Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES
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MAGNETS AND ELECTROMAGNETS

ASSIGNMENT 8

MAGNETS and ELECTROMAGNETS

In Assignment 5 we studied the effects produced by an electric field. We found that a charged body was surrounded by a region wherein other objects were attracted. We said that an *electric field of force* existed in this region. The law concerning electric charges, and of course the electric field surrounding the charged bodies, is: *like charges repel and unlike charges attract.*

In this assignment we are going to study the *magnetic field of force.*

Everyone is familiar to a certain extent with the *magnetic field of force,* or as it is commonly called, *magnetism.* Most of us have at some time or other experimented with small magnets, used them to pick up nails, small bits of iron, etc. Magnetism makes a fascinating plaything, but it is also very important in our everyday life. It is used in the compasses which guide ships at sea, in electrical generators which supply the electrical power for our homes, in our radio and television receivers, in electronic computers, and in countless other applications.

Many centuries ago, the Greeks learned that certain pieces of ore possessed the ability to attract particles of iron. Since this was a very mysterious happening, pieces of this ore were carried as good luck charms. No practical application was made of magnetism for several centuries until it was found that if an elongated piece of this ore was suspended on a string, it would always align itself in a northerly direction. For this reason the ore was called *"lodestone",* meaning "leading stone". The first compasses were made in this fashion. It was later discovered that pieces of iron could be magnetized by "stroking" a lodestone with a piece of iron. These pieces of iron, after being magnetized, would act as magnets themselves, and could be used for compasses. A piece of iron (or steel) which holds its magnetism for a long period of time is called a *permanent magnet.*

Permanent Magnets

Let us find some of the characteristics of a permanent magnet. A permanent magnet, in the form of a bar, has two ends. These ends are called the *poles* of the magnet. The end which will point in a northerly direction, if the magnet is allowed to rotate, is called the *North-seeking pole,* or *North pole.* The other end of the magnet is called the *South-seeking pole,* or *South pole.*

If a small piece of iron is brought close to a permanent magnet, the magnet will attract the piece of iron, and "draw" the iron to it. This happens while the magnet and piece of iron are still separated. The force from the magnet extends into the air surrounding the magnet. This region in which the magnetic force acts is called the *magnetic field of force,* or more often the *magnetic field.* This magnetic field is usually considered to exist in the form of lines of force which leave the magnet at the north pole and return at the south pole. This is illustrated in Figure 1. Notice in this figure that the lines of force are concentrated at the ends of the magnet and spread out near the center of the magnet. The north pole on this magnet is marked N, and the south pole is marked S. If a bar magnet is placed under a piece of paper, and iron filings are sprinkled on the paper, the iron filings will arrange themselves in a pattern as shown in Figure 1 (without the arrowheads of course).

There are two general classifications of materials as far as magnetism is concerned; magnetic and non-magnetic. A magnetic material is one which will be attracted by a magnet. Iron and steel are the best known magnetic materials. Nickel and cobalt are also attracted by a magnet, but to a lesser degree. All other materials are non-magnetic. For example, a piece of copper or silver is unaffected if brought close to a magnet. There are few materials which are actually slightly repelled by a magnetic field. This action, however, is so weak, that it is of no practical value.

The fundamental law of magnetism is: *Like poles repel and unlike poles attract.* This is the phenomenon which makes the magnet act as a compass, or "point to the north". The earth itself is a magnet. The two magnetic poles of the earth are located within a few hundred miles of geographic poles. The entire earth is surrounded by the magnetic field of this giant magnet. When another magnet is pivoted so that it is free to rotate, the *north seeking* pole of the magnet will be attracted by the earth's magnetic pole near the north geographic pole. The magnet or compass will point to the earth's magnetic pole. The law of magnetism states that the *unlike poles* attract, therefore the magnetic pole located near the north geographic pole is actually a south magnetic pole since the north poles of the compasses are attracted by this magnetic pole.

To further demonstrate the laws of magnetism, let us look at Figure 2. At (A) in this figure we see a small compass. The north pole of this compass is shown darkened so that it can be determined which pole of the compass is the north pole. In (A) the compass is acted upon by the earth's magnetic field, and the north pole of the compass points north. In (B) of this figure the compass is shown close to the north pole of a permanent magnet. The field of this permanent magnet is much stronger than the earth's magnetic field, so the compass rotates on its axis and the south pole of the compass points to the north pole of the magnet. In (C) of this figure the compass is brought close to the south pole of a magnet. Now the north pole of the compass is attracted by the south pole of the magnet.

The attraction of unlike poles and repulsion of like poles is due to the action of the magnetic fields. In Figure 1 we saw the pattern of the magnetic field around a bar magnet. In Figure 3 we see the pattern of the magnetic field if two bar magnets are held with their north poles adjacent. Notice how the fields oppose each other, trying to force the magnets apart.

Figure 4(A) shows the field of force around the ends of two bar magnets with their opposite poles adjacent. Notice that in this case the lines of force do not repel each other, but aid each other. The magnetic field between these two unlike poles is much stronger than it would be around the poles of either of the bar magnets, if they were not close together. One way then of obtaining a strong magnetic field is to bring two unlike poles close together. This can be done with two bar magnets as illustrated, but can be accomplished more simply by bending a single bar magnet in the middle, and making it in the shape of a horseshoe. This shape of magnet is used in most meters which are used to measure d-c current and voltage. A typical horseshoe magnet, and a diagram of the field of force around it, is shown in Figure 4(B).

A strong magnetic field is desirable since it is a field of *force* and if we have a stronger field we can do more work with it. We could pick up heavier pieces of iron, etc., than we could with a weak field. When a magnet is used in a meter, a strong field will make the meter more sensitive. That is, for the same amount of current, the meter deflection will be greater.

A number of theories have been advanced to explain magnetism. The latest theory, and the one which appears most logical, fits in very well with the electron theory. According to this theory, the atoms or molecules in all matter are small magnets. In an unmagnetized piece of material the molecular magnets are arranged in a random manner. This is shown in Figure 5 (A). The net result of these small magnetic fields is zero. When this bar becomes magnetized, the molecular magnets are lined-up as shown in Figure 5(B). The magnets are now aiding each other, and their fields all add up to produce a strong magnetic field about the bar.

Most permanent magnets are made from hard steel. In such a material, it is difficult to magnetize the bar, or line-up the molecular magnets, but after they are lined-up they will hold this position for long periods of time. If a piece of soft steel or iron is magnetized, it is a simple matter to align molecular magnets, but when the magnetizing force is removed, the molecular magnets return readily to their original position and the bar does not retain its magnetism. It is possible to magnetize a piece of iron or steel by stroking it with another magnet. We will soon discuss a much simpler and more effective way of doing this.

Up to this point we have discussed only permanent magnets. Permanent magnets are used in meters, speakers, motors, T.V. receivers, etc.

Electromagnets

There is another form of magnetism which plays an important part in electronics and television. This is the *electromagnet.* An electromagnet is a magnetic field which is produced by electric current.

Figure 6 shows a large electromagnet which is used for handling scrap iron. The operator lowers the large disc on the end of the boom over the scrap metal and closes a switch on his control panel. The disc becomes a very powerful magnet and attracts the scrap iron, holding it securely. Then the operator moves the vehicle to the desired location and opens the switch on his control panel. The electromagnet loses its magnetism and drops the scrap iron.

Figure 7 shows a very common form of electromagnet. It is a doorbell. When you press the doorbell switch, current flows through the circuit from D, through the coils of wire, and through the contact screw to B. This current flow causes the coils to become magnets and they attract the soft iron armature. This armature is held away from the magnets by spring tension, but when the coils become electromagnets the armature moves to the right, toward the magnets, and the hammer strikes the bell. If the coils remain electromagnets the hammer would remain against the bell, but this does not happen because as the armature moves to the right, the circuit is broken and current no longer flows through the coils. The circuit is broken because, as the armature moves to the right, the movable contact which is fastened to the armature also moves to the right, and is no longer touching the contact screw. This opens the circuit, current no longer passes through the coils, and they are no longer magnetized. The spring tension returns the armature to its original position. After the armature returns to its original position, the entire cycle repeats itself. Study Figure 7 to satisfy yourself that you see just how this action takes place.

These two examples were shown to give an idea of what happens, before we find out how it happens. We find from these two examples that magnetism can be produced by passing an electric current through a coil of wire. When the current stops flowing, the electromagnetic field no longer exists.

How The Field Of An Electromagnet Can Be Produced

Now let us find out how this electromagnetic field is produced. If a piece of wire is connected to a battery as shown in Figure 8, current will flow through the wire in the direction indicated. This wire will be encircled by a magnetic field. If a small compass is passed around the wire as indicated in Figure 8, the compass needle will take the positions indicated. If the connections to the battery are reversed, the current will be flowing through the wire in the opposite direction, and the compass will point in the opposite directions to those indicated in Figure 8. In each case the compass indicates the direction of the surrounding magnetic field. The magnetic field around the wire is in the form of concentric circles.

If a piece of wire is thrust through a sheet of paper as shown in Figure 9, and is then connected to a battery, a magnetic field will encircle the wire. If iron fillings are sprinkled on the sheet of paper, they will align themselves in a pattern as shown in Figure 9.

If we know the direction of electron flow through a wire, we do not need compasses to determine the direction of the magnetic field. Check the following rule with direction of magnetic field indicated by the compass needles in Figure 8. *If we grasp the conductor with our left hand so that our thumb points in the direction of electron flow, the remaining four fingers of our left hand will curl in the direction of the magnetic field around the conductor. This is called the left-hand rule.* Remember, the magnetic field is considered "to flow" from north to south outside of the magnet. The left-hand rule is demonstrated in Figure 10(A).

In Figure 11(A) we used the left-hand rule to determine the direction of the field around the conductor at five different locations. Check the position of arrowheads on the tiny loops until you are satisfied that they are correct.

If we double the amount of current flowing through the wire, the magnetic field will be twice as strong. The best way to obtain a strong field, however, is to wind the wire in the form of a spiral or coil.

In Figure 11(B) we have made a coil with the wire. Check each loop around the wire. Has every loop been shown with its arrowhead in the correct direction? Notice, that inside the coil the field direction is from right to left at every point. If we wind the "turns" of our coil more closely together (Figure 12), we have most of the magnetic field passing straight through the center of the coil and out the left hand end. The left end of the coil acts like the North Pole of a permanent magnet because the field is leaving that end. If we reverse the direction of current in the coil, the left end of the coil will be a South Pole.

It is easy to see what happens when we wind the wire in the form of a coil. Some of the magnetic field will still encircle individual wires in the coil. However, the fields produced by adjacent wires are in opposite directions between the wires and tend to cancel each other. Most of the field then will encircle the coil, end to end, as shown in Figure 12.

Another application of the left-hand rule makes it easy to determine which end of a coil will have a north magnetic pole. This application of the left-hand rule is demonstrated in Figure 10(B). If the coil is grasped with the left hand so that the fingers point in the direction of the current flow, the thumb will point to the north pole of the electromagnet. Apply this rule to the coil in Figure 12, and see if you agree with the marking of the poles of the electromagnet in the diagram.

The strength of the magnet field about a coil may be increased by adding more turns to the coil, or by increasing the amount of current flowing through it.

The coil of copper wire in an electromagnet is used to produce a magnetic field. This magnetic field, by itself, will not be strong enough to operate the doorbell buzzer, to say nothing of the steel-yard electromagnet. We have to add iron for a magnetic core in order to obtain very strong magnetic fields. The addition of an iron core to an electromagnet may increase the magnetic field as much as 100 or more times.

As was pointed out in the discussion of permanent magnets, each molecule of a material has its own magnetic field. If a piece of soft iron is inserted in the coil of an electromagnet and current is caused to flow through the coil, the magnetic field of the coil will pass through the soft iron core. This magnetic field will cause the molecular magnets in the soft iron core to "line-up" as shown in Figure 13(B). The lining-up" of these molecular magnets in the core material will produce a magnetic field much greater than that produced by the coil alone.

Soft iron is used as the core of electromagnets because it is easy to line-up the molecular magnets in a piece of soft iron. Also, when the electrical circuit is broken by opening the switch, as shown in Figure 13(A), the molecular magnets return to their original positions, and the electromagnet loses its magnetism. Thus, in the steel yard electromagnet, the scrap iron will be dropped when the operator opens the switch on his control panel, and in the doorbell the armature will return to its original position when the contact is opened.

It was mentioned previously, that there is a simple method of producing permanent magnets. This is done by placing a piece of hard steel inside a coil of wire and passing a *very strong* current through the coil. A very strong current is needed because a strong magnetic field is required to line up the molecular magnets in the hard steel. After this hard steel has been magnetized, it will retain its magnetism after the current in the electromagnet is stopped.

We will sum up the fundamental principles we have covered so far:

1. A magnetic field is the field of force which surrounds a magnet.

2. A magnet has two poles, North and South.

3. Like magnetic poles repel each other.

4. Unlike magnetic poles attract each other.

5. Permanent magnets are made with hard steel and retain their magnetism.

6. Any piece of wire carrying an electric current has a magnetic field around it.

7. We can increase the magnetic effect of an electric current by increasing the amount of current or by winding the wire in the form of a coil, and, in this case, the magnet so produced is called an electromagnet.

8. If we place a soft iron core in the coil of wire carrying current, we can obtain very strong magnetic fields. The soft iron core becomes magnetized and adds its strong magnetic field to the magnetic field of the coil.

9. The Left Hand Rule can be used if we need to know which end of a coil is the North Pole and which is the South Pole.

Units of Measurement of Magnetism

We have seen that the *magnetic line of force* is a closed loop or path, passing from the north pole to the south pole of a magnet. The space through which these lines of force act is called the *magnetic field.*

To a great extent, the action of a magnetic circuit can be compared to the action of an electric circuit.We learned in Assignment 6 that in an electric circuit, the current flowing was dependent upon two things, the e.m.f., or voltage and the resistance. To state this as a formula we may write:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Notice that this means that the amount of effect produced (current flow) is equal to the force applied (volts or e.m.f.) divided by the opposition (resistance).

In a magnetic circuit, the effect produced is the magnetic lines of force, or *flux* as it is commonly called. The magnetic force, that is, the force which tends to produce magnetism, is called the *magnetomotive force* (abbreviated mmf). The opposition to the passage of magnetic lines of force, or flux, through a material is called the *reluctance* of the material.

The formula for magnetic circuits is:

$$\text{Flux} = \frac{\text{Magnetomotive Force}}{\text{Reluctance}}$$

Notice that in this formula, the effect produced is equal to the force applied, divided by the opposition.

The unit of magnetic flux is the *maxwell.*

The unit of magnetomotive force is the *gilbert.*

Reluctance is measured in gilberts per maxwell.

These units were named for famous scientists who devoted a great deal of time to the study of magnetism.

If we examine the formula for magnetic circuits carefully we are able to see the reason for several things that have been mentioned. For example, it was stated that the magnetic field (flux) around a coil could be increased, if the current flowing through the coil were increased. The formula shows that this would be true, for with an increased current through the coil the mmf would be greater, and consequently the flux would be increased. It was also stated that more flux would exist if an iron core were placed in a coil of wire carrying a current. The iron core offers less opposition to the magnetic lines of force, or in other words, has a smaller reluctance, than air. It can be seen that if the reluctance is made smaller in the formula, that the flux will increase.

There are two other terms which are used when considering magnetic materials. These are *permeability* and *retentivity.*

Permeability is just the opposite of reluctance. Reluctance is a measure of the opposition offered to magnetic lines of force. Permeability is a measure of the ease with which lines of force can be set up in a material. The more permeable a material is, the better it will "conduct" magnetic lines of force, and consequently the better core it will make for an electromagnet. The permeability of air and all non-magnetic materials is 1. The permeability of iron is about 50. Silicon steel has a permeability of about 3,000, and some special magnetic materials have permeabilities of as high as 10,000. This means that if a core of this special magnetic material is added to a coil of wire which is carrying current, the magnetic field will be increased 10,000 times.

Retentivity is a measure of the ability of a piece of material to retain its magnetism, after the magnetizing force is removed. For some applications, high retentivity is desirable, and for some applications, low retentivity is desirable. The material used for permanent magnets should have high retentivity. After these pieces of material have been magnetized, it is highly desirable for them to retain their magnetism for many years. The cores of most electromagnets are made of material with low retentivity. This is because in most cases, it is desirable for the electromagnet to lose all of its magnetism when the current flow to the coil is stopped. For example, when the operator of the steelyard crane shown in Figure 6, opens the switch on his control panel, the current to the coil is stopped, and the electromagnet should become demagnetized, so that the scrap iron can be dropped.

Let us now study a few applications of the electromagnetic principles. One application of electromagnets is in relays.

Relays

Relays are switches which may be controlled from some remote position. They consist of an electromagnet and one or more sets of contacts. Three typical relays are shown in Figure 14. Examine these pictures and identify these parts on the relays.

(1). Electromagnet. This is the circular shaped part near the center of each. These electromagnets are wound with a large number of turns of wire and have soft iron cores.

(2). Armature. This is the movable part of the relay which is held away from the electromagnet by spring tension.

(3). Contacts. There are two parts to each contact, the movable contact and the fixed contact.

Notice the contact on the relay shown in Figure 14(A). The *fixed* contact is mounted rigidly on the insulated mounting block. When the electromagnet on this relay is *not* turned on, the movable contact is held away from the *fixed* contact by the spring tension on the armature. When the electromagnet is turned on, or energized, as the act of turning on an electromagnet is commonly called, the movable contact is pulled down with the armature and is held against the fixed contact. Such a set of contacts is called a *normally open set of contacts.* It is possible to have a relay with contacts which are held closed by the spring tension, and then are opened by the action of the electromagnet. These contacts are called *normally closed contacts.* The relay shown in Figure 14(B) has a combination of these two types of contacts. Let us see how it would work. The movable contact is on the armature. When the electromagnet is not energized, the spring tension holds the movable contact against the top fixed contact. This contact is normally closed. When the relay coil becomes energized, the armature pulls down and opens this top contact circuit, but at the same time the movable contact is pulled against the lower contact and closes this circuit. The relay in Figure 14(C) has two sets of contacts (only one set is completely visible in the picture). Each of these sets has one normally open and one normally closed contact.

Relays may be purchased with almost any arrangement and number of contacts. They are used very widely in transmitters and in electronic equipment.

Figures 15(A) and 15(B) show a very simple circuit using a relay. In Figure 15(A) the switch in the *control circuit,* in series with the electromagnet coil and the battery, is open. Therefore, there is no current flowing through the coil and it is not magnetized. The contacts in the *controlled circuit* are "open" and no current flows through the lamp.

In Figure 15(B) the switch in the control circuit is closed. Current flows through the electromagnet coil. When the electromagnet becomes magnetized, it draws the armature toward it, to the left in the drawing, and closes the contact in the controlled circuit. (Current flows from the battery in the controlled circuit, through the closed contact and the lamp, lighting the lamp.) To turn the lamp off it is only necessary to open the switch in the control circuit.

The question might arise, why not just put a switch in the lamp circuit and not use a relay. The answer to this is that the switch in the control circuit is a small switch and will handle only a small current. If the lamp in the circuit is a large lamp it will have a large current flowing through it, and this large current would ruin the small switch. There is also the matter of convenience to be considered. The switch may be located remotely from the relay, thus a few small switches on a control panel may control a group of large relays at some remote point.

Let us show another example where a relay would be used. In a two-way radio installation in a police car there is a receiver and a transmitter. They are each drawing current from the battery, and will discharge the battery rapidly if they are both turned on at the same time. There is no reason for having them both on at the same time, since it is not possible to transmit and receive at the same time. This problem could be solved by having separate switches on the transmitter and receiver and turning one on and the other off each time, but this is very inconvenient, and sooner or later the operator will fail to turn one off while the other is on and will discharge the battery. This could be solved very simply by using a relay and a circuit as shown in Figure 16. The switch in the control circuit is mounted on the microphone. The B+ (this is the positive high voltage) from the power supply is connected to the movable contact on a relay. The normally closed contact is connected to the receiver, and the normally open contact is connected to the transmitter. When the switch on the microphone is not closed, the receiver is operating. When the operator wants to transmit he merely closes the switch on the microphone, usually by pressing a button, and the receiver will be turned off and the transmitter turned on. The relay does the job conveniently and will never "forget" and leave both units on at the same time.

Motor and Generator Action

Motors, generators and most electric meters depend on magnetic fields for their operation. In Figure 17 we have shown a core that is being magnetized by a coil which is carrying current. We have shown the North and South Poles. In an actual case we might have several hundred (rather than 3) turns in the coil. We know that there is a magnetic field in the air between the North and South Poles. We say that the field is from North to South in this "air-gap". If we dip our hands in salt water to make good electrical contact we can perform the following experiment.

Take a piece of heavy copper wire (about ¼ inch in diameter) and grasp one end in each hand. Push the wire through the magnetic field as shown. If the magnetic field is strong enough you can get quite a "shock". When you withdraw the wire you will again get a shock. The faster you move the wire through the magnetic field, the stronger the shock. Moving the wire through the field has caused a voltage to be induced in the wire. Let us repeat this statement. Any time a conductor is moved through a magnetic field, a voltage will be induced (or developed) in the conductor.

We can perform the same experiment in a safer and more accurate fashion. In Figure 18 we have a small horseshoe permanent magnet. (We could use a weak electromagnet.) We have connected the two test leads of a sensitive galvanometer to the ends of a loop of wire. (A galvanometer is a sensitive voltmeter.) The galvanometer needle will kick in one direction when we pass the "loop" down through the magnetic field. The needle will kick in the opposite direction as we bring the loop back up through the field. The speed with which we move the wire loop through the field will determine how strong a kick we give the needle in the galvanometer.

Huge generators in power-houses operate on this one simple principle. In most large generators the wire "stands still" and the magnetic field is made to move. The effect is the same however. All we need is a conductor, a magnetic field and motion. The galvanometer in Figure 18 would register if we held the wire in one position and moved the magnet up and down.

In Figures 17 and 18 we have examined the fundamentals of generator action. A wire has been moved through a magnetic field and a voltage has been induced in it.

Figure 19 illustrates motor action. Here again we have a magnetic field. We can use either a permanent magnet or an electromagnet to obtain the magnetic field. We use a battery to force an electric current through the wire. We will not have to move the wire this time. The wire will move itself. It isn't difficult to see why. Why did the compass needle move when we placed it near one of the poles of a magnet in Figure 2? It was the action of ***two*** magnetic fields.

In Figure 19 we have two magnetic fields. We have a strong field from the North to South pole of the large magnet. We also have a magnetic field around the wire which is carrying a current. In Figure 20 we have an enlarged view of the wire in the magnetic field. The arrows indicate the direction of the magnetic fields. Assume that the current in the wire is "into the paper". By the Left Hand Rule then, the field around the wire is counter-clockwise as shown. The interaction of the two fields causes the lines of force between the North and South poles of the magnet to be distorted, or bent, as shown in Figure 20(A). One property of magnetic lines of force is that they attempt to establish themselves in as short a path as possible. They are often considered to be elastic. Visualize the lines of force between the poles of the magnet as stretched rubber bands. If they were stretched out of shape as shown, they would force the wire to the right in the diagram. That is just what the magnetic lines of force do. They attempt to shorten their length and in so doing, force the conductor to the right. This movement to the right will continue until the conductor is forced to the extreme right edge of the magnetic field as shown in Figure 20(B).

Figures 19 and 20 have a demonstrated fundamental motor action. A wire carrying current is placed in a magnetic field, and is caused to move by the interaction of two magnetic fields.

Action of a D-C Meter

In previous assignments we spoke of meters which are used to measure d-c current. These instruments operate on the principle of the interaction of two magnetic fields. The principle of the operation of meters is shown in Figure 21. A permanent magnet is used to obtain one magnetic field. A coil of wire is mounted on pivots and is located in the field of the permanent magnet. Small spiral springs on the pivot shaft hold the coil at right angles to the magnetic field when no current is flowing through the coil. When current is passed through the coil, it becomes an electromagnet and its magnetic field attempts to line up with the field of the permanent magnet. This causes the coil to rotate. A pointer on the pivot shaft indicates the amount of current flowing through the coil. With no current flowing, the meter reads zero, and as the amount of current is increased the pointer moves up the scale of the meter. The more current flowing through the coil, the farther the coil will rotate against the spiral springs. When as much current as the meter is designed to handle flows through the coil, the coil will be lined up across the air gap in the permanent magnet so that the magnetic fields will be lined up. Remember that the magnetic field of a coil is through the entire coil as shown in Figure 12.

These explanations of generator action, motor action, and action of d-c meters show only the fundamentals of the actions. Each of these subjects will be studied in detail later in the training program.

In this assignment we have learned the basic principles of magnetism. In our progress through the training period we shall learn to apply these basic principles in the study of various electronics circuits. We will learn that these magnetic effects make possible the selection of the desired radio station from the thousand on the air, make possible the operation of electronics equipment from the 110V a-c power lines, and in fact, make electronics possible.

"HOW TO PRONOUNCE . . . "

(Note: The accent falls on the part shown in CAPITAL letters.)

armature	(ARR-mah-churr)
galvanometer	(gal-vah-NOMM-ett-urr)
magnetomotive	(mag-KNEE-toe-motive)
molecular	(moe-LEKK-you-lurr)
molecule	(MOLL-eh-kewl)
permeability	(purr-mee-ah-BILL-ity)
reluctance	(ree-LUKK-tanss)
retentivity	(ree-tenn-TIVV-ity)

Test Questions

Be sure to number your Answer Sheet Assignment 8.

Place your Name and Associate Number on *every* Answer Sheet.

Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. Is the magnetic field *strongest* or *weakest* at the poles of a permanent magnet?
2. Will like magnetic poles *repel* or *attract* each other?
3. Will the magnetic field of an electromagnet become stronger or weaker if more current is passed through the coil?
4. How can we increase the magnetic field of a coil of wire without changing the number of turns on the coil or the current? ADD IRON CORE
5. (a) What happens if a piece of iron is brought close to a permanent magnet? ATTRACT
   (b) What happens if a piece of aluminum is brought close to a magnet? NOTHING
6. In the circuit shown in Figure 22, will the right end of the coil be the *North* or the *South* pole of the electromagnet?
7. What is a relay? ELECTROMAGNETICLY CONTROLLED SWITCH
8. Does a straight piece of wire carrying a current have a magnetic field? YES
9. What happens when we move a copper wire through a magnetic field? VOLTAGE INDUCED
10. What happens when we pass a current through a copper wire which is located in a magnetic field? WIRE IS REPELLED

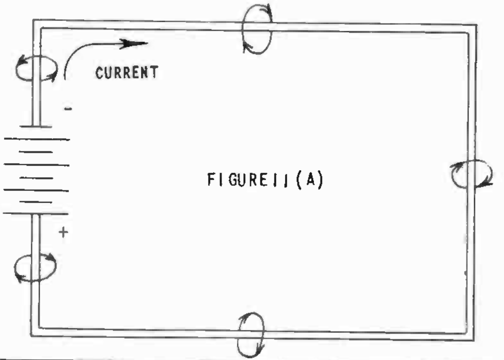


FIGURE 11 (A)

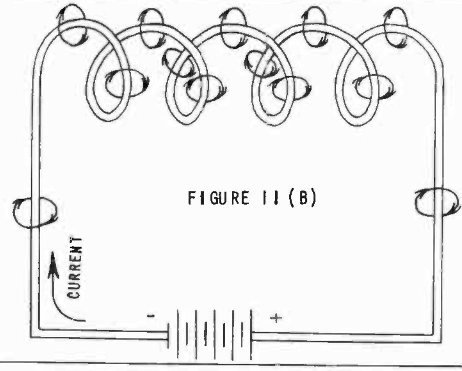


FIGURE 11 (B)

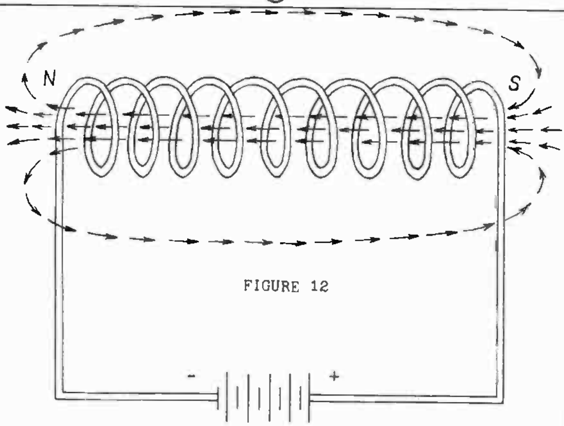
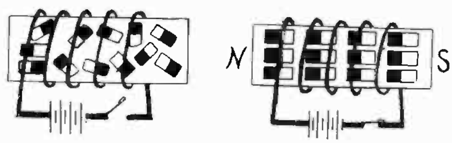


FIGURE 12



A B

FIGURE 13

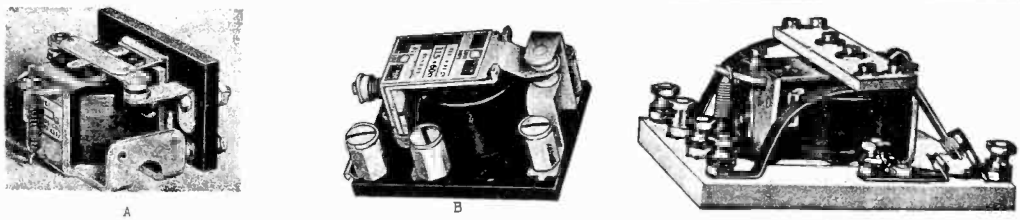
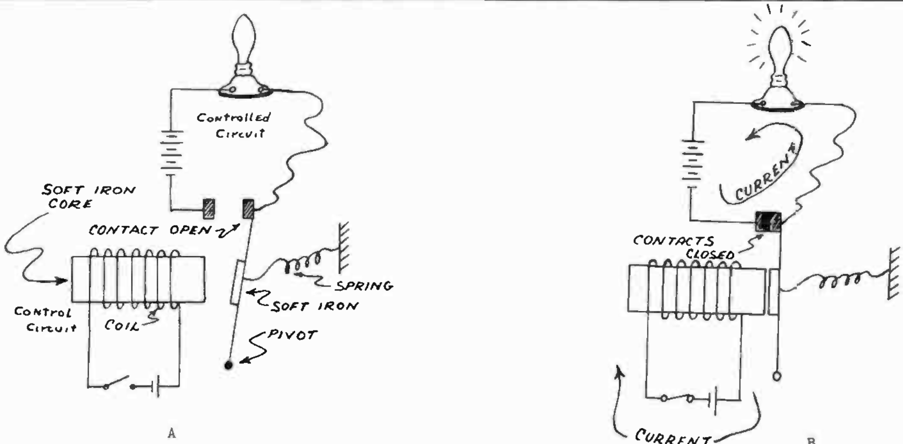

A B C

FIGURE 14



A B

FIGURE 15

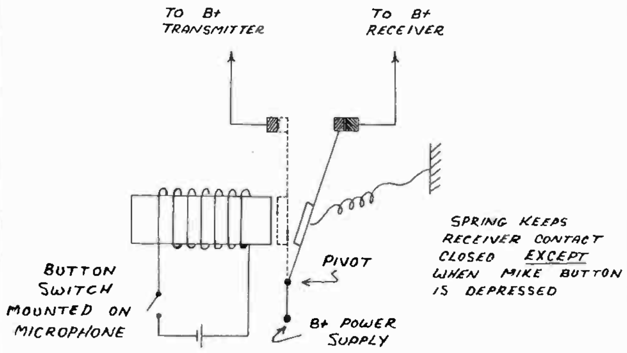


FIGURE 16

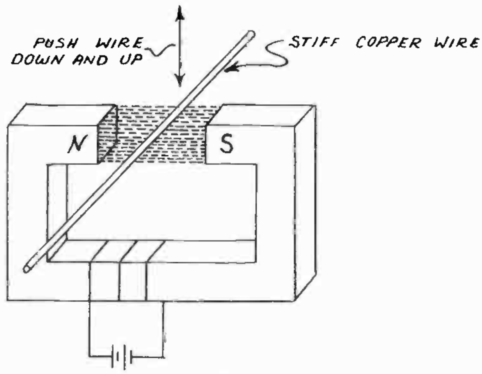


FIGURE 17

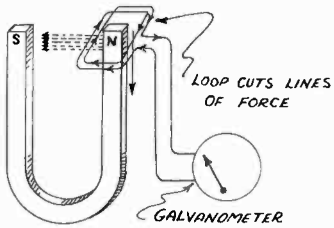


FIGURE 18

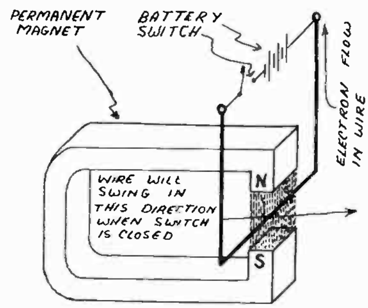
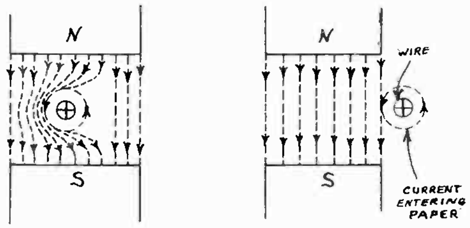


FIGURE 19



(A) FIGURE 20 (B)

CHECK THE DIRECTION OF CURRENT FLOW AND MAGNETIC FIELD FOR THE MOVABLE COIL. ARE YOU CERTAIN THE COIL IS POINTED IN THE RIGHT DIRECTION?

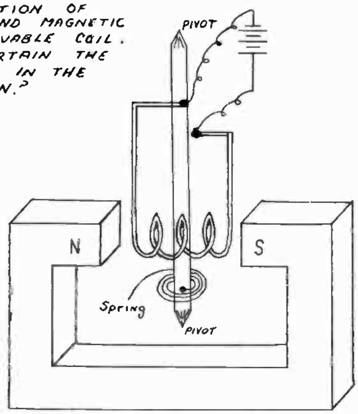


FIGURE 21

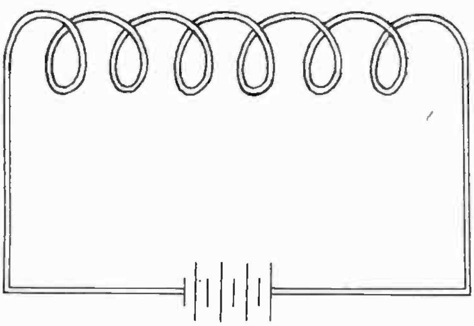


FIGURE 22

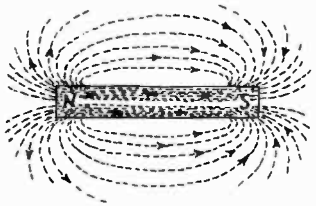


FIGURE 1

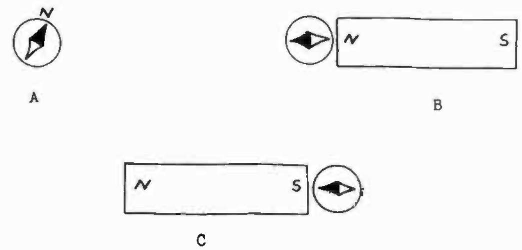


FIGURE 2

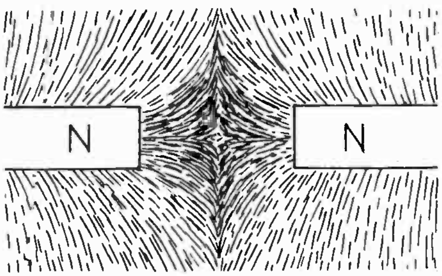


FIGURE 3

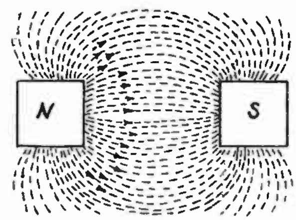


FIGURE 4 (A)

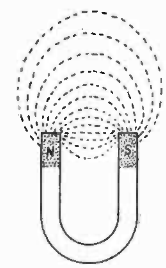


FIGURE 4 (B)

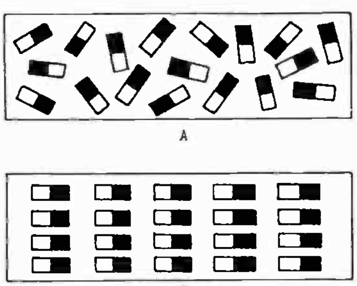


FIGURE 5

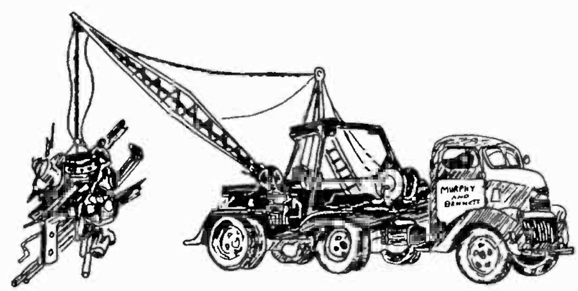


FIGURE 6

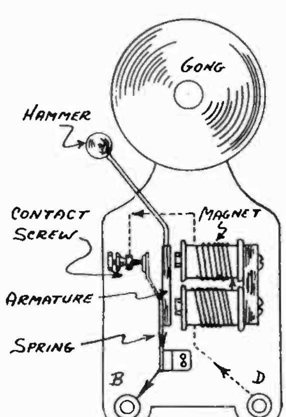


FIGURE 7

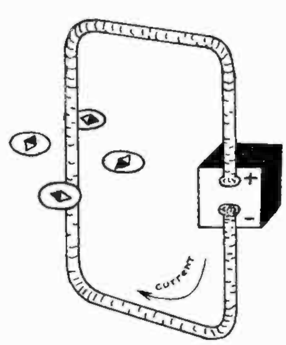


FIGURE 8

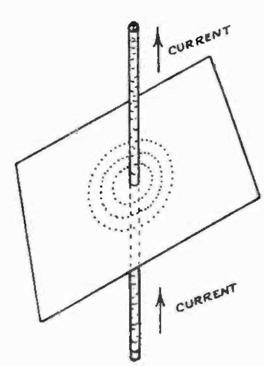


FIGURE 9

THE LEFT-HAND RULE IN USE

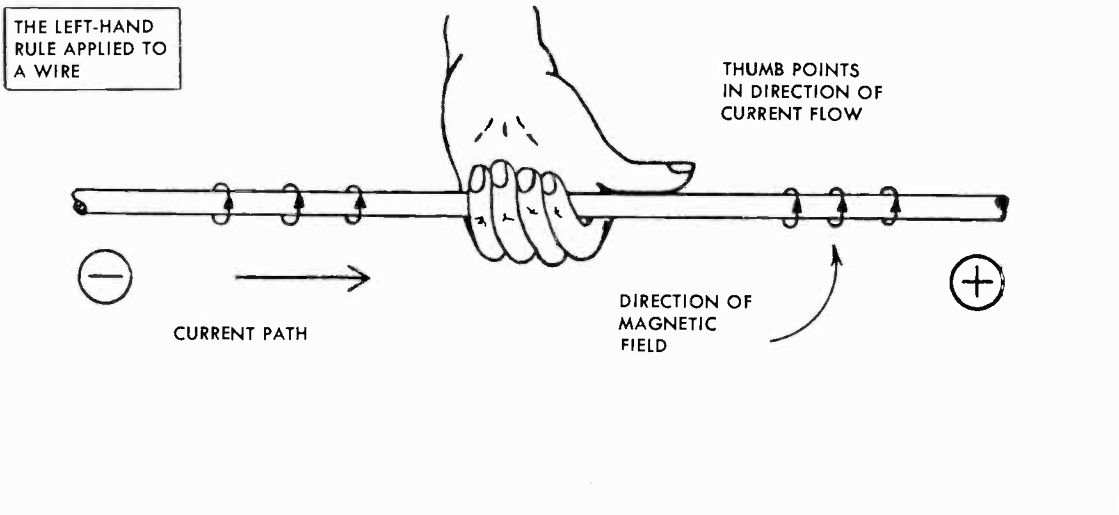


FIGURE 10 (A)

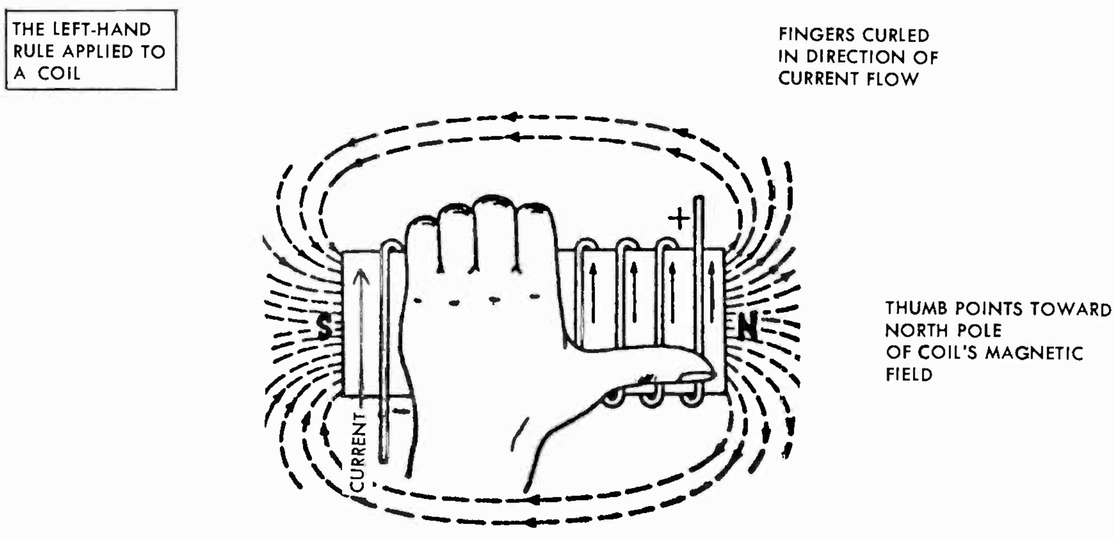


FIGURE 10 (B)