ELECTRICITY'S SILENT PARTNER
- MAGNETISM
(Fundamentals of Electricity - Part II)

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I. Introduction

In our journey through the world of electricity we have seen and learned a lot. We know electricity is a flow of electrons from atom to atom within substances called conductors. We know other materials do not let electrons flow, and are called insulators. Combinations of conductors and insulators make up devices we use to control electricity to serve us. Electricity also has a rate of flow (amperes) as well as pressure (voltage).

We also explored many of the uses and benefits of electricity and something about how it works to produce heat and light for us. However, we still have only part of the picture.

Changing electricity into heat or light isn’t the only way electricity works for us. Electric motors operate appliances in the house or power trains along railroad tracks. Electricity can produce sound, too. Fortunately, we can control electricity to serve our needs in many ways.

To understand more of the world of electricity, let’s look at electricity’s working partner — magnetism. We’ll see how electricity and magnetism work together. And, we’ll even see how magnetism can be used to produce electricity.

Electricity is a powerful form of energy — and in partnership with magnetism it’s really unbeatable!

II. Mysterious Magnetism

In ancient times, people found certain rocks that stuck together. This was certainly mysterious, but not much use was found for these odd rocks until it was discovered that, when allowed to turn freely, one side would always turn to the north.

The Chinese were the first to use these stones for a practical purpose about 5000 years ago. They found that, on journeys, if they carried one of the strange rocks suspended from a string, it would always point toward the North Star, thus helping guide them on their way. They called the rocks “lodestones”, which means “leading stone”. The early explorers and sailors used these lodestones to find their way on sea voyages.

Meanwhile, on the other side of the world about 2000 years ago, the Greeks found the same unusual kind of rock near a city called Magnesia. They named the rock “magnetite” for the city near which they found it.

The strange power of this rock, which is the same as that of the lodestone, is called “magnetism”. Rocks like this are called “natural” magnets.

Our planet earth is itself a large natural magnet. The reason the lodestones always turned north was due to the magnetism of the earth.

The area around a magnet is called a magnetic “field.” This field cannot be seen, but we know it exists.
Magnetic fields are one of the important things in our study and use of electricity. If it were not for magnetic fields, we would not have electric motors. Telephones, radios, television and many other things we use every day also depend on magnetic fields.

We can see the magnetic field indirectly by sprinkling iron filings on a sheet of paper which has been placed over a magnet. If we gently tap the paper, we will see the iron filings arrange themselves into a pattern of lines that connect each end of the magnet.

*Materials Needed*

- A sheet of paper
- Iron filings
- A U-shaped permanent magnet

The ends of the magnets are called “poles.” They are the points where the strength of the magnet is the greatest. To tell them apart, one end has come to be called the north pole, the other end the south pole — regardless of whether the magnet is in the shape of a bar or bent around into the shape of a “U” or a horseshoe. The north pole is at the end of the magnet which points north when the magnet swings freely.

We say that the lines of the magnetic field leave the magnet at the north pole, and re-enter it at the south pole.

Just as like electric charges repel (drive away) each other and dissimilar electric charges attract, two north or two south magnetic poles will repel each other. A north pole and a south pole attract one another.

Someone once found that when a natural magnet is stroked with a piece of iron, then the iron itself becomes a magnet. Why should this be?

Modern scientists believe that magnets are made of millions of small particles called molecules, which are in turn made of atoms. Each molecule is itself a tiny magnet. In an unmagnetized bar of iron, the molecules have no regular arrangement, and produce no magnetic field outside the bar. Under the influence of a magnet, however, the molecules arrange themselves so that their magnetic fields are aligned in the same direction. The magnetic field is, therefore, strengthened and extends outside the bar itself.

You can demonstrate this yourself by making your own magnet that you can use as a simple compass.
Check your newly magnetized needle with an inexpensive compass. Hold the compass near the north pole of the needle. What happens? Does the south pole of the needle attract the north or south pole of the compass? See if you can prove the rule that like poles repel and unlike poles attract.

If a bar magnet is broken in two, each half becomes a magnet with its own north and south poles. It is thought that this process of breaking in two could continue until the pieces are the molecules themselves, each with a north and south pole.

You can show this by using your magnetized steel needle. Use wire cutters to cut the needle into short lengths. (Cover the needle with a cloth to keep the pieces from flying.) By using the compass you can show that each piece is a complete magnet. Hold one end, then the other, of each piece to the compass. Each piece has both a north and south pole.

Only certain kinds of metals can be made into magnets: These are iron, steel, nickel, cobalt and special combinations of metals (alloys) such as Alnico (made of aluminum, nickel and cobalt).

Iron does not hold its magnetism very long. Magnets made of steel hold their magnetism for a long time, as do those made of special metals. Magnets such as these are called "permanent" magnets. Some common materials that cannot be magnetized or attracted by a magnet are copper, brass, glass, paper, plastic and many others.

So now we have our permanent magnets and know something about how they work. But where does electricity fit into all of this? Let's see how we can make magnetism from electricity — as well as from other magnets.
III. Electromagnets

Did you know that electricity can produce magnetism? The fact that it can is what makes electric motors run. It also makes possible buzzers, door chimes and automatic washers.

Demonstrating the magnetic field around a current-carrying wire.

In 1819, a Danish scientist by the name of Oersted discovered that there was a magnetic field around a wire carrying electric current. You can show that this is so with your compass.

Materials Needed
- An inexpensive compass
- A dry-cell battery
- Enameled copper wire
- Iron filings
- A sheet of cardboard

Connect one end of a wire loop to one terminal of a battery and run the wire directly over the compass. Touch the other end of the wire to the other battery terminal. What happens to the compass needle? The compass needle proves there is a magnetic field around the wire when current is flowing.

Iron filings can be used to see what this field looks like. Punch a small hole in a sheet of cardboard, pass the wire from the battery through the hole, and connect the other end of the wire to the remaining battery terminal. Holding the cardboard level, sprinkle iron filings on the cardboard near the wire. If you lightly tap the cardboard, you will see the filings arrange themselves in a circular pattern around the wire.

Making an electromagnet

What happens if we wind the wire into a coil?

Materials Needed
- A large 30-penny nail
- Small steel nails or tacks
- Enameled copper wire
- A dry-cell battery

Take a 30-penny nail and wrap about 10 turns of the wire tightly around it. Leave enough wire at each end to connect the ends to the battery terminals. Now, touch the end of the nail to a pile of small steel nails or tacks. What happens? You have made an electromagnet.

The nail was magnetized by the current flowing through the wire from the battery. If
you remove the wire from the battery most, if not all, of the tacks will fall. This is because without current there is no magnetism. This idea is used in making bells, buzzers and even huge electromagnets large enough to pick up car bodies in salvage yards.

Did you know that your electromagnet has a north and south pole just like a permanent magnet? You can prove this by holding first one end of the electromagnet, then the other, near your compass. How does the compass needle behave?

Now, reverse the wires of your electromagnet at the battery. Place it near the compass again. What happens? Changing the wires, which changed the direction of current flow, reverses the poles of an electromagnet. That’s something you certainly can’t do with a permanent magnet!

How can we make our electromagnet stronger?

*Additional Materials Needed*

A second dry-cell battery

Wrap 50 turns of wire around the nail and connect it again to your battery. Does the electromagnet pick up more tacks? Your magnet should be stronger because the greater number of turns of wire, the stronger the magnetic field.

Let’s try something else. Get a second battery and connect it in series with the first battery.

Hook up the leads of your wire-wrapped nail to the end terminals of the two-battery combination. Once again touch the magnet to the pile of tacks. The magnet is even stronger. This is because increased current makes the magnetic field more powerful.

Electromagnets are much more useful than permanent magnets. They can be made much stronger than permanent magnets, and they can be controlled by changing the current.

There are many uses for strong electromagnets. A crane with an electromagnet can be used to move iron and steel. The crane operator turns on the magnet switch to pick up heavy loads of scrap metals. He opens the switch to drop the scrap. A permanent magnet would not do the job. It would not be strong enough and you could not turn it on and off.

Obviously, being able to create magnets from electricity is quite useful!
IV. Working with Electromagnets

Now that we know how to make electromagnets from coils of wire, we can use these magnets to make some simple devices.

One of the most simple uses of electromagnets comes from their ability to switch a magnetic field on and off at will, and very quickly. This use is in bells and buzzers. These devices are very common and have many uses. They are most often seen in the form of doorbells, although many homes use ringing chimes instead of a simple bell. The bells or buzzers that let you know when classes have started or finished at school is another example.

Alarms that use bells and buzzers can warn us when it’s time to get up, or if the building is on fire or if a burglar is trying to break in. Buzzers and bells can be controlled by clocks, temperature controls, automatic “trip” switches and other means. Most often, though, they are controlled by a simple push button.

Let’s make a simple buzzer to see how it works.

Materials Needed

Eight ft. of No. 18 insulated wire
One 1 in. x 3 in. x 6 in. block of soft wood (pine)
One strip of tin ½ in. wide x 10 in. long from a tin can
Two 10-penny nails
Two carpet tacks
One 6-volt lantern battery or
Four ½-volt dry-cell batteries

Tools Needed

Pocket knife, pliers and hammer

Follow These Steps

1. Wind 100 turns of No. 18 wire around a 10-penny nail. Leave about 6 inches of wire free at the top. See Step 1.
2. Drive magnet nail into board as shown on sketch.
3. Bend the piece of tin into shape as shown on sketch.
4. Remove 1 in. of insulation from end of wire at top of magnet nail.
5. Place end of bare wire under tin strip. Use two carpet tacks to fasten tin strip and wire to board. Be sure tin strip does not touch the magnet nail.
6. Cut a piece of No. 18 insulated wire 18 in. long. Remove 1 in. of insulation from each end of wire.

7. Drive one end of wire into the hole with contact nail. Be sure to drive nail at exactly the right place. Free end of tin strip must be under nail head, but not close enough so tin rubs the nail itself.

8. Check two things before connecting the battery or batteries. The tin strip must be close to the head of the magnet nail, but not touching it. The end of the tin strip must also be under the head of the contact nail. See that the strip won’t rub the contact nail as it moves up and down.

9. Remove 1 in. of insulation from the end of wire coming from magnet nail.

10. Connect the two wires to the batteries in series or a 6-volt battery. Your buzzer will make a noise, if you have followed directions.

What makes your buzzer “buzz”? Just follow the flow of electricity from the battery and back to it. Let’s start at the battery and follow the wire to the contact nail. It goes up the nail, across the metal strip, through the wire of the magnet and returns to the battery. This is a closed circuit and electrons are flowing.

Your buzzer has a magnet similar to the one you made with a 30-penny nail. When electricity flows, it is a magnet. The moment the wires are connected to the battery, the circuit is closed, and the magnetism pulls the strip down against the head of the magnet nail. Now, what happens? As the strip bends down, it moves away from the head of the contact nail. That causes an open circuit. The electromagnet is turned off. Its holding power is lost. The metal strip springs back up and touches the contact nail. Then the whole action starts all over again.

The above action takes place very fast. The electromagnet turns on and off in only a fraction of a second. This causes a clicking sound. The clicks happen so fast they sound like a buzz. So, you have used a buzzer to change electricity into sound.

An electric bell works much like a buzzer, except the metal strip is attached to a clapper that strikes a bell — producing a ring instead of a click.

Let’s take a look at a typical electric bell and see how much like a buzzer it is. The diagram shows how a bell is usually put together.

A push on the button, normally held “open” (off) by means of a spring, sends the current from the battery or transformer through the circuit.

You will see that the current passes first through two small coils of wire, and each coil has at its center a piece of soft iron called the core. When the current is on, the core becomes magnetized and attracts another piece of iron called the armature with its clapper attached.

This action rings the bell, but it also breaks the current by pulling the spring away from the screw on its return to the power supply.
With the power off, the electromagnet lets the spring return the armature to its normal position. Contact is made again, and the cycle starts all over again — just as long as you continue to push on the button.

What if you didn’t want your buzzer to click as rapidly as possible, but only when you closed a switch? If you could do this, you would have the basis for a telegraph system.

Samuel Morse discovered this in 1840, and his discovery gave us the telegraph. Before this, the fastest way to send a message across the country was by pony express. Mr. Morse’s invention changed all that. With your own telegraph system you can send messages between rooms and even between two buildings.

![Fig. 1 Telegraph key](image)

**Materials Needed For One Telegraph Station**

Cut wood in following dimensions, before coming to the meeting:

- Two pieces 7 in. x 2½ in. x ¾ in.
- One piece 6 in. x 2½ in. x ¾ in.
- One piece 4 in. x 2½ in. x ¼ in.
- Two pieces 4 in. x 1 in. x ¾ in.
- One piece 2½ in. x 1¾ in. x 1½ in.
- One piece 5½ in. x ¾ in. x ½ in.
- Sheet metal, screws and small nails
- Fifteen ft. of No. 24 or similar size hookup wire
- Stove bolts -two ¼ in. x 1¼ in. flat head
  - two 3/16 in. x 1 in. round head
  - one 3/6 in. x ¾ in. flat head
- Machine bolts - one ¼ in. x 2½ in.
  - one ½ in. x 3 in.
- Wing nuts - two ¼ in.
  - two 3/16 in.
- One 6-volt lantern battery
- Rubber band
- Stiff cardboard disks
- Tacks
- Washers
- Glue

**Tools Needed**

Hammer, saw, screwdriver, twist drills, hand or power drill

**Building The Telegraph**

1. Assemble and drill the wood parts of the telegraph key and sounder as shown in Figures 1-4. Use glue and finishing nails to put them together.
2. Cut and bend a piece of sheet metal to form the key as shown in Figure 1. It should be about 4 in. x 1 in.
3. Attach one end of the key to the board with a ¼-in. x 1¼-in. flathead stove bolt. Countersink the hole in the bottom so the head of the bolt will be flush with the bottom of the board. Secure the bolt with a wing nut. Place another bolt and wing nut under the other end of the key. When the key is depressed, it should make contact with the top of the wing nut.

4. Make the electromagnet for the sounder by winding 50 turns of hookup wire on the ¼-in. by 3-in. bolt. Put stiff cardboard discs at each end of the coil to hold the wires in place. The ends of the electromagnet wires will be under the wing nuts on top of the sounder.

5. Referring to Figures 2-4, install the electromagnet and the sounder arm in the sounder frame. Put the bolt through the end of the sounder arm that goes under the coil. Make certain the sounder arm moves up and down freely.

6. The bolt in the electromagnet will not lose all of its magnetism when the current stops flowing. This will cause the sounder to remain in the up position. A rubber band looped over the sounder arm with only slight tension will pull the arm down the instant the current stops.
7. Wire the key, sounder and battery together as shown in Figure 5. If you wish to connect your telegraph station to another, simply run two wires from the terminals on your sounder to the terminals of the sounder at the second station.

8. When you press the telegraph key you will hear a click at the sounder. When you release the key, you will hear another click. If you connect your telegraph station to another, both sounders will click when either key is depressed. You are now ready to start sending messages.

It takes a little practice to send messages with a telegraph. First, you must learn the Morse Code. Then you must learn how to make dots and dashes with your telegraph. A “dot” (.) is a “click” with a pause before and after. A “dash” (-) is two quick “clicks” with a pause before and after.

Examples: The letter “A” which is represented by a dot and a dash (-.) would sound like this: PAUSE “CLICK” PAUSE “CLICK” PAUSE.

Let’s try the word “ME.” The letter “M” is represented by two dashes, and the letter “E” is represented by a dot.
V. Magnetism Helps You Measure Electricity

By now you can see that electricity and magnetism are closely tied to one another. Aside from being quite useful to do work for us, this relationship between magnetism and electricity helps us keep track of electricity by letting us measure its flow and pressure, or voltage. This is what makes electrical instruments work.

Instruments that can detect or measure the flow of electricity have helped to make possible the wonders of electricity as we know them today. Scientists in laboratories need measuring devices for experiments leading to new uses of electricity. Power suppliers must have instruments that tell what the generating equipment is doing and to measure the amount of electricity being sold to users. Factories need instruments that check on electrical equipment to make sure electricity is being used properly.

Most electrical instruments depend on the action of magnetism created by an electric current. Remember when we detected the magnetic field around a wire connected to a battery by using a compass? That was actually a simple electrical instrument or meter.

How sensitive is your simple electric meter?

Now, we are going to make a simple battery to use as a test! Take a copper penny and a dime, and clean off any corrosion or film with a bit of fine sandpaper. Now, take a piece of blotting paper about the size of the penny and dip it into strong salt water. Place the damp blotting paper between the penny and dime. Then place one wire between the dime and blotting paper and the other wire between the paper and penny. Be sure you have good metal-to-metal contact between the wires or "leads" and the coins.

At the instant you squeeze the leads against the coins, watch what happens to the compass needle. It should move for an instant from the north position each time you press the wires against the two coins.

This movement tells you that the little coin battery you have just made produces a very weak electric current. Even so, your instrument should be able to detect it.

Now let's make a meter that is a little more practical to use. A galvanoscope is an instrument that detects the presence of electric currents. It sounds complicated but it is really quite simple. It is named in honor of an Italian professor named Galvani who made important early experiments with electricity.

Materials Needed

- Insulated wire, about 6 ft.
- An inexpensive compass
- A copper penny
- A dime
- A small piece of blotting paper
- Strong salt water

Take about 5 ft. of wire and wrap it around your compass, keeping the turns bunched together as much as you can. Leave about six inches extended at both ends of the wire for leads, and scrape the insulation off the last inch of each end. Rotate the coil and compass until the needle and coil are parallel, both pointing north and south.
A refinement of the galvanoscope is today’s galvanometer. Other related instruments are the voltmeter (measures volts) and ammeter (measures amps). These are very important instruments to the electrical engineer and electrician.

Let’s make a galvanoscope.

**Materials Needed**

Two batteries; one large, one small
A glass or anything 3 to 4 in. in diameter
Paper clips
About 8 ft. of single strand enameled or doorbell wire
Cellophane or plastic tape
A block of wood about 3 in. x 4 in.
Two thin wood blocks about ½ in. x 2 in.
Two small nails
Glue, wax (to be melted) or copper staples
A glass of strong salt water
Two flashlight batteries

**Tools Needed**

Hammer

Using a glass or anything 3 to 4 in. in diameter, wind about 20 turns of wire in a “bunched” coil. Keep a few inches free at both ends. Wrap the coil at several points with tape to keep it from unwinding.

Make a wood base for your coil. The compass supports can be thin wooden blocks. Attach the blocks with glue, melted wax or copper staples. Do not attach them with steel nails or tacks. Hammer in two nails for terminals as shown in the figure above. Hold the coil in the slot between the wood blocks and fasten each end to the nail terminals. Place the compass on the supports and rotate the base so that the compass needle and coil are parallel, pointing north and south.

Now you can test your galvanoscope by measuring the voltage of batteries. Your meter can show you what difference the size of a dry-cell battery makes in the voltage it supplies.

To test the voltage of batteries we must be able to control our galvanoscope. To do this, connect a glass of strong salt water in series with the large battery. Make sure the wire ends immersed in the salt water are scraped free of enamel.

With one of the batteries connected to the galvanoscope, move the wires in the salt water first closer, then farther apart around the rim of the glass (keeping them parallel to each other) while watching your compass needle. When the
needle stays at a small angle off directly north, lock the wires in the salt water in place with paper clips.

Now disconnect the battery you have been using and connect a smaller battery. If both batteries are fresh, the compass needle should return to almost the same spot. This proves that both batteries regardless of size put out the very same voltage. The larger ones, however, are designed to last longer.

What else can we do with your meter? Let’s see if we can tell the difference between a series connection of two batteries and a parallel connection.

Using the salt solution as in the previous experiment, connect two flashlight batteries in series. The compass needle should move about twice as far as it did with one battery connected.

This shows that when you connect batteries this way you double their voltage.

Now place the batteries side by side and connect the two top terminals and the two bases. This is called a parallel connection. The compass needle should move only as much as it did for one battery. You can see that this arrangement does not double the voltage, even though you used two batteries.

While you have this hookup, try reversing the position of the leads connected to your batteries. Notice that reversing the direction of current flow in the coil causes the compass needle to swing in the opposite direction.

You can use your electric meter to show others how they can detect whether a battery is producing current, which way the current is flowing and whether a current is strong or weak.
VI. Motion from Electricity

Since we know magnets can move pieces of metal around, and since magnetism can be produced by electricity, we already have some idea of how electricity can produce motion. Of course, the major way in which this is done is with an electric motor.

Few people realize how important electric motors are in our everyday lives. Electric motors run so quietly that they are hardly heard. Also, electric motors have a long life. They require little maintenance so that they often outlast the equipment which they power.

How many electric motors do you have at home? Chances are you guessed too low. Count the electric motors you have in use and make a list. Be careful! This can be tricky! Don't forget the little electric motors that drive electric clocks, and those in small appliances, those that power the pumps and sprayers in washing machines, etc. See how many you can list.

What is there about electric motors that make them so popular? They are efficient, economical and easy to operate automatically. They are compact, run quietly and cause no air pollution. It is not necessary to store fuel nearby. They operate with a minimum of vibration and are not affected by hot or cold temperature.

Since electric motors are so important, we should know how they work. You have seen how permanent magnets and electromagnets work, and how like poles repel each other while unlike poles attract. Now we will see how this can be applied to the operation of an electric motor.

What happens when we place a permanent magnet near an electromagnet? Try this with your electromagnet nail and your permanent bar magnet. You will see that like poles repel, unlike poles attract, just as with two permanent magnets. Place the electromagnet and permanent magnet on a table top so unlike poles are end to end and they cling together.

But — remember how reversing the wires on an electromagnet reverses the poles? Carefully now, while the ends of your electromagnet and permanent magnet are together laying on a table, reverse the leads to the battery. What happens? The bar magnet is now repelled.

If you mounted the permanent magnet on a pivot, and placed its north pole next to the south pole of your electromagnet and then switched the leads to the battery, the permanent magnet would spin on its pivot away from the electromagnet until it made a complete half turn and the unlike poles were together again. If you reversed the leads again, it would spin another half turn. If you kept reversing the electromagnet leads every half turn of the permanent magnet, and could do this fast enough, you would have a simple electric motor. In fact, this is roughly how an electric motor works. Of course, a motor that required someone to reverse electrical leads (very quickly) all of the time would not be very practical.
In an actual electric motor, the *spinning* magnet is an electromagnet whose poles are changed back and forth constantly, while the stationary magnet keeps its poles the same. Of course in a real motor, the changing of the poles is done automatically by changing the current direction. Also, the stationary magnet is shaped around the path of the rotating magnet in a real motor, to have the benefit of the attracting and repelling forces from both poles, thereby doubling the effect.

Let's now make a simple electric motor.

**Materials Needed**

One roll of No. 24 enameled wire

One roll of electrician's tape
Three 4 in. (20-penny) nails
Four 2½ in. (8-penny) nails
Four 3 in. brads (10-penny)
Board for motor base, 4 in. x 6 in. x ¾ in.
Two staples or 4 small brads
Two tacks
Two 3-volt dry-cell batteries (or a 6-volt transformer)

**Tools Needed**

Pocket knife, hammer, vise (or 2 pairs of pliers)

First, we will make the "rotor" or "armature," the spinning part of our motor.

Wrap about 1½ in. of a 4-in. nail with two layers of tape. This will be the shaft.

The iron core will be made of two pairs of 2½ in. nails. Wrap tape around each pair with heads and points alternated. Center a pair on each side of the shaft.

Place the pairs about 1 in. from the head of the shaft nail. Wrap them together with two layers of tape from tip to tip.

Start at the shaft and wind No. 24 enameled wire to one end and back. Then do the same on the other end. Always wind in the same direction. Leave 6 in. of spare wire at start and finish.

Now, we will make the "commutator." A commutator reverses the current automatically and keeps the electromagnet spinning.

Scrape all insulation off the ends of the wire. Bend the bare ends back and forth as shown. Lay them flat over the taped shaft, one on each side of the shaft. Hold the commutator down with narrow strips of tape.
Wrap tightly near the core and at the opposite end.

Next we will make the “stator” or “field” — the magnet that stays in one position and whose poles do not change. This could be a U-shaped permanent magnet, but we can use an electromagnet here, too.

Make the core by bending two 4-in. nails in the middle at right angles. Space the heads about 3 in. apart to form a horseshoe. Wrap together with two layers of tape.

Wind about 400 turns of wire around the center. Leave 4 in. of spare wire at start and finish. Attach to wood base at each end of the wire with staples or small brads bent over.

Finally, we will assemble the armature supports and the “brushes.” The brushes are simply wires that transmit electricity to the commutators. Since the commutator is spinning with the rotor, it cannot be directly connected to a source of current. The current-carrying wires must “brush” against the commutator to transfer the current — so these wires are simply called “brushes.”

Scrape the insulation from the ends of two 6-in. pieces of wire. Tack them to the base and bend them as shown to make brushes. Drive two pairs of 3-in. finishing nails into the base about 3¼ in. apart and in a line midway between the field poles. Wrap wire around the supports to form armature bearings. Scrape insulation off ends of wire from the field. Connect one end to a brush wire.
Now, let’s connect our motor and make it work.

Adjust the position of commutator and tension of brushes against it for best operation. Take the armature off the motor and connect the commutator wires to a dry-cell battery. Test the polarity of each end of the armature with a compass. Switch the connections on the commutator and test again. See how the compass needle changes direction?

With the armature still off, connect the field coil directly to the dry cell. Test the polarity of each end of the field with the compass. How can you reverse the polarity? Try it. It’s easy.

Reassemble the motor again and start it. Push the field poles slightly out of alignment with the turning armature. What happens to the motor’s speed? Can you explain why?

A motor then is simply two electromagnets. The stationary electromagnet is called the stator, while the rotating electromagnet is called the rotor or armature. A basic electric motor consists of only four main parts just discussed: stator, rotor, commutator and brushes. A motor works because the spinning magnet keeps trying to line up opposite poles with the stationary magnet.

There are many kinds of motors. What you have just made is a DC motor, since it operates on direct current. There are also motors which operate on AC (alternating current) and are used around the home and in businesses. We’ll learn more about these motors later on in our journey through the world of electricity.
VII. Making Electricity from Magnetism

We know that we can make magnetism from electricity and have put together electromagnets and a simple motor. But did you know that you can turn the tables and produce electricity from magnetism?

In 1831 an English scientist named Michael Faraday discovered that magnetism can produce electricity. The effect is called “electromagnetic induction,” because a magnetic field “induces,” or causes, an electric current in a wire.

Magnetism can produce electricity simply by moving a conductor through a magnetic field so that there is relative motion between the conductor and the field. Motion is the key. It does not matter whether the conductor or the magnet moves, so long as one moves with respect to the other. In a sense, the conductor cuts the magnetic lines of force. Let’s see how electricity can be produced.

Materials Needed

Your galvanoscope
Insulated wire, about 6 ft.
An empty paper towel spool
A bar magnet
A dry-cell battery

You can show this using your galvanoscope that you made earlier. Simply disconnect the battery from the galvanoscope and connect one end of a rather long (2 or 3 ft.) insulated wire to one of the galvanoscope leads. Wrap the wire loosely for several turns around an empty paper towel spool. Then slide the spool out gently, leaving an open coil of wire. Connect the remaining lead to the other galvanoscope wire.

Now, be sure the compass and the large galvanoscope coil are lined up pointing north and south. Next, hold a fairly strong bar magnet by one end and steadily (but not too slowly) pass the magnet through the open coil. What happens to the compass?

Move the magnet more rapidly. Now what does the compass do? The faster you move the magnet, the greater amount of electric current is produced.

The same effect can be achieved without physical motion just by changing the magnetic field itself. This can be done by using an electromagnet instead of a permanent magnet. Let’s see how this works.

Carefully slip the paper towel spool back into the coil made above. Take another length of wire and wrap it around the same way as the original coil. You now have two different coils on the same core. Connect one lead wire of the new coil to a dry cell. Now, touch the free end of the remaining wire of the new coil to the battery terminal. What happens to the compass in your galvanoscope? It should move for an instant and return to its original position. What happened?

As you touched the wire to the dry cell, completing the circuit, you created an electromagnet out of the coil of wire. As the magnetic field built up from zero to its full strength as the current began to flow, it had the same effect as moving the permanent magnet through the coil.
So, a changing electric current is needed to produce a changing magnetic field to induce an electric current in another wire. Opening and closing a switch is a rather impractical way to produce a constantly changing electric current. What could be used instead?

If AC (alternating current) electricity is constantly changing, this could be used to produce a changing magnetic field. If we connected an AC source to our first coil, we would have a constantly changing magnetic field produced around the coil. The field would have its north pole at one end of the coil during one part of the AC cycle (while the current is flowing in one direction), and would then reverse poles during the second part of the AC cycle (while the current is flowing in the opposite direction).

Not only would we have a constantly changing magnetic field around our coil, but its north and south poles would be switching back and forth from one end to the other, 60 times per second. What would this do to our second coil?

The changing magnetic field in the first coil would of course induce an electric current in the second coil, just as when we used DC current and played with the switch. However, since the magnetic field in the first coil would be alternating its north and south poles constantly from one end to the other, the electricity induced in the second coil would flow first in one direction, then the other. In other words, the electricity flowing in the second coil would be AC current, too!

This brings us to an important point. Unless physical motion is used (like moving a magnet near a coil of wire), the only practical way electricity can be induced in a coil of wire is to apply AC current to an electromagnet nearby. You will see why this is important when we study transformers a little later.

NOTE: Don't try this experiment by plugging your coils into a regular AC outlet at home. The voltage is too high and it is dangerous.

So a changing magnetic field can produce an electric current. How much current is produced depends on the strength of the magnetic field, and how fast it is changing (the rate of speed at which a conductor or coil cuts the magnetic field).

To generate electricity we can use a changing electric current to produce a changing magnetic field, and then motion in a motor, or we can reverse the process. By physically moving a conductor in a magnetic field, we can produce an electric current. Using the simple DC motor you made earlier, let's try to produce electric current.

**Materials Needed**

- Your DC motor
- One 4-in. nail
- Tape
- A dry-cell battery
- A small light bulb or your galvanoscope
- Two thin strips of aluminum foil

First, we'll have to make a few changes

Using a bent 4-in. nail and some tape, add a crank to the shaft of the armature. Separate the wires to the stator coil and the wires to the brushes. Connect the stator coil wires to a dry
cell, and the wires from the brushes either to a small light bulb or to your galvanoscope. Now, turn the crank on your generator. What happens? Turn the crank faster. What happens then? You have just made a simple DC generator.

This can be turned into an AC generator simply by changing the commutators. Wrap the shaft with a thin strip of aluminum foil that makes contact with one of the commutator wires. Make sure the foil doesn’t touch the other commutator wire. Wrap another strip of aluminum foil around the shaft beside (but not touching) the first strip, and making contact with the other commutator wire. Place the armature back on its supports. Now bend the brushes so that one wire slides over one of the foil strips and the other wire slides over the other foil strip. Make sure the stator leads are still connected to the dry cell, and connect the brushes to the galvanoscope.

Now, turn the armature crank. What happens to the compass? If you hooked up your galvanoscope to the motor, you will find the needle of the compass will swing first one way and then the other as you turn the crank. This means you are producing alternating current. Large commercial generators work in this way, but their armatures are turned by steam, gas or water.
VIII. Other Ways Electricity and Magnetism Work Together

We have seen how electricity and magnetism work together — to produce one from the other and to produce motion by working as a team.

There are other ways they work together, too — very important ways that help us control electricity and use it for our convenience. For example, there is a device with which you can vary the level of voltage, all the while keeping the amount of power delivered by the electricity unchanged. This device requires the use of both electricity and magnetism. It is called a transformer.

Suppose you had a piece of equipment — like a doorbell — that required 6-volt electricity to operate. However, you might only have 120-volt electricity available at the wall outlets in your house. If you go ahead and use the higher voltage, you would surely burn out the equipment. What can you do? The answer is to use a transformer.

You will remember how we produced an electromagnet from electricity. In effect, we had half of a transformer. You also remember how we showed that electricity could be induced in a coil of wire by using a changing magnetic field. We can now put these two effects together to make a transformer.

The basic construction of a transformer consists of a primary coil and a secondary coil insulated from each other, but wound on the same doughnut-shaped iron core.

When alternating current flows in the primary coil, an alternating magnetic field is established. Most of the lines of force of this field bend around through the iron core, since magnetism prefers metal to air. In other words, we have made an electromagnet out of the primary coil.

As noted earlier, this electromagnet has its north and south poles alternating back and forth from one end of the coil to the other in step with the cycles of the alternating current. Now, we come to the second side of the transformer.

When the alternating magnetic field is set-up in the iron core due to the primary coil, the changing magnetic field induces an electric current in the secondary coil. Of course, this current alternates from one direction of flow to the other in step with the alternating magnetic field in the core. So, AC electricity flows from the second coil.

AC in — AC out. If that's all we're going to do, why all the fuss? Why not skip the transformer and connect the primary directly to the secondary? The answer lies in the fact that the transformer is a control device. It allows us to vary the voltage in an AC circuit as needed. We can do this very simply — by keeping track of the number of turns of wire in each coil.

If we want less voltage coming out of the transformer than goes in, we make sure there are fewer turns of wire in the secondary coil than in the primary. This is called “stepping down” the voltage. If we want more voltage than we start with, there should be more turns in the secondary. This is known as “stepping up” the voltage.

In fact, we can vary the voltage exactly in this manner. If we want to cut the voltage in
half, we put half as many turns of wire in the secondary coil as we put in the primary coil. If we want only a fourth as much, we use one-fourth as many turns. If we want five times the original voltage, our secondary coil should have five times as many turns of wire. It's as simple as that!

It's important to remember that transformers will not work on DC electricity. A DC source would set up a magnetic field in the core from the primary winding, all right, but this field will not induce an electric current in the secondary coil. Can you tell why?

Transformers are very useful. They can help us use electricity better — in everything from electric train sets to huge electric power stations — wherever we need to change the amount of voltage used.

Another way electricity and magnetism work together to serve us is in speakers — in all sound equipment from portable radios to the huge public address systems used in stadiums and theaters.

You know electrical energy can produce sound energy because we have already examined buzzers and bells that make noise. But, we can also use electricity to produce sound energy in varying patterns — such as voices or music.

Loudspeakers convert variations in electrical energy into similar variations in sound energy, with the intermediate step being magnetic energy. Let’s see how this works.

A simple loudspeaker consists of a U-shaped permanent magnet placed so that its poles are near, but not touching, a thin steel plate or diaphragm. Around each leg of the magnet is wound a coil. The coils are connected to a source of electricity which varies according to the vibrations of a voice or musical tune. The coils thus become electromagnets which add their magnetism to that of the permanent magnet. The magnetic field of the electromagnets, however, varies constantly according to the varying electric current. This means a varying magnetic field acts on the steel diaphragm, bending it closer in toward the magnet the stronger the field. If this happens fast enough, the steel diaphragm will literally vibrate and produce sound waves.

Something similar to this happens when you pluck a guitar string. The string vibrates so fast that it makes the air around it vibrate and produce sound waves.

In the case of a loudspeaker, the steel diaphragm is the “string” and a varying magnetic field does the “plucking.” Since the magnetic field varies according to a voice or music signal, the steel diaphragm vibrates according to the signal, and that in turn sets up sound waves that vary according to the signal — so you actually hear the original voice or music.

A telephone receiver works in the same manner. The voice of your friend traveling as a varying electric current through the telephone wires enters the receiver and causes the magnetic field to change rapidly according to his voice. This makes a steel diaphragm vibrate according to the field, and that sets up sound waves which you hear as his voice.

We'll look at more ways electricity and magnetism work together in later units.
IX. Electricity: The Great Magician

How would you think that electricity is most like a magician? Because it’s invisible? Perhaps — but then so is the wind. The real “magic” of electricity is the manner in which it can perform and change itself into something else.

The “something else” is another form of energy. All electrical devices and gadgets you own and which are used in businesses and industries are simply machines that change electrical energy into other kinds of energy. The work of scientists and engineers has gone into the development of such machines and many jobs and careers depend on their manufacture and sale.

We have seen that electrical energy can be changed into light energy. That gives us electric lights to read and work by. Light can beautify and add excitement to our buildings and neighborhoods by night — as well as increase our safety.

We also saw how electrical energy is changed into heat energy to cook our food, warm our homes or even melt steel in huge electric furnaces for industry. Electrical energy can also be turned into magnetic energy which can be used to lift heavy loads or to help control equipment. Also, electrically-produced magnetic energy serves as a step in changing electricity into motion.

Motion produced by electricity is of course important in electric motors, which quietly and reliably power many things from clocks to food mixers, to washing machines to power tools, and large machines in industries.

Electrically produced motion can also produce sound. Bells, buzzers and loudspeakers and telephone receivers are examples. This has helped revolutionize the way we communicate and has led to the development of the telegraph, telephone, radio, TV and other devices. We even saw how electrical energy can be changed into chemical energy, as in electroplating. But all of this is only part of the story.

As we noted before, we have to get the electricity in the first place. Since we can’t just go out and dig it up or raise it from seeds, we have to change other forms of energy into electricity first. Chemical energy is converted to electricity in batteries. Energy of motion and magnetic energy combine to produce electricity in generators.

Electric power suppliers usually use several steps to make electricity: they start with the chemical energy in coal or oil — or atomic energy in uranium — to produce heat. The heat is changed to motion through the pressure of hot steam. This energy of motion, a fast rotating “windmill” or “turbine,” is changed to electric energy.

As we will learn later, electricity can be produced from sound, as in microphones and telephone mouthpieces. Light can even produce electricity, as in the photo-electric cells that open doors automatically.

This is really the story, then, of how we use electricity. By converting heat, chemical, light, sound or energy of motion to electricity, we can send that energy to another location. At the end of its trip, we can then change the electricity back into light, heat, motion, sound or whatever form of energy we need to use.

That is what really makes electricity almost magic. In a way, it helps us move our energy resources around invisibly and instantly, without hard labor.

In later parts of our journey through the world of electricity, we’ll learn more about how this “magical energy” works, and how you can work with it.

The next unit, Unit III, in the Electric Energy program is Working With Electricity. This unit is a practical how-to manual with lessons dealing with the basic equipment for distributing electricity in the home and ways of working with them.

The unit covers wiring systems; lights and good lighting practices; selection, operation and maintenance of appliances; home environment control equipment; the measurement and conservation of energy; general maintenance and safety practices; and general industry career information.
Glossary of Terms

Ammeter — An instrument which measures the amount of current flow in a circuit (Lesson V).

Armature — The revolving electromagnet in an electric motor or generator (Lesson VI).

Brush — The sliding, slipping contact which transfers electric current to the armature of an electric motor, or from the armature of a generator (Lesson VI).

Commutator — The contact fastened to the axis of the armature of a motor or generator which transfers electric current to or from the brushes (Lesson VI).

Compass — An instrument using a balanced, rotating permanent magnet which always points north to the earth’s north magnetic pole (Lesson II).

Core — The metal form around which the wires of an electromagnet or transformer are wrapped, and which serves to channel the magnetic field (Lesson III).

Diaphragm — A thin metal sheet which moves or vibrates in a changing magnetic field, as in a loudspeaker or telephone receiver (Lesson VIII).

Electromagnet — A magnet formed by the magnetic field produced around an electric current (Lesson III).

Galvanoscope — An instrument which uses the magnetic field produced around an electric current to measure amperage and voltage (Lesson V).

Generator — A device which uses the interaction of changing or moving magnetic fields with conductors to produce electric current (Lesson VII).

Induction — The phenomenon by which an electric current in one circuit can cause an electric current to flow in another circuit without being connected to that circuit, by using changing magnetic fields (Lesson VII).

Lodestone — Name first given to natural magnetic stones (Lesson II).

Magnet — A device which attracts certain metals; such as iron, steel, nickel and cobalt (Lesson II).

Magnetic Field — The area in which force of attraction surrounding a magnet is effective or measurable (Lesson II).

Magnetism — The attractive force shown by magnets (Lesson II).

Molecule — The smallest unit of any material which still has the same properties as the material. Composed of atoms of elements which make up the material (Lesson II).

Pole — An area at either end of a magnet where the magnetic field is the strongest (Lesson II).

Primary — The first coil of a transformer into which electricity is brought. Produces a changing magnetic field in the core (if the electricity is “AC”) (Lesson VIII).

Rotor — The revolving electromagnet in an electric motor or generator (Lesson VI).

Secondary — The second coil of a transformer, in which an electric current is induced by the changing magnetic field in the core (Lesson VIII).

Solenoid — An electromagnet in which the core is free to move in and out of the coil under influence of the magnetic field (Lesson III).

Stator — The outer, stationary electromagnet in an electric motor or generator (Lesson VI).

Transformer — A device which uses the interaction of electric current and magnetism to raise or lower the voltage or amperage in an electric current (Lesson VIII).

Voltmeter — An instrument which measures the amount of electrical pressure, or voltage, in a circuit (Lesson V).