Study Group 5

ELECTRONIC FUNDAMENTALS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York, N. Y.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 9

POWER AND VOLTAGE DIVISION

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Theory Lesson 9

INTRODUCTION

In earlier lessons, you learned that before electric current can flow in a circuit, the electrical pressure (voltage) must overcome the opposition to current flow caused by the resistance of the circuit. You know that there is no such thing as a perfect conductor, and that all electrical circuits offer some resistance to the flow of current. The electrical energy used in overcoming the resistance produces heat. Unless the purpose of the circuit is for heating, this energy that produced it is wasted.

9-1 ELECTRICAL POWER

A power line that carries electricity from a central generating plant to a house ten miles away, as shown in Fig. 9-1, uses up electric power. To see how this is so, let's put it in figures. Let the resistance of the power line be 5 ohms and the current flowing through it be 4 amperes. Then:

$$E = I \times R = 4 \times 5 = 20 \text{ volts}$$

If the voltage at the generator is 120 volts, then the voltage available at the house (with 4 amperes flowing) is only 100 volts. Twenty volts is lost in the power line.

In Lesson Five, you learned that power is the rate of using energy, and that the unit of electrical power is the *watt*. In d-c circuits, Ohm's Law for power is: Power (in watts) is equal to the product of the voltage and the current. This is written:

$$P = E \times I, \quad \text{or} \quad P = EI$$

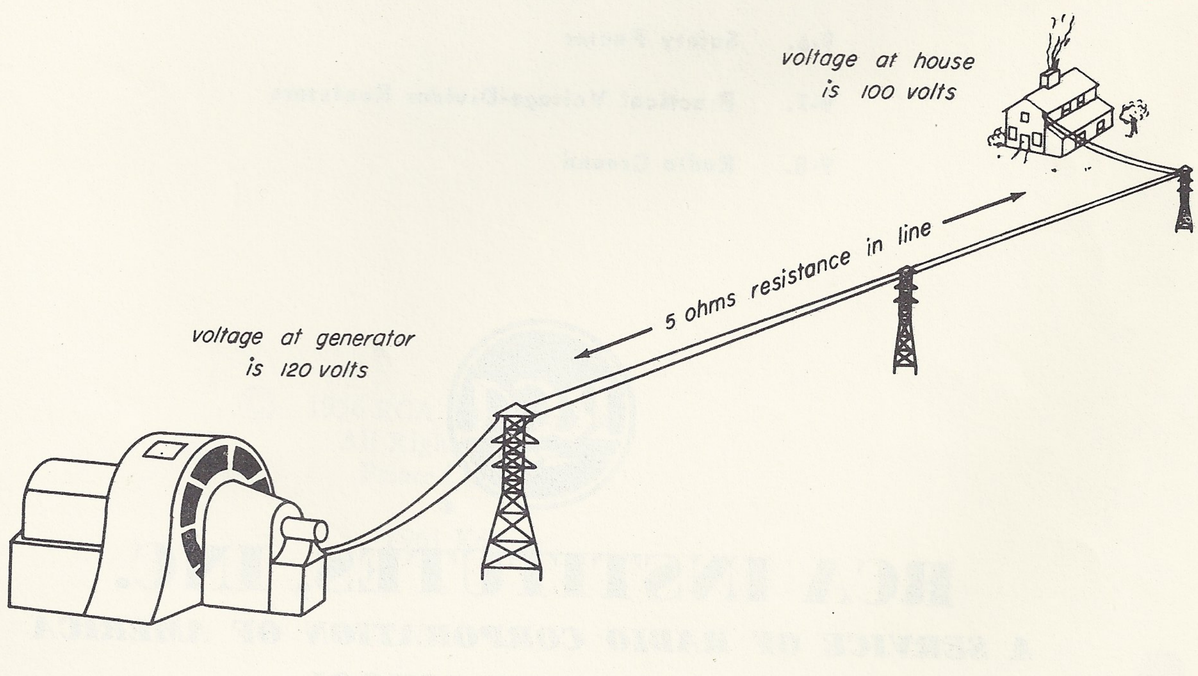

Fig. 9-1

So, if the voltage in the power line is 20 volts and the current flowing through it is 4 amperes, then:

$$P = E \times I = 20 \times 4 = 80 \text{ watts}$$

This 80 watts is the power used up in the line. At the same time, the power used at the house may be written as:

$$P = E \times I = 100 \times 4 = 400 \text{ watts}$$

The power used at the house is useful power, while the power consumed in the line is wasted power.

There are other formulas that you can use in order to help you in finding power. For example, suppose that you do not know how much current is flowing but that you do know the resistance and the voltage. In such a case, you can find the power by using the following formula:

$$P = \frac{E^2}{R}$$

Here's how we get this formula. From Ohm's Law, we know that:

$$I = \frac{E}{R}$$

So, we substitute

$(\frac{E}{R})$ for (I)

in the formula, $P = E \times I$, in this way:

$$P = E \times \frac{E}{R} = \frac{E^2}{R}$$

Let's see how this formula works in the example we used before. We know that the voltage drop in the power line is 20 volts and the resistance is 5 ohms. So:

$$P = \frac{E^2}{R} = \frac{20 \times 20}{5} = \frac{400}{5} = 80 \text{ watts}$$

Another formula for calculating power is:

$$P = I^2R$$

$\frac{P}{R} = I^2$

Let's see how we get this formula. We know that $E = I \times R$, so if we substitute $(I \times R)$ for (E) in the formula, $P = E \times I$, we get $P = I \times R \times I = I^2 \times R$. Applying this formula to the same example as before, we know the current in the power line is 4 amperes and the resistance is 5 ohms. So:

$$P = I^2 \times R = 4 \times 4 \times 5 = 80 \text{ watts}$$

9-2. POWER RATING OF RESISTORS

Resistors must be able to *dissipate* (get rid of) the heat developed in them by the power they consume. The power (and heat) in the resistor increases rapidly as the current through it is increased, because the power depends upon the *square* of the current. Let's examine the change in power that takes place when there is a change in the amount of current. Let's assume that 5 amperes of current flows through a 100-ohm resistor. Then:

$$P = I^2R = 5 \times 5 \times 100 = 2{,}500 \text{ watts}$$

If we double the value of the resistor, we get:

$$P = I^2R = 5 \times 5 \times 200 = 5{,}000 \text{ watts}$$

However, if the current is doubled, then

$$P = I^2R = 10 \times 10 \times 100 = 10{,}000 \text{ watts}$$

This shows *four times* the power by doubling the current and only *two times* by doubling the resistance value. So, a little change in current can make a large change in power.

When a resistor is used within the rated limits, heat is able to escape from the resistor as rapidly as it is produced. When the resistor is overloaded (in other words, when it is caused to carry more power than it was made to), heat develops faster than it can escape. As you know, some resistive mater-

ials increase in resistance as the temperature rises and some carbon resistors decrease in resistance with a rise in temperature. In either case, the resistance in the overloaded circuit is no longer the same. This may make a great difference in the performance of the circuit. Of course, if the temperature rises high enough, the resistor may burn up.

The resistors used in radio and television are rated by the amount of power they can safely handle. Figure 9-2 shows some of the sizes of carbon composition and wirewound resistors used in radio and television receivers. As you can see, in general, the larger the resistor, the higher is its power rating in watts. Resistors made by most manufacturers can withstand some overloading without damage or excessive heat. However, it is good practice not to exceed the power indicated by the manufacturer's rating. Therefore, before choosing a resistor for an electric or electronic circuit, always be sure that it can handle the power required by the current flowing in the circuit. For example, if a circuit calls for a 4,000-ohm resistor with 10 ma flowing through it, we calculate the power:

$$P = I^2R = 0.01 \times 0.01 \times 4{,}000$$
$$= 0.4 \text{ watt}$$

However, if the current flowing through the resistor is increased to 20 ma, we find the power consumed is:

$$P = I^2R = 0.02 \times 0.02 \times 4{,}000$$
$$= 1.6 \text{ watts}$$

In the first case, we might use a 1/2-watt resistor. In the second case, a resistor with a 2-watt rating or higher is called for. We will have more to say about this later in this lesson.

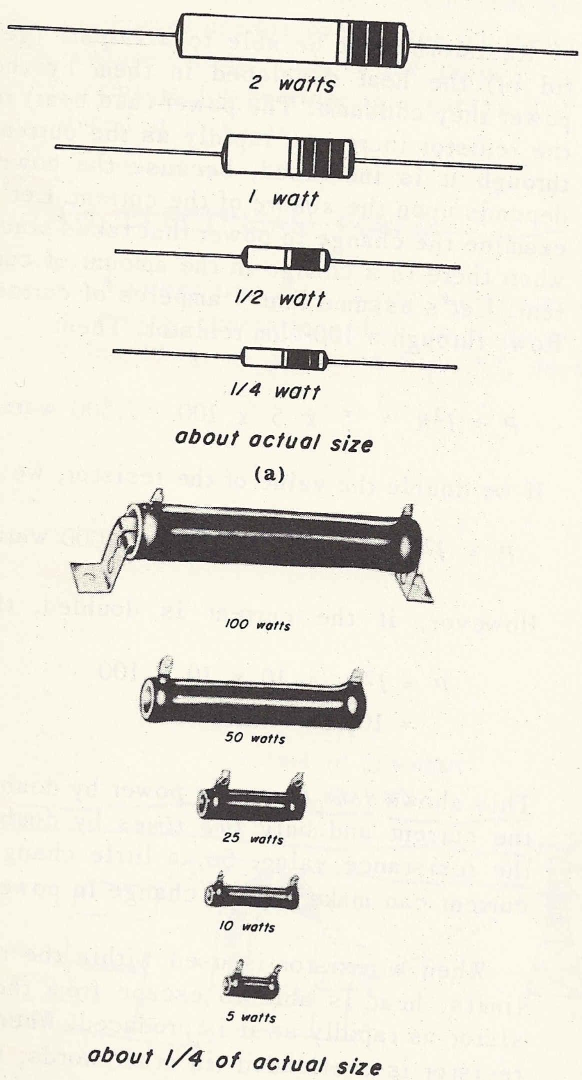

Fig. 9-2

9-3 VOLTAGE DIVISION

Resistors are often used in radio and television receivers to divide large voltages so that each individual circuit may receive the exact voltage it needs. How this is done can be explained simply. Figure 9-3 shows a 6-volt battery with two series resistors connected across its terminals. One resistor

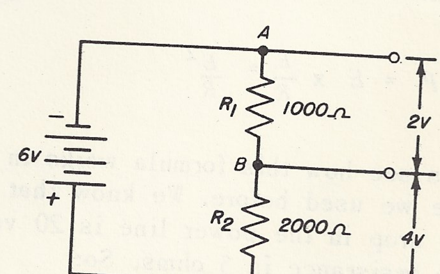

Fig. 9-3

has a resistance of 1,000 ohms; the other has 2,000 ohms. The voltage drop across R_1 and R_2 will be in proportion to the resistances of R_1 and R_2. This means that R_2, having twice the resistance of R_1, will have twice the voltage drop across it. R_1 has one-third the resistance of the total resistance (R_1 and R_2.) So, it has one-third of the total voltage across it. The resistor R_2 has two-thirds of the total resistance, so it has two-thirds of the voltage. So, between terminals *B* and *C*, a meter would measure four volts. Between terminals *A* and *B*, a meter would measure two volts. If we make R_1 one million ohms and R_2 two million ohms, the voltage drops are still the same because the ratio of the resistances is the same. If R_1 were 200 ohms and R_2 were 400 ohms, the voltage drops would be the same, for the same reason as before.

Let's use Ohm's Law to prove these statements. For example, in the original circuit, R_t = 3,000 ohms. Therefore:

$$I_t = \frac{E}{R} = \frac{6}{3{,}000} = 0.002 \text{ amp}$$

This is a series circuit, so:

$$I_t = I_{R1} = I_{R2}$$

$$E_{R1} = I_{R1} \times R_1 = 0.002 \times 1000 = 2 \text{ volts}$$

$$E_{R2} = I_{R2} \times R_2 = 0.002 \times 2000 = 4 \text{ volts}$$

In the second resistor combination, R_1 equals 1 megohm, and R_2 equals 2 megohms. Therefore:

$$R_t = R_1 + R_2 = 3 \text{ megohms}$$

$$I_t = \frac{E}{R_t} = \frac{6}{3{,}000{,}000} = 0.000002 \text{ amp}$$

$$I_t = I_{R1} = I_{R2}$$

$$E_{R1} = I_{R1} \times R_1 = 0.000002 \times 1{,}000{,}000 = 2 \text{ volts}$$

$$E_{R2} = I_{R2} \times R_2 = 0.000002 \times 2{,}000{,}000 = 4 \text{ volts}$$

In the third case, R_1 equals 200 ohms and R_2 equals 400 ohms. So:

$$R_t = R_1 + R_2 = 200 + 400 = 600 \text{ ohms}$$

$$I_t = \frac{E}{R_t} = \frac{6}{600} = 0.01 \text{ amp}$$

$$I_t = I_{R1} = I_{R2}$$

$$E_{R1} = I_{R1} \times R_1 = 0.01 \times 200 = 2 \text{ volts}$$

$$E_{R2} = I_{R2} \times R_2 = 0.01 \times 400 = 4 \text{ volts}$$

From this we can see that, in a series circuit, the voltage drops are in proportion to the resistance of each part of the circuit. We may use this same principle to divide any voltage in any needed amounts. Bear in mind, however, that this method of voltage division may be used only when voltage is needed *without current flow.* This means that if a circuit is connected to points *B* and *C*, as in Fig. 9-4, no current may be drawn by the applied circuit. Where voltage and current are both required, voltage dividers are calculated in an entirely different manner, as we will see later in this lesson.

When selecting resistors for this type of voltage divider, you must remember that the total resistance acts as a load to the voltage source. While voltage-divider circuits offer an equal load to any equal voltage source, the power lost in voltage-divider resistors is sometimes more important when the voltage source is a battery. This is because of the relatively high cost of battery power, especially primary-battery power. If the voltage source is a battery, therefore, it is desirable to select resistors of high values so that little load is placed on the battery.

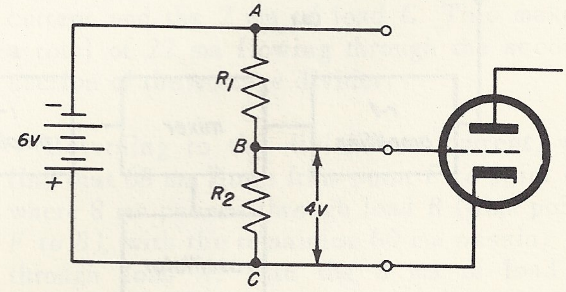

Fig. 9-4

9-4 POTENTIOMETERS

In radio and television, a potentiometer is a resistor with a movable sliding arm It usually looks like the one shown in Fig. 9-5*a*. Inside, it may look something like the one shown in Fig. 9-5*b*. The resistor may be either wirewound or carbon. One end of the resistor is connected to terminal *A* and the other end is connected to terminal *B*. The sliding arm is connected to the center terminal *C*. The moving arm may be adjusted so that it touches any part of the resistor. Figure 9-5*c* shows a schematic diagram of a potentiometer with its terminals *A* and *B* connected to a voltage source. Moving the arm toward terminal *A* causes the greater portion of the source voltage to appear across terminals *C* and *B*. Moving the arm closer to terminal *B* causes less of the source voltage to appear between *C* and *B*. As we know from the earlier part of the lesson, the percentage of the source voltage across *C* and *B* will be the proportion of the resistance of *C* and *B* to the total resistance. Practically all volume controls of all radios make use of the potentiometer. Fig. 9-5*d* shows a combination block and schematic diagram showing a volume-control circuit widely used in radio and television receivers.

9-5 PRACTICAL VOLTAGE DIVIDERS

Up until now, we have considered voltage dividers that provide different voltages without drawing current. In radio and television receivers, there is a need for such voltage dividers. However, there is also a great need in these receivers for voltage dividers capable of providing current at different voltages. A simple 5-tube radio receiver may draw current from its power-supply section at three or four voltage levels. For example, let's consider a receiver that requires 60 ma at 250 volts, 8 ma at 100 volts, and 2 ma at 75 volts. To figure the value of resistance needed for such a voltage divider requires a knowledge of Ohm's Law.

Sometimes the voltage divider circuit of a receiver uses a single wirewound resistor with taps similar to those shown in Fig. 9-6*a*. Figure 9-6*b* shows such a resistor connected to the power-supply section of a radio receiver. We do not know, at this time, the values of R_1, R_2, and R_3. We must find them. Because we are not ready to discuss the parts that make up a power supply, the power-supply section is shown as just a box with two terminals. The total voltage

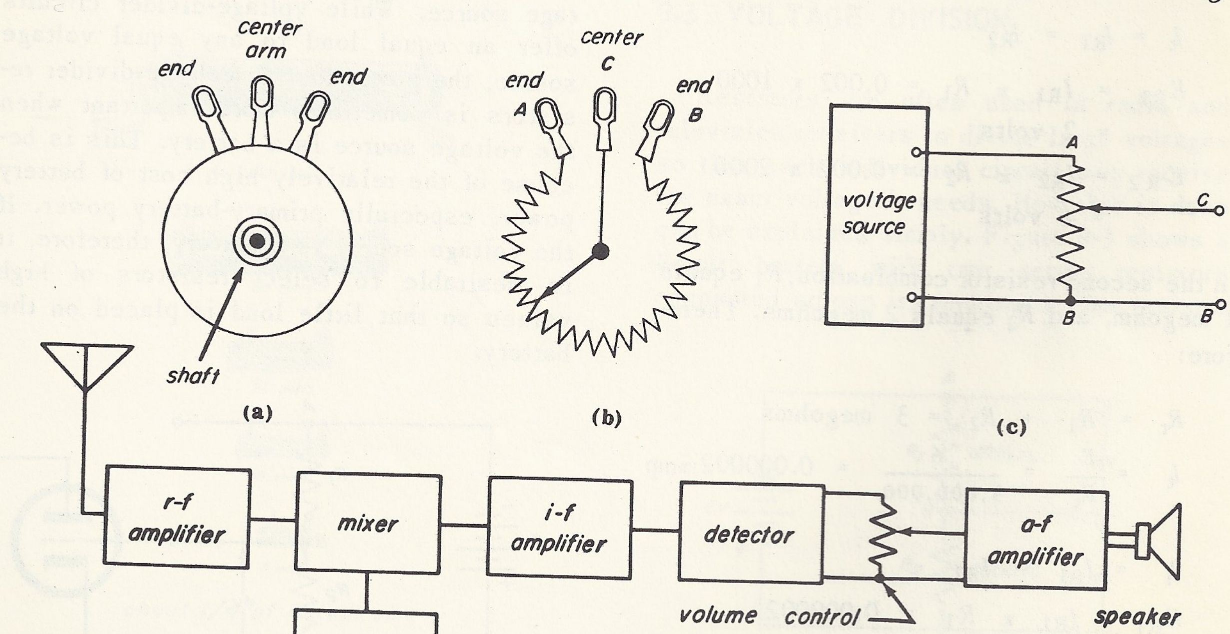

Fig. 9-5

delivered by the power supply is 250 volts, selected because it supplies the maximum voltage required in the problem presented in the paragraph above. This voltage appears across the ends of the voltage divider resistor at terminals *A* and *D*.

The receiver in our problem requires a total of 70 ma of current. When designing power supplies and figuring the values of voltage-divider resistors, it is customary to include a certain amount of current that is called *bleeder current*, which flows through the voltage-divider resistor at all times when the power supply is turned on. The reason that bleeder current is included is discussed fully in a later lesson on power supplies. For our problem, we will assume a value of 20-ma bleeder current. Therefore, the total current drawn from the power supply is 90 ma, which we find by adding the currents as follows:

60 ma at 250 volts
8 ma at 100 volts
2 ma at 75 volts
20 ma bleeder current
90 ma total current

The currents drawn from the power supply and voltage divider circuit are used in certain electronic circuits that include electron tubes and other radio parts. The 60 ma at 250 volts may supply correct operating potentials to the electrodes of several tubes. However, this 60-ma load on the power supply may be represented by a resistor, as in Fig. 9-6*c*. This load is shown in the diagram as a resistor labeled load *A*. At the 100-volt level, 8 ma are required, and this is represented by load *B*. At the 75-volt level, 2 ma are required, and this is represented in the diagram by load *C*. By examining the diagram, it can be seen that the 60 ma current of load *A* does not flow through the voltage divider at all. Looking at Fig. 9-6*c* and *d*, if we follow the path of the current from the negative terminal of the power supply, we find that the current leaving the power supply is 90 ma. At point *D*, the current divides between *E* and *C* with 20 ma bleeder current flowing through the first section of the voltage divider resistor R_1.

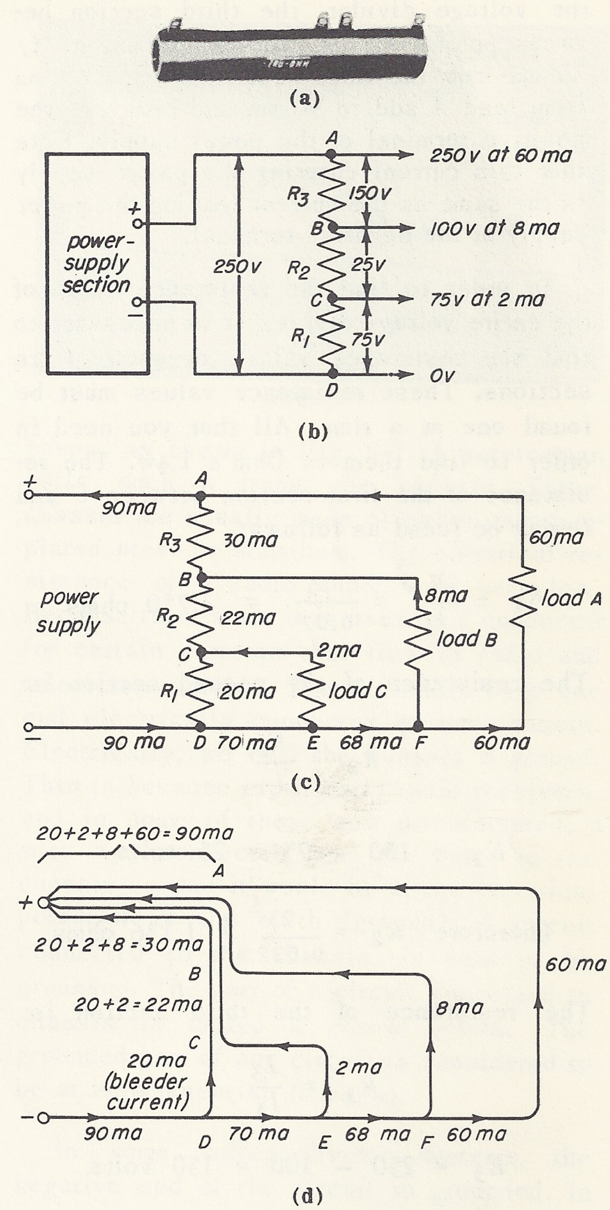

Fig. 9-6

The remaining 70 ma flow on from *D* to *E*, where 2 ma flow through load *C* (between points *E* and *C*). The current flowing from *C* to *B*, in the second section of the voltage divider R_2 is the sum of the 20-ma bleeder current and the 2 ma of load *C*. This makes a total of 22 ma flowing through the second section of the voltage divider.

Returning to the division of current, we find that 68 ma flows from point *E* to point *F*, where 8 ma passes through load *B* (from point *F* to *B*), with the remaining 60 ma passing on through load *A*. With the 8 ma of load *B* added to the 22 ma of the second section of

the voltage divider, the third section between points B and A carries 30 ma. At A, 30 ma from the third section R_3 and 60 ma from load A add to 90 ma and return to the positive terminal of the power supply. Note that this current entering the power supply is the same as the current leaving the power supply at the negative terminal.

In order to find the resistance value of the entire voltage divider, it is necessary to find the resistance values of each of its sections. These resistance values must be found one at a time. All that you need in order to find them is Ohm's Law. The resistance of the first section between C and D may be found as follows:

$$R_1 = \frac{E}{I_1} = \frac{75}{0.02} = 3{,}750 \text{ ohms}$$

The resistance of the second section is:

$$R_2 = \frac{E_2}{I_2}$$

$$E_2 = 100 - 75 = 25 \text{ volts}$$

$$\text{Therefore } R_2 = \frac{25}{0.022} = 1{,}136 \text{ ohms}$$

The resistance of the third section is:

$$R_3 = \frac{E_3}{I_3}$$

$$E_3 = 250 - 100 = 150 \text{ volts}$$

$$\text{Therefore, } R_3 = \frac{150}{0.03} = 5{,}000 \text{ ohms}$$

To find the total resistance of the voltage divider, we add the individual resistance values. So:

$$R_t = R_1 + R_2 + R_3 = 3{,}750 + 1{,}136 + 5{,}000 = 9{,}886 \text{ ohms}$$

In addition to knowing how much resistance is in each section of a voltage divider, it is also necessary to figure the power rating. In calculating the power rating of a tapped wirewound voltage divider, we use the power formula, $P = I^2R$. The current used in the calculations must be the highest current flowing in any part of the voltage divider. The highest current flowing through any section of the voltage divider is 30 ma. So:

$$P = I^2R = 0.03 \times 0.03 \times 9{,}886 = 8.9 \text{ watts (approximately)}$$

9-6 SAFETY FACTOR

Most radio, television, and other electronic engineers include a *safety factor* when calculating the power rating of resistors and other parts. The idea behind the safety factor is to allow for an overload. The safety factor generally used in calculating power ratings of resistors is two. This means simply that the actual power the resistor is supposed to handle is multiplied by two. So, applying the safety factor, we multiply 8.9 x 2 and get 17.8 watts. Tapped wirewound resistors for voltage dividers usually must be made to order. So, when ordering a quantity of these voltage-divider resistors, we would specify the nearest higher commercial size. In this case, 20-watt resistors would be used.

9-7. PRACTICAL VOLTAGE-DIVIDER RESISTORS

Tapped wirewound voltage-divider resistors are used in radios and television receivers. However, they are made to order for the particular receiver or circuit for which they are designed. This calls for special operations in manufacture. They are somewhat costly to replace when one section burns out or otherwise becomes defective. Some servicemen suggest replacing only the defective section with a single resistor of the proper value. Sometimes there is not enough space for another resistor. In such cases, the entire voltage divider must be replaced. However, even if there is enough space, the defective section may still cause trouble. So, the best practice is to replace the whole voltage divider, if at all possible.. Resistors having adjustable taps can be used.

Today, in many pieces of equipment, the sections of a voltage divider are made

up of individual resistors. In most cases, these resistors are carbon composition resistors, which are considerably less expensive than wirewound resistors. Also, they take up, somewhat less space. What is more, if one resistor breaks down, it alone is the one to be replaced. Each is selected with a power rating based on the current flowing through it, which need not be as much as the maximum current flowing in the voltage divider circuit.

Let's see how using individual resistors cuts down on the power rating. The power of each resistor in Fig. 9-6 may be calculated separately:

$$P_{R1} = (I_{R1})^2 \times R_1 = 0.02 \times 0.02 \times 3{,}750 = 1.5 \text{ watts}$$

$$P_{R2} = (I_{R2})^2 \times R_2 = 0.022 \times 0.022 \times 1{,}136 = 0.54 \text{ watts}$$

$$P_{R3} = (I_{R3})^2 \times R_3 = 0.03 \times 0.03 \times 5{,}000 = 4.5 \text{ watts}$$

By applying our safety factor, we find that R_1 should be a 3-watt resistor, R_2 should be 1.08-watt resistor, and R_3 a 9-watt resistor. Carbon composition resistors are normally produced with ratings of 1/2 watt, 1 watt, 2 watts, and sometimes 3 and 5 watts. Wirewound resistors are normally produced with ratings of 5, 10, 20, 25, 50, 80, and 100 watts. So, for our first resistor we would choose a standard 3-watt carbon composition resistor. Instead of ordering a 3,750-ohm resistor, we would order the nearest stock size, which might be either 3,600 or 3,900 ohms. For resistor R_2, we would use a standard 1-watt resistor with a standard stock value of 1,100 ohms. For R_3, we would select a standard 5,000-ohm, 10-watt wirewound resistor. These resistors would occupy much less space than one tapped wirewound resistor. What is more, if one resistor broke down, it alone would have to be replaced.

9-8. RADIO GROUND

Radio and television receivers are normally assembled on metal frames or

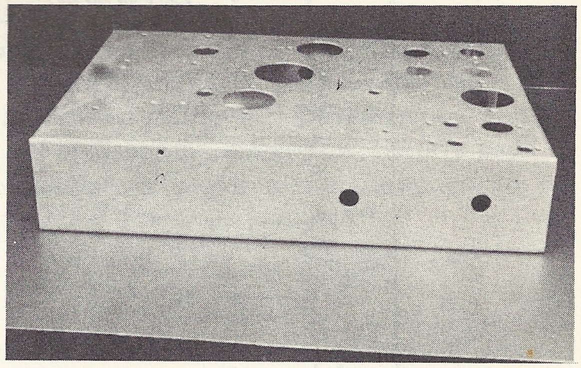

Fig. 9-7

bases, as shown in Fig. 9-7. A serviceman calls such a frame the *chassis*. These chassis are usually made of either cadmium-plated steel or aluminum. The electrical resistance of a radio chassis is very low. Because this is so, it is used as a conductor for certain currents that flow in radio and television circuits. These circuits have one end electrically connected to the chassis. Electrically, we call the chassis a *ground*. This is because in all early radio receivers, and in some of those now manufactured, a wire was connected from the earth to the chassis so that it would be at the electrical potential of the earth (ground). A circuit connected to the chassis, is said to be *grounded*. The part of a circuit connected to chassis is called a *ground return*. The grounded part of any circuit is considered to be at zero potential (0 volts).

In some voltage-divider systems, the negative end of the circuit is grounded. In some cases, however, it is necessary for one or more of the voltages needed in a receiver to be negative with respect to zero. When these voltages are obtained from the voltage-divider circuit, the negative end of the power supply is not connected to the chassis. Instead, some other point in the voltage divider is connected to the chassis (ground), as shown in Fig. 9-8. In this voltage divider, point D is grounded (as shown by the ground symbol). All voltages in a positive direction from point D are said to be *above ground*, and all voltages in a negative direction from point D are said to be *below ground*. All voltages above ground are measured with ground as the negative end and all voltages below ground are measured with ground as the positive end. Ground is, there-

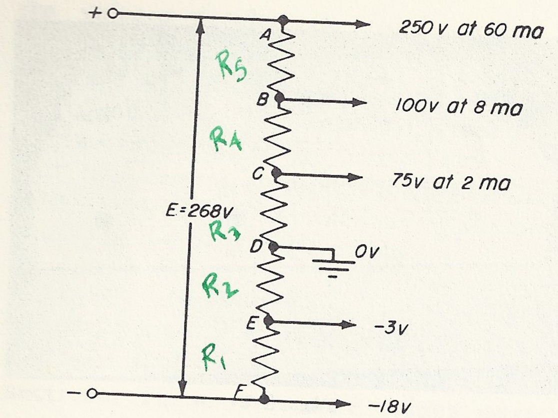

Fig. 9-8

fore, a reference point with a potential of zero volts. We could ground any point of the voltage-divider circuit. All we need do is to change a few circuit connections in the radio or television receiver. For example, we could ground the positive end of the voltage supply and have all of the voltages negative with respect to ground. However, radio and television receivers are designed so that some voltages are above ground and some are below ground.

The voltage divider shown in Fig. 9-8 has two voltage levels that are negative with respect to ground. One is –3 volts and the other is –18 volts. The total voltage delivered by the power supply is 268 volts, which is the sum of the 250 volts above and the 18 volts below ground.

This voltage divider differs in several ways from the one we just calculated. For us to understand these differences, it is necessary to calculate the resistance values of each section of such a voltage divider. In order to simplify our problem, we will use the same current requirements as in the last voltage divider. Therefore, we will assume that we need 60 ma at 250 volts, 8 ma at 100 volts, 2 ma at 75 volts, with 20 ma of bleeder current. The negative voltages are used for their potentials only, and no current is needed at these points. Figure 9-9 shows the voltage divider with resistors representing the three current loads. Because no current is drawn at the –3-volt and –18-volt levels, no load is shown at these points. The diagram also shows the current paths. Examine the diagram carefully and you will see that the negative return of the three load circuits is at the zero potential, or ground level. Therefore, the entire 90 ma delivered by the power supply passes through the first and second sections of the voltage divider (R_1 and R_2). With this knowledge we can calculate the resistance values of each section of the voltage divider:

$$R_1 = \frac{E_{R1}}{I_{R1}}$$

E_{R1} is the difference between –3 and –18 volts, which is 15 volts. Therefore:

$$R_1 = \frac{15}{0.09} = 167 \text{ ohms}$$

In a similar manner,

$$R_2 = \frac{E_{R2}}{I_{R2}} = \frac{3}{0.09} = 33 \text{ ohms}$$

$$R_3 = \frac{E_{R3}}{I_{R3}} = \frac{75}{0.02} = 3{,}750 \text{ ohms}$$

$$R_4 = \frac{E_{R4}}{I_{R4}} = \frac{25}{0.022} = 1{,}136 \text{ ohms}$$

$$R_5 = \frac{E_{R5}}{I_{R5}} = \frac{150}{0.03} = 5{,}000 \text{ ohms}$$

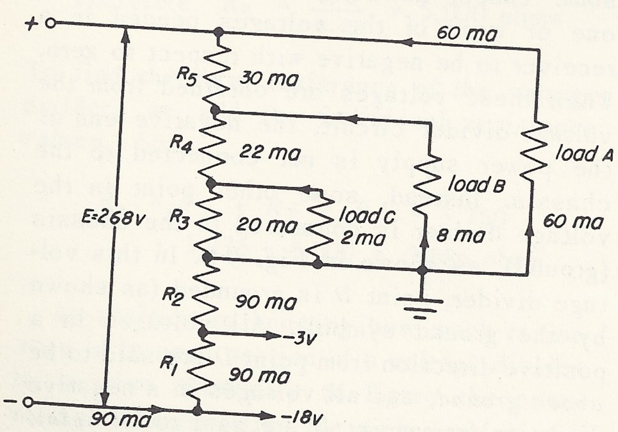

Fig. 9-9

As you can see, this voltage divider differs from the first one in the two added resistance sections and in the amount of applied voltage. However, if we use a single tapped wire-wound resistor for this voltage divider, we will see a considerable difference in the power rating of this voltage divider as compared with the first one. As you know, the power rating of a single voltage-divider resistor is determined by the greatest current flowing in any section. The highest current flowing in this voltage divider is the 90 ma flowing through R_1 and R_2. Adding the resistance values of the five sections of the voltage divider, we get a total of 10,086 ohms. The power rating of the voltage-divider resistor is:

$$P = I^2R = 0.09 \times 0.09 \times 10{,}086$$
$$= 82 \text{ watts}$$

Multiplying 82 watts by our safety factor, 2, we see that a resistor with 160-watts rating is needed, which is considerably more than the 20-watt rating of the first voltage divider. In this case, therefore, it definitely pays to break the voltage divider up into separate resistors. Then:

$$P_{R2} = (I_{R2})^2 \times R_2 = 0.0081 \times 33$$
$$= 0.27 \text{ watts}$$

In this case a 1/2-watt carbon resistor will do very nicely.

$$P_{R1} = (I_{R1})^2 \times R_1 = 0.0081 \times 167$$
$$= 1.4 \text{ watts}$$

Here, a standard 3-watt carbon resistor, or a 5-watt wirewound resistor will handle the power. The remaining three resistors are rated the same as in the previous problem.

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 9

POWER MEASUREMENT

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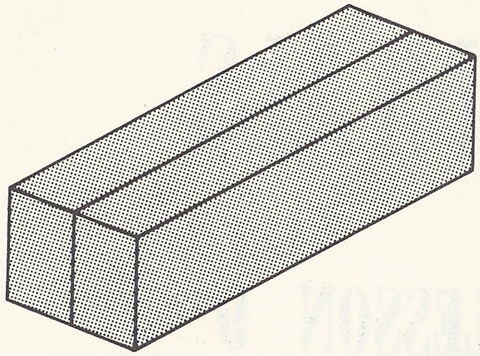
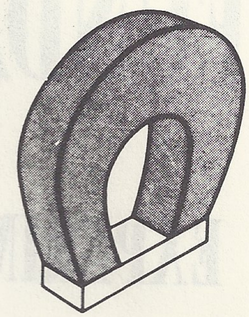


two bar magnets



horseshoe magnet with keeper

All the parts in Kit 5 are listed below. Check the parts you receive against this list. Make sure you have the correct quantity of every item. If a part is either missing or defective upon arrival, request a replacement from Department R, Home Study School, RCA Institutes, Inc., 350 West 4th Street, New York 14, N.Y. *Your request must include your name and student number, the complete name and description of the part copied from the Item column below, the Quantity missing or defective, and the reason you are asking for a new part.*

KIT 5
BILL OF MATERIALS

Quantity	Item
1	Container of iron filings
2	Alnico bar magnets
1	Horseshoe magnet and keeper
1	Compass
¼ lb	Plain enamel magnet wire
1	40-penny iron nail
1	Resistor, 15 ohms, ½ watt
1	Resistor, 4.7 k-ohms, ½ watt, 10%

Experiment Lesson 9

OBJECT

1. To calculate d-c power by using voltage and current measurements.

2. To determine the effect that a change in load has upon the voltage division of a voltage divider.

3. To set up a voltage-divider circuit that provides voltages that are positive and negative with respect to a reference point (ground).

INFORMATION

In Theory Lesson 11, *D-C Meter Theory*, you will learn that power can be measured directly in watts by using a special kind of meter called a *wattmeter*. However, it is possible to discover how much power a piece of d-c equipment consumes by measuring the voltage that appears across the equipment and the current that flows through it. Then, by using the Ohm's law formula, $P = E \times I$, we can find the power. In the experiments that follow, you will do this.

EXPERIMENT 9-1

To determine the power consumed by a resistor.

Equipment Needed.

The resistor board assembled in Experiment Lesson 1.

Three 1.5-volt dry cells and the alligator clips used in Experiment Lesson 7.

Soldering iron, cloth, and solder.

4. Short lengths of hook-up wire used in Experiment Lesson 7.

Procedure.

Step 1. Solder a short length of hook-up wire to one lead of the 220-ohm resistor on the breadboard.

Step 2. Solder the other end of the same lead to the 100-ohm resistor, as shown in Fig. 9-1.

Step 3. Make sure that the three 1.5-volt cells are connected in series aiding to form a 4.5-volt battery and that there is an alligator clip attached to each terminal.

Step 4. Clip the negative terminal of the battery to the free end of the 100-ohm resistor. Connect the positive terminal to the free end of the 220-ohm resistor, as shown in Fig. 9-1.

Step 5. Set up your multimeter for service on the 5-volt d-c range.

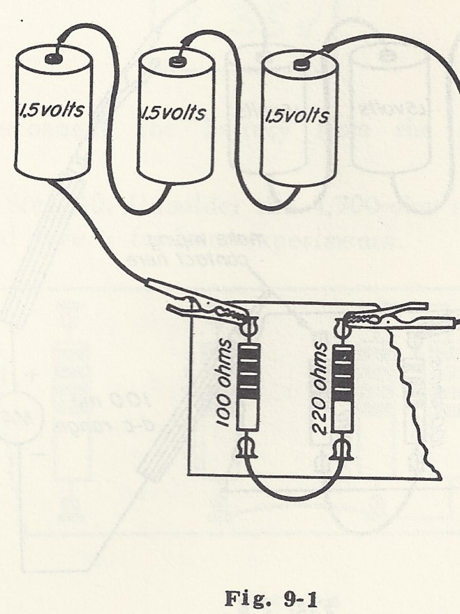


Fig. 9-1

Step 6. Measure and record the voltage across the 100-ohm resistor here:

1,3v

Step 7. Measure and record the voltage across the 220-ohm resistor here:

3,1v

Step 8. Measure and record the total voltage across both resistors here:

4,52v

Step 9. Remove the battery clip from the 220-ohm resistor.

Step 10. Set your multimeter to measure current on the 100-milliampere d-c range.

Step 11. Clip the positive terminal of the battery to the red (+) test lead.

Step 12. With the negative test prod, make a wiping contact with the free end of the 220-ohm resistor. At the same time, watch the meter. If the pointer rises too rapidly and too far toward the right, remove the meter from the circuit and check your circuit to see that it agrees with Fig. 9-2.

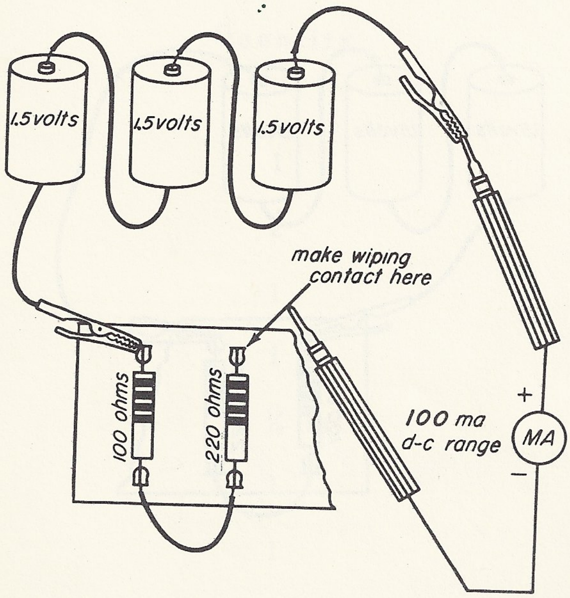


Fig. 9-2

Step 13. Connect the negative test prod to the free end of the 220-ohm resistor and record the current reading here:

13,5 ma

Step 14. Use the formula for power, $P = E \times I$, to calculate the power consumed by the 100-ohm resistor. Record the value here:

,01755 w

1,3
,0135
65
39
13
,017555

Step 15. Calculate the power consumed by the 220-ohm resistor. Record the value here:

.04185

3,1
,0135
155
93
31
,04185

Discussion. With the rated values of the 100- and 220-ohm resistors, there should have been a resistance of about 320 ohms. The meter resistance (10 ohms on the 100 MA range) is small compared to 320 ohms and may be neglected here. By using Ohm's law, you can see that the current flowing in the circuit is equal to 4.5 volts divided by 320, which equals about 0.014 amperes (14 ma). Therefore, the value of current that you measured in Step 12 should have been about 14 ma. The voltage across the 100-ohm resistor may then be calculated by using Ohm's law:

$$E = I \times R = 0.014 \times 100 = 1.4 \text{ volts}$$

The voltage across the 220-ohm resistor may be found in the same manner:

$E = I \times R = 0.014 \times 220 = 3.1$ volts

The voltage reading you got in Step 6 should have been about 1.4 volts, and the reading in Step 7 should have been about 3.1 volts. If the values that you measured differed greatly from these, check the voltage reading that you made at Step 8. If it is less than 4.4 volts, your voltage readings should be slightly off. However, if the voltage is 4.4 or more, make sure that the battery is removed from the circuit and then use your ohmmeter to measure the resistance of the 100-ohm and 220-ohm resistors. If the resistance values are about what they should be, repeat the experiment. Be careful to take very accurate readings. If your current and voltage readings are about what they should be, you will find that the power consumed in the 100-ohm resistor is about 19.6 milliwatts (0.0196 watts), and the power consumed by the 220-ohm resistor is about 43 milliwatts (0.043 watts).

EXPERIMENT 9-2

To determine the effect that a change in load has upon a voltage divider.

Equipment Needed.

Equipment used in Experiment 9-1

The resistors used in Experiment Lesson 2

Procedure.

Step 1. Connect and solder one end of the 10,000-ohm resistor to the 1,000-ohm resistor on the breadboard, as in Fig. 9-3.

Step 2. Clip one terminal of the 4.5-volt battery to the free end of the 1,000-ohm resistor and the other terminal to the free end of the 10,000-ohm resistor.

Step 3. Set up your multimeter for service on the 5 VDC range.

Step 4. Measure the voltage across the 1,000-ohm resistor and record it here:

4 V

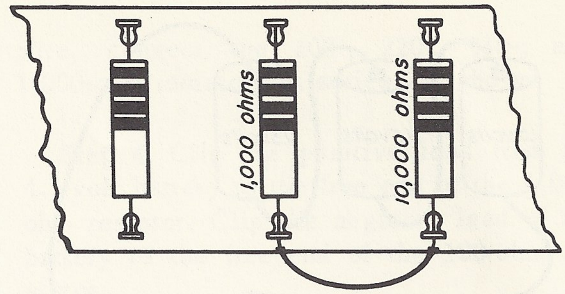


Fig. 9-3

Step 5. Measure the voltage across the 10,000-ohm resistor and record it here.

4,05 V

Disconnect the battery from the resistors.

Step 6. Connect and solder the 4,700-ohm resistor that you received in Kit 5 across the 10,000-ohm resistor, as in Fig. 9-4.

Step 7. Connect the battery across this combination of resistors.

Step 8. Measure the voltage across the 1,000-ohm resistor and record it here:

1,5 V

Step 9. Measure the voltage across the two parallel resistors and record it here:

3,35 V

Disconnect the battery from the circuit.

Step 10. Unsolder the 4,700-ohm resistor and save it for later experiments.

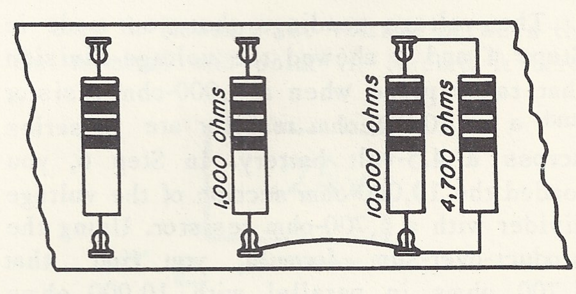


Fig. 9-4

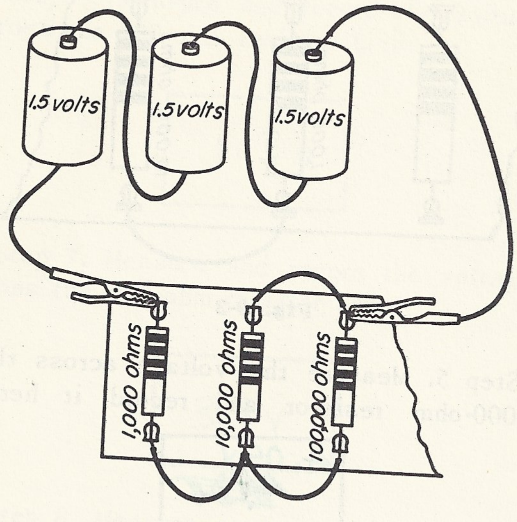


Fig. 9-5

Step 11. Connect and solder the 10,000-ohm and 100,000-ohm resistors of the resistor breadboard in parallel.

Step 12. Connect the battery across the resistor circuit, as shown in Fig. 9-5.

Step 13. Measure the voltage across the 1,000-ohm resistor and record it here:

4v

Step 14. Measure the voltage across the parallel-connected 10,000-ohm and 100,000-ohm resistors and record it here:

4v

Disconnect the battery from the circuit.

Discussion.

The voltage readings that you made in Steps 4 and 5 showed the voltage division that takes place when a 1,000-ohm resistor and a 10,000-ohm resistor are in series across a 4.5-volt battery. In Step 6, you loaded the 10,000-ohm section of the voltage divider with a 4,700-ohm resistor. Using the product-over-sum formula, you find that 4,700 ohms in parallel with 10,000 ohms equal:

$$\frac{4{,}700 \times 10{,}000}{4{,}700 + 10{,}000} \quad \frac{47{,}000{,}000}{14{,}700}$$

$$= 3{,}200 \text{ ohms approx.}$$

Placing the 4,700 ohms in parallel with the 10,000-ohm resistor made that part of the circuit act like 3,200 ohms. As a result, the voltage distribution changed. Where the readings taken in Steps 4 and 5 were about 0.4 of a volt and 4.1 volts, the voltage now became about 1 volt across the 1,000-ohm resistor and about 3.5 volts across the two parallel resistors.

On the other hand, when the 100,000-ohm resistor was placed as a load across the 10,000-ohm resistor, there was so very little difference in the voltage distribution that you could well ignore it. In other words, the voltage distribution remained just about the same as it was when we had only the 1,000-ohm and the 10,000-ohm resistors in series.

The greater the load (the less the resistance of the load) that we place across any section of a voltage divider, the greater is the change in the distribution of voltage. Therefore, we never can calculate the value of any section of a voltage divider until we first know the value of the load that will be placed across it.

EXPERIMENT 9-3

To set up a voltage-divider circuit that provides voltages that are positive and negative with respect to a reference point (ground).

Equipment Needed.

The equipment used in the previous experiments in this lesson.

One tie terminal used in Experiment Lesson 2.

One screw to mount the tie terminal.

Information. In the following experiments, keep track of the polarity of your test leads

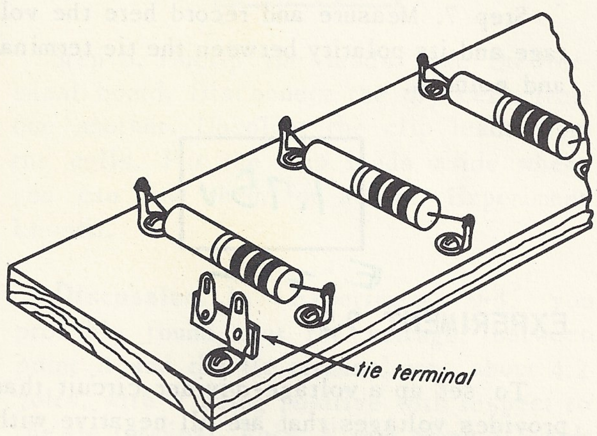
as you check each voltage measurement. Keeping a record of the polarity is very important; unless you do this, your work on these experiments will be wasted and you will not learn what you are supposed to learn from them.

Procedure.

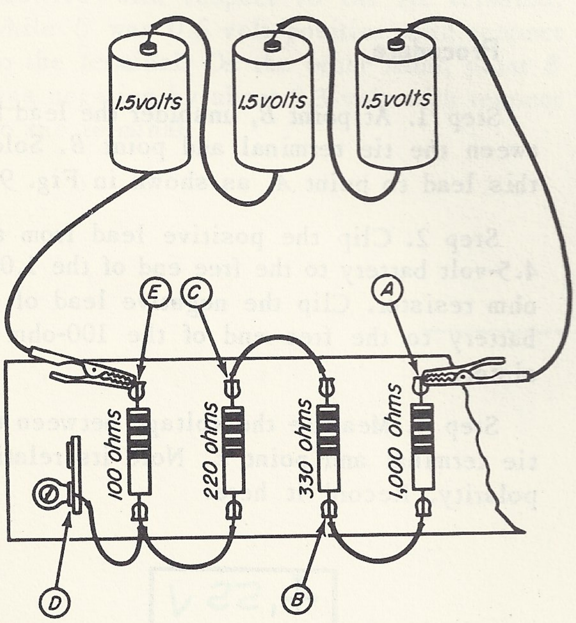
Step 1. Mount the tie terminal on the resistor breadboard, as shown in Fig. 9-6*a*.

Step 2. Use a short length of hook-up wire to connect the near end of the 100-ohm resistor to the tie terminal, as shown in Fig. 9-6*b*.

Step 3. Using short lengths of hook-up wire, connect the 100-, 220-, 330-, and 1,000-ohm resistors in series, as shown.



(a)



(b)

Fig. 9-6

Step 4. Clip the positive lead from the 4.5-volt battery to the free end of the 1,000-ohm resistor. Clip the negative lead of the battery to the free end of the 100-ohm resistor.

Step 5. Using the 5 VDC range of your multimeter, measure the voltage between the tie terminal (point *D*) and point *A*. Record it here:

4.25v

A = +

Note, too, the polarity of point *A* with reference to the tie terminal.

Step 6. Measure the voltage between point *B* and the tie terminal. Record it here:

1.5 v

B = +

Note the polarity as before.

Step 7. Measure the voltage between the tie terminal and point *C* and record it here:

.6v

C = +

Note the polarity at point *C* with respect to the tie terminal.

Step 8. Measure the voltage between the tie terminal and point *E*. Record it here:

.25v

E = −

Note the polarity with respect to the tie terminal.

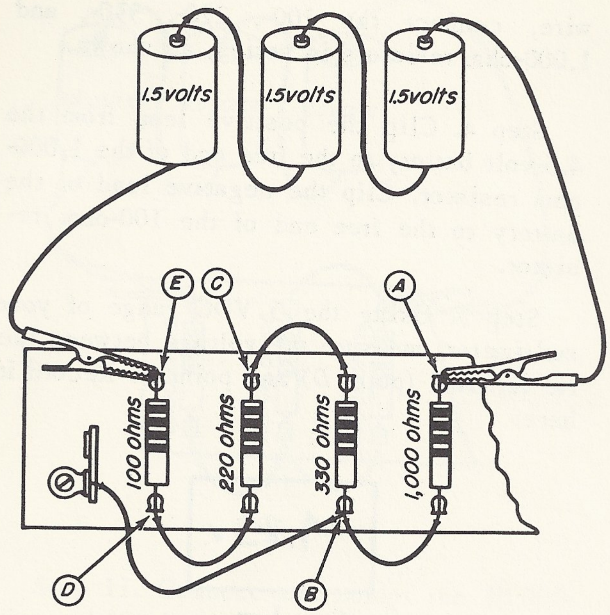


Fig. 9-7

EXPERIMENT 9-4

To set up another voltage divider that provides voltages that are positive and negative with respect to a reference point (ground).

Procedure.

Step 1. At point *D*, unsolder the lead between point *D* and the tie terminal.

Step 2. Solder the free end of this lead to point *B*, as shown in Fig. 9-7.

Step 3. Clip the positive lead from the 4.5-volt battery to the free end of the 1,000-ohm resistor. Clip the negative lead of the battery to the free end of the 100-ohm resistor.

Step 4. Measure the voltage between point *A* and the tie terminal and note its polarity with reference to the tie terminal as before. Record the polarity and voltage here:

2,65

A = +

Step 5. Measure the voltage between point *C* and the tie terminal. Note its polarity with respect to the tie terminal. Record the polarity and voltage here:

.9v

e = —

Step 6. Measure and record here the voltage and its polarity between the tie terminal and point *D*:

1,5 v

D = —

Step 7. Measure and record here the voltage and its polarity between the tie terminal and point *E*:

1.75v

E = —

EXPERIMENT 9-5

To set up a voltage-divider circuit that provides voltages that are all negative with respect to a reference point (ground).

Procedure.

Step 1. At point *B*, unsolder the lead between the tie terminal and point *B*. Solder this lead to point *A*, as shown in Fig. 9-8.

Step 2. Clip the positive lead from the 4.5-volt battery to the free end of the 1,000-ohm resistor. Clip the negative lead of the battery to the free end of the 100-ohm resistor.

Step 3. Measure the voltage between the tie terminal and point *E*. Note its relative polarity. Record it here:

4,55 v neg.

Step 4. Measure and record the voltage between the tie terminal and point *C*. Note its polarity:

3.6 V

~~4.25 V~~
neg.

Step 5. Measure and record the voltage between the tie terminal and point *D*. Note its polarity:

4.25 V
neg.

Step 6. Unclip the leads from the terminal board. Disconnect the dry cells from one another. Unsolder the clip leads from the cells. Put the clip leads aside where you can find them for a later Experiment Lesson.

Discussion. In Experiment 9-3, you probably found that the voltage between point *A* and the tie terminal was about 4.2 volts, with *A* being positive with respect to the tie terminal. Point *B* was about 1.5 volt positive with respect to the tie terminal, while *C* was 0.6 volt positive with respect to the terminal. On the other hand, point *E* was negative by about 0.3 volt with respect to the terminal.

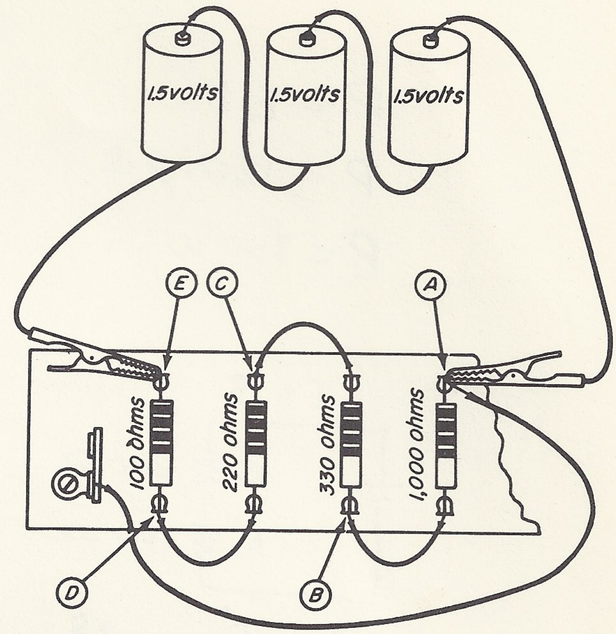


Fig. 9-8

In Experiment 9-4, point *A* was about 2.7 volts positive with respect to the tie terminal. Point *B* was 0 volts, point *C* was about 0.9 volt negative, point *D* was about 1.5 volts negative, and point *E* was about 1.8 volts negative with respect to the tie terminal. In Experiment 9-5, all voltages were negative with respect to the tie terminal.

If we consider the tie terminal to be our ground connection, you can see that it is possible to have any number of voltages positive or negative with respect to ground or to any other reference point that we wish to set up.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 10

MAGNETISM AND ELECTROMAGNETISM

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Theory Lesson 10

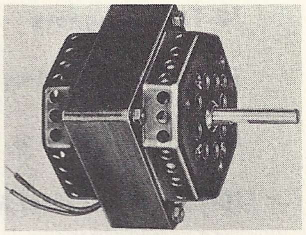
INTRODUCTION

So far, your study of radio and television theory has been concerned mostly with electricity. But now, it is necessary for you to learn something about *magnetism.* Magnetism is the property of certain materials to attract iron, steel, and other similar metals. It is also the name of the study of magnets, their fields, and their actions. A *magnet* is a body that has the power to attract and hold magnetic materials such as iron, steel, nickel, cobalt, and the alloys of certain metals. A *magnetic field* is the region surrounding a magnet in which the force of the magnet affects other magnetic objects. A knowledge of magnets and their fields is important to you in your study of radio and television theory. Without it, you cannot understand how many radio and television circuits work. Unless you know something about magnetism, the theory of electric motors, generators, transformers, and loudspeakers must forever remain a mystery. Even your multimeter depends upon the action of magnetic fields. Therefore, it is clear that you must learn something about magnetism before you can continue your study of radio and television theory.

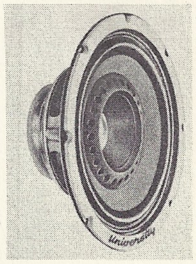
Many hundreds of years ago, it was found that pieces of a certain mineral attracted other pieces of the same mineral. This mineral also had another unusual ability. When a piece of it was suspended so that it was free to turn in any direction, one end would always come to rest pointing toward the north. The mineral was first called *lodestone.* Later, large amounts of it were found near Magnesia, a city in Asia Minor, and it came to be called *magnetite.* From this came the terms *magnet* and *magnetism.* Pieces of magnetite are sometimes called *natural magnets,* since they show magnetic characteristics in their natural form – the form in which they are taken from the earth. However, natural magnets are not too important in our study of radio, since man-made magnets can be made much stronger.

10-1. MAGNETS

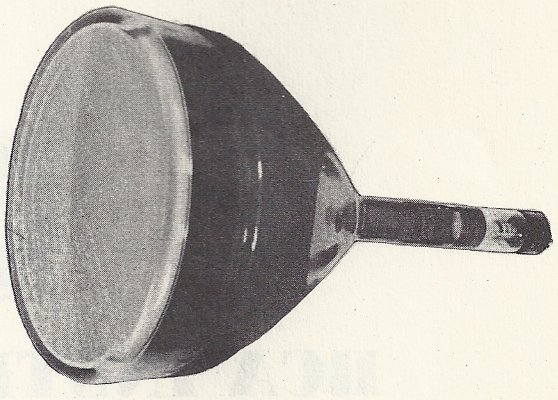
Most of the magnets used today are called *artificial magnets* because they are man-made and not natural. An artificial magnet can be made by stroking a piece of magnetic material with a piece of magnetite. Such a magnet would be very weak because the



(a) Electric Motor



(b) Loudspeaker



(c) Television Picture Tube

Fig. 10-1. Some Uses of Magnets

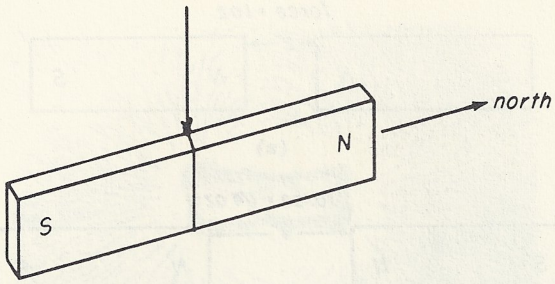


Fig. 10-2

magnetizing force of the magnetite itself is weak. A better way to make an artificial magnet would be to place a piece of magnetic material in a coil of wire that has electric current flowing through it. Using this method with special magnetic alloys, we can make very strong magnets.

Artificial magnets may be divided into two groups: *temporary magnets* and *permanent magnets*. A magnet made of iron, soft steel, or nickel will lose its magnetism almost as soon as it is removed from the magnetizing force. Such a magnet is called a temporary magnet. On the other hand, magnets made from hardened steel and modern magnetic alloys keep their magnetism for long periods of time. They are called permanent magnets.

Both temporary and permanent magnets are widely used in radio work. For example, temporary magnets are used in transformers, and relays, while permanent magnets are used in headphones, magnetic phonograph pickups, meters, and some kinds of loudspeakers.

Magnetic Poles. We said that if a magnet is suspended so that it can turn freely, one end always comes to rest pointing north. This end is called the *north-seeking pole*, or simply, the *north pole*. The other end is called the *south pole*. That free-moving bar magnets act this way can be seen by suspending a bar magnet from a string, as shown in Fig. 10-2. The pole that faces north is marked *N* and the pole that faces south is marked *S*.

You can learn another very important fact about magnets from the same suspended magnet. Look at Fig. 10-3. Let's bring the north pole of another magnet close to the north pole of the suspended magnet, as in Fig. 10-3*a*. The north pole of the suspended magnet *moves away;* we say that it is *repelled* by the north pole of the other magnet.

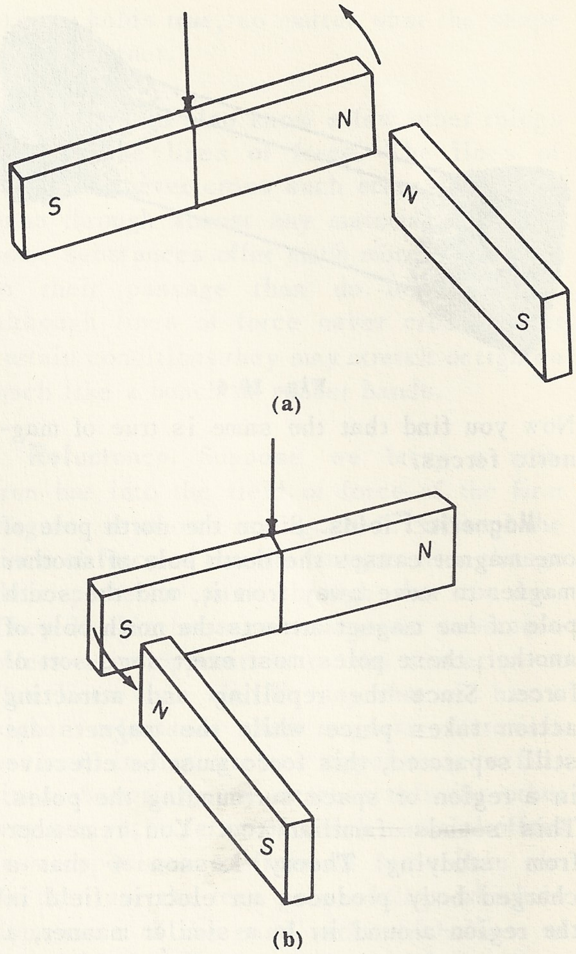


Fig. 10-3

If we now bring the north pole of the second magnet near the south pole of the suspended magnet, the south pole of the suspended magnet *moves nearer;* that is, it is *attracted* by the unlike pole. This is shown in Fig. 10-3*b*.

This is one of the most important principles of magnetism. *Like poles repel each other, and unlike poles attract each other.* This should sound familiar. Perhaps you've noticed that this law of magnetic forces is very much like the law of electrical charges. In Theory Lesson 4, you learned that like charges repel and unlike charges attract.

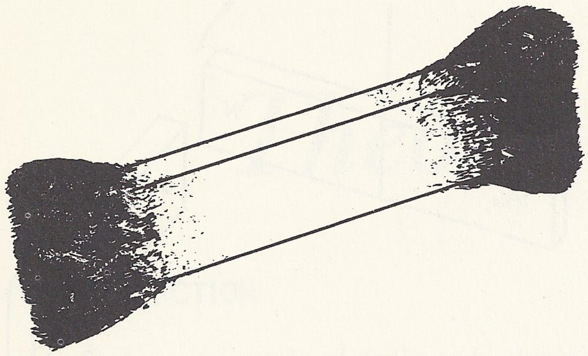


Fig. 10-4

Now you find that the same is true of magnetic forces.

Magnetic Fields. Since the north pole of one magnet causes the north pole of another magnet to move away from it, and the south pole of one magnet attracts the north pole of another, these poles must exert some sort of force. Since the repelling and attracting action takes place while the magnets are still separated, this force must be effective in a region or space surrounding the poles. This sounds familiar too. You remember from studying Theory Lesson 4 that a charged body produces an electric field in the region around it. In a similar manner, a magnet produces a magnetic field, which we have defined as the region surrounding a magnet in which its force affects other magnetic objects.

We can get an idea of this magnetic field by dipping a bar magnet into a jar of iron filings. The filings cling to the ends of the magnet in clusters, as shown in Fig. 10-4, with hardly any filings near the center of the bar. This shows that the magnetic strength – or *field strength* – of a bar magnet is greatest at its poles and least at the center of the bar. If we could measure this very carefully, we would find that it is exactly the same at each pole.

Now we come to another very important principle of magnetism. We know that like poles repel and unlike poles attract. The strength with which they attract or repel each other depends not only on the strength of their poles, but also upon the distance between them. For example, in Fig. 10-5*a*,

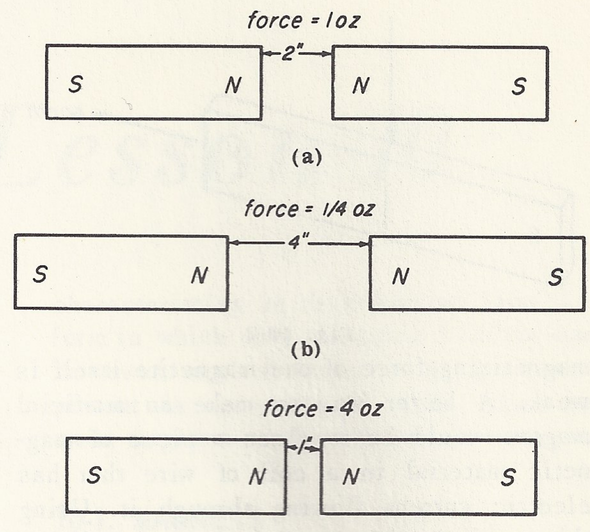
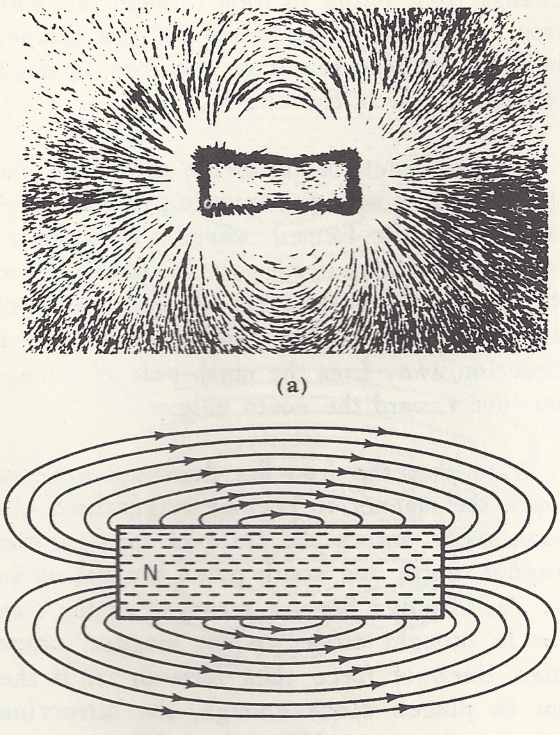


Fig. 10-5

two bar magnets are placed so that their poles are 2 inches apart. Let's suppose that in this position, the two bar magnets repel each other with a force of 1 ounce. If the magnets are moved away from each other until they are 4 inches apart, as shown in Fig. 10-5*b*, the repelling force will be only ¼ ounce; if the magnets are moved toward each other so that their poles are only 1 inch apart, as in Fig. 10-5*c*, the repelling force will be 4 ounces, or four times as great as it was when the magnets were 2 inches apart. You can see that the strength of the magnetic field decreases when the poles are farther from each other.

Lines of Force. The pattern of the field of force exerted by a magnet can be seen by placing a sheet of paper, cardboard, or glass over a bar magnet and sprinkling iron filings on it. If the sheet is tapped gently, the iron filings arrange themselves into a definite pattern, as shown in Fig. 10-6*a*. This is what happens. Each iron filing becomes magnetized when it enters the field of force of the bar magnet. Hundreds of tiny magnets are thus created. These magnetized filings line themselves end to end and form many curved lines. In part *b* of the figure, the lines extending from one pole of the magnet to the other are redrawn. These lines represent the magnetic force exerted by the bar magnet, and are called *lines of force*, or *flux lines*.



(a)

(b)

Fig. 10-6

The lines of force also show the general direction of magnetic force. We can see that the lines tend to spread outward from each pole and travel in loops to the other pole. Still another characteristic of lines of force can be seen by the use of a compass, as shown in Fig. 10-7. If you place a compass at different points around a bar magnet, and note the direction in which the needle points at each position, you will find that the needle follows the lines of force. The lines begin at the north pole of the magnet and travel in a loop to the south pole. So, we say that the direction of any line of force is from the north pole to the south pole. This

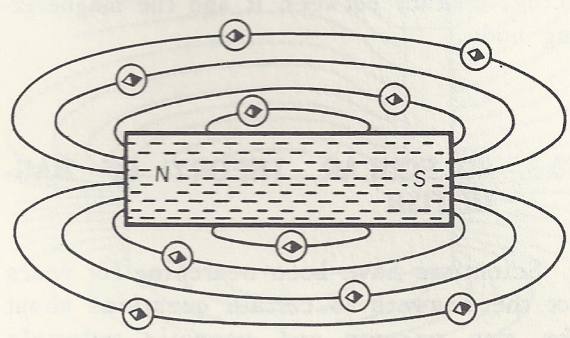


Fig. 10-7

always holds true, no matter what the shape of the magnet.

You should also know a few other things about these lines of force. The lines of force can never cross each other. They can pass through almost any material, although some substances offer much more opposition to their passage than do others. Also, although lines of force never cross, under certain conditions they may stretch or tighten much like a bunch of rubber bands.

Reluctance. Suppose we bring a soft-iron bar into the field of force of the first magnet, as shown in Fig. 10-8. Some of the lines of force of the first magnet now change their paths to pass through the iron bar. They do this because a magnetic substance offers less opposition to the formation of flux lines than air. We say that air has a higher *reluctance* than magnetic materials because it has greater opposition to flux lines. Sometimes we express this the other way around, in terms of which material offers less opposition to lines of force than air. We then use the term *permeability*, which is a measure of the ease with which lines of force can form in a material. Air, therefore, has a low permeability, which is the same as saying that it has a high reluctance. The permeability of all materials is compared with that of air. So, we say that air has a permeability of *1*. The permeability of non-magnetic materials is the same as that of air, while some magnetic alloys have permeabilities thousands of times as great as that of air.

What would happen to the lines of force if, instead of an iron bar, we brought another

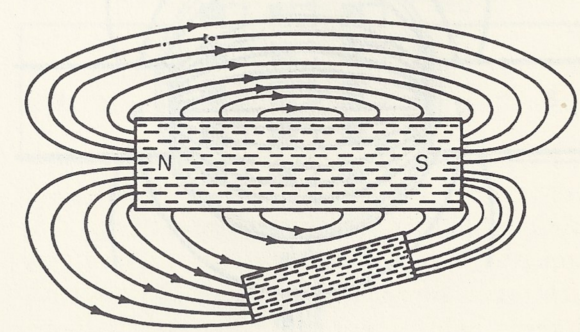


Fig. 10-8

magnet into the magnetic field? Figure 10-9*a* shows that when the north poles of two magnets are brought near each other, the lines of force from one north pole seem to push away from those of the other north pole. Part *b* of the figure shows what happens when unlike poles are brought near to each other. The lines of force seem to tighten between the two poles, drawing them closer. This, of course, is in keeping with what you already know – that like poles repel and unlike poles attract.

10-2. MAGNETISM BY INDUCTION

Now that we know something about the field of force that surrounds a magnet, we can get a better idea of how magnetic materials may be magnetized. Figure 10-10*a* shows the lines of force around a bar magnet. Suppose that we bring a bar of soft iron near the magnet. Part *b* of the figure shows that some of the lines of force of the magnet change their paths to form through the soft-iron bar. This is because, as you learned before, the reluctance of the iron is much less than that of the air.

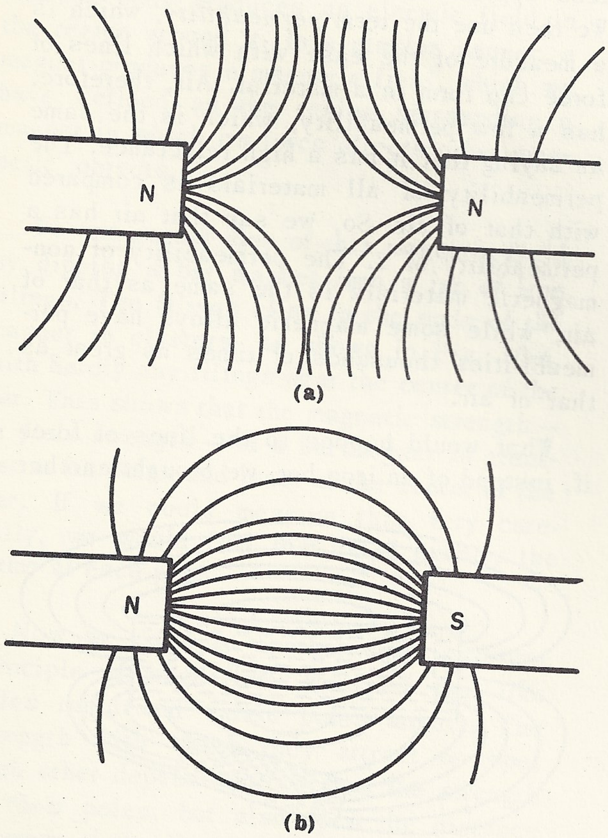


Fig. 10-9

As the lines of force are formed in the iron bar, they set up magnetic poles in it. A south pole is formed where the lines of force enter, and a north pole is formed where they leave. This bears out our description of lines of force – that they always have a direction away from the north pole of a magnet and toward the south pole.

Note that the iron bar does not have to touch the magnet to become magnetized. As soon as it enters the field of force of the magnet, north and south poles are set up in it. These poles become stronger as the iron bar is brought closer to the magnet, since more lines of force then form in it. If the bar is placed close enough, the attraction between the two unlike poles will cause the bar to be drawn to the magnet, as in part *c* of the figure. In part *d*, another iron bar is added. It, too, becomes magnetized as the lines of force pass through it. Note the polarity of the bars; the magnetic lines still point toward the south poles and away from the north poles.

When a magnetic material is magnetized by being brought close to a magnet, we say that it is magnetized by *induction*. This simply means that magnetism is *induced* or *set up* in the magnetic material without it actually touching the magnet. A magnetic material can be magnetized by touching it or rubbing it against a magnet. This means that the material is magnetized by means of actual contact between it and the magnetizing body.

10-3. MOLECULAR THEORY OF MAGNETISM

Scientists have been searching for years for the answers to certain questions about the way magnets and magnetic materials behave. They have come up with many ideas

and theories about what happens in a piece of magnetic material when it is being magnetized. Among them, there is one called Weber's Theory, which is also known as the *molecular theory of magnetism.*

According to this theory, each molecule of a magnetic material acts like a tiny magnet. If we break up a permanent magnet into very small pieces without heating or jarring them, we find that each small piece forms a magnet with its own north and south poles. It is believed that were we to continue to break up such a magnet into its molecules, we would find that each molecule would be a tiny magnet. Before the material is magnetized, these tiny magnetic molecules are arranged so that their poles point in all possible directions, as shown in Fig. 10-11*a*. When a magnetic substance is magnetized, the molecules are forced by the magnetizing field to arrange themselves in the direction of the flux (lines of force) of the field. As a result, a piece of magnetic material that is completely magnetized has

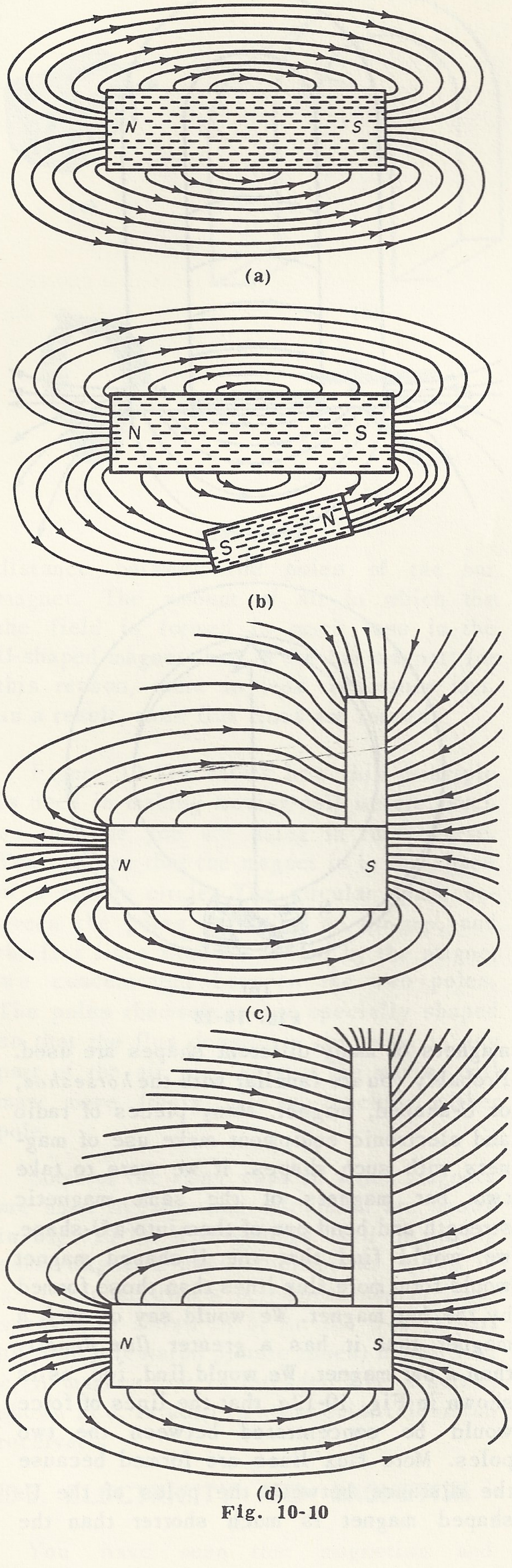


Fig. 10-10

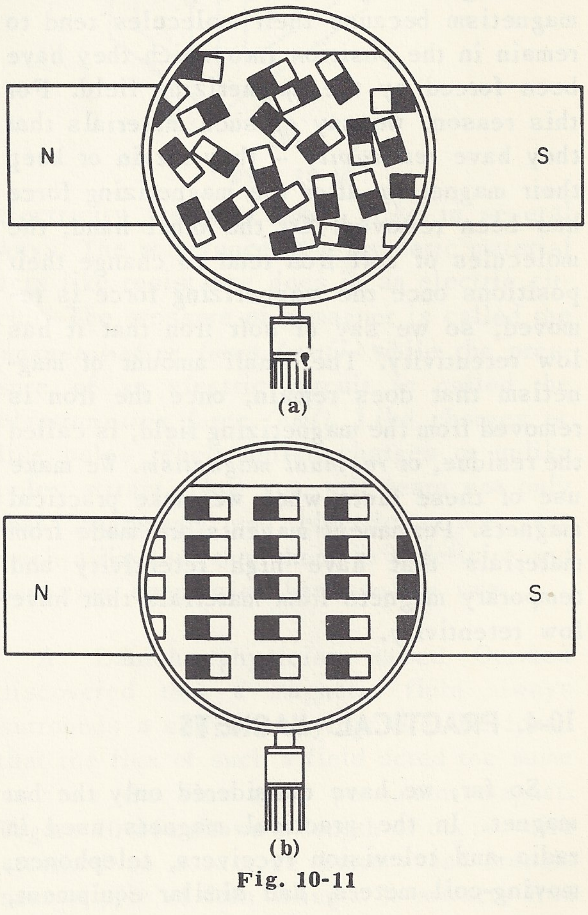


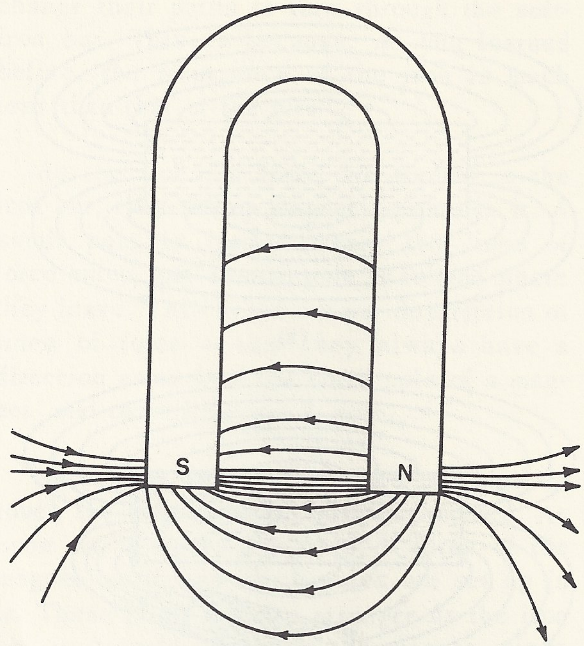
Fig. 10-11

all of its molecules arranged in an orderly manner, as shown in Fig. 10-11*b*. If the magnetizing force is weak, only a few of the molecules will arrange themselves in the direction of the magnetizing field. More molecules are arranged in this manner as the intensity of the field is increased, until the point is reached when all of the molecules of the magnetic material have arranged themselves in the direction of the magnetizing field. When this point is reached, we call it *saturation*. Then, no matter how much the magnetizing field may be increased, there is no further change in the arrangement of molecules.

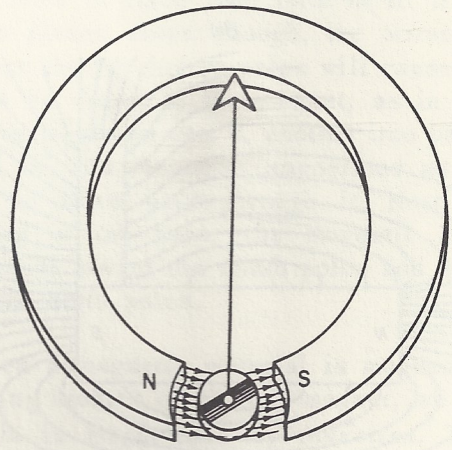
Hard steel and magnetic alloys, such as Alnico and Permalloy, require a very intense field to magnetize them, because their molecules do not turn easily. A piece of soft iron, because its molecules turn more easily than do those of the harder magnetic materials, may be magnetized with a much weaker magnetizing force. However, when the hard steel and magnetic alloys are removed from the magnetizing field, they retain their magnetism because their molecules tend to remain in the position into which they have been forced by the magnetizing field. For this reason, we say of such materials that they have *retentivity* – they retain or keep their magnetism after the magnetizing force has been removed. On the other hand, the molecules of soft iron tend to change their positions once the magnetizing force is removed; so we say of soft iron that it has low retentivity. The small amount of magnetism that does remain, once the iron is removed from the magnetizing field, is called the residue, or *residual magnetism*. We make use of these facts when we make practical magnets. Permanent magents are made from materials that have high retentivity and temporary magnets from materials that have low retentivity.

10-4. PRACTICAL MAGNETS

So far, we have considered only the bar magnet. In the practical magnets used in radio and television receivers, telephones, moving-coil meters, and similar equipment, magnets of many different shapes are used. Probably you are familiar with the *horseshoe*, or U-shaped, magnet. Many pieces of radio and electronic equipment make use of magnets with such shapes. If we were to take two bar magnets of the same magnetic strength and bend one of them into a U-shape, we would find that the U-shaped magnet would form more flux lines than those formed by the bar magnet. We would say of such a magnet that it has a greater *flux density* than a bar magnet. We would find, too, as is shown in Fig. 10-12*a*, that the lines of force would be concentrated between the two poles. More flux lines are formed because the distance between the poles of the U-shaped magnet is much shorter than the



(a)



(b)

Fig. 10-12

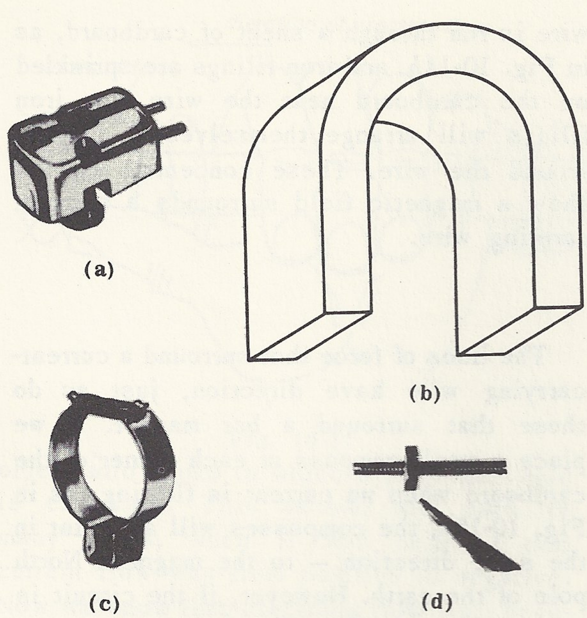


Fig. 10-13

distance between the poles of the bar magnet. The amount of air in which the the field is formed is much less in the U-shaped magnet than in the bar magnet; for this reason, there is less reluctance and, as a result, more flux lines are formed.

Figure 10-12*b* shows how this principle is used in making moving-coil meters, such as the one you are using in this course. You can see that the magnet is in the shape of a broken circle. The circular space between the poles is called an *air-gap*, and the flux lines that are formed by the magnet are concentrated between the two poles. The poles themselves are specially shaped so that the flux density is the same in any part of the air gap, so that the moving coil may move freely without touching either pole.

Some of the many ways in which magnets are used in radio and television are shown in Fig. 10-13. A magnet is used in making some magnetic phono pickups as shown in *a*. A magnet from a permanent-magnet loudspeaker is shown in *b*. An *ion trap* (a part used on television picture tubes) appears in *c*. A magnet that is threaded like a screw, shown in *d*, is used in some color television receivers.

10-5. ELECTRICITY AND MAGNETISM

You have seen that magnetism and electricity are very much alike in several ways. The reluctance of a magnetic material acts like resistance does in an electric circuit. The pressure of a magnet is called the *magnetomotive force (mmf)*, while the pressure of an electric circuit is called the *electromotive force (emf)*. Like charges or like poles repel; unlike charges or unlike poles attract. Now you will learn not only that magnetism and electricity are very much alike, but that there is a definite and important connection between the two.

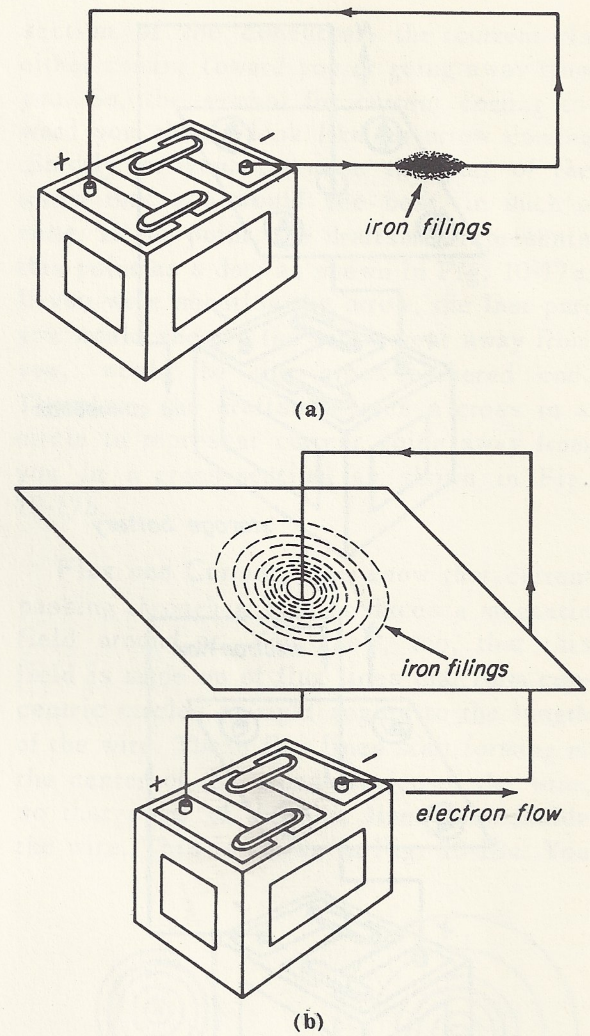


Fig. 10-14

A Danish physicist named Oersted discovered that a magnetic field always surrounds a current-carrying wire. He found that the flux of such a field acted the same way as the flux of a permanent magnet. Figure 10-14*a* shows a length of copper wire attached to a storage battery and brought near a pile of iron filings. It attracts iron filings just as does a bar magnet. If the

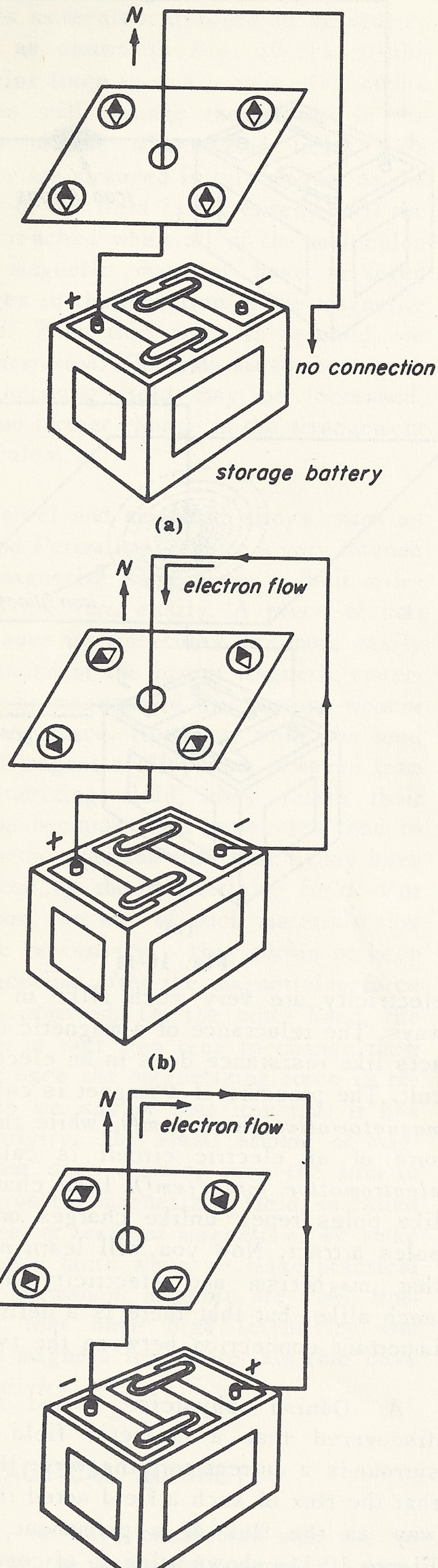


Fig. 10-15

wire is run through a sheet of cardboard, as in Fig. 10-14*b*, and iron filings are sprinkled on the cardboard near the wire, the iron filings will arrange themselves in circles around the wire. These concentric circles show a magnetic field surrounds a current-carrying wire.

The lines of force that surround a current-carrying wire have direction, just as do those that surround a bar magnet. If we place a small compass at each corner of the cardboard when no current is flowing, as in Fig. 10-15*a*, the compasses will all point in the same direction – to the magnetic North pole of the earth. However, if the circuit is completed, as in Fig. 10-15*b*, the compasses will point in the direction of the flux lines set up by the current flowing in the wire. We can be sure that the magnetic field is there because if we open the circuit, the compasses will again all point north.

Now suppose we reverse the connections to the battery – that we make the current flow in the other direction, as in Fig. 10-15*c*. The compasses again point in the direction of the flux lines. However, the direction of flux is opposite to that in Fig. 10-15*b*. This means that the direction of the magnetic field around a current-carrying wire depends on the direction of the current.

Left-Hand Rule. An easy way to find out the direction of the flux lines is to use the *left-hand rule*, as shown in Fig. 10-16. Grasp the current-carrying wire in your left hand, with your thumb pointing in the direction of electron (current) flow. Your fingers will then point in the direction of the flux lines. This rule also works the other way; if you know the direction of the lines of force, you can tell the direction of the current flow. To do this, grasp the conductor with your left hand, with your fingers pointing in the direction of the flux lines. Your thumb will then point in the direction of the current flow.

It is possible that you may find some

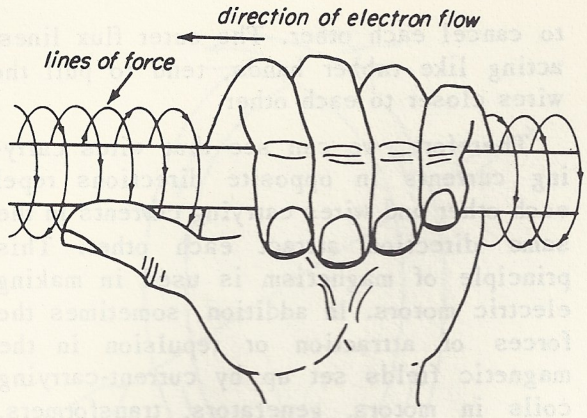


Fig. 10-16

older radio books in which a *right-hand rule* is explained. This method was used for many years, when it was believed that current flow was from positive to negative. Now we know that electrons flow from negative to positive; we use the left-hand rule.

Symbols for Current Flow. You know that we may show direction of current flow either by means of arrows running parallel with circuits or by drawing arrow heads on lines representing circuits. Sometimes, it is necessary to show the direction of current flow in a cross-sectional view of a wire. In drawings of this kind, we use two special symbols to represent the direction of current flow. In a drawing where you see the cross section of the conductor, the current is either coming toward you or going away from you. So, the symbol for current coming toward you should look like an arrow coming directly at you. Because the part of the arrow that you would see best, in such a case, is the point, the draftsman represents this point as a dot, as shown in Fig. 10-17*a*. If you were shooting the arrow, the last part you would see, as the arrow went away from you, would be the cross-feathered end. Therefore, the draftsman uses a cross in a circle to represent current going away from you in a cross-section, as shown in Fig. 10-17*b*.

Flux and Current. You know that current passing through a wire produces a magnetic field around it. You know, too, that this field is made up of flux lines that form concentric circles at right angles to the length of the wire. These flux lines start forming at the center of the cross-section of the wire, so that some of the flux lines form inside the wire. This is shown in Fig. 10-18*a*. You

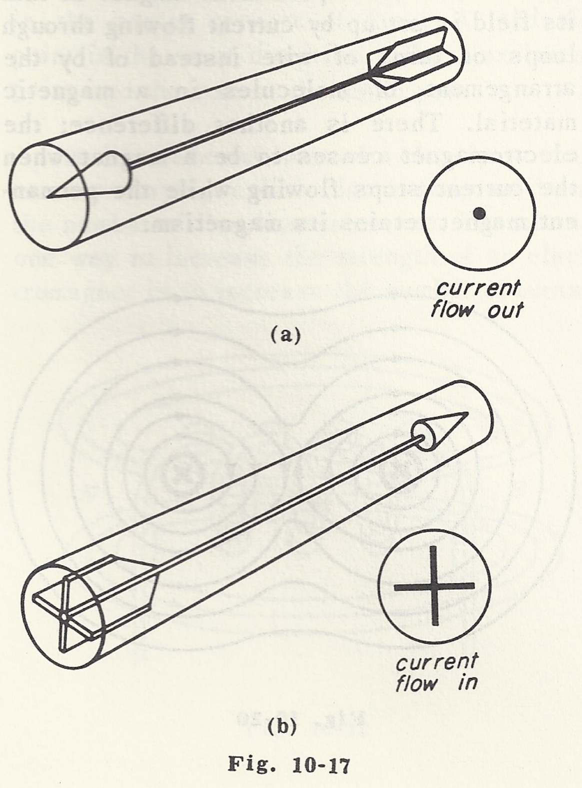


Fig. 10-17

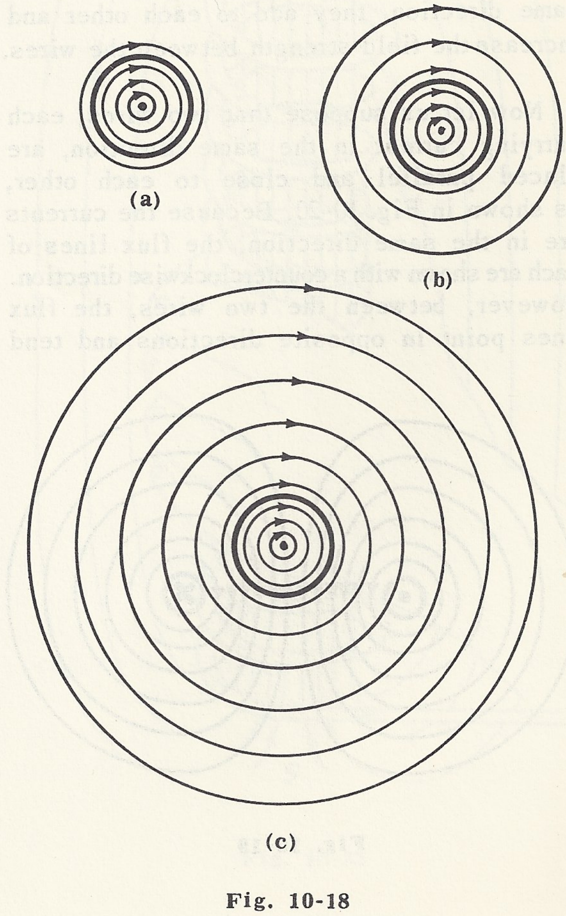


Fig. 10-18

see a cross-section of a wire with current flowing toward you. This being so, the flux lines have a clockwise direction. If the current is increased, as in Fig. 10-18*b*, more flux lines are formed, and the field spreads out from the wire. If the current is still further increased, as in Fig. 10-18*c*, the field expands also. From this, you can see that the greater the current that flows through a wire, the greater is the magnetic field.

Flux and Parallel Wires. Suppose that two wires, each carrying current in a direction opposite to the other, are placed parallel and close to each other. Each wire will have its own field, as shown in Fig. 10-19. Because the currents are opposite in direction, the flux lines, too, are opposite; one field is clockwise and the other field is counterclockwise. However, *between the two conductors*, the flux lines of both conductors point in the same direction. Flux lines pointing in the same direction tend to push away from each other, so flux lines between the wires repel each other. Because the flux lines between the wires point in the same direction, they add to each other and increase the field strength between the wires.

Now let us suppose that two wires, each carrying current in the same direction, are placed parallel and close to each other, as shown in Fig. 10-20. Because the currents are in the same direction, the flux lines of each are shown with a counterclockwise direction. However, between the two wires, the flux lines point in opposite directions and tend to cancel each other. The outer flux lines, acting like rubber bands, tend to pull the wires closer to each other.

Therefore, we can see that wires carrying currents in opposite directions repel each other and wires carrying currents in the same direction attract each other. This principle of magnetism is used in making electric motors. In addition, sometimes the forces of attraction or repulsion in the magnetic fields set up by current-carrying coils in motors, generators, transformers, and other electric equipment is so great that damage to equipment may occur when currents are suddenly increased by short circuits or other causes.

Flux and a Current-Carrying Loop. We have seen that a magnetic field exists around a length of current-carrying wire. Now suppose that we bend the current-carrying wire to form a loop, as shown in Fig. 10-21. The drawing shows that all the flux lines point *into* the loop on one side and *out* of the loop on the other side. This is like a permanent magnet, in which the flux points into the south pole and out of the north pole. So, by forming the wire into a loop, we produce an *electromagnet* with a north pole and a south pole. An electromagnet differs from a permanent magnet in that its field is set up by current flowing through loops or turns of wire instead of by the arrangement of molecules in a magnetic material. There is another difference; the electromagnet ceases to be a magnet when the current stops flowing while the permanent magnet retains its magnetism.

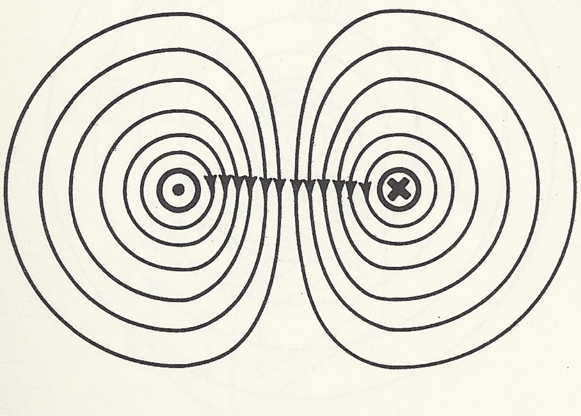


Fig. 10-19

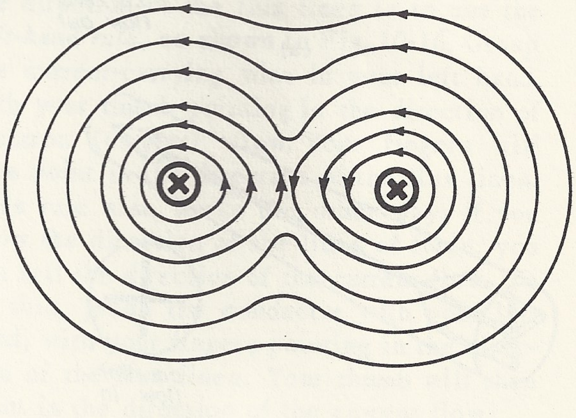


Fig. 10-20

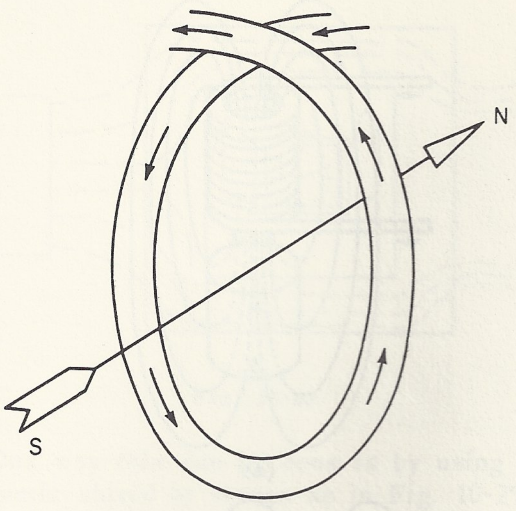


Fig. 10-21

Flux and Turns of a Current-Carrying Coil. A single turn of wire does not produce a very strong magnet, so practical electromagnets are normally made from many turns of wire. Figure 10-22 shows a current-carrying coil of four turns. Each turn is parallel to the next one, so the effect is the same as having parallel current-carrying wires. If the turns are close together, only few flux lines form between the turns, and these lines cancel each other. The outer flux lines of each turn link together to form the field around the coil. The flux lines concentrate in the center or *core* of the coil, and all point in the same direction. The flux lines point into the core at the south pole.

As the number of turns of a closely-wound, current-carrying coil is increased, so does the number of flux lines increase. Therefore, one way to increase the strength of an electromagnet is to increase the number of turns.

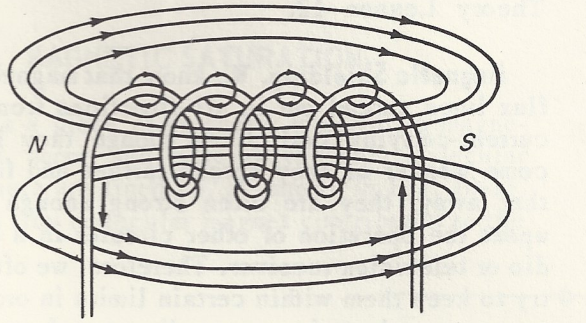


Fig. 10-22

Left-Hand Rule for a Current-Carrying Coil. The magnet polarity of a coil can be found by the *left-hand coil rule,* illustrated in Fig. 10-23. Grasp the coil with your left hand with your fingers pointing in the direction of current flow. Your thumb will then point in the direction of the coil's north pole.

Flux and the Core Material. You know that the magnetic flux of a current-carrying coil can be increased by increasing the current flowing through the coil or by increasing the number of turns in the coil. A third way in which the flux can be increased is by winding the coil around a core material that has a higher permeability than that of air. A coil with a soft-iron core, for instance, produces a much stronger field than an air-core coil of the same number of turns. A core made of powdered iron that has been pressed together may have a permeability of from

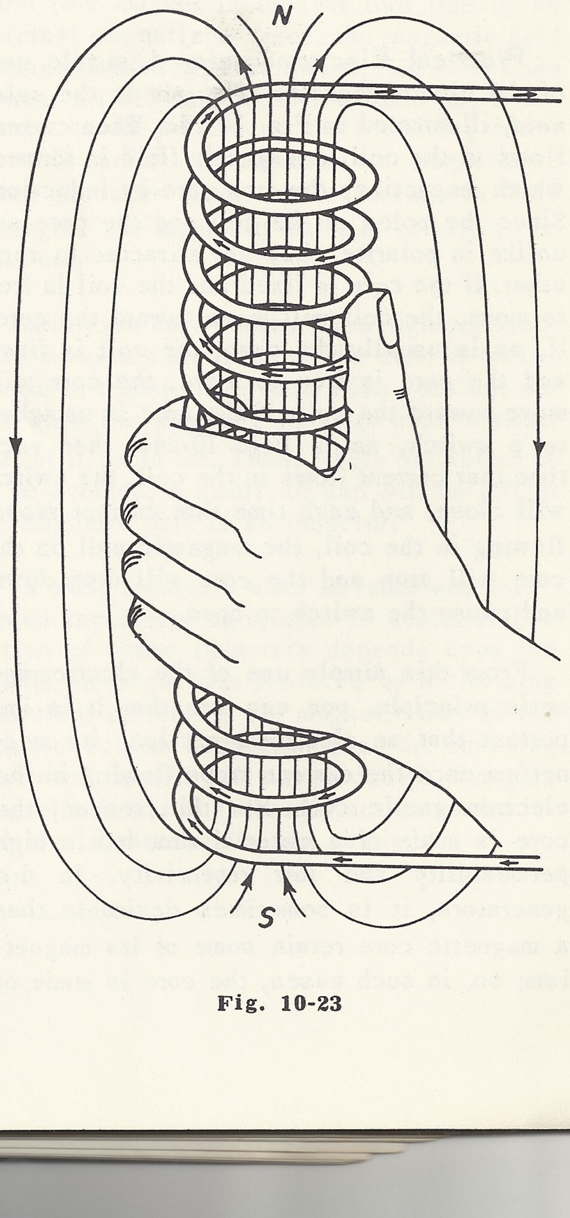


Fig. 10-23

50 to 100 times that of air. Radio and television coils that use such cores form many times the number of flux lines that a similar air-core coil might form. Other materials, known as *ferrites*, have a permeability of well over 1,000. They are also used in radio and television coils.

We can see that the strength of an electromagnet depends mainly on three things:

1. The amount of current flowing in the coil; the greater the current, the greater is the magnetic flux.

2. The number of turns in the coil; the greater the number of evenly spaced turns, the greater is the magnetic flux.

3. The permeability of the core material; the greater the permeability, the greater is the magnetic flux.

Practical Electromagnets. A simple use of the electromagnetic principle is the *solenoid*, illustrated in Fig. 10-24*a*. When current flows in the coil, a magnetic field is formed, which magnetizes the iron core by induction. Since the poles of the coil and the core are unlike in polarity, they are attracted to each other. If the core is fixed and the coil is free to move, the coil will move toward the core. If, as is usually the case, the coil is fixed and the core is free to move, the core will move toward the coil. If the core is attached to a switch, as in Fig. 10-24*b*, then each time that current flows in the coil, the switch will close, and each time that current stops flowing in the coil, the magnetic pull on the core will stop and the core will drop down and cause the switch to open.

From this simple use of the electromagnetic principle, you can see that it is important that an electromagnet lose its magnetism once the current stops flowing in the electromagnetic coil. For this reason, the core is made of a material that has a high permeability and low retentivity. In d-c generators, it is sometimes desirable that a magnetic core retain some of its magnetism; so, in such cases, the core is made of

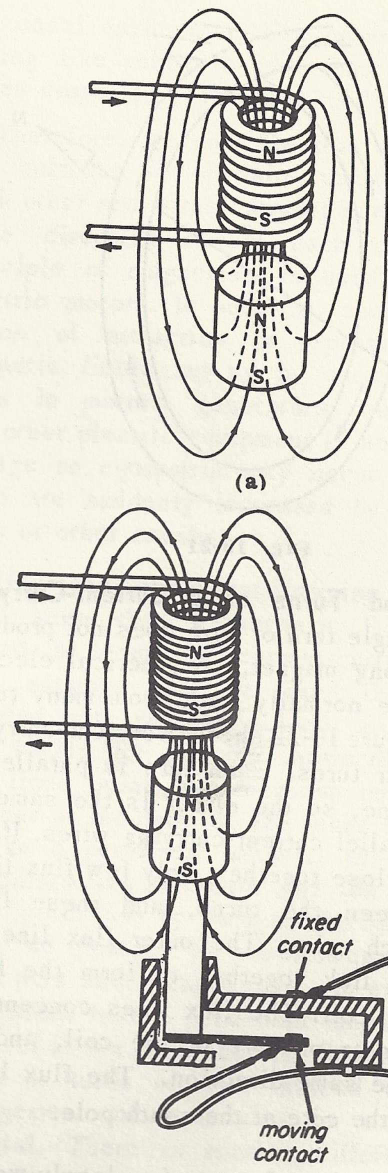


Fig. 10-24

a material that will hold some of its magnetism after the current stops flowing in the coil. This is discussed more completely in Theory Lesson 12.

Magnetic Shielding. We know that magnetic flux lines spread out in all directions from a current-carrying coil. Even though they become weaker as they spread farther and farther away, they are often strong enough to upset the operation of other circuits in a radio or television receiver. Therefore, we often try to keep them within certain limits in order to prevent them from spreading too far and interfering with other circuits.

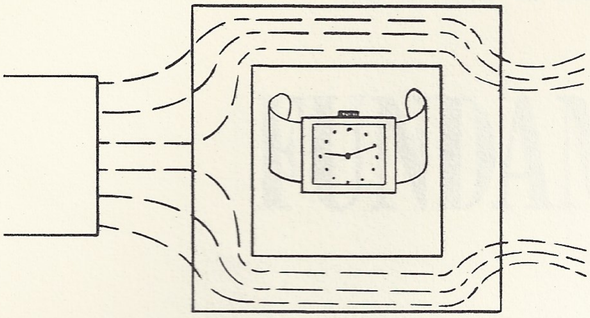


Fig. 10-25

One way this can be done is by using a magnetic shield or screen as in Fig. 10-25. This is usually a case or can of soft iron. Since flux lines form in a magnetic material more easily then in air, most of them will form in the shield. A shield is necessary to keep some components isolated from the magnetic field around other components.

Demagnetizing. Sometimes a tool, a watch, or some other instrument becomes magnetized by accident. When this happens, it is necessary to know how to *demagnetize* whatever has become accidentally magnetized. By demagnetizing, we mean the removal of the magnetism and the restoration of the article to its original condition. The simplest way to do this is to place the watch or other article in the field set up by an alternating current. For example, you can use a 1,000- to 3,000 ohm field coil from an old electrodynamic speaker connected to an a-c supply, as shown in Fig. 10-26. Place the watch in or near the center (core) of the coil. Then move the watch very slowly away from coil and its field. Do not try to rush the movement away from the a-c field or you will have to do the demagnetizing all over again.

10-6. MAGNETIC SATURATION

As a piece of magnetic material is magnetized, more and more of the tiny molecular magnets are lined up, as shown in Fig. 10-11. Each tiny molecular magnet contributes to the

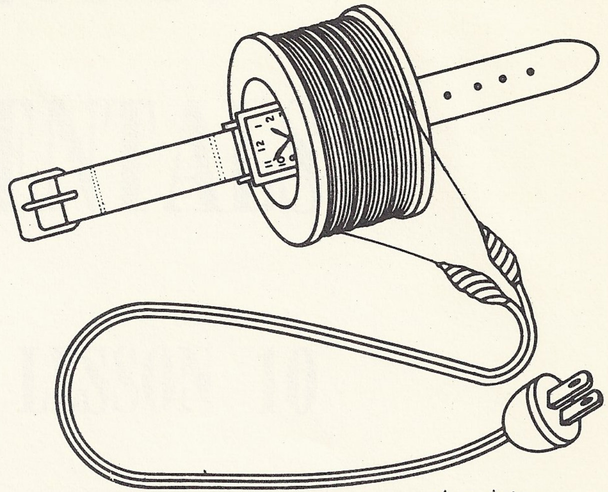


Fig. 10-26

field strength of the total magnet. Thus, as each tiny magnet is brought into line by an external magnetizing force, the magnetic field strength produced is increased. However, when almost all the molecules are lined up, it becomes harder to line up the remaining ones. At this point, an increase in magnetizing force produces little or no increase in field strength. The magnetic material is said to be *saturated.*

Saturation only occurs when high permeability materials are used as the core of an inductor or transformer. Saturation does not occur when the magnetic path, or even a small part of it, is in air. Thus, where saturation is to be avoided, a small air gap will be left in the magnetic path of an inductor.

In most inductors used in radio and television receivers, saturation is avoided. The action of these inductors depends upon the change in magnetism produced by a changing electrical current. If the magnetic core of the inductor is near saturation, then the changing electrical current will not produce a changing magnetic field. The desired action of the inductor will therefore not be obtained.

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 10

MAGNETIC EXPERIMENTS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

350 West 4th Street, New York 14, N. Y.

Experiment Lesson 10

PART ONE

OBJECT

The object of the experiments in Part One of this lesson is to learn:

That a magnet attracts certain materials and not others.

How the lines of force are distributed.

How the lines of force are distributed between the poles of a bar magnet.

That the direction of the lines of force may be observed.

How two bar magnets affect each other.

How the shape of a magnet affects the density of the field.

How magnetic material can be used as a magnetic shield.

That some materials are magnetically transparent.

PREPARATION

Study Theory Lesson 10, *Magnetism and Electromagnetism.*

INFORMATION

In this experiment lesson, you are going to work some simple experiments with magnets. What you learn from these experiments, and from Theory Lesson 10, *Magnetism and Electromagnetism,* will be interesting in itself. However, even more important is the fact that what you learn about the principles of magnetism will be of great importance to your understanding of radio and TV.

You have learned from your study of the theory of magnets that magnets attract and repel because of the lines of force between their poles. In the following experiments, we are going to work with these lines of force in different ways.

EQUIPMENT NEEDED

- Two bar magnets
- Horseshoe magnet
- Iron filings
- Sheet of paper
- Sheet of cardboard
- Three small iron or steel nails
- Compass
- Copper penny
- Dime
- Brass screw
- Small steel or iron tacks

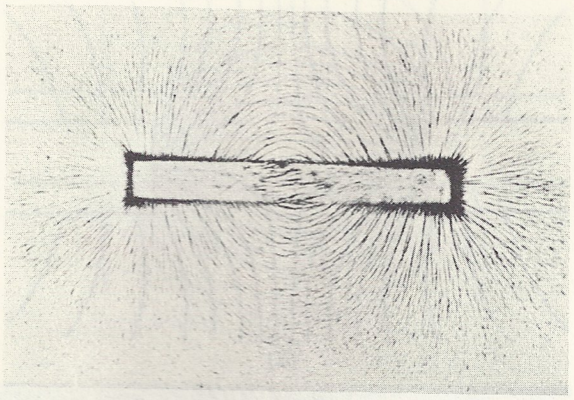
EXPERIMENT 10-1

To try to attract various materials with a bar magnet.

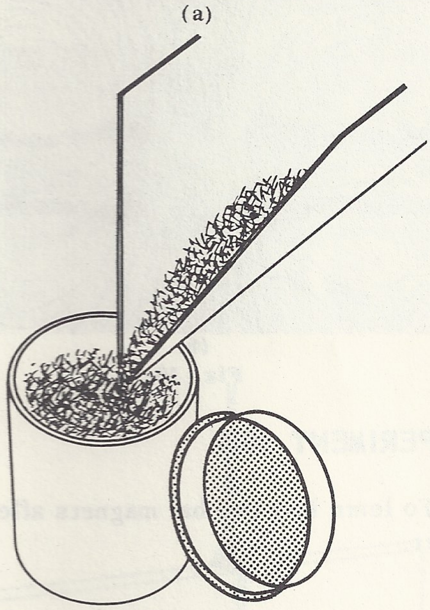
Procedure.

Step 1. Place a small iron nail on the table and bring the bar magnet close to it. Remove the nail from the magnet.

Step 2. Place the copper penny on the table and bring the magnet close to it. The magnet will not attract the penny.



(a)



(b)

Fig. 10-1

Step 3. Place the dime on the table and bring the magnet close to it. The magnet will not atttact the dime.

Step 4. Place the brass screw on the table and bring the magnet close to it. The magnet will not attract the screw.

Discussion. From the experiment you just performed, you were able to see that a magnet will attract some materials and not others. The nail is made of a magnetic material, and so the magnet attracted it. The other objects you tried to attract with the magnet are made of non-magnetic materials, and so the magnet did not attract them. From this experiment, you can see that a simple test of whether or not a material is magnetic is to try to attract it with a magnet.

EXPERIMENT 10-2

To see the path of the lines of force between the poles of a bar magnet.

Procedure.

Step 1. Place the bar magnet long-side down on the table.

Step 2. Place a piece of cardboard on top of the magnet and a piece of paper on top of the cardboard. The magnet should be under the center of the cardboard.

Step 3. Lightly sprinkle some iron filings on the sheet of paper. Tap the paper. The filings will arrange themselves in the pattern shown in Fig. 10-1*a*. The paths made by the filings are the paths of the lines of force between the poles of the magnet.

Step 4. Carefully pick up the paper and pour the filings back into the container, as shown in Fig. 10-1*b*.

Discussion. In this experiment, you were able to observe the effect on the iron filings of the lines of force between the poles of a bar magnet. You were able to see that the filings were concentrated at the poles of the magnet; therefore, you proved that the lines of force are most concentrated at the poles of the magnet. You were able to notice the form of the lines of force between the north and south poles. Be sure you understand exactly what you have proved in this experiment before you go on to the other experiments. If necessary, go back to Theory Lesson 10, *Magnetism and Electromagnetism*, and re-read the material that will help you to understand this experiment.

EXPERIMENT 10-3

To observe the direction of the lines of force between the poles of a bar magnet.

Procedure.

Step 1. Place a compass next to the

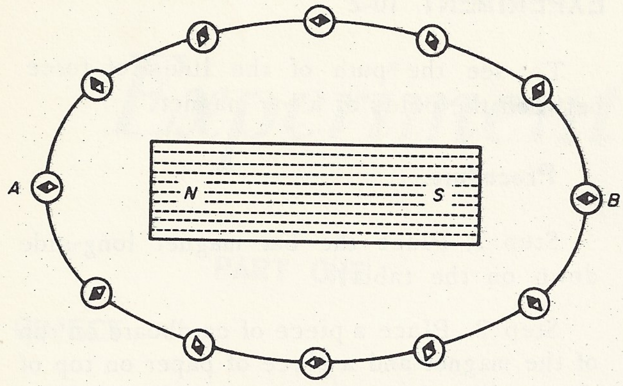


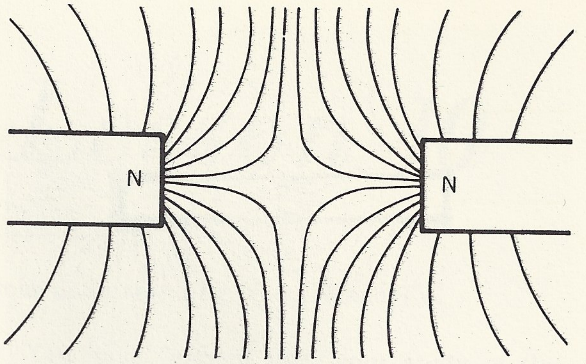
Fig. 10-2

north pole of the bar magnet, as shown in position *A* of Fig. 10-2. With the compass in this position, the compass needle will be deflected as shown in the figure. (If the needle points in the opposite direction, the compass is at the south pole of the magnet and should be moved to the north pole.)

Step 2. Move the compass along the path shown in the figure toward the south pole. Observe the deflection of the needle as the compass is moved. The needle will point in the direction of the lines of force, from the north pole to the south pole of the magnet, as shown in Fig. 10-2. When the compass reaches position *B*, the needle will be pointing toward the south pole, as shown in the figure.

Step 3. Move the compass along the other side of the magnet from the south pole to the north pole. Observe the deflection of the needle of the compass. Once more, the needle will point in the direction of the lines of force between the two poles of the magnet, as shown in Fig. 10-2.

Discussion. The deflection of the compass needle is caused by the lines of force that form the magnetic field of the magnet. The deflection of the needle is in the same direction as the lines of force. Therefore, the compass needle always points in the direction of the lines of force, and the compass can be used to determine the direction of the lines of force. It is important to understand this point.



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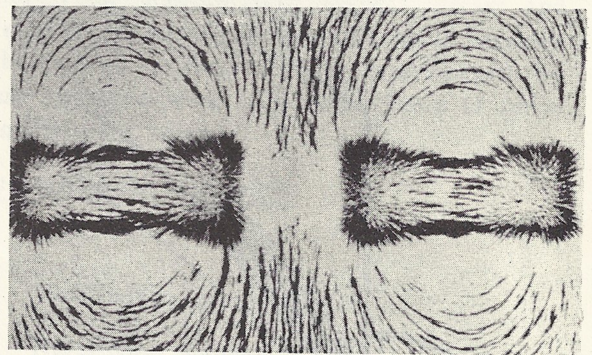


(b)

Fig. 10-3

EXPERIMENT 10-4

To learn how two bar magnets affect each other.

Procedure.

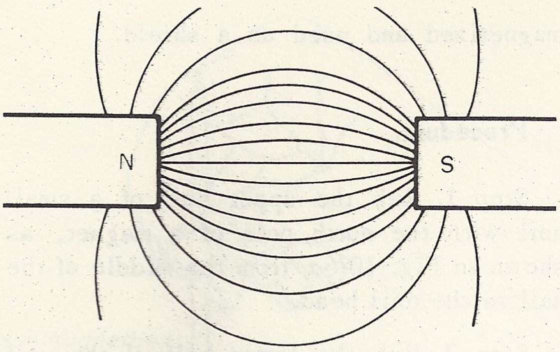
Step 1. Place two bar magnets on the table, with the north pole of one facing the north pole of the other, as shown in Fig. 10-3*a*.

Step 2. Cover the magnets with a sheet of cardboard, and cover the cardboard with a sheet of paper.

Step 3. Lightly sprinkle iron filings on the paper. Observe the pattern that the filings form. If the pattern you see does not look similar to the pattern shown in Fig. 10-3*b*, tap the paper lightly.

Step 4. Remove the cardboard and paper from the magnets and pour the iron filings back into the can.

Step 5. Place the two bar magnets with



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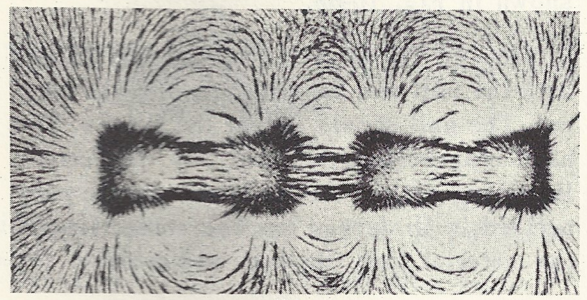

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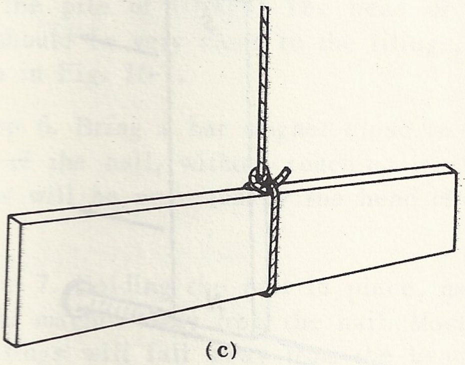


(c)

Fig. 10-4

the north pole of one facing the south pole of the other, as shown in Fig. 10-4*a*. Repeat the operations in Steps *2* and *3*. The filing pattern should look like the one shown in Fig. 10-4*b*. Notice that the lines of force around each magnet look much like the lines of force around the magnet in Experiment 10-2. Note that the lines of force about the two facing poles are much straighter.

Step 6. Tie a string around the center of the bar magnets, as shown in Fig. 10-4*c*. Hold the string between the fingers of one of your hands. Wait for the magnet to stop swinging and turning. Look at your compass and notice which way is north. The north pole of your suspended bar magnet will also point north. Bring the north pole of the other magnet close to the north pole of the suspended magnet. Notice that the suspended magnet is repelled by the magnet you bring close to it.

Step 7. Repeat Step 6 with the north pole of the suspended magnet facing the south pole of the other magnet. The magnets are attracted to each other. After you remove the other magnet and the suspended magnet comes to rest, notice that the north pole of the suspended magnet again points to the earth's north pole.

Discussion. When similar poles of two bar magnets face each other, the lines of force of one magnet repel the lines of force of the other magnet. You noticed that when these similar poles are brought together, one magnet repels the other. You were able to see that when opposite poles of two bar magnets face each other, the lines of force reinforce one another. As a matter of fact, the two bar magnets tend to have a pattern of lines very similar to the field of force of a single bar magnet. When opposite poles of two bar magnets are brought close to each other, the magnets are attracted to each other.

Therefore, you have proved that when the lines of force oppose, there is repulsion. When the lines of force reinforce one another, there is attraction. So, you can see how very important it is to know which poles of a pair of magnets you are dealing with when you are trying to produce attraction or repulsion.

You noticed too that, when the suspended magnet stopped swinging and there was no other magnet near, it pointed north. The north pole of a free-swinging magnet always points north. This is one way by which we can tell the north pole of a magnet.

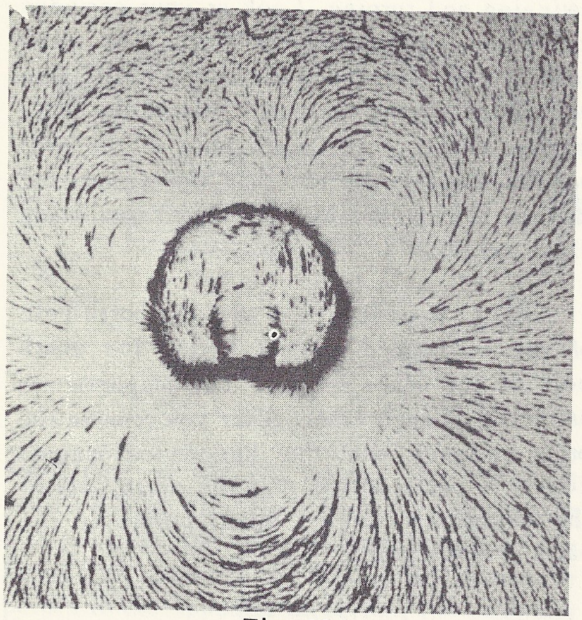


Fig. 10-5

EXPERIMENT 10-5

To see the pattern of the lines of force between the poles of a horseshoe magnet.

Procedure.

Step 1. Place the horseshoe magnet on the table and place a piece of cardboard and a sheet of paper over it.

Step 2. Sprinkle iron filings over the paper and observe the pattern the iron filings make. If the pattern you see does not look like the pattern in Fig. 10-5, tap the paper lightly.

Step 3. Remove the paper and cardboard and pour the iron filings back into the can.

Discussion. You saw that the lines of force are concentrated between the poles of the horseshoe magnet. Because the poles are close together, it is easier for lines of force to form. So, there are more of them. As you learned in Theory Lesson 10, the closer the poles, the stronger is the magnetic field.

EXPERIMENT 10-6

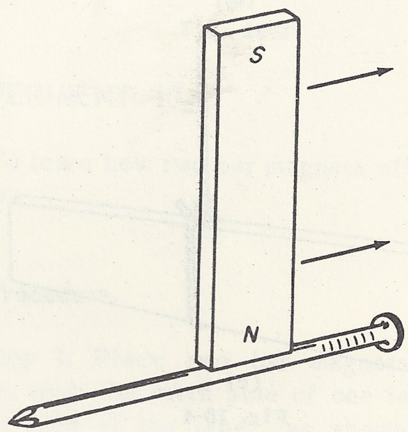
To learn how magnetic material can be magnetized and used as a shield.

Procedure.

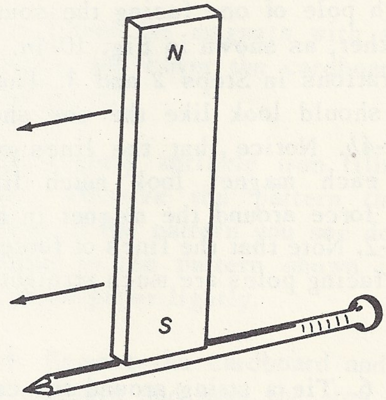
Step 1. Rub the upper half of a small nail with the north pole of a magnet, as shown in Fig. 10-6*a*, from the middle of the nail to the nail head.

Step 2. Rub the lower half of the nail with the south pole of the magnet, stroking from the middle of the nail to the tip, as shown in Fig. 10-6*b*.

Step 3. Try to pick up some iron filings with the nail you have rubbed with the magnet. The nail should attract the filings. You have magnetized the nail by induction. How long a time the nail will remain magnetized will depend on the retentivity of the material from which it was made.



(a)



(b)

Fig. 10-6

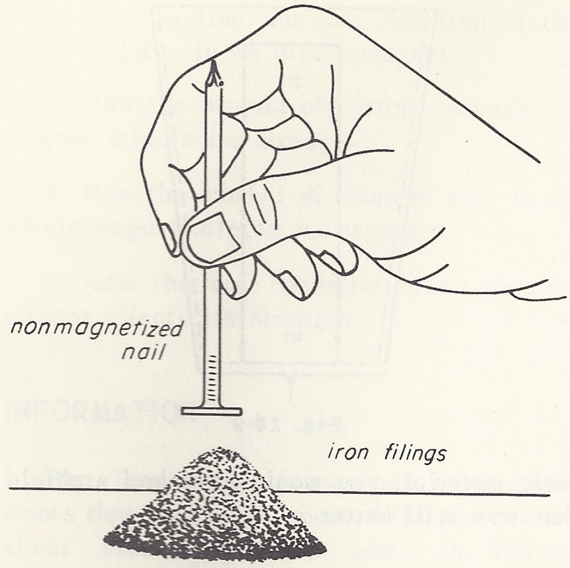


Fig. 10-7

Step 4. Sprinkle some iron filings in a little pile on a piece of paper and place the paper on the table.

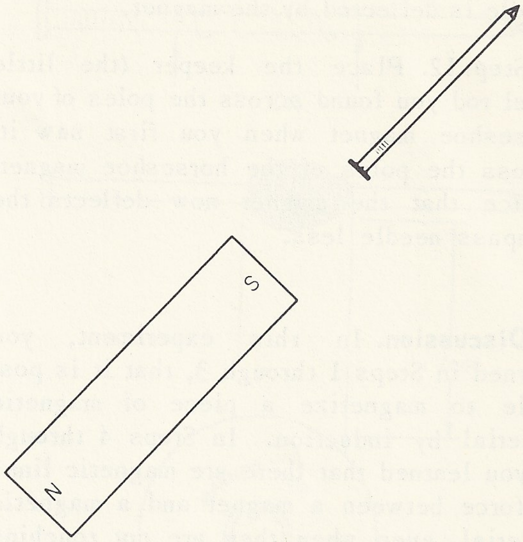
Step 5. Hold another nail, head down, over the pile of filings. The head of the nail should be very close to the filings, as shown in Fig. 10-7.

Step 6. Bring a bar magnet close to the point of the nail, without touching it. The filings will be attracted by the head of the nail.

Step 7. Holding the nail in place, move the bar magnet away from the nail. Most of the filings will fall away from the head of nail. Wipe off the filings that still stick to the head of the nail.

Step 8. Hold another nail over the pile of iron filings. Touch the nail with a bar magnet. The filings will be attracted to the head of the nail. Move the bar magnet away from the nail. Most of the filings will fall away from the head of the nail. Wipe the rest of the filings off the nail.

Step 9. Place the magnet and nail on the table with the nail just far enough away from the magnet so that it is not attracted by the magnet, as shown in Fig. 10-8*a*. Cover the magnet and the nail with a sheet of cardboard and a sheet of paper. Sprinkle from filings on the paper and observe the



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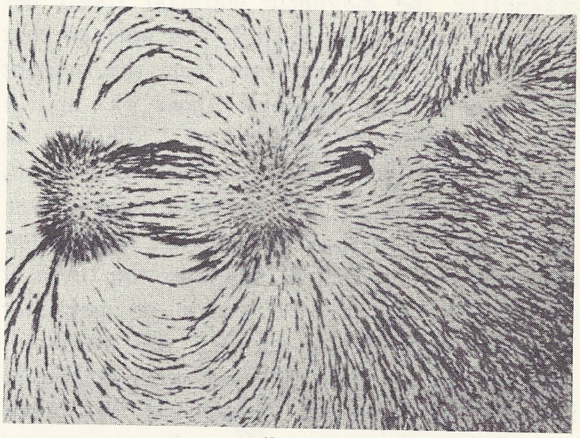


(b)

Fig. 10-8

pattern the filings make. You will see that the lines of force do not go directly from one pole of the magnet, but are deflected through the nail, as shown in Fig. 10-8*b*. The nail provides a better path for the magnetic lines of force than the air; that is, the steel nail offers less *reluctance* to the lines of force than air does. Pour the filings back in the can.

Step 10. Imagine that you were able to surround the bar magnet with such nails. The magnetic lines of force would then travel from one pole of the magnet, around the low-reluctance path provided by the nails, and to the other pole of the magnet.

Step 11. Place your horseshoe magnet on the table. Place your compass on the table near the magnet. Observe that the compass

needle is deflected by the magnet.

Step 12. Place the keeper (the little steel rod you found across the poles of your horseshoe magnet when you first saw it) across the poles of the horseshoe magnet. Notice that the magnet now deflects the compass needle less.

Discussion. In this experiment, you learned in Steps 1 through 3, that it is possible to magnetize a piece of magnetic material by induction. In Steps 4 through 6, you learned that there are magnetic lines of force between a magnet and a magnetic material, even when they are not touching each other, and that these lines of force magnetize the magnetic material itself becomes a magnet. In Step 7, you noticed that even when the magnetism from the magnet no longer affected the nail, there was still a little magnetism left in the nail. This is an example of residual magnetism. In Step 8, you were able to see residual magnetism again when you took the magnet away from the nail. In Step 9, you saw how the lines of force pass through a piece of magnetic material rather than through the surrounding air. So, in Step 10, you were asked to imagine what would happen if you used a circle of iron nails placed around the magnet to provide a path of low reluctance for the lines of force. You were able to see that, if you provided such a path, you could guide the lines of force so that they would be in the path you provided. If it is possible to guide lines of force as you choose, then of course it is possible to keep them away from places where you do not want them. In Steps 10 and 11 you used the keeper to provide a path for the lines of force between the poles of your horseshoe magnet. By providing this path, you reduced the effect of the magnet on the compass. Thus, you shielded the compass from the magnet. Of course, your shield was not perfect. If you had been able to put your magnet in a box made of soft iron, the shielding would have been better. And, if you had been able to put that box inside another soft iron box and had been able to keep the two boxes separated by a nonmagnetic material, you would have had a shield that was still better.

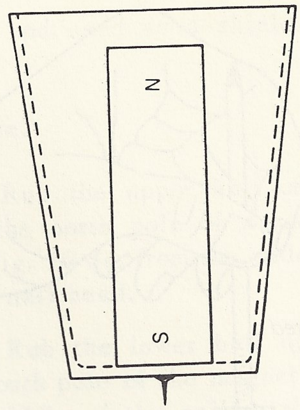


Fig. 10-9

EXPERIMENT 10-7

To see that some materials have so little effect upon the passage of magnetic lines of force that we can speak of them as being magnetically transparent.

Procedure.

Step 1. Place one bar magnet in a water glass.

Step 2. Place a tack on the table.

Step 3. Hold the glass with the magnet in it over the tack. The tack will be attracted by the magnet and will stick to the bottom of the glass, as shown in Fig. 10-9.

Step 4. Remove the magnet and put it in an aluminum pot. Hold the pot over the tack and observe that the tack is attracted to the bottom of the pot, where the magnet is.

PART TWO

OBJECT

The object of the experiments in Part Two of this lesson is to learn:

1. How to find out the direction of the lines of force in an electromagnet.

2. How the amount of current through the magnet affects its strength.

3. How the number of turns of wire in the electromagnet affects its strength.

4. How the core material of an electromagnet affects its strength.

INFORMATION

Part Two of this lesson has four experiments that will prove some of the statements about electromagnetism made in Theory Lesson 10. By making a simple electromagnet and experimenting with it, you will see these principles work. Do the following experiments on a wooden bench or table; do not use a metal table.

EQUIPMENT NEEDED

Magnet wire

Nail

Two 1.5-volt cells

Compass

15-ohm resistor

EXPERIMENT 10-8

To learn the direction of the lines of force around an electromagnet.

Procedure.

Step 1. Unwind about one foot of magnet wire from the spool. Then wind 200 turns of the magnet wire around the nail in the direction shown in Fig. 10-10*a*. When you have finished winding, unwind about one foot more of wire, as shown in Fig. 10-10*b*, and cut the wire with your cutting pliers.

Step 2. Remove 1/2 inch of the insula-

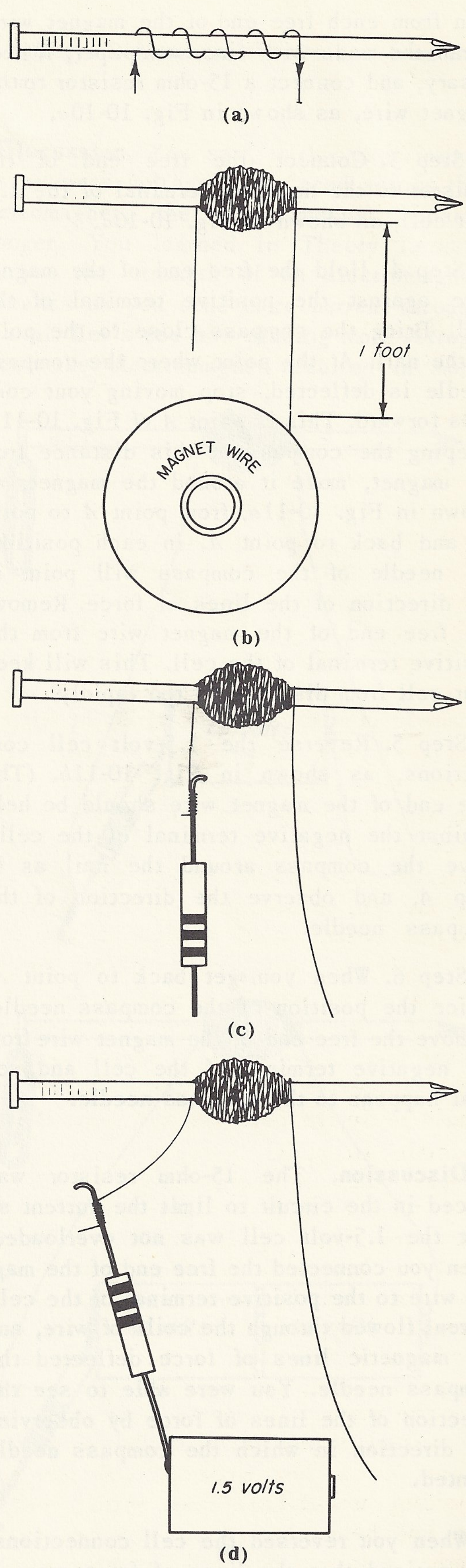


Fig. 10-10

om each free end of the magnet wire; the ends with fine sandpaper, if nec-, and connect a 15-ohm resistor to the wire, as shown in Fig. 10-10*c*.

3. Connect the free end of the r to the negative terminal of the 1.5- ll, as shown in Fig. 10-10*d*.

4. Hold the free end of the magnet gainst the positive terminal of the ring the compass close to the point ail. At the point where the compass is deflected, stop moving your com- ward. This is point *A* of Fig. 10-11*a*. the compass at this distance from net, move it around the magnet, as Fig. 10-11*a*, from point *A* to point back to point *A*. In each position, dle of the compass will point in ction of the lines of force. Remove end of the magnet wire from the terminal of the cell. This will keep from discharging too rapidly.

5. Reverse the 1.5-volt cell con- as shown in Fig. 10-11*b*. (The of the magnet wire should be held he negative terminal of the cell.) compass around the nail as in and observe the direction of the needle.

. When you get back to point *A*, position of the compass needle. e free end of the magnet wire from ive terminal of the cell and see ens to the compass needle.

sion. The 15-ohm resistor was the circuit to limit the current so .5-volt cell was not overloaded. onnected the free end of the mag- the positive terminal of the cell, ed through the coils of wire, and tic lines of force deflected the eedle. You were able to see the the lines of force by observing n in which the compass needle

reversed the cell connections, that the lines of force were in the opposite direction.

If you apply the left-hand rule you learned in Theory Lesson 10, you will see that your thumb points to the north pole. Therefore, you know the direction of the flux, since flux direction is from the north pole to the south pole.

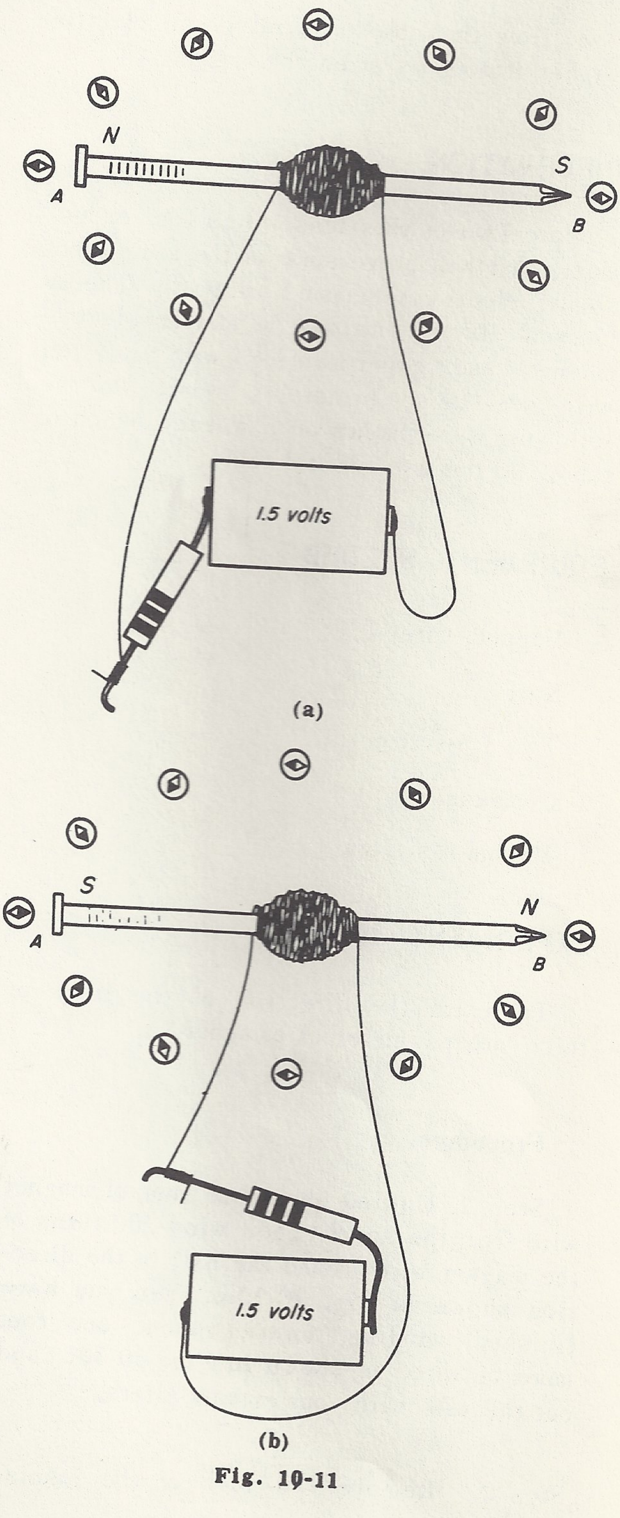


Fig. 10-11

When you disconnected one end of the magnet wire from the circuit, the compass needle no longer was deflected, because there was no current, and, therefore, no magnetic lines of force. In other words, an electromagnet can operate only when current is supplied to it, and it can be made to stop operating when current is cut off. A permanent magnet, on the other hand, is always a magnet. Electromagnets are very useful in electrical and radio circuits in which we want to have magnetism some of the time and no magnetism at other times. You will learn how we use electromagnetism in other ways when you study radio circuits in lessons to come.

EXPERIMENT 10-9

To learn how the amount of current flowing through the electromagnet affects its strength.

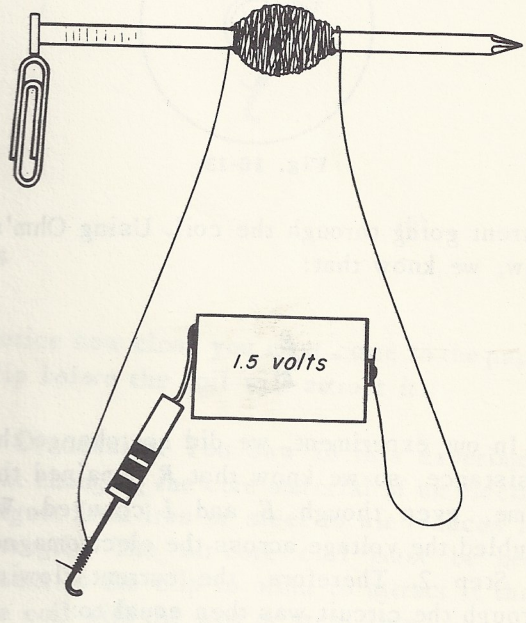
Procedure.

Step 1. Put a paper clip on the table on which you are working. Hold the electromagnet over the paper clip. Touch the free end of the magnet wire to the positive terminal of the 1.5-volt cell. Bring the magnet close enough to the paper clip to pick the clip up, as in Fig. 10-12*a*. Observe how close to the paper clip you must bring the magnet before the paper clip is attracted. If possible, measure the distance with a ruler. Remove the magnet wire from the negative terminal of the cell.

Step 2. Connect the negative terminal of a second 1.5-volt cell to the positive terminal of the cell you have been using. You now have a 3-volt battery connected to one end of your electromagnet.

Step 3. Holding the free end of the magnet wire against the positive terminal of the battery, try to pick up the paper clip, as shown in Fig. 10-12*b*. Observe how far from the paper clip the magnet is when it attracts the clip. Measure this distance, if possible. Remove the free end of the magnet wire from the battery. Disconnect the resistor from the battery.

Discussion. You saw, in this experiment, that as more voltage was placed across the electromagnet, the electromagnet became stronger. You learned in Theory Lesson 10 that the strength of an electromagnet increases as you send more *current* through the coil. Let's see how placing more *voltage* across the electromagnet resulted in more



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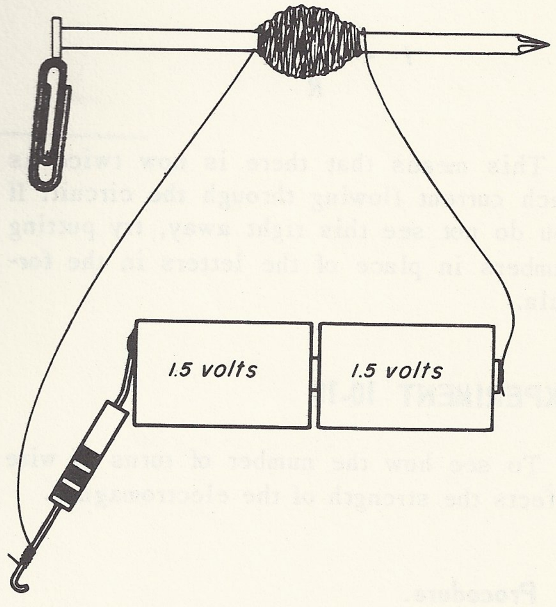


(b)

Fig. 10-12

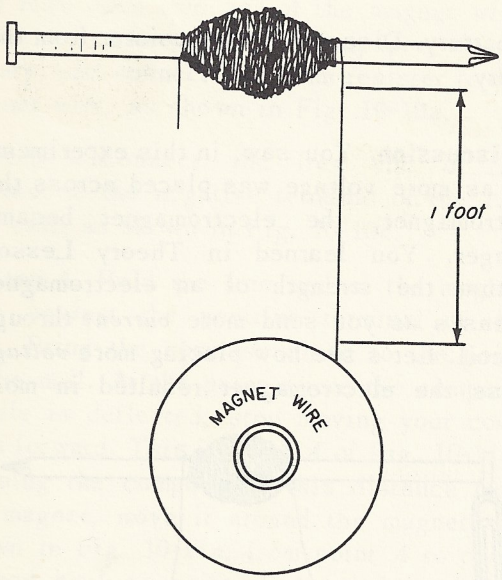


Fig. 10-13

current going through the coil. Using Ohm's Law, we know that:

$$I = \frac{E}{R}$$

In our experiment, we did not change the resistance, so we know that *R* remained the same, even though *E* and *I* changed. We doubled the voltage across the electromagnet in Step 2. Therefore, the current flowing through the circuit was then equal to:

$$I = \frac{2E}{R}$$

This means that there is now twice as much current flowing through the circuit. If you do not see this right away, try putting numbers in place of the letters in the formula.

EXPERIMENT 10-10

To see how the number of turns of wire affects the strength of the electromagnet.

Procedure.

Step 1. Splice one free end of the magnet wire to the free end of the magnet wire on the spool and wind an additional 200 turns of wire around the nail in the same direction as the first 200 turns. (Don't worry if you lose count; one or two turns more or less do not affect this experiment.) Unwind one foot more of wire, as shown in Fig. 10-13, and cut the wire from the spool. Clean 1/2 inch of insulation from the free end and, if necessary, clean the free end with sandpaper. You now have a coil with 400 turns.

Step 2. Connect the free end of the 15-ohm resistor to the negative terminal of the three-volt battery.

Step 3. Hold the electromagnet over a paper clip and touch the free end of the magnet wire to the positive terminal of the battery. Observe how close you must bring the magnet to the paper clip before the clip is attracted. Measure this distance, if possible.

Step 4. Remove the free end of the magnet wire from the positive terminal of the battery.

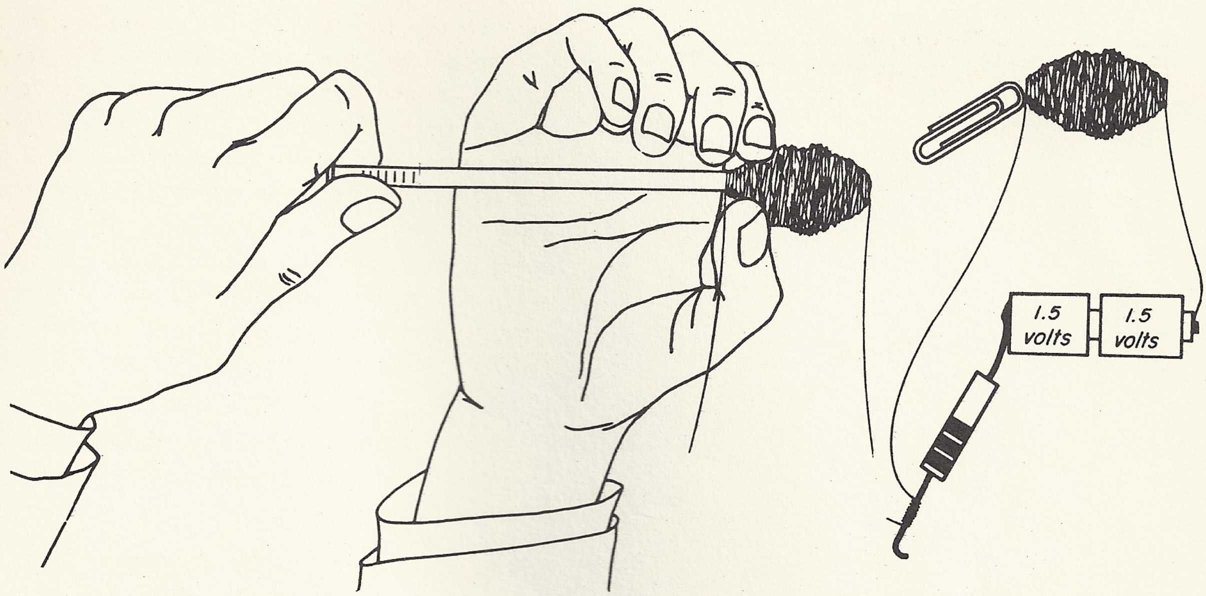
Discussion. By doubling the number of turns on your electromagnet, you were able to make it about twice as strong. In Experiment 10-9, when the electromagnet had only 200 turns and was connected to the 3-volt battery, it had to be held close to the paper clip before it attracted the clip. With 400 turns, when the magnet was held about twice as far away from the clip as when it had 200 turns, it still was able to pick up the clip.

EXPERIMENT 10-11

To see how the core of an electromagnet affects its strength.

Procedure.

Step 1. Without unwinding the wire, remove the 400-turn coil from the nail by holding the coil with one hand to prevent the turns from loosening while you slip the nail



(a) (b)

Fig. 10-14

out, as shown in Fig. 10-14*a*. It may be necessary to wiggle the nail back and forth to loosen it from the coil.

Step 2. Hold the coil over the paper clip and touch the free end of the magnet wire to the 3-volt battery, as shown in Fig. 10-14*b*. Notice how close you must come to the paper clip before the coil will attract it.

Discussion. You saw in this experiment that changing the core material of an electromagnet from iron or steel to air reduces its strength. The air-core coil must be held closer to the clip in order to attract it than the coil with the iron or steel core.