasoline; as the load is taken off the gasoline supply is cut off little by little. This arrangement is so delicate that even with rapidly changing load the engine speed always remains practically the same.

Generators are built either for the standard 110 volts or for 30 volts. Practically the only advantage of the higher voltage is that it permits the use of standard 110-volt motors, heating appliances, and so on. On the other hand, the lower voltage has a very considerable advantage. In the first place, it is safer. Further, it allows storage batteries to be used to much better advantage. For 30 volts, 16 cells in series fill the requirements perfectly. With 110 volts 55 or more cells would be needed; such a number would be very expensive and take up far too much room.

For storage cells either the new nickel-iron or the lead cell can be used. The lead costs a little less and answers all purposes just as well, since it does not need to be moved, and is in a position where it should always receive good care. Remember that the life of a storage battery depends more on the way it is used than on the work it does.

The switchboard is really the nervous center of your plant, especially if it is the automatic or semi-automatic type. On a semi-automatic board, for instance, there would be three switches: one in the lighting circuit, one in the battery circuit, and a small single-pole switch for ignition. With these the batteries can be used alone, the engine can be used alone, or engine and batteries can be used together, with the batteries acting as an electrical "balance wheel." On the back of the switchboard is an automatic cut-out which is between the battery and dynamo, and opens when the dynamo stops or even falls below a certain speed. A voltmeter and ammeter on this board tell the operator the electrical condition of his circuits.

AN UP-TO-DATE SET

The plant illustrated in Fig. 285 is one of the most desirable for general lighting of farms and country

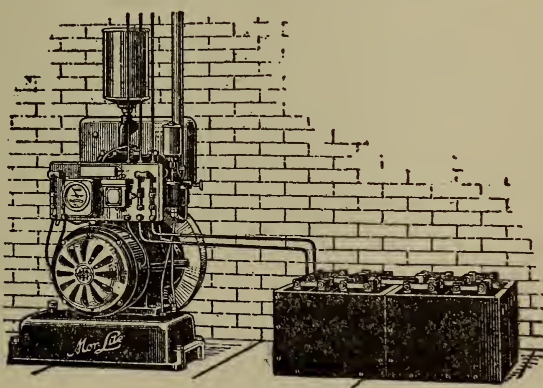


Fig. 285.—The engine and dynamo of this set are mounted on the same shaft.

homes. The vertical engine runs either on kerosene or gasoline, using one fuel as efficiently as the other. The shaft of the direct-current generator runs in ball-bearings, so that a very small part of the power generated is lost in friction. At the right of the engine is shown the storage battery. This supplies light whenever the engine is not running.

In complete sets of this sort the storage battery helps in other ways than just by giving light at odd times. In the style known as the "semi-automatic" it cranks up the engine in much the same way as the most modern electric starters that are installed in automobiles. The dynamo is temporarily run as a motor. It turns the engine over strongly a few times. As soon as gasoline and air are drawn into the cylinder and ignited the engine speeds up and the dynamo is again converting work into electricity instead of changing the electricity from the storage battery into work. When the battery is charged and the engine running the cells act as a sort of shock absorber; that is, the little variations in generator voltage are smoothed right out and the light is made perfectly even and regular.

When in use every night such a "semi-automatic" set needs very little attention indeed. The chances are that it will run best when let entirely alone except for oiling, cleaning, and charging, according to directions which the manufacturers always supply. Of course, water will have to be added to the cells once in awhile, but never put acid in except when you clean the sediment from the bottom of the jars. The water should be pure; use distilled water if it can be had.

Sets without the "semi-automatic" feature are made with an engine entirely separate from the dynamo, the power being carried by leather belting. Of course, the advantage of such an arrangement is that you can use the engine for other work by simply slipping the belt off the dynamo and putting it on the pulley of the line shaft or whatever you want to drive. Such a plant is illustrated in Fig. 283.

By taking the case of a particular house you can form some idea of estimating the needs of a private lighting plant. Suppose the house has ten rooms in all. There is the library, sitting-room, dining-room, kitchen, and one bedroom downstairs. Upstairs are four bedrooms and a billiard room. This would require about 25 lights, and they could be arranged to advantage as follows:

Library	4
Living-room	4
Dining-room	4
Kitchen	1
Pantry	1
Billiard-room	1
Bedrooms	4
Bath-room	1
Hall	3
Porch	1
Cellar	1
Total	25

For general use 20-watt lamps, which give about 16 candle-power, are usually considered big enough. With a 30-volt plant each of these lamps would take a current of $\frac{3}{4}$ ampere. With all the lamps burning there would be about 15 amperes flowing in the main conducting wires. For use on these circuits wire at least as large as No. 10 rubber covered would be needed. No. 12 could be used for the branches. It can be run in any of the ways described in the preceding chapter.

The storage battery has to meet two requirements: It must be of the right voltage, which depends on the number of the cells alone, and it must have enough current capacity to supply the lamps commonly used for at least one entire evening, which depends only on the size of the cell. For the plant described the capacity should be 50 ampere-hours or more. It would then run all the necessary lights if the plant should fail. For instance, nine of the lights could be burned for ten hours, if desired, before the battery had to be recharged. As the best plants are made now, the battery is charged whenever the number of lights is small, and helps out the engine when extra work is put on it.

COST OF ELECTRIC LIGHTS

Of course, the deciding question in putting in electric light on a farm or in a country home is very often one of expense. "How much will the light cost?" This depends very much on circumstances, but you can always figure quite closely for your own conditions. After you have decided just how many lamps you want, estimate how many are apt to be lit at once and how many hours every night each one will burn. This will allow you to figure both the kilowatts needed and the kilowatt hours used. For instance, if 10 lamps burned four hours each, the current consumed would amount to 40 lamp-hours, or since each lamp takes about $\frac{3}{4}$ of an ampere it would be $\frac{3}{4} \times 40$, or 30 ampere-hours. The E. M. F. of the system is 30 volts, so the power delivered would be 900 watt-hours. For safety a 1-kilowatt generator and a $1\frac{1}{2}$-horse-power engine would probably be used, since as many as 20 lights might be lighted at one time. At medium loads the engine would probably use slightly more than 1 pint of gasoline an hour. For the whole evening, say from 7 until 11, about $\frac{1}{2}$ gallon would be used. This would make each light for the evening cost about a cent for its four hours' use. So electricity, even when you generate it yourself, is very cheap when the great convenience of it is considered.

CHAPTER XV

Gas Engine and Automobile Electricity

Anybody around a farm or shop will tell you that the fellow who can find out what the trouble is, and make necessary repairs when anything goes wrong with a piece of machinery, is just as big a help as the one who is clever at building labor-saving devices. Where a gasoline engine is in use you will always be welcome if you can point quickly to the source of trouble when there is a hitch and set matters right again. It is not such a trick after all, if you go about it systematically and study the most common causes of trouble.

First, it is necessary to understand the principle of the internal combustion engine. "Internal combustion" means that the fuel is burned inside the cylinder instead of at some outside point under a boiler. At the bottom of the whole thing is the fact that a hot gas takes up a great deal more room than a cooler one. You can prove this to yourself by holding a toy balloon near a stove. As the balloon gets warmer it grows larger and larger; then the pressure is too great for the rubber to hold and the balloon explodes.

In the gasoline engine the heat is supplied by gasoline vapor and air that comes into the cylinder. An electric spark sets fire to the mixture, and it expands with a good deal of force. There is no way for it to escape, so it pushes the piston outward. In doing this the action is just about like that in a small cannon. With the cannon the explosive mixture in the form of powder is packed behind the projectile. A cap ignites the charge; the gas presses with a sudden and enormous energy, and the shell starts on its way. In the engine the gasoline and air take the place of the powder, and

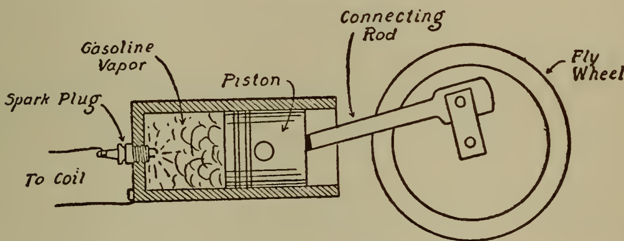


Fig. 286.—How spark ignites gasoline mixture and turns flywheel.

you have a piston instead of a shell. A strong piston rod and crank keep the piston from being blown clear out; the flywheel, added to these, helps to turn the violent explosions into useful work. The carburetor simply mixes the gas and air in the right proportions; the valves allow the mixture to be taken in and the burned gases disposed of.

In this general way practically all gasoline engines are alike. The first big difference to consider is in the way the gas comes into the cylinder and the way it is got rid of. This divides the engines into "two-cycle" and "four-cycle" machines. The word "cycle" means a complete round of motions. To go back to the cannon: a "cannon-cycle" would be, first, loading; second, firing; third, taking out the empty shell. Then you would start all over. In the engine, "two-cycle" means that there are two strokes to a cycle; "four-cycle," that there are four strokes to each complete set of movements. The proper names for the cycles of these engines would really be "two-stroke cycle" and "four-stroke cycle," but these terms are too long for common use.

You will see the difference more clearly by following out the movement in each case. In the two-cycle engine these are:

Expansion Stroke.—Electric spark ignites explosive mixture of air and gasoline in cylinder, forcing the piston outward. At the end of this stroke a "port" is uncovered, allowing gas to rush in from the crank case and force the burned gases out.

Compression Stroke.—Gas is compressed ready for another ignition, and at the same time a new charge is drawn into the crank case.

In the four-cycle type of engine the spark comes only half as often. The cycle here is as follows:

Intake Stroke.—Explosive mixture of fuel and gasoline is drawn into the cylinder.

Compression Stroke.—Valves are closed and explosive mixture is compressed. Just before this stroke is finished the spark occurs and the mixture is ignited.

Power Stroke.—The piston is driven outward and the flywheel turned.

Exhaust Stroke.—Piston carried back again expels the burned gases from the cylinder. This completes the four operations of the cycle.

Each of these engines has its special field. The two-cycle type, which runs at slower speed, is very widely used for motor-boats, and also to supply power for shop and farm work. Four-cycle engines are made in all sizes and used for all purposes. Many gasoline and kerosene engines are made in this type. Automobile engines and racing-boat engines are all four-cycle engines.

In both cases the ignition or explosion of gas is brought about by an electric spark. It may be produced either by a spark-plug or by a make-and-break arrangement, but the important things are that it must always be hot enough to ignite the explosive mixture, and that it is timed to jump at just the right instant.

The spark-plug is simply a spark-gap like the one described in Chapter V. A set of batteries is connected in the primary of an induction-coil and a contact arranged so that the circuit is closed and broken at just the proper instant. The low voltage current in the primary then induces a much higher one in the secondary, and a hot little spark jumps across the space between the metal terminals of the plug. The gasoline mixture around it ignites and the piston is pushed outward. This is the process of high-tension ignition.

With a make-and-break system a much more reliable spark is claimed, and only a very simple and small coil is needed. With this, one of the points inside the

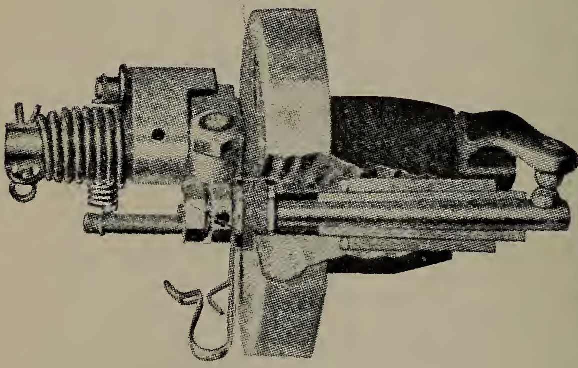


Fig. 287.—Make-and-break igniter.

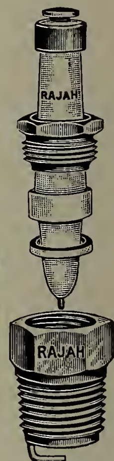


Fig. 288.—Spark-plug.

cylinder is fixed solid; the other one moves. At the right time they touch together, and then are suddenly pulled apart at the proper moment by a little latch and trip arrangement geared to the shaft. A spark passes when the break is made and the explosive gas is ignited. On account of the low voltage used the make-and-break scheme is sometimes called low-tension ignition. It is wired as shown in Fig. 290, when used with a magneto,

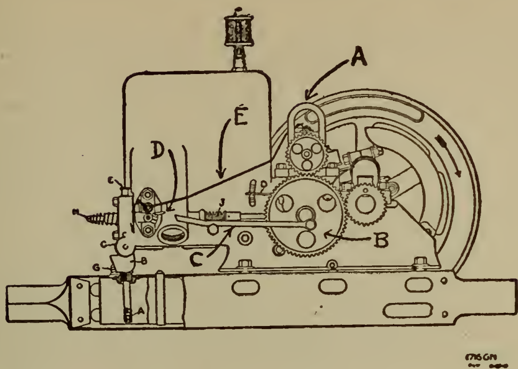


Fig. 289.—Electrical parts of make-and-break ignition system: *A*, Magneto; *B*, magneto gear; *C*, igniter trip rod; *D*, igniter; *E*, connection from magneto to igniter.

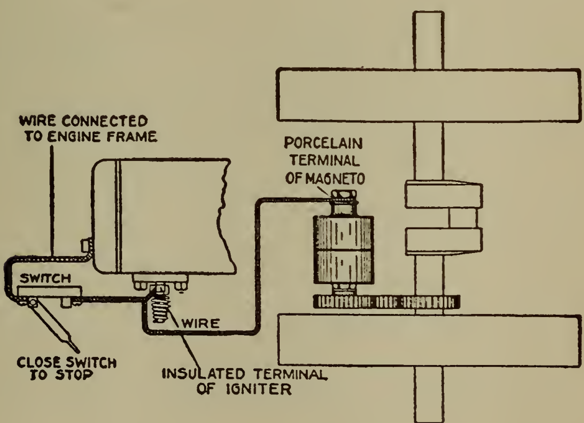


Fig. 290.—Connection for magneto with make-and-break ignition.

or as in Fig. 291, where combination battery and magneto arrangement is desired.

Some experts claim that the jump spark is best, and others stand up for the make and break; each one of them has good points that are not disputed. For automobiles and high-speed marine engines the jump spark is always used. For lower speed stationary machines the reliability of the make and break is a strong point in its favor.

When you hunt for spark trouble in either one of the systems have a regular method and stick to it, no matter what you think the fault might be.

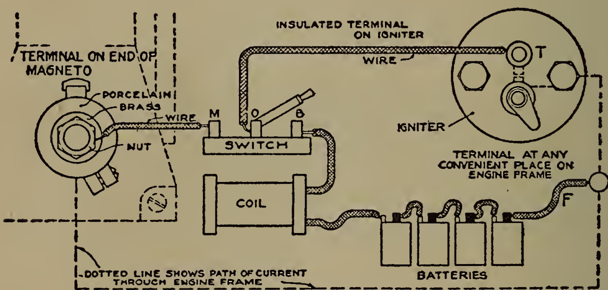


Fig. 291.—Wiring for both battery and magneto.

This may take a little longer in some cases, but it generally saves time in the end. Weak spots are less liable to be overlooked. Here is one method that you can follow: First, see that the igniter switch is closed. If the engine has a jump spark, the next thing is to unscrew the terminal from the plug and hold the end very close to the end connection. Have some one give the flywheel a few quick turns. If the spark jumps across the little gap, you may be sure that the ignition is all right. If not, any one of several things may be the matter.

First, trace the wiring right from the batteries, and make sure that all connections are tight and that no wires are broken. Sometimes a break is quite hard to find on account of the heavy insulation. Look over the insulation and see that it is not worn or scraped off at any point. Next unscrew the spark-plug and see that the little points are perfectly clean. The carbon deposit that sometimes forms on them hinders or even prevents passage of the spark. This deposit must be cleaned off with a fine file or a piece of sandpaper. Make sure, too, that the wire tips are separated by just the right distance. There should be just room enough to slip a worn dime between the two points.

If the engine uses a make-and-break system, the electrodes should be taken out and examined to see if they touch together, also to find if they separate properly when the latch is tripped. Sometimes the little buttons become worn; if this is the case, they can be removed and new ones put in with very little trouble.

Of course, there may be other causes of a tie-up, such as a bad mixture of gas or carburetor trouble, but these can be traced out and each gone after in its own way. By keeping the engine clean, using new batteries, and watching for insulation trouble you will be able to very largely avoid all ignition trouble, whether you use dry batteries or magneto, jump spark or make and break.

AUTOMOBILE ELECTRICITY

In an automobile the ignition is a little more complicated. There are four or more sparks instead of one. They must all be strong and must come at just the right time. In addition to the wiring for ignition there is the lighting system, the storage battery, and the self-starter.

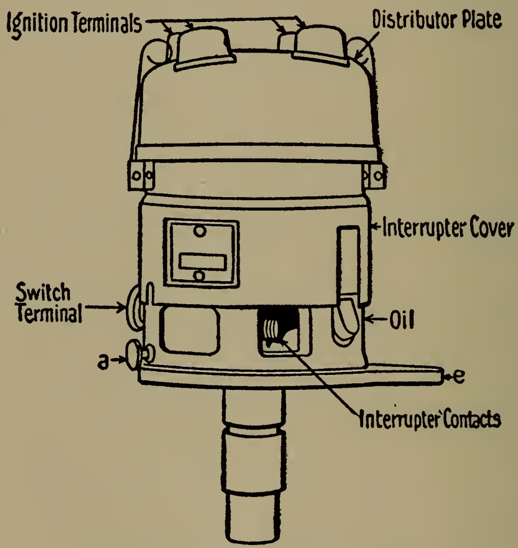


Fig. 292.—Automobile ignition unit.

All of this makes rather a complex arrangement of electrical apparatus on the automobile. Some cars have six circuits or even more, with a separate fuse for each circuit, and wiring almost as complicated as in a factory using motors and lamps. The up-to-date machines use a motor for starting, a generator for lighting and ignition, and a storage battery to serve the two. Even the common forms of ignition device are far from being simple. One of these is illustrated in Fig. 292. From the diagram of this (Fig. 293) it will be seen that the main parts are: (1) Induction-coil; (2) Condenser;

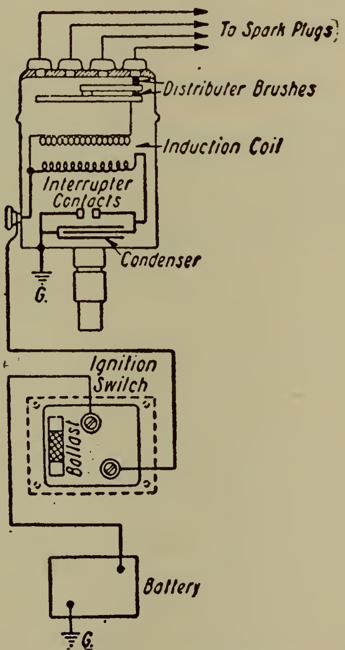


Fig. 293.—Ignition system for automobile.

(3) Interruptor; (4) Distributor—each with a very definite duty. The coil raises the voltage to the point where a spark jumps between the spark-plug points. The interruptor breaks the primary circuit. The condenser makes the break very sudden. The distributor

simply directs the spark to each cylinder in its proper turn.

For lighting alone an electric generator driven from the engine shaft either by a belt, chain, or gears is used. This supplies direct current, and is used with a set of storage cells, so that the lamps can be lighted whether the engine is running or not. In connection with such a system a regulator has to be used. Otherwise the lamps would burn out if the engine ran very fast, or they would be very dim when the engine ran

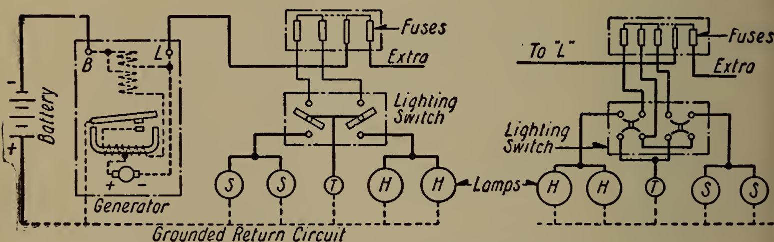


Fig. 294.—How automobile lights are wired.

slowly. When the engine is not running at all the lights are supplied by the battery. The principle of such a regulator is indicated in Fig. 294. As the engine comes to a speed that corresponds with about eight miles an hour the switch closes and the generator supplies current. When the engine goes still faster the little switch opens and closes very rapidly, so that the voltage at the lamps is cut down by just the proper amount. A complete diagram of wiring for automobile lamps is shown in Fig. 295.

Ignition and lighting systems are often combined, so that current is supplied for both purposes by one

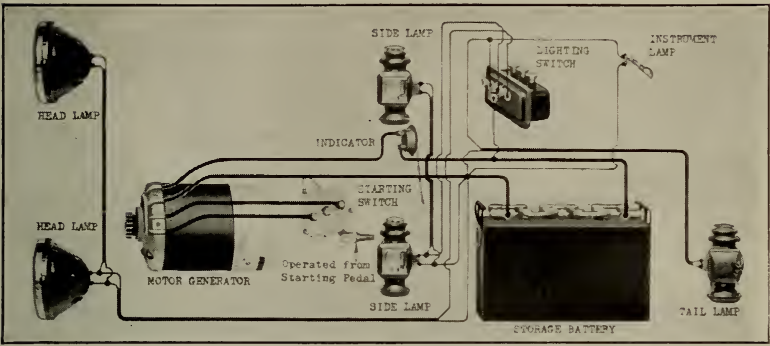


Fig. 295.—How an automobile is wired.

generator, helped out by a set of storage cells. This arrangement is shown in Fig. 296.

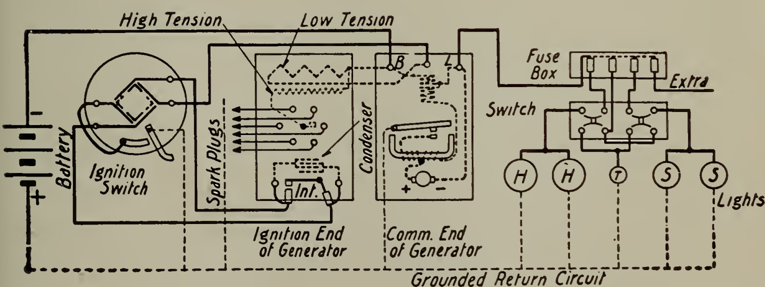


Fig. 296.—Lighting and ignition system.

With a little extra machinery and wiring a generator and motor can do all the work of ignition, lighting, and also start the engine. Such systems are saving a lot of work for motorists, but sometimes cause more or less annoyance. Nothing is more annoying than an electric starter that does not start. The inside of one of these electric starters is so simple that a little search will generally show what trouble exists, if you understand just what the action is. In the first place, the power is supplied by a motor connected to a set of storage batteries and geared to the engine shaft. The motor runs much faster than the engine. On one system the little gear is slid into position with a foot lever. The same motion closes a switch and starts the motor at work. When the engine takes hold and reaches a certain speed it throws the pinion and gear out of mesh, opens the switch, and stops the motor. You can trace the connection on a system of this sort from Fig. 297.

Another starting system does away with the foot lever entirely. With this you simply press a button. A switch closes and the motor starts. The pinion is not keyed fast onto the shaft, but runs loosely on a thread. It is forced into position by the thread whenever the motor is started. One thing necessary is that the teeth must always strike together properly and must never lock. This is provided for by making the shaft of the pinion in two pieces. They are held together by a strong spiral spring. There is always a little give to the spring, so that the pinion slips until it comes into the proper position and the teeth of the

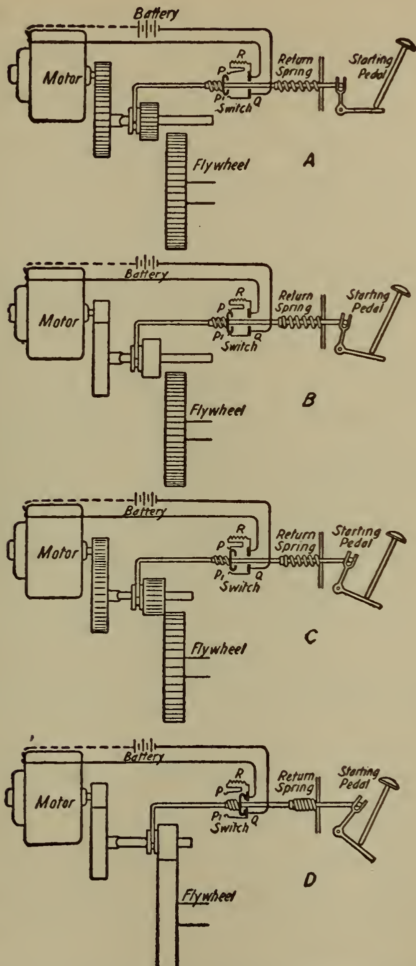


Fig. 297.—Electric starter operated with foot pedal.

pinion slide into mesh with those of the gear. You can see how this arrangement works by referring to

Fig. 298. As nearly all the systems use batteries, a word about their care will not be out of place. To begin with, see that the cells are kept charged and that the liquid is kept at the same level all the time. Remember that only the water evaporates, so only pure water should be added.

The batteries which are used carefully, kept filled with distilled water to a proper level, and let alone are

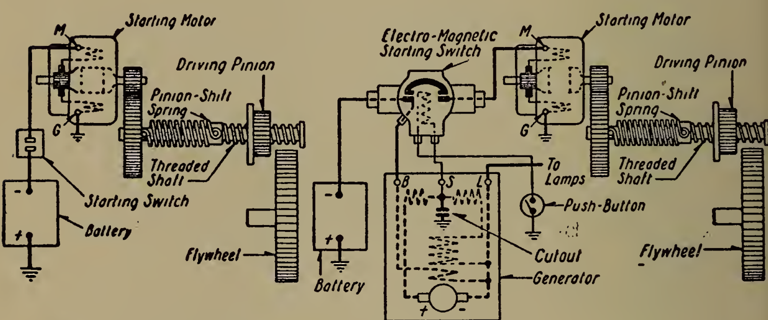


Fig. 298.—Electric starter with hand or foot switch and push-button.

the ones that give best service. It is not use but *abuse* that wears out storage batteries.

Wiring is much the same in all the systems. The current is usually carried one way on heavily insulated cable, and returns through the iron frame of the engine and automobile. This simplifies the work of hunting for trouble a good deal, as you only have to look over about half the length of wire you would otherwise need to inspect. As to the actual method of running the wiring, it is best to familiarize yourself with whatever system is used on the car you are interested in. Follow out the wiring and find just where each wire goes, and why. Learn what each switch controls. Then when there is any trouble with the electrical equipment you will be prepared to trace it down.

CHAPTER XVI

Making and Installing Lamps and Fixtures

If you have furnished your room with the Mission chairs, table, and other pieces described in the American Boys' Workshop you can go right ahead and make lamps that fit in with the rest, and will add a good deal to the appearance and effect of all the furniture. They are really not so hard to make as some of the other pieces of electrical equipment, and are extremely useful in a plain everyday way.

At first thought it may seem that colored glass, brass work, and so on, are needed to make even the simplest sort of lamp, but these are not really necessary, at least to begin with. Of course, substantial woodwork is necessary for the base, or support, but very good shades can be made from even such simple materials as cardboard and colored tissue-paper. Do not try to use heavy pasteboard for the work, but secure a sheet of the thinner, tougher Bristol board. This will fold along a crease without weakening or cracking.

As a first trial in lamp-shade making a simple shade should be fixed for a drop light. If the work is neat the result will be surprisingly attractive, and will give you the experience to go ahead successfully with bigger shades. For this a piece of Bristol board 10 by 20 inches will be the principal need. Mark this out care-

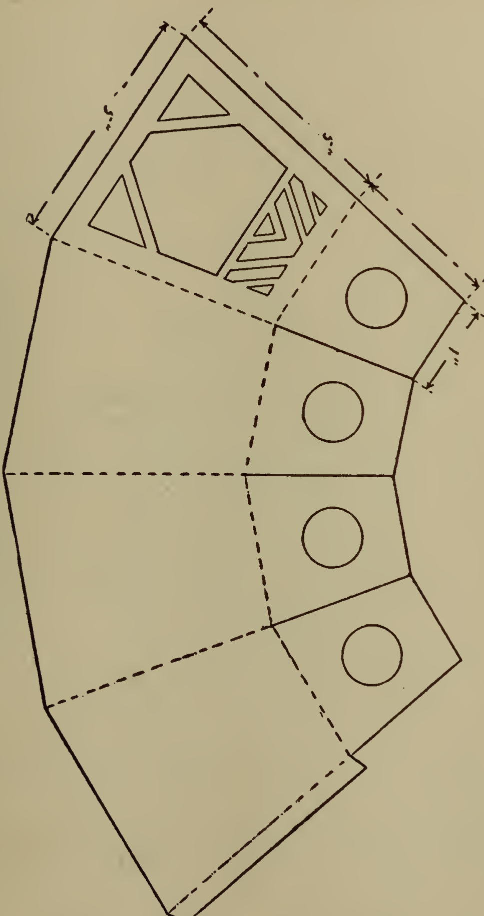


Fig. 299.—Pattern for drop light shade.

fully with a sharp lead pencil in the form illustrated by Fig. 299. This must be done accurately or the shade will never look right. Cut out along the lines marked with the heavy line, and then along each one of the dotted lines mark with a table knife or the back of a penknife blade. This should be done with a ruler so that the mark will be perfectly straight. It then makes folding easy and insures a straight, neat fold. The patterns on the shade should be cut with a very sharp

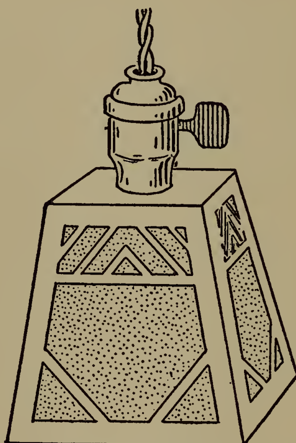


Fig. 300.—Finished shade for drop light.

knife. This makes a much better job than is possible with shears.

The shade is now ready to be folded and pasted. The little end flap "A" should be pasted under the corner, and the top flaps are simply pasted firmly one on top of the other. After the paste has dried mark out a circle on the top, using a lamp socket for drawing the mark to the proper size. Cut just inside the line with a sharp knife, and slip over the ring at the end of the lamp socket. The shade will thus be held firmly in place and will be properly placed on the socket.

Larger shades can be made in much the same way for lamps already in use. It cannot be expected that these will last quite as long or stand the hard knocks as well as a shade made from sheet brass, but there are many

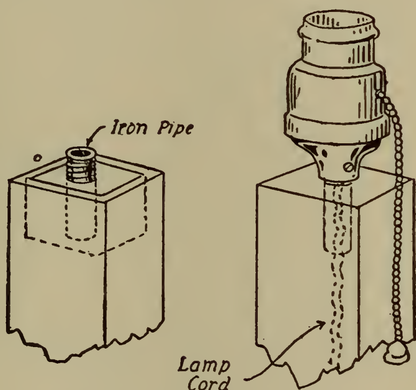


Fig. 301.—Mounting the socket on the standard.

places where they answer quite as well. They are so cheap and easily made that the whole house can be decorated with them for a Hallowe'en party or St. Patrick's Day party without much time or money being put into the work.

If you want to make an entire table lamp that is both substantial and decorative you will need to do a little carpenter work, some glass cutting, and metal working. The result will more than pay you, for the lamp will be really substantial and the equal of one you would buy. As to materials, the principal things needed are a piece of ¼-inch board for the standard, a

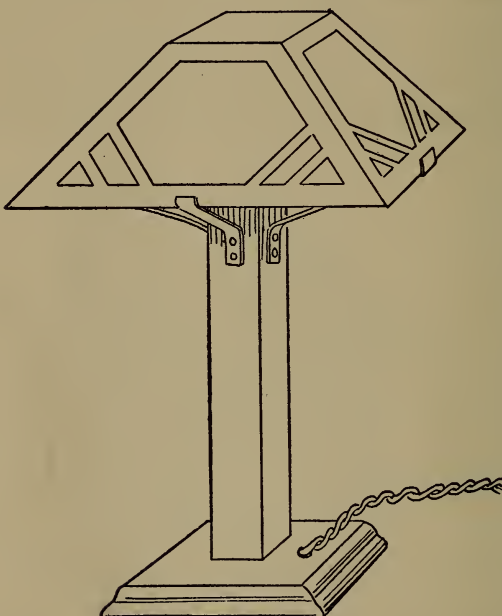


Fig. 302.—Table lamp.

1-inch board for the base, and a sheet of brass or copper 17 by 17 inches in size.

Make the base 7 inches square and mortise a square hole in the center as shown. The standard is made of the ¼-inch strips fastened with small brads. In the top of this the lamp socket is fastened firmly by screwing it on a piece of $\frac{1}{8}$- or $\frac{1}{4}$-inch pipe fixed in a block of wood, and the lamp cord dropped down through the hollow standard. By cutting a groove outward along the bottom of the base, and boring a hole upward, the cord is brought out for connection to the socket. Four supports for the shade complete the standard of the lamp. These should be made from sheet-brass strips each $6\frac{1}{2}$ inches long. Two holes bored through one end

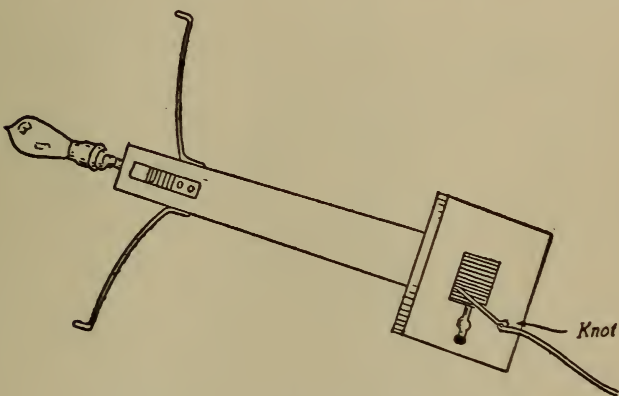


Fig. 303.—How cord runs to lamp.

receive the screws that hold the brass to the standard, while the other tip is turned up slightly to hold the shade in place.

For the shade, cut the sheet-brass with tin shears according to Fig. 304. The bends should be made over the edge of a vise so that they will be true and workmanlike. Bore $\frac{1}{8}$-inch holes to fasten the edges together and the top piece in place. Considerable care should be taken with the riveting, as any faults in this respect are apt to show up quite plainly.

At this point the four pieces of colored glass should be cut to fit. They are held in place by the four little tongues that were left when the sheet of brass was cut.

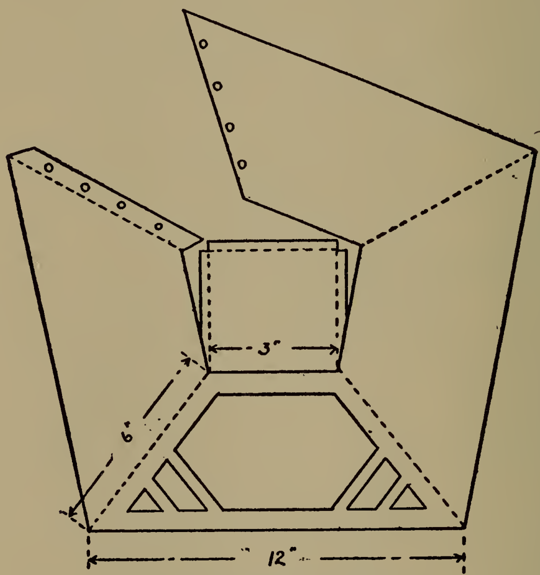


Fig. 304.—Shade for table lamp.

These should be bent over the glass just as firmly as possible so that there is no chance of the pieces rattling.

The base can now be stained with the desired color and the brass work finished. If it is desired to have this remain bright a coat or two of lacquer should be applied. This keeps the metal from tarnishing.

If you want pretty lights on the wall they can be made in much the same way. These are really more for decoration than for light, and so smaller lamps than usual can be used with good results. The bracket which supports the lamp is made hollow, and built in

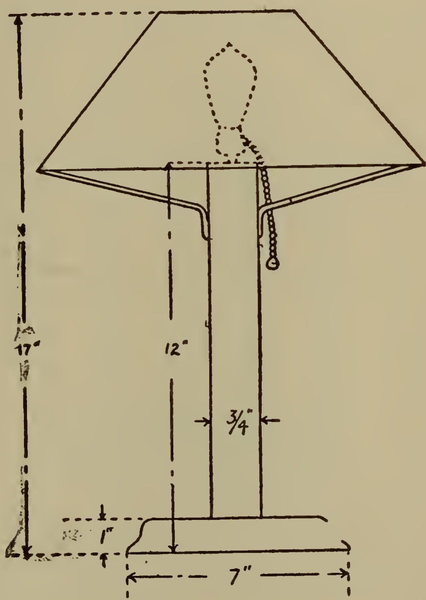


Fig. 305.—Dimensions of table lamp.

about the same manner as the table lamp already described.

For general illumination the shower fixture is used a great deal, is quite decorative, and no harder to make than an ordinary two- or four-light chandelier. For the fixture shown (Fig. 306) the four shades may be made from either light wood or fibre board. These can be cut in a design similar to the one shown in Fig. 308, and colored glass or tissue-paper put inside to give the art-glass lamp effect. In the top piece of the shade a hole may be made for the brass tip of the socket. In this socket screw a $\frac{1}{4}$-inch piece of $\frac{1}{8}$-inch iron pipe.

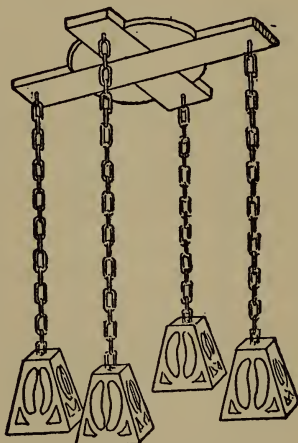


Fig. 306.—Shower fixture.

The shade and lamp will then be held up by this pipe. A hole bored through the end of the pipe will take one link of the chain as indicated in Fig. 307. The other end of the chain is to be linked with a screw-eye fastened to the ceiling plate. Four pieces of chain cut to the same length will be needed. The ceiling plate can be very simply made from two pieces of 1-inch board joined in the middle at right angles. The conductors

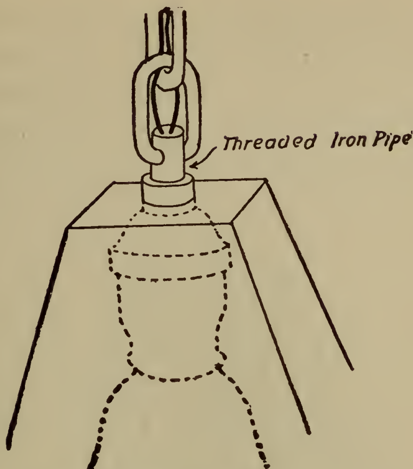


Fig. 307.—How shade is fastened to chain.

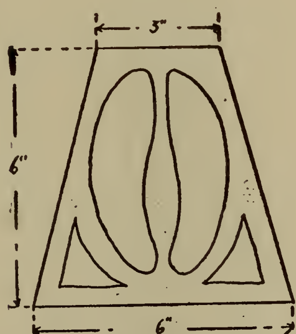


Fig. 308.—Side for shower fixture shade.

can be run in grooves in the upper side of the arms, and are usually carried down to the lights intertwined with the links of the chain.

A little desk light such as the one illustrated in Fig.

309 makes a very attractive gift and is even easier to make up than the large table lamp. For this the shade may be cut out of thin wood with a scroll saw or made of heavy cardboard. The stand can be made either of a hollow piece or solid with a hole bored through it

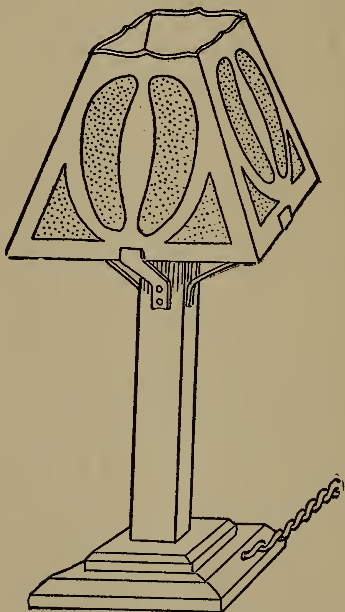


Fig. 309.—Desk lamp.

for the cord. The socket used should be provided with a pull-chain.

For the living-room a piano lamp is both convenient and ornamental. This can be made according to Fig. 312, from a piece of 2-inch square material for the center, and four strips of $\frac{3}{4}$-inch board for legs. The legs should be very carefully marked, and should all curve just exactly alike. The best way of getting the same shape is to cut a pattern from stiff paper, fasten it to the wood with pins or small tacks, and mark care-

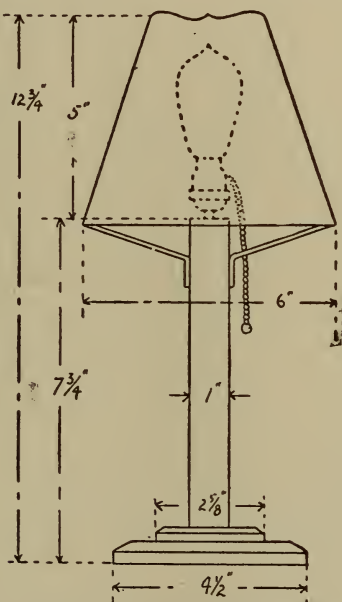


Fig. 310.—Details of desk lamp.

fully around the edge. The legs can be attached with long screws or pegs to the square central post. To conceal the wires one of them may be run in a groove under each of two legs. Of course, a long hole will have to be bored down the center piece to start the wires through. In this hole put a piece of $\frac{1}{8}$- or $\frac{1}{4}$-inch iron pipe. To this fix a "tee," and in the "tee" screw two pieces of short threaded pipe bent to a small angle. Sockets with the proper sized threaded part may be screwed right on these pipes, and the joint will be very solid. This practically completes the lamp standard. Additional pieces may be set at the bottom for greater

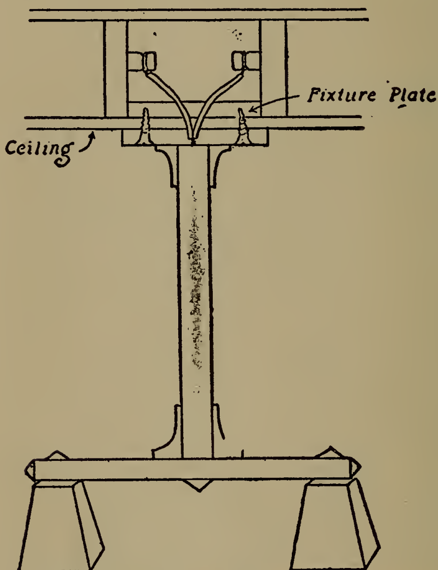


Fig. 311.—How fixture is hung by fastening to fixture plate.

strength if desired. Staining depends on the finish of the other furniture.

A very attractive silk shade can be made on a simple wire frame by mother or sister. This frame should be supported by four wires running upward from a point near the top of the standard.

All of these shades are decorative as well as useful, and considerable attention should be paid to the work-

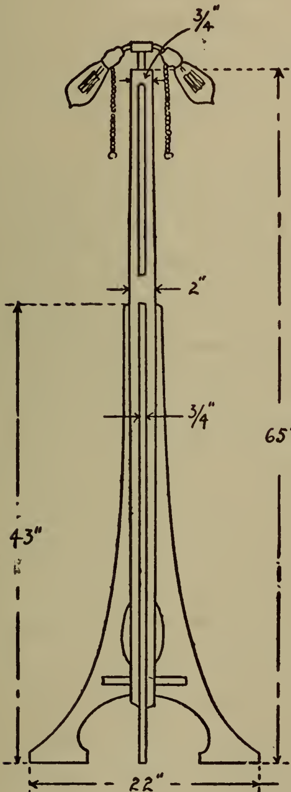


Fig. 312.—Dimensions of piano lamp.

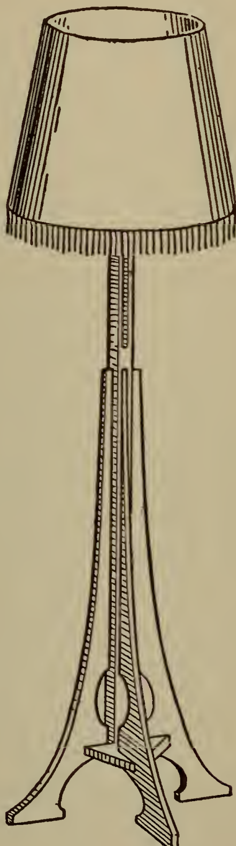


Fig. 313.—Finished piano lamp.

manship in them. The boards should be plained very smoothly, and then rubbed down with fine sandpaper.

After this they can either be polished or stained to match the other furnishings of the room.

The glass may be any color that is obtainable. Green is probably the best, as it is generally considered restful to the eyes. Do not make the mistake of using a lot of pieces of different colors. The result will be much better if you stick to the same style and tints in all the lamps that you build.

When it comes to installing these lamps, the most important thing is to see that they are fixed firmly in place. For the chandelier long screws should be used, and these should run through the plaster and lath of the ceiling and into a wooden plate set between the rafters as described in Chapter XIII. There is no chance then of its falling down the first time it is subjected to a heavy or unusual strain. Placing the lamps in the rooms or around the walls is largely a matter of taste. The matter of wiring has to be considered as well as the effect you want to produce. Well-placed lamps, solidly built and firmly set in place, are indeed a credit to any boy. If he has wired his home, as well as built and installed the fixtures, he may well consider that his knowledge of the principles of electricity has brought him a large and permanent return. Through the work of his own hands he has enabled himself and his family to enjoy the greatest and best of our electrical blessings—electric light.

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