INTRODUCING YOU TO ELECTRONICS

1B

RADIO-TELEVISION-ELECTRONICS

PIONEER HOME STUDY RADIO-TV SCHOOL

NATIONAL RADIO INSTITUTE

WASHINGTON, D. C.

ESTABLISHED 1914

STUDY SCHEDULE NO. 1

By dividing your study into the steps given below, you can get the most out of this part of your NRI Course in the shortest possible time. Check off each step when you finish it.

☑ 6. Answer the Lesson Questions.

☑ 7. Start Studying the Next Lesson.

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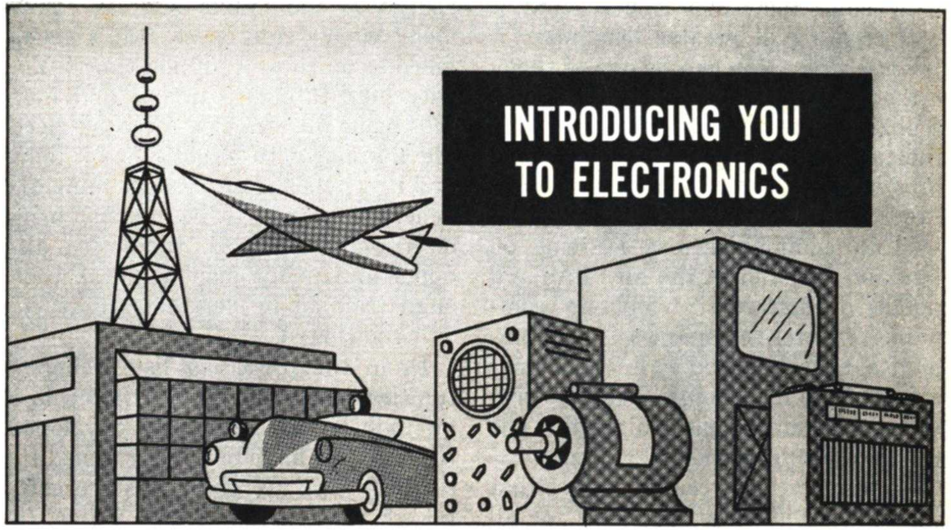

DECIDING to study the NRI course is one of the wisest decisions of your life. Why? Because this course has been planned and written from beginning to end especially for men who must do their studying at home, usually after their regular day's work.

The amount of education you now have is of less importance than an unswerving ambition to succeed. The first lesson starts right at the beginning assuming that you know nothing about electronics, and prepares you for the more advanced second lesson. Each new technical or special word, each symbol, and each abbreviation is explained the first time it appears. Since in the second book and in each of the following books that you will study, you will be building on what you have learned in previous books, it is important for you to understand each new idea as it is presented before going on to the next subject. Do not make the mistake of skipping over a section that you do not at first understand. Usually if any sections of a lesson at first seem difficult, you will be able to understand them completely by re-reading them several times.

The surest way to keep from failing is to be determined to succeed. Make a sincere promise to yourself right now, that you are going to finish the NRI course and succeed in electronics.

OPPORTUNITIES

Let us look at a few of the opportunities that are available to the qualified technician. As an NRI graduate you will be in a position to choose your opportunity, instead of waiting for it to come to you.

In radio, for instance, there are hundreds of different job opportunities in entertainment broadcasting alone. You might think that television has eliminated the opportunities in this field of radio. The actual facts are that almost every week new radio stations are licensed by the FCC and that the annual radio receiver production in this country is close to 10,000,000 receivers.

Television has not eliminated opportunities in the radio field, instead it has created new opportunities of its own. The demand for broadcast technicians and television servicemen has never been fully satisfied since television first swept across the country.

Now color television is here, and it will create still greater demands for trained men. You can be one of them.

Another fact that people fail to realize is that there are many opportunities outside the entertainment broadcasting field. There are thousands of fascinating well-paid jobs for men in communications systems on land, on sea, and in the air. Fire and police departments, telephone companies, power companies, gas companies, railroads, and airlines are only a few of the many organizations using radio communications equipment. The use of radio in industrial communications is in fact increasing so fast that finding frequency assignments for all the new stations is becoming a serious problem.

Electronic equipment is also becoming more and more important in industry. Electronics in industry represents a tremendous new field, the surface of which has just been scratched. Electronic equipment is used to count finished components coming off assembly lines, it is used to inspect manufactured parts, it is used to control precision machines, automatically making possible the high-speed production of items that could formerly be made only manually by highly skilled operators. Electronics is used in oil refineries, in the manufacturing and quality-control of new cars, in the new plastics industry and in many other fields, too numerous to mention. As a matter of fact, there is hardly an industrial process in which electronics cannot be put to use advantageously. Here is a field of unlimited opportunities; a field that is just developing.

There are still many other opportunities. You may some day find yourself in a theatre installing, adjusting, and repairing the electric eye in the sound amplifier system. You may go to ball parks and conventions to take charge of the public address equipment which can boost man's feeble voice as much as a million times. You may hike through canyons and foothills using modern electronic prospecting equipment to locate new oil fields and new deposits of precious minerals. Wherever there is equipment using electronic principles, there are also opportunities for men with the thorough training in electronics that you will soon have.

From the preceding list of opportunities you might think that this is an industry already fully developed. Actually we have barely scratched the surface. You are going to see breathtaking new developments which far outshadow even the miracle of color television. Because your NRI training is built upon a sound foundation, you will be prepared for the undreamed-of jobs that will soon be created by new developments. You will not only learn about equipment in use today, but you will also learn the fundamental ideas in back of the operation of tomorrow's equipment. Once you understand this basic theory, you will be able to understand new developments as they come along. You will understand how they work, because you will know the fundamentals. New electronic equipment will not use new circuits, it will use the basic circuits you will be studying but in new ways.

Now you are ready to go—ready to start your study of electronics. At first we will study a few basic ideas and then we will use these ideas in building up some simple circuits. Make sure you fully understand the ideas and circuits as they are presented. Even the most complex electronic equipment is made up of nothing more than a large number of the simple circuits that you will study in your early lessons.

Electricity

Electricity and magnetism play an important part in the operation of all electronic equipment. But what is electricity? What is magnetism? If you learn the answers to these two questions once and for all now, you will have the foundation for everything else you will study and work with in your electronics career. Let us take up electricity, first.

USES OF ELECTRICITY

We have only to look around us to see many ways in which electricity is used. It is used to provide light; the chances are that you have an electric light burning to read this book. Electric energy is being converted or changed into light by the electric light bulb.

Electricity is used to provide heat. Appliances such as electric space-heaters, ranges, and irons convert electrical energy into heat. The heat may be used for cooking your food, warming your home, ironing your clothes, or many other everyday tasks.

Electricity is used to provide mechanical power that can be converted into motion. Electric streetcars and trains convert electrical energy into motion by means of large electric motors.

Electricity is used to produce sound. Your radio receiver takes the electrical energy from the wall outlet and converts it into the sound you hear coming from the loudspeaker.

There are many other uses of electricity, but these few serve to illustrate its usefulness. We have seen it used to produce light, heat, motion, and sound. But what is electricity, that it can do all these things? Electricity is not light, nor is it heat, nor sound, nor motion, but it is something that can be converted into all these different forms of energy. Electricity itself is a form of energy. It is electrical energy. An electric light bulb simply converts the electrical energy into light. A heater converts the electrical energy into heat, and a motor converts electrical energy into mechanical energy. But this only points out uses of electricity, it still leaves our question of what electricity is, unanswered. Let us see if we can find the answer.

WHAT ELECTRICITY IS

We will start our discussion of what electricity is by describing a few simple experiments that were performed by scientists many years ago. These experiments led to the understanding of electricity that we have today. You do not have to perform these experiments. We are describing them only to help you understand electricity.

If two small glass balls are suspended by threads as shown in Fig. 1, the weight of the glass balls will cause them to hang straight down as shown. Now if we take a piece of silk cloth and rub the balls with the cloth and then suspend them, instead of hanging straight down as they did be-

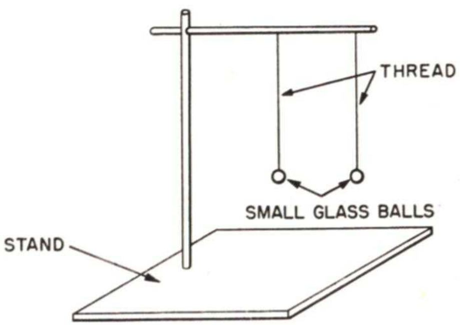

FIG. 1. Two small glass balls suspended by threads will hang vertically because of the weight of the balls.

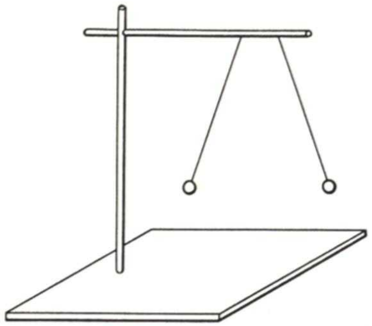

FIG. 2. Two glass balls that have been rubbed with a silk cloth move apart.

fore, the balls will tend to swing out as shown in Fig. 2 as though some force were pushing them apart. Actually, there must be some force pushing them apart; rubbing the balls with the silk cloth has produced the force.

The same experiment can be performed using two small hard-rubber balls. Again, before the balls have been rubbed with the silk cloth they will hang vertically, but once they have been rubbed with the silk cloth they will push each other apart. Again rubbing the small balls with the silk cloth has produced a force which pushes the balls apart.

There are two important points illustrated by these experiments. First, rubbing the balls with the silk cloth produced a force that pushed the balls apart. We call this force a "charge". The act of producing this force is called "charging". We say that the balls are "charged."

Second, let us consider what happened when we rubbed the glass balls with the silk cloth. When we rubbed the two balls, we charged them. Since both balls were charged in the same way, it is logical to assume that we have placed the same kind of a charge on the two balls. But the two balls pushed each other apart. We had similar results when we charged the two rubber balls. They also repelled each other. From these experiments we can conclude that if two objects are charged with the same kind of a charge, they will repel each other. This is a basic electrical law, and it is usually stated: **like charges repel.**

Now, if the same experiment is performed using one small glass ball and one small rubber ball, we would observe an entirely different effect. When the balls are rubbed with the silk and then suspended, instead of moving apart, the two balls would move toward each other as shown in Fig. 3. If they are placed close enough together, they will move toward each other until they touch. Once the two balls touch each other, they will begin to move apart to hang straight down. They will probably swing past the straight-down point and then swing back together and touch again. This cycle may be repeated several times until eventually the balls will hang straight down as they would if they had not been charged in the first place. Now let us see what conclusions we can draw from this experiment.

We have seen that rubbing the two balls with the silk cloth charged them as before. This we know is true because a force was produced on the two balls, otherwise they would simply hang straight down. We also know that the forces produced on the two

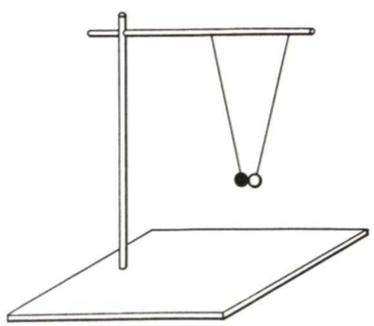

FIG. 3. The charged glass and rubber balls will move together and touch each other.

balls were such that the balls did not repel each other, at least at first, because the two balls moved together and touched. Since we have seen from the previous experiments that like charges repel, these charges must have been unlike. In other words, there must be a different kind of charge on the glass ball from the one on the rubber ball. We identify these two different kinds of charges by saying that the charge on the glass ball is *positive* and that the charge on the rubber ball is *negative*.

These simple experiments lead us to a fundamental important rule, ***"like charges repel; unlike charges attract."*** Remember this rule, it is important. You will use it throughout your entire career in electronics. You will soon use this simple rule to help explain the operation of many electronic devices.

Now let us proceed with our study of electricity to see if we can explain more fully what happened in the experiments we have just described. To do this we must study the electron theory.

The Electron Theory. Everything on this earth is made up of tiny particles. You can see for yourself that the earth is not one solid piece of material, it is made up of tiny particles of sand and stone and rock. Even the smallest grain of sand is itself made up of millions of still smaller particles, so small that they cannot be seen even with the most powerful microscope.

The smallest particle of a substance that retains the original properties of the substance is called an "atom." All atoms of a given substance are alike. In other words, the smallest particle of a piece of copper that still is and resembles copper is called an atom. A small piece of copper is

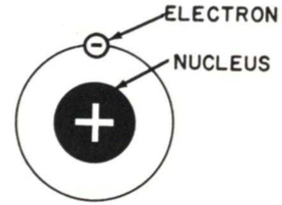

FIG. 4. The hydrogen atom.

made up of billions of these small atoms each identical to the others.

But the atom is not the smallest particle, the atom itself is made up of still smaller particles. Scientists have identified a number of different particles from which the atom is made. However, we are interested in only two of these particles, the nucleus* and the electron. We are more interested in the electron than we are in the nucleus.

The nucleus is the center of the atom. The nucleus of each atom has a certain amount of electricity; another way of saying this is to say that the nucleus has an electrical charge. The electrical charge on the nucleus is different for different elements. In other words, the nucleus of a hydrogen atom has a different charge from that of the nucleus of a copper atom. However, all hydrogen nuclei (the plural of nucleus) have the same charge, and all copper nuclei have the same charge.

Around the nucleus of the atom are electrons. These electrons travel in an elliptical path (a somewhat circular path that has been squashed, like an egg or a football) around the nucleus of the atom in much the same way that the earth travels around the sun.

The simplest atom is the hydrogen atom, shown in Fig. 4. In the hydro-

* To be strictly correct we should not call the nucleus a particle, because it is made up of smaller particles. However, for our purposes we can consider the nucleus as one particle.

gen atom, the nucleus has a charge of 1, and revolving around it is one electron. The electron also has a charge; this charge is exactly equal to but opposite to the charge on the nucleus. The charge on the electron neutralizes the charge on the nucleus so there is no charge on the atom; in other words one charge exactly balances the other, so the net effect is zero. The charge on the nucleus of the atom is the positive charge we found on the glass ball, and the charge on the electron is the negative charge we discovered on the hard rubber ball. You will see why this is so, later on in this discussion.

Now let us take a look at another atom, the helium atom shown in Fig. 5A. In the helium atom, the nucleus has a positive charge of 2. To completely neutralize this positive charge there are two electrons.

Another atom is the lithium atom. The nucleus of this atom has a positive charge of 3. To neutralize this charge there are three electrons. However, instead of having three electrons in the one ring, or shell as it is sometimes called, there are two electrons in the first ring as shown in Fig. 5B and one electron in a second ring.

The first ring of an atom never has more than two electrons, the additional electrons needed to balance the charge in the nucleus arrange themselves in other rings. The second ring may have as many as eight electrons;

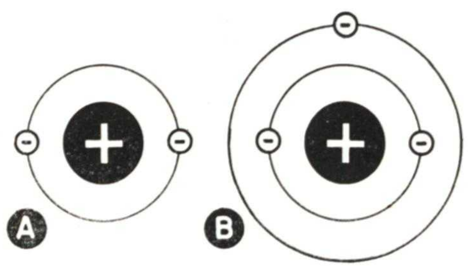

FIG. 5. The helium atom is shown at A; the lithium atom at B.

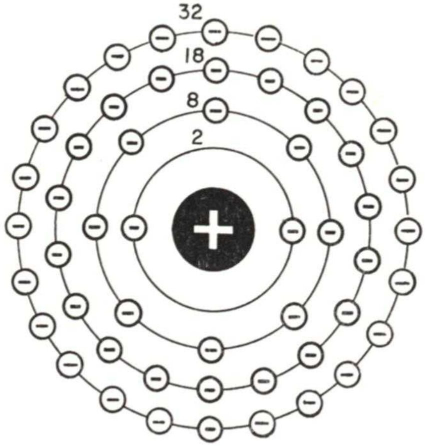

FIG. 6. The maximum number of electrons there can be in each of the first four rings of any atom.

if there are more than ten electrons, a third ring is formed.

Fig. 6 shows the nucleus of an atom and the first four rings of electrons that can form around it. The numbers in each ring indicate the maximum number of electrons there can be in any one ring. Remember that these numbers are the maximum number of electrons—there can be less than the maximum number of electrons in at least one of the rings. For example, refer back to the lithium atom that we have shown in Fig. 5B and you will see that the first ring is filled, it has two electrons, but the second ring which, as we saw in Fig. 6 can have as many as eight electrons, has only one.

The characteristics of a material are governed by the way in which the various electron rings are filled. For example, the neon atom shown in Fig. 7 has two rings of electrons around the nucleus. The nucleus has a positive charge of 10 units. The first ring has two electrons in it, and the second ring has eight electrons in it. Each ring has the maximum number of electrons it can hold. Neither of the rings can accept any additional electrons,

nor are they willing to give up any electrons. The particular element with this type of atom is a very stable element. The chemists call it an inert element, by this they mean it will not combine chemically with other elements.

Now let us look at the atom shown in Fig. 8. The nucleus of this atom has a + charge of 11. It has two electrons in the first ring, eight electrons in the second ring, but only one electron in the third ring. The first and second rings of the atom are full, they cannot hold any additional electrons. These electrons are held closely to the nucleus; there is no way they can get away from the nucleus, nor is

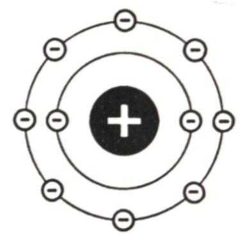

FIG. 7. The atomic structure of the gas, neon. Because both rings are filled with electrons, this gas is a very stable element —it will neither give up nor accept electrons.

there any way any additional electrons can be forced into either of these two rings. However, the single electron in the third ring is not held very closely to the nucleus. This is the atomic structure of the metal sodium. This is a very unstable metal. In its pure form it is so unstable that to keep this form, it must be kept submerged in oil, and it is only a curiosity because it is of no practical use!

A somewhat similar atom is the copper atom shown in Fig. 9. There are two electrons in the first ring, eight in the second, eighteen in the third, and one in the fourth. Although

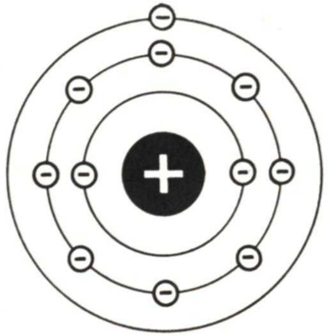

FIG. 8. The metal sodium has 2 electrons in the first ring and eight in the second ring, but only one in the third or outer ring.

copper has only one electron in its outer ring, it is a much more stable element than sodium. If we apply some external force to a copper atom, we can easily knock the outermost electron loose, and it might move into the outer ring of a near-by atom. This atom will then have two electrons in the fourth ring. It then has one more electron than it needs to completely neutralize the charge on the nucleus. The tendency is for the atom to get rid of this extra charge as quickly as possible. Either the new electron that moved into the fourth ring will be

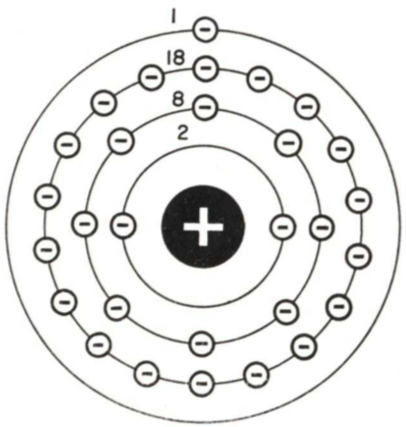

FIG. 9. The nucleus of the copper atom has a positive charge of 29. Around the nucleus there are normally 29 electrons arranged as shown above.

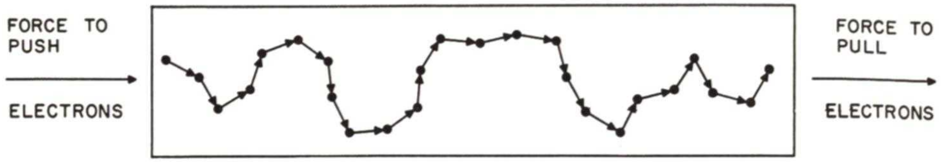

FIG. 10. The movement of electrons along a wire.

forced out of this ring, or the original electron in the fourth ring will move out. In any case, whichever of the two electrons leaves this fourth ring will move over to a near-by atom, and it in turn will upset the balance of this atom and either move on itself, or force the electron in the outer ring of this atom out.

Once an electron has been dislodged from the outer ring in this manner, it more or less starts a chain reaction, hitting electrons in the outer rings of other atoms, causing these electrons to move about in the material. If we have a wire made up of a material of this type and to one end connect a device that will push an extra electron into the wire, and connect something to the other end that will tend to pull an electron out of the other end of the wire, we will have a movement of electrons along the wire. They will be pushed from one end and pulled at the other. The extra electron that is forced into one end of the wire will move into the outer ring of one atom. This will force the lone atom in the outer ring out of the atom and into the next atom. This electron in turn will force another electron out of a near-by atom, moving it along the wire. The path that might be followed by this reaction is shown in Fig. 10.

Now before going on let us explain the action of the charged rubber and glass balls. When the glass ball is rubbed with the silk cloth, the friction of rubbing the ball removes some of the electrons from the ball. Once the electrons have been removed, there are not enough electrons left to completely neutralize the positive charges on the nuclei. Therefore the glass balls will have a positive charge on them.

When we rub the rubber balls, the rubber balls take electrons from the silk cloth so they will have more electrons than are needed to completely neutralize the positive charges on the nuclei of the atoms. Therefore the rubber balls will have a negative charge on them.

When we charge one glass ball and one rubber ball and suspend them near each other, they will be attracted because unlike charges attract. When they move together and touch, some of the extra electrons on the rubber ball will leave the rubber ball and move over to the glass ball and partly make up for the shortage of electrons on the glass ball. When this happens, the balls may swing apart, but the charges will not be completely neutralized, so the balls will swing back together again and a few more electrons will move from the rubber ball over to the glass ball. This swinging back and forth will continue until enough electrons have moved from the rubber ball to the glass ball to reduce the force of attraction between the two balls until it is no longer strong enough to cause the balls to swing together.

SUMMARY

We have covered a great deal of material in this section, and the chances are you will not be able to remember all of it. We do not expect you to remember all the details, but you should remember the points reviewed in the following summary.

1. Like electric charges repel, and unlike electric charges attract.

2. All material is made up of extremely small particles called atoms.

3. All the atoms of a given substance are identical.

4. Atoms are made up of a nucleus, which has a positive charge, and a number of electrons, which have a negative charge, and will exactly neutralize the positive charge of the nucleus so the net charge on the atom should be zero.

5. In some atoms an electron can be easily displaced.

Current Flow

In the preceding section you have seen how an electron being knocked out of its atom forces additional electrons out of their atoms and sets them in motion. We have also pointed out that if we apply some force to push the electrons at one end of a wire and another force to pull the electrons from the other end, we could start a movement of electrons from one end of the wire to the other. A device that is capable of doing this is a battery. A battery, by means of the chemical action that occurs inside it, will push electrons from one terminal and pull them into the other. If a wire is connected between the two terminals of a battery, electrons will flow as shown in Fig. 11 from one terminal, through the wire, back to the other terminal of the battery and then through the battery and finally back to the first terminal again. This is called an electric circuit. Electrons will continue to follow this circular path until the path or circuit is broken by disconnecting the wire from one terminal of the battery or until the chemical action of the battery is exhausted. Notice that there must be a complete path for the electrons to travel. An electron leaving one terminal of the battery must be able to travel through a complete circuit, through the battery, and back to the terminal from which it left.

You probably know that the terminals of many batteries are marked; one is marked with a + sign and the other with a — sign. The terminals are marked like this so you can tell from which terminal the electrons will leave the battery and to which terminal the electrons will return. Now, can you tell from which terminal the electrons are going to leave the battery? Remember our experiment with the glass balls. When we charged the glass balls we placed a like charge on the two balls and they pushed each other apart. Now an electron has a negative or — charge. Which terminal is going to push electrons away, and which terminal will attract them?

The answer to these two questions is just what you might expect from the law of charges. We said like charges repel, therefore the negative terminal of the battery will push the

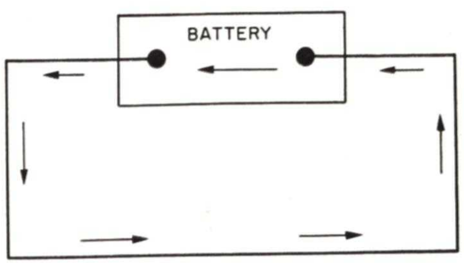

FIG. 11. A wire connected between the two terminals of a battery provides an electric circuit through which electrons can flow.

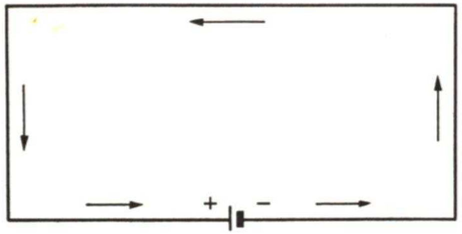

FIG. 12. The schematic diagram of a simple circuit.

negative electrons out of the battery. The positive terminal of the battery will attract the electrons, because it has the opposite charge on it. In Fig. 12 we have repeated the circuit shown in Fig. 11; however, this time we have used the symbol that is used on radio diagrams to identify a single-cell battery. Notice that we have used one short heavy line and one longer thin line. The short heavy line identifies the negative terminal of the battery, and the long light line the positive terminal. We have also marked the terminals with — and + signs so there will not be any confusion. Remember the symbol used for the battery, you will see it many times in your electronics career.

Symbols like this are used on all electronic diagrams to indicate the various parts. There is a different symbol for each part. Using a simple symbol instead of trying to show the actual part makes the diagrams much easier to understand. These diagrams using symbols are called "schematic" diagrams. We will teach you each symbol as you come to it so you will not have to learn a whole lot of them at once.

CONDUCTORS AND INSULATORS

There are a number of materials from which one or two electrons in the outer ring of electrons can be displaced. Copper, silver, aluminum, iron, and most other metals are examples of this type of material. Since electrons can be displaced from these materials, it is easy to set them in motion in a wire made of this type of material, and cause a current to flow through the wire. These materials are called *conductors*. They are so called because they will conduct or transmit an electric current; in other words, a current flow can be set up through them.

There is no such thing as a perfect conductor. All conductors offer some resistance, or opposition, to an electric current. Silver is the best known conductor, but it is used only in special applications because it is too expensive. Copper, which is almost as good a conductor as silver, is used in most wire because it is much cheaper than silver.

There are other materials which will not readily give up any electrons. A material having its outer ring full of electrons has no place to permit any additional electrons to move into the atom, nor will it permit any electrons to move from any of its rings. This type of material is called an *insulator*. It normally will not pass or conduct an electric current.

There is no such thing as a perfect insulator. Even in materials having all the electron rings filled, an electron will occasionally escape, particularly if enough force is applied to the material. However, the number of electrons that will escape is usually so small that for all practical purposes we can say that these materials will not conduct current. When an extremely high force is applied to this type of material, electrons may be forced out, and the material will break down, and will no longer be usable as an insulator.

In your study of electronics, you will be concerned with both conductors and insulators. Conductors will be used to make the current flow where you want it to flow. Insulators will be used to keep it from flowing in places where you do not want it. By the use of conductors and insulators, electrical circuits can be built.

SEMI-CONDUCTORS

We have already pointed out that a material that will conduct an electric current is called a conductor, and a material that will not conduct an electric current is called an insulator. Many materials fall into one of these two classifications. However, there are materials that fall into a third group midway between the two. They are neither good conductors nor good insulators. Sometimes they can be made to act like conductors; at other times they can be made to act like insulators. Materials of this type are called "semi-conductors". Examples are germanium and silicon. These two materials are used in transistors. A transistor is often called a semi-conductor. You will learn more about transistors later in this lesson.

THE AMPERE

As you probably realize, the strength of the current flowing in electrical circuits will not always be the same. The strength of the current depends on the number of electrons set in motion. The number of electrons set in motion depends upon the force applied to the circuit, and also on the material used in the circuit. Some materials give up one or two electrons more readily than others, and as a result it is easier for the electrons to move through the circuit than in circuits made up of other materials that will not give up their electrons so easily.

We must have some way of knowing how much current there is flowing in a circuit. A movement of one or two electrons past a point in a circuit in a period of one second represents an extremely small current, so small in fact that it would be of no useful value. Before a current can be useful there must be a tremendous number of electrons moving past each point in the circuit. It would be impractical to try to count the number of electrons, so instead, a unit of current called the "ampere" has been devised. The ampere represents a useful number of electrons flowing past a given point in the circuit per second. The actual number of electrons that will pass the point is unimportant. However, a standard ampere has been set up, and all current measurements are made in relationship to this standard ampere. If the number of electrons flowing in the circuit is twice the number represented by 1 ampere, then the current flowing in the circuit is 2 amperes. If it is ten times the standard ampere, the current flowing is 10 amperes.

In electronics we are often concerned with currents much smaller than an ampere, so we have devised the units called the "milliampere" and the "microampere". A milliampere is one-thousandth of an ampere, and a microampere is one-millionth of an ampere. In other words, there are 1000 milliamperes in 1 ampere, and 1,000,000 microamperes in 1 ampere. There are 1000 microamperes in a milliampere.

The word ampere is usually abbreviated "amp." Therefore in your studies, you will see the words amp, milliamp, and microamp. To make these words plural we simply add an "s", for example, amps, milliamps, and microamps. Milliamperes is also often abbreviated ma.

THE VOLT

When we were discussing the ampere, we said that the amount of current that will flow in a circuit depends upon the force applied to the circuit. We should have some means of measuring this force. The force is called "electromotive force", or "voltage", and it is measured in volts. Again, you do not have to be concerned about exactly how much force there is in 1 volt; the important thing is to know that the number of volts indicates the amount of force applied to a circuit, and the higher the voltage, the more force is being applied to the circuit.

As with amperes, we often deal with small parts of a volt, and therefore we use the millivolt and the microvolt, which are one-thousandth and one-millionth of a volt, respectively.

By way of interest you might like to know that the voltage of a conventional flashlight cell is approximately 1½ or 1.5 volts. Storage batteries used in automobiles were 6 volts up until about 1954, and now most car manufacturers use a 12-volt battery. The electric light bulbs and appliances in most homes are designed to operate on a voltage of about 115 volts.

THE OHM

The amount of current that will flow in a circuit depends upon one other thing besides the force applied to the circuit. This is how readily the material will give up electrons and let them move through the circuit. Some materials will give up electrons quite readily and let them move through the circuit with little or no opposition. However, other materials will not give up electrons so readily, and they offer considerable opposition to the flow of current. This opposition to current flow is called "resistance". The resistance of a material depends upon how readily it will allow electrons to move through it. Resistance is measured in "ohms". Again, you need not know the exact definition of a standard ohm, the important thing to know is that resistance is the opposition to current flow in a circuit and that it is measured in ohms.

Often the resistance in the circuit is so high that it runs into more than a million ohms. We use the expression "megohm" to mean a million ohms. 6 megohms would be 6,000,000 ohms. Megohm is usually abbreviated "meg" and so we would call a 6-megohm resistor, "6 megs".

OHM'S LAW

We have said that the current that flows in a circuit depends upon the force or voltage applied to the circuit and on the opposition or resistance in the circuit. In other words, the current depends on the voltage and the resistance.

If in an electrical circuit a voltage of 1 volt is applied to a circuit having a resistance of 1 ohm, a current of 1 ampere will flow in the circuit. If we double the voltage so that the voltage is 2 volts and the resistance is still 1 ohm, the current that will flow in the circuit will be 2 amps. On the other hand, if the voltage were 1 volt, and we doubled the resistance to 2 ohms, the current that would flow in the circuit would be only one-half amp.

This relationship between current, voltage, and resistance, is known as "Ohm's Law". We will use Ohm's Law many times in future lessons. For the present, all you need to remember is that the current depends upon the voltage and the resistance. The higher the voltage, the more current will flow in the circuit. Increasing the resistance of the circuit, on the other hand, will cause the current to decrease.

SUMMARY

Here are the important points you should remember from this section of the lesson:

1. If a battery is connected to a wire made up of a material from which some of the electrons can be displaced, electrons will move from the negative terminal of the battery through the wire to the positive terminal, and through the battery back to the negative terminal, making a complete circuit.

2. A movement of electrons through a circuit is called a current.

3. A conductor is a material that will readily permit an electric current to flow through it.

4. An insulator is a material that will not readily permit an electric current to flow through it.

Magnetism

Magnetism is as important in electronics as electricity. Without magnetism there would be no electronics industry at all, for magnetism and electricity work together to make all our modern electronic devices possible.

PERMANENT MAGNETS

As you undoubtedly already know, a magnet will pick up or attract small pieces of steel or iron. Minerals that have this property are found buried in the ground in some parts of the world. These minerals are usually called natural magnets.

A piece of iron or steel can be made into a magnet by stroking it in one direction with a magnet. When a piece of iron or steel is made into a magnet in this way, we say it is "magnetized". Magnets made in this way are called "permanent" magnets, because they will retain their magnetism almost indefinitely.

Originally, almost all manufactured permanent magnets were made of iron or steel, but most modern permanent magnets are made of an alloy called "Alnico". Alnico is a mixture of aluminum, nickel, and cobalt. Very strong lightweight magnets can be made with this material, which retain their magnetism even better than magnets made of iron or steel.

Now let us study some facts about magnets and magnetism. When a magnetized steel needle is placed on a cork, and the cork is floated in water, the needle will always line up in a direction corresponding closely to north and south. This magnetic experiment is illustrated in Fig. 13. This phenomenon led to the first practical use for magnets, in compasses used by early sea voyagers and travellers. Compasses are made simply of a mag-

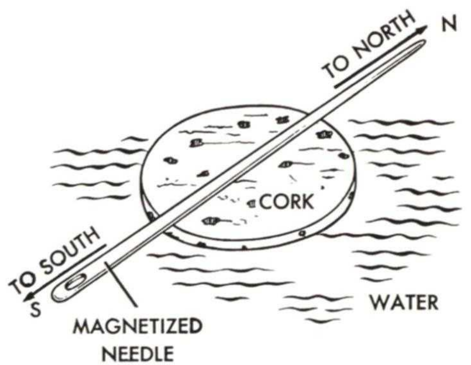

FIG. 13. If a magnetized needle is placed on a floating flat piece of cork, the needle will line up in the north and south directions like a compass, because it lines up with the magnetic field of the earth. In electronics, we produce magnetic fields much stronger than those of the earth.

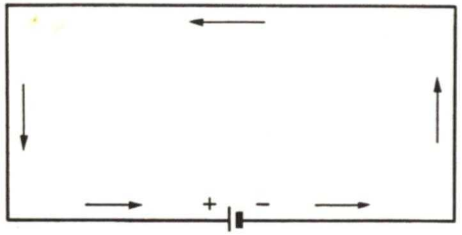

FIG. 12. The schematic diagram of a simple circuit.

negative electrons out of the battery. The positive terminal of the battery will attract the electrons, because it has the opposite charge on it. In Fig. 12 we have repeated the circuit shown in Fig. 11; however, this time we have used the symbol that is used on radio diagrams to identify a single-cell battery. Notice that we have used one short heavy line and one longer thin line. The short heavy line identifies the negative terminal of the battery, and the long light line the positive terminal. We have also marked the terminals with — and + signs so there will not be any confusion. Remember the symbol used for the battery, you will see it many times in your electronics career.

Symbols like this are used on all electronic diagrams to indicate the various parts. There is a different symbol for each part. Using a simple symbol instead of trying to show the actual part makes the diagrams much easier to understand. These diagrams using symbols are called "schematic" diagrams. We will teach you each symbol as you come to it so you will not have to learn a whole lot of them at once.

CONDUCTORS AND INSULATORS

There are a number of materials from which one or two electrons in the outer ring of electrons can be displaced. Copper, silver, aluminum, iron, and most other metals are examples of this type of material. Since electrons can be displaced from these materials, it is easy to set them in motion in a wire made of this type of material, and cause a current to flow through the wire. These materials are called *conductors*. They are so called because they will conduct or transmit an electric current; in other words, a current flow can be set up through them.

There is no such thing as a perfect conductor. All conductors offer some resistance, or opposition, to an electric current. Silver is the best known conductor, but it is used only in special applications because it is too expensive. Copper, which is almost as good a conductor as silver, is used in most wire because it is much cheaper than silver.

There are other materials which will not readily give up any electrons. A material having its outer ring full of electrons has no place to permit any additional electrons to move into the atom, nor will it permit any electrons to move from any of its rings. This type of material is called an *insulator*. It normally will not pass or conduct an electric current.

There is no such thing as a perfect insulator. Even in materials having all the electron rings filled, an electron will occasionally escape, particularly if enough force is applied to the material. However, the number of electrons that will escape is usually so small that for all practical purposes we can say that these materials will not conduct current. When an extremely high force is applied to this type of material, electrons may be forced out, and the material will break down, and will no longer be usable as an insulator.

In your study of electronics, you will be concerned with both conductors and insulators. Conductors will be used to make the current flow where you want it to flow. Insulators will be used to keep it from flowing in places where you do not want it. By the use of conductors and insulators, electrical circuits can be built.

SEMI-CONDUCTORS

We have already pointed out that a material that will conduct an electric current is called a conductor, and a material that will not conduct an electric current is called an insulator. Many materials fall into one of these two classifications. However, there are materials that fall into a third group midway between the two. They are neither good conductors nor good insulators. Sometimes they can be made to act like conductors; at other times they can be made to act like insulators. Materials of this type are called "semi-conductors". Examples are germanium and silicon. These two materials are used in transistors. A transistor is often called a semi-conductor. You will learn more about transistors later in this lesson.

THE AMPERE

As you probably realize, the strength of the current flowing in electrical circuits will not always be the same. The strength of the current depends on the number of electrons set in motion. The number of electrons set in motion depends upon the force applied to the circuit, and also on the material used in the circuit. Some materials give up one or two electrons more readily than others, and as a result it is easier for the electrons to move through the circuit than in circuits made up of other materials that will not give up their electrons so easily.

We must have some way of knowing how much current there is flowing in a circuit. A movement of one or two electrons past a point in a circuit in a period of one second represents an extremely small current, so small in fact that it would be of no useful value. Before a current can be useful there must be a tremendous number of electrons moving past each point in the circuit. It would be impractical to try to count the number of electrons, so instead, a unit of current called the "ampere" has been devised. The ampere represents a useful number of electrons flowing past a given point in the circuit per second. The actual number of electrons that will pass the point is unimportant. However, a standard ampere has been set up, and all current measurements are made in relationship to this standard ampere. If the number of electrons flowing in the circuit is twice the number represented by 1 ampere, then the current flowing in the circuit is 2 amperes. If it is ten times the standard ampere, the current flowing is 10 amperes.

In electronics we are often concerned with currents much smaller than an ampere, so we have devised the units called the "milliampere" and the "microampere". A milliampere is one-thousandth of an ampere, and a microampere is one-millionth of an ampere. In other words, there are 1000 milliamperes in 1 ampere, and 1,000,000 microamperes in 1 ampere. There are 1000 microamperes in a milliampere.

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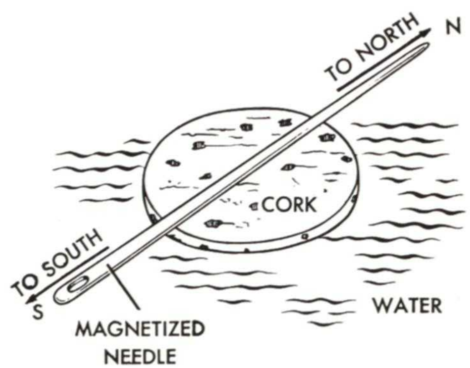


FIG. 13. If a magnetized needle is placed on a floating flat piece of cork, the needle will line up in the north and south directions like a compass, because it lines up with the magnetic field of the earth. In electronics, we produce magnetic fields much stronger than those of the earth.

netized piece of steel that is mounted on a delicately pivoted bearing that will turn as easily as the cork in water.

POLES OF A MAGNET

The ends of a permanent magnet are called "poles"; this name was probably given to the ends of a magnet because the ends pointed toward the poles of the earth when the magnet was free to pivot on an axis. The pole that points toward the north pole of the earth was originally called the "north-seeking" pole. However, for simplicity, the name has been shortened to the *north pole*. The magnetic pole that points to the south pole of the earth is called the *south pole*.

If two magnets are brought near each other, you will find that the north pole of one magnet will *repel* the north pole of the other. Similarly the south pole of one magnet will *repel* the south pole of another magnet. However, the north pole of one magnet will *attract* the south pole of the other magnet. The reason why a compass always points in a north-south direction, is that the earth itself is a magnet, and one pole of this large magnet is near the north geographic pole, and the other pole is near the south geographic pole. The north pole of the earth attracts one of the poles of the magnet and repels the other. The south pole of the magnet attracts the pole that is repelled by the north pole, and repels the pole attracted by the north pole. Therefore, the magnet will point in a direction so that one pole points toward the north magnetic pole and the other pole points toward the south magnetic pole.

Notice the similarity between the attraction and repulsion of magnetic poles and the attraction and repulsion of electric charges. You already know that like charges repel and unlike charges attract. ***In magnets, like poles repel and unlike poles attract.*** This is a fundamental law of magnetism; you should remember it.

MAGNETIC LINES OF FORCE

There are lines of force surrounding a permanent magnet. You can actually trace out the lines of force around a magnet by using a small compass. If you bring the compass near the north pole of the magnet, the south pole of the compass will be attracted to the north pole of the magnet. The compass needle will line up with the magnetic lines of force. If you move the compass needle as shown in Fig. 14, you will be able to trace out the magnetic lines of force. The lines of force are shown coming from the north pole of the magnet and going to the south pole. We do not know for sure whether or not this is true, but there is considerable evidence that the lines of force actually do go from the north pole to the south pole and therefore we will base our explanations on this assumption.

Another experiment that can be performed to show the lines of force around a magnet is to place a thin sheet of cardboard over a magnet and then sprinkle iron filings evenly over

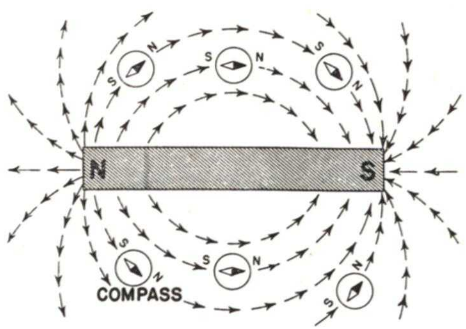


FIG. 14. A small compass can be used to trace magnetic lines of force near a permanent magnet.

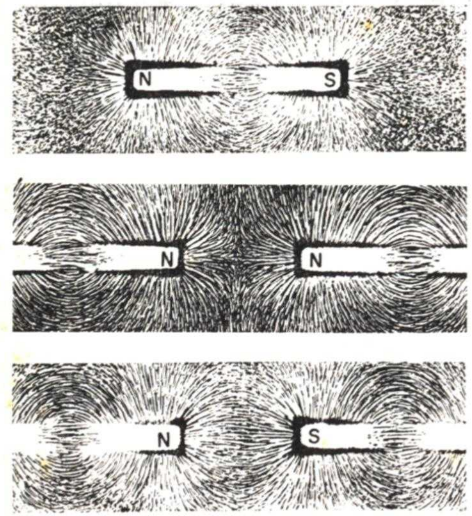


FIG. 15. If iron filings are placed on a sheet of cardboard over permanent magnets, they will trace out lines of force as shown here.

the sheet of cardboard. Tap the cardboard gently, and the iron filings will arrange themselves in definite lines producing the pattern shown at the top in Fig. 15.

If two magnets are arranged so that their north poles are placed close together and then iron filings are sprinkled on a cardboard placed over the magnets, the iron filings will arrange themselves as shown in the center in Fig. 15. Notice that you can see the lines of force from the north poles of the two magnets actually repelling each other. You would get a third pattern by placing the north pole of one magnet toward the south pole of another and sprinkling iron filings on a cardboard. The pattern you would get in this case would be like the one shown at the bottom in Fig. 15. Here you can see the attraction between the north pole and the south pole of the two magnets.

The lines of force coming from a magnet are called *"magnetic lines of force"*. There are similar lines of force surrounding electrically charged objects. The lines of force around an electrically charged object are called *"electric lines of force"*.

ELECTROMAGNETS

Many years ago scientists discovered that an electric current flowing through a wire produced a magnetic field in the space around the wire. This is called "electromagnetism". The circular lines of force around the wire can actually be traced out with a compass. There will be many of these magnetic rings that surround the entire length of the wire. The magnetic lines of force close to the wire will be much stronger and more easily detected than those out some distance from the wire as shown in Fig. 16. However, even with a comparatively weak current flowing through a wire, magnetic lines of force can be detected some distance from the wire, with sensitive equipment.

Even though the magnetic lines of force around a current-carrying wire can be detected, the magnetic field will be quite weak unless the current flowing in the wire is extremely strong. However, by winding the wire in the form of a coil, a strong magnet can be made. When the wire is bent into a

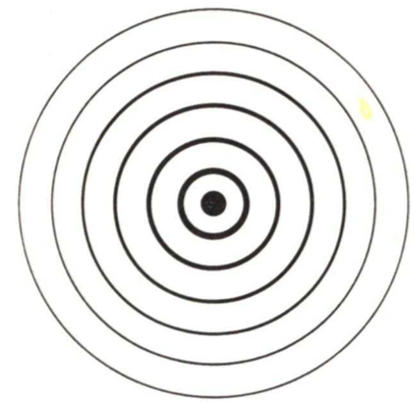


FIG. 16. When electrons flow through a wire, magnetic lines of force surround the wire. This is a cross-sectional view.

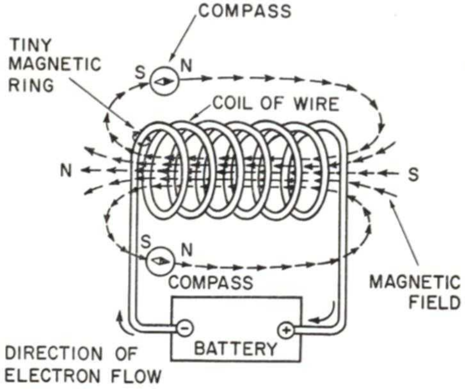


FIG. 17. The more turns of wire we have in a coil, the stronger the magnetic field will be when electrons flow through the coil.

loop, the circular magnetic rings pass through the center of the coil in the same direction and reinforce each other as shown in Fig. 17.

This type of magnet is called an "electromagnet". The magnetic effect exists only as long as the current is flowing through the wire. Once the current is stopped by opening the circuit, the magnetic effect will disappear. Many parts used in electronic equipment depend upon the basic principles of electromagnetism to operate.

The electromagnet shown in Fig. 17 can be made much stronger by inserting an iron bar inside the coil. The iron bar is called a core. The increase in the strength of the magnet will depend upon the type of core material used. Usually soft iron is used, because it increases the strength of the magnet the most. The soft iron also has several other advantages.

You probably wonder why inserting a core inside the coil makes the magnet stronger. The answer to this question is that the iron core is made up of millions of tiny particles of iron. Each of these particles is itself a magnet having a north pole and a south pole. Ordinarily these tiny magnets are not arranged in any definite pattern. One might point in one direction, another in a second direction, and a third in still another direction as shown in Fig. 18A. As a result, the magnetic field of one magnet is cancelled by the magnet field of another. However, when the iron core is placed in the magnetic field inside the current-carrying coil, the magnetic field produced by the coil causes the particles to line up and all point in the same direction as shown in 18B. When this occurs, the entire bar becomes one strong magnet. However, most of the tiny particles are kept lined up only by the magnetic field produced by the current flowing in the coil. Once this field is removed by opening the circuit so that current can no longer flow through the coil, most of the tiny particles will return to their random arrangement so they will no longer be pointing in one direction, and most of the magnetic field will disappear.

INDUCED CURRENTS

We have seen that there is a magnetic field around a current-carrying wire, and that if current flows through

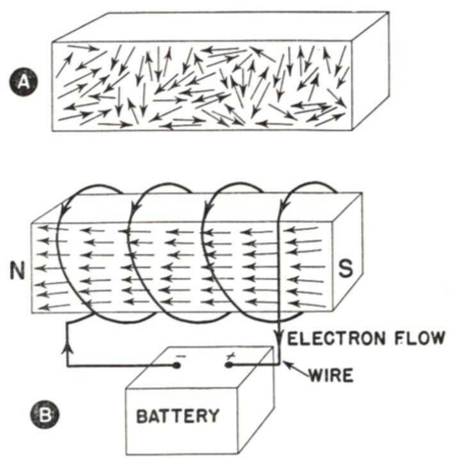


FIG. 18. In an unmagnetized bar of iron at A, the tiny magnets in the iron do not line up; if the bar of iron is magnetized, they will line up as at B.

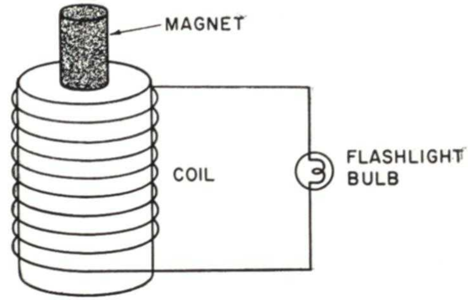


FIG. 19. If a magnet is moved in and out of a coil connected to a flashlight bulb, the magnetic lines of force cutting the turns of wire on the coil will induce a voltage in the coil, and the voltage will cause a current flow through the flashlight bulb.

a coil, an electromagnet will be produced. Now, is the opposite true? In other words, if a coil is placed in a magnetic field, will a current flow through the coil? Let us look at the experiment illustrated in Fig. 19. We have shown a coil wound on a hollow form. The ends of the coil are connected to a small flashlight bulb. Here we have used a combination of a pictorial drawing for the coil and a schematic symbol for the bulb.

If a magnet is moved inside the hollow form, the light will light while the magnet is being moved into the coil. Once the magnet is completely inside the coil and no longer moving, the light will no longer light. When the magnet is moved out of the coil, the light again will light. If the magnet is moved quickly in and out of the coil, the lamp will light and remain lighted. In other words, as long as the magnet is moving inside the coil, a current will flow in the coil and through the flashlight bulb. This current flows because a voltage is induced in the coil. The voltage causes the current to flow. The voltage is called an "induced" voltage and the current an "induced" current. The voltage will be induced in the coil only as long as the magnetic field is in motion. The magnetic lines of force moving through the turns of wire on the coil are said to cut the turns of wire on the coil; the voltage is induced as long as the magnetic lines of force are cutting the turns of wire on the coil.

A second demonstration of an induced voltage is shown in Fig 20. Here two coils are wound on the same form and placed near each other. It is customary on schematic diagrams to use letters to designate the various parts. L is usually used for coils. We have marked the coils L1 and L2 to make them easy to refer to. One coil, which we have marked L1, is connected to a flashlight cell through a switch, and the other coil, marked L2, is connected to a flashlight bulb. We have shown the schematic symbol for the switch, and labeled it SW. This makes three schematic symbols you should now know—the battery, the light bulb, and the switch. When the switch is closed and current starts to flow in L1, there will be a voltage induced in L2, and a glow will be seen in the flashlight bulb. However, this glow will last for only an instant after the switch is closed. When the switch is opened and the current flow in L1 is interrupted, the bulb again will glow, indicating that this, too, induced a voltage in the second winding.

The explanation of this action is the same as for the voltage induced

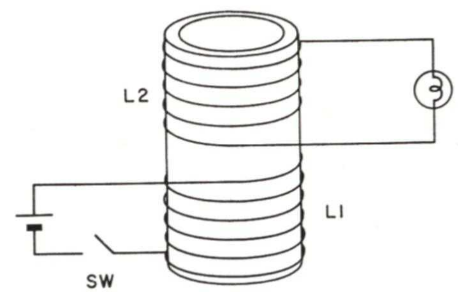


FIG. 20. When the circuit to L1 is opened or closed, a voltage will be induced in L2.

by the magnet moving in and out of the coil in Fig. 19. When the circuit is completed by closing the switch, current starts to flow in the coil. But the magnetic field that accompanies the current flow does not build up instantly; it takes just a short time for this field to build up. While the field is building up, the magnetic lines cut L2, just as they cut the coil when the magnet was moved into the coil in Fig 19. These magnetic lines of force cutting L2 induce a voltage in L2, which causes a current to flow through it and the flashlight bulb. When the circuit is opened, the magnetic field must disappear. While it is doing this, the lines cutting L2 are again changing. Once again the changing magnetic field produced by L1 induces a voltage in L2 and current flows in L2.

It is important for you to realize that whenever the magnetic field around a coil *changes,* there will be a current induced in the coil. Remember this, it is important; you will be dealing with induced voltages as long as you are in the field of electronics.

SUMMARY

Again, you are not expected to remember all the details described in the section on magnetism. This information is presented so you will have a complete picture and as a result be able to understand magnetism completely.

The important points that you should remember from this section are as follows:

1. A magnet has a north pole and a south pole.

2. Like magnetic poles repel; unlike magnetic poles attract.

3. There is a magnetic field around a current-carrying wire.

4. An electromagnet can be made by passing a current through a coil.

5. Inserting an iron core into an electromagnet will result in a stronger magnetic field.

6. If the magnetic lines of force cutting a coil change, there will be a voltage induced in the coil. If the coil is connected into a complete circuit, current will flow in the circuit.

Electronic Components

By electronic components we simply mean parts used in electronic equipment. Both words, parts and components, are used in industry; therefore, we will use both words so you will be familiar with them.

In the rest of this lesson, you will study a few of the parts found in electronic equipment. You will not learn all of the details of how these parts work, but you will start to study the operation of these parts so you will have a general understanding of how they operate. In later lessons you will study these components in more detail and learn much more about them.

You have already seen the schematic symbol for a single cell battery, for a light bulb, and for a switch. You will learn the symbols used for several other parts. It is important that you learn these symbols as you go along. Symbols are used to draw schematic diagrams. Schematic diagrams tell you how the various parts are connected together. You must learn how to read this type of diagram. It's quite a job to try to learn these symbols all at once, but if you take them one at a time as you come to

them in your lessons and also learn how to read the simple diagrams shown in the early lessons, you will soon find that the schematic diagrams are quite simple to follow, and that you will have no difficulty even with large complex diagrams.

BATTERIES

You already know that a battery is a device that can force electrons through a circuit. You know that a battery has two terminals, a positive terminal and a negative terminal. Now, let us look at a simple flashlight cell to learn a little more about how it is made and how it operates.

Flashlight Cells. A sketch of a simple flashlight cell is shown in Fig. 21. The outer case of the cell is made of zinc. In the center of the cell is a round carbon rod. The rod runs almost the full length of the cell, missing the bottom of the case by only about one-quarter of an inch. A chemical mixture is packed into the cell, surrounding the carbon rod and filling the zinc case. This mixture is brought up almost to the top of the zinc case. Molten pitch or a similar substance is then poured on top of the chemical to seal the cell.

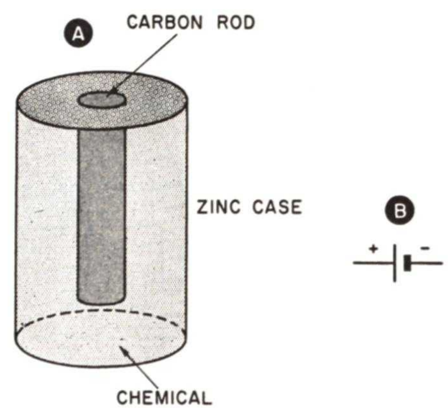


FIG. 21. Pictorial drawing (A), and schematic symbol (B) of a dry battery.

When a wire is connected from the zinc case, which is the negative terminal of the cell, to the carbon rod which is the positive terminal of the cell, the chemical action inside the battery will force electrons out of the zinc case, through the wire and back to the carbon rod. The electrons that reach the carbon rod are then pulled out of this rod again by the chemical action of the battery, pushed through the chemical mixture and to the zinc case. The electrons are then ready to leave the zinc case and flow through the circuit again.

The number of electrons that any single cell can force through the circuit will depend upon several things. The resistance of both the wire and the battery will affect the total number of electrons the cell can force around the circuit. It will also depend upon the size of the carbon rod and the zinc case. Of course, the more electrons that are flowing in the circuit at any one time, the stronger the current and also the shorter the life of the battery.

The battery can continue to force electrons through the circuit until the acid in the chemical mixture in the battery has eaten a hole in the zinc case. When this happens, the acid remaining in the battery will soon evaporate, and the battery will no longer be usable.

A single flashlight cell has a voltage of about 1.5 volts. When a higher voltage is needed, several flashlight cells can be connected to each other to provide a higher voltage. When cells are connected to provide a higher voltage, we say they are connected in "series". You have probably seen a flashlight that uses two flashlight cells. This type of flashlight uses a 3-volt flashlight bulb. When you put the cells in the battery, you insert them so that the carbon tip of the first cell touches the center tip on the base of the bulb. You put the second cell in the battery so that the carbon tip of the second cell touches the zinc case of the first cell. Then, when you put the cover on the end of the flashlight, the cover will touch the zinc case of the second cell and complete the circuit to the threaded side of the bulb, which is the other terminal of the bulb. A sketch of how the flashlight cells and the bulb are arranged is shown in Fig. 22A. In a flashlight of this type the current flows from the negative terminal of the second cell through the flashlight case and the switch to the bulb, through the bulb to the positive terminal of the first cell, through the chemical mixture in the first cell to the zinc case, which is the negative terminal, from the zinc case to the positive terminal of the second cell, through the chemical mixture and back to the negative terminal (the zinc case) of the second cell. The schematic diagram of this circuit is shown in Fig. 22B. Notice how much simpler and more convenient the schematic is than the pictorial type of drawing.

In a schematic diagram, a continuous line represents a connection. This may be actually a connecting wire, as was shown in Fig. 12, or it may be some other type of connection. In the flashlight shown in Fig. 22, the connections on one side of the circuit are formed by the bulb and the cells touching each other, and on the other side of the circuit by the case of the flashlight.

When flashlight cells are connected in this way, we say that they are connected in *series*. The total voltage from the two cells connected in series is *twice* the voltage of one cell—in other words 3 volts. If three cells are connected in series, the voltage will be 4.5 volts, and if four cells are connected in series, the voltage will be 6 volts.

When cells are connected in series, they are called a battery. Dry-cell batteries capable of supplying voltages as high as 90 volts are used in some electronic equipment. The batteries are simply made of a large number of 1.5-volt cells connected in series to give the required voltage. A 90-volt battery would have sixty 1.5 volt cells connected in series. Two views of a 6-volt battery made up of four cells, and the schematic symbol for it are shown in Fig. 23.

Other Types of Batteries. The flashlight cell is one type of battery. There are many other types of batteries. For example, there is the storage battery used in automobiles. Another type of battery that is found frequently in equipment using transistors is the mercury battery. Different types of cells have different voltages. The flashlight cell has a voltage of about 1.5 volts; a single cell of a storage battery has a voltage

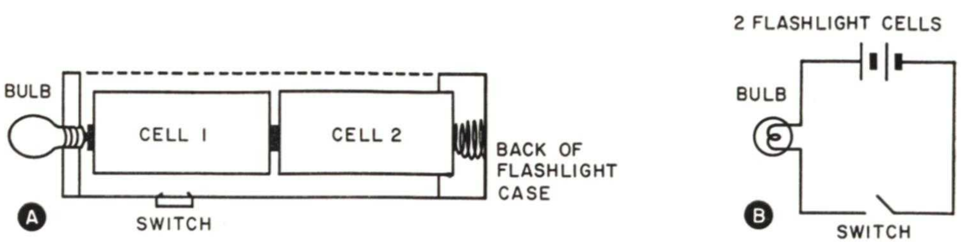


FIG. 22. Two flashlight cells used in series to power a 3-volt flashlight bulb are shown at A. The schematic diagram of this circuit is shown at B.

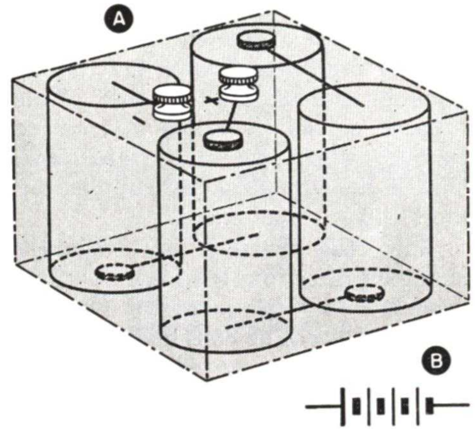


FIG. 23. The construction of a 6-volt battery made up of four 1.5-volt cells. The four cells are connected in series to give the required voltage.

of approximately 2 volts. Older cars use a battery made up of three cells with a total voltage of about 6 volts. The newer cars use batteries having six cells and a total voltage of about 12 volts. The mercury cell has a voltage of about 1.34 volts. Therefore a mercury battery made up of three cells has a voltage of about 4 volts.

Batteries are made in all sizes and shapes. Some batteries made especially for portable equipment are extremely small, other batteries such as storage batteries for automobiles are quite large and heavy. You will see many different types in your electronics career.

TRANSFORMERS

Probably no device has done more for the electronics industry than the transformer. The transformer has made it possible for power companies to supply homes and industry with electric power economically. Without economical power there could be no electronics industry. There is hardly a piece of electronic equipment made that does not use one or more transformers.

In spite of the importance of the transformer, it is basically a simple device. A transformer in its simplest form is nothing more than two coils mounted close to each other. The two coils we discussed in Fig. 20 actually can be called a transformer. Two typical transformers and the schematic symbols for them are shown in Fig. 24. The transformer shown in Fig. 24A consists of two coils wound on a cardboard coil form. This type of transformer is called an *air-core* transformer. The one shown in Fig. 24B is made of two coils wound on an iron core. This type is called an *iron-core* transformer.

You have already seen how a transformer works. When we discussed the two coils wound on the same form in Fig. 20, we pointed out that if the current in the winding marked L1 changed, there would be a voltage induced in L2. This is how a transformer works. Two coils are wound on a common form, so any magnetic lines of force produced by one coil will cut through the other. If the current through one of the coils changes, the magnetic field around that coil will change. This changing magnetic field will induce a voltage in the second coil.

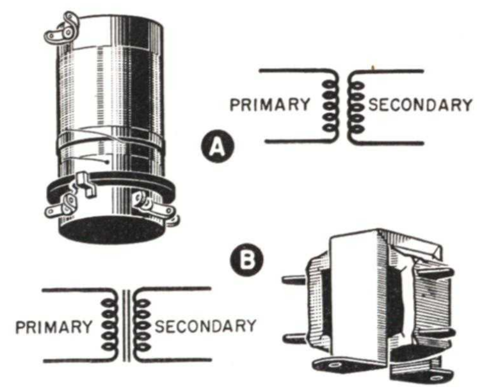


FIG. 24. A shows an air-core transformer with its schematic symbol, and B shows an iron-core transformer with its schematic symbol.

You might wonder how we change the current through the one coil in order to produce the changing magnetic field. To answer this question, let us consider the current supplied by a battery. The current always flows from the negative terminal of the battery through the circuit and back to the positive terminal. Since this current always flows in the same direction it is called *direct current*. We abbreviate this "dc".

Now look at the circuit shown in Fig. 25. Here we have two flashlight cells arranged with two switches mechanically connected to work at the same time, so that we can connect first one cell and then the other to winding L1 on the transformer. (The mechanical connection between the two switches has been left off, to simplify the drawing.) We have labeled the cells B1 and B2. When B1 is connected to the transformer, current will flow through the transformer in one direction. When B2 is connected to the transformer, the current will flow through L1 in the opposite direction. If the switch is thrown first into one position and then into the other, and

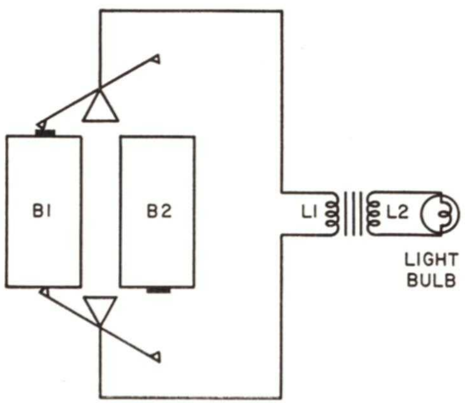


FIG 25. By means of a switch that can be thrown back and forth rapidly, the current through L1 can be reversed rapidly. The rapidly changing current will result in a changing magnetic field that will induce a voltage in L2.

this action is kept up rapidly enough, we will have a current that is continually reversing, flowing first in one direction and then in the other. This type of current is called *alternating current*, which we abbreviate "ac". This is the type of power supplied by most power companies.

Since this current is constantly changing direction, the magnetic field produced by the current flowing through L1 will be continually changing, and therefore we will have a voltage being induced in L2 all the time. Of course, since the magnetic field inducing this voltage is continually changing polarity, the voltage induced in L2 will be continually changing. The voltage induced in L2 will be an ac voltage.

One very useful thing about transformers is that the voltage induced in L2 will depend upon the number of turns on both L1 and L2 and the voltage applied to L1. (The "number of turns" means the number of times the wire in the coil is wound around the core.) To provide a convenient method of identifying the windings on the transformer, L1 is called the "primary" and L2 the "secondary". If L2 has more turns than L1, the voltage induced in L2 will be higher than the voltage applied to L1, and the transformer is called a "step-up" transformer. If L2 has fewer turns than L1, the voltage induced in L2 will be less than the voltage applied to L1, and the transformer is called a "step-down" transformer. If L1 and and L2 have the same number of turns, the voltage induced in L2 will be approximately the same as the voltage applied to L1, and the transformer is called a "one-to-one" transformer. This is usually written 1:1. It simply means that the voltage obtained from the secondary will be the same as the voltage applied to the primary.

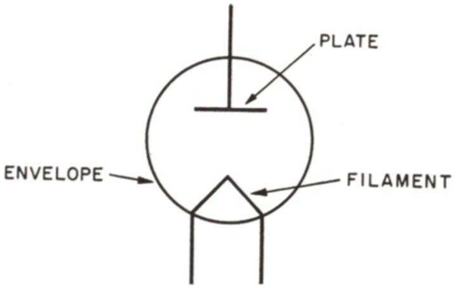


FIG. 26. The schematic symbol of a two-element (diode) tube.

Voltages both higher and lower than those normally supplied by the power company are needed in electronic equipment. Transformers are used to provide these voltages.

VACUUM TUBES

Vacuum tubes are so widely used today, that almost everyone has seen one. Almost every piece of electronic equipment in use today contains one or more tubes. Since tubes are so widely used, it is important for you to learn something about their operation as soon as possible.

History. One of the early discoveries that led to the development of the vacuum tube was made by Thomas A. Edison when he was conducting experiments to try to improve his newly invented electric light bulb. He had placed a metal plate inside the glass bulb along with a filament such as you can see in a clear glass electric light bulb. He wanted to see if the presence of the plate would improve the performance of his electric lamp. However, adding the plate did not improve the light. The experiment might have been a total failure, but Edison did notice that if the circuit between the plate and the filament was completed, there was a small current flow in the circuit. He did not know why this current flowed, and since it did not improve the performance of his electric light, he did not perform any further experiments with the plate inside the lamp. However, Edison did report his findings, and other experimenters worked to try to find out what caused this current flow and also to try to develop some useful applications of this effect.

The Diode Tube. It remained for a scientist named Fleming to explain the effect that Edison had observed. Fleming built a tube with a plate and a filament sealed inside a glass envelope from which all the air was evacuated. A tube like this is called a diode tube; diode means it has two elements, the *plate* and the *filament*.

The schematic symbol used to identify a diode is shown in Fig. 26. The filament and the plate are labeled. The "envelope" is the glass or metal bulb of the tube. You should remember these symbols, because you will see them throughout your course, and in schematic diagrams of electronic equipment.

If a battery is connected to the filament as shown in Fig. 27A, a current will flow through the filament. The filament is made of a material that will quickly become red hot when current flows through it. As it gets

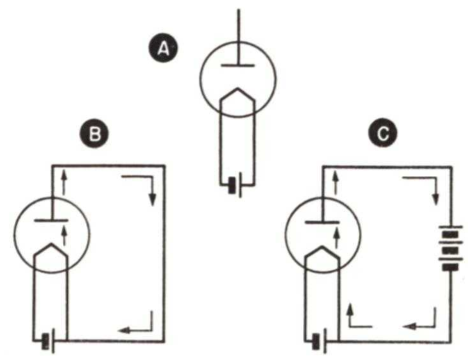


FIG. 27. The filament of a diode is heated as shown at A. When a diode is connected as shown in B, a small current will flow in the direction indicated by the arrows. When a battery is added as in C, a much stronger current will flow.

hot, some of the electrons fly off into the space around the filament. We say the filament is "emitting electrons".

These electrons that leave the filament form a cloud of electrons around the filament. This cloud of electrons has a negative charge, and tends to force any additional electrons leaving the filament, back to the filament. At the same time, the filament, having lost electrons, has become positively charged.

Now let us see what happens if we connect a wire from the plate to the filament as shown in Fig. 27B. Some of the electrons will hit the plate, and will be attracted through the wire back to the filament to replace the lost electrons. This small current is the effect Edison noticed, and is called the "Edison Effect".

If we connect a battery in the plate circuit as shown in Fig. 27C, it will attract many more of the electrons leaving the filament, and a much larger current will flow.

The battery in the filament circuit serves no purpose except to heat the filament. The circuit action would be the same if it were possible to heat the filament by a torch or some other means.

Current will flow through a diode tube in only one direction. If the polarity of the battery connected to the plate is reversed so the negative terminal is connected to the plate, there will be no current flow in the circuit. You can easily see why this will happen. The electrons flying off the filament have a negative charge. If any of these electrons should fly off with enough speed to travel over near the plate, they will be repelled by the negative voltage on the plate of the tube, and will therefore travel back to the filament of the tube.

The diode tube is still used today in certain applications. However, one additional improvement was needed in vacuum tubes to make radio and television and the other electronic miracles we know today, possible. This improvement was made by another scientist named De Forest; he added a third element to the vacuum tube.

The Triode Tube. The third element added to the tube by De Forest is called a "grid". The schematic symbol for a triode tube is shown in Fig. 28. The grid is represented by the dashed line between the filament and the plate. It is usually a coil of fine wire wound around and near the filament of the tube. The addition of the grid to the tube makes it possible for the tube to amplify signals. Modern triode tubes may amplify weak signals as much as 100 times.

The ability of the triode tube to amplify signals comes from the fact that the grid of the tube is much closer to the filament than the plate. In other words the distance between the filament and the plate is several times the distance between the filament and the grid. Because the grid is closer to the filament, a small change in grid voltage will greatly affect the current flowing from the filament to the plate of the tube. Since the plate is some distance from the filament, a small change in plate voltage would have much less effect on the current flowing through the tube.

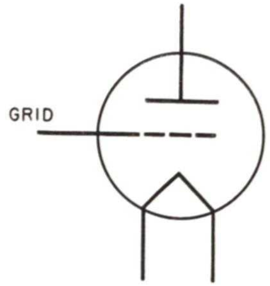


FIG. 28. The schematic symbol for a triode.

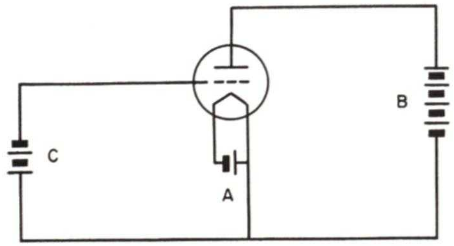


FIG. 29. A triode tube showing how three batteries are used to provide the necessary operating voltages.

In the circuit shown in Fig. 29, notice that the battery connected in the plate circuit is connected as it was in Fig. 27B, with the positive terminal connected to the plate of the tube, and the negative terminal connected to the filament. If we disregard the grid, we can see that this tube will act very much like a diode. The electrons will fly off the filament and be attracted by the positive voltage on the plate of the tube. Current will flow through the tube as it did in the diode.

However, notice that the third battery is connected so that its negative terminal is connected to the grid of the tube and its positive terminal is connected to the filament. This *negative* voltage on the grid of the tube will repel electrons back to the filament. This means that the electrons coming off the filament will be affected by two forces. They will be attracted by the positive voltage on the plate, and repelled back toward the filament by the negative voltage on the grid. The two forces are actually working against each other.

Now the problem is which force will win out. This depends on a number of things, but remember that the grid is much closer to the filament than the plate is. Therefore, when an electron flies off the filament, it will immediately be affected by the negative voltage on the grid of the tube. In fact, if the grid voltage is made high enough, the grid will repel the electrons with such force that none will be able to get through the grid and over to the plate.

Placing such a high voltage on the grid of the tube that no electrons can reach the plate is done in some special cases; however, usually the voltage placed on the grid is not this high. The voltage placed on the grid is usually about midway between zero and the voltage needed to stop the flow of current completely. This voltage put on the grid is called "grid bias" or more simply "bias".

Now let us see what happens when we use a triode to amplify a small ac signal. Look at the circuit shown in Fig. 30. In this circuit a small signal is fed into the primary of the transformer T1. This signal will cause a weak ac current to flow through the primary of the transformer, and this current will induce an ac voltage in the secondary. The voltage across the secondary of the transformer is connected in series with the grid bias voltage supplied by battery C. When the voltage across the secondary is positive at point 1 and negative at point 2, the net voltage on the grid will then be the sum of the voltage supplied by battery C and the voltage between terminals 1 and 2 of T1. This means the negative voltage on the grid will be increased. This will cause the current flowing from the filament to the plate to *decrease*. When the

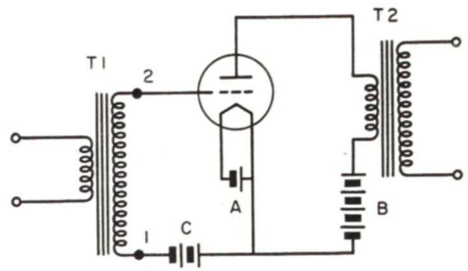


FIG. 30. A triode tube used as a voltage amplifier.

polarity of the voltage across the secondary of the transformer T1 is negative at point 1 and positive at point 2, it will subtract from the grid bias voltage. This means the voltage between the grid and the filament will be reduced, and when this happens the current flowing from the filament to the plate of the tube will *increase.*

Now we have seen how the signal voltage applied between the grid and the filament will cause the current flowing from the filament to the plate to vary. This varying current will flow through the primary of T2 and induce a voltage in the secondary. This voltage across the secondary of T2 will be many times the original voltage applied to the primary of T1, because small changes in grid voltage will produce large changes in the current flowing through the tube. Hence there will be a large variation in the current flowing in the primary of T2, which will result in a large induced voltage in the secondary.

The amplifier shown in Fig. 30 is called a "transformer-coupled" amplifier. In a "transformer-coupled" amplifier it is easy to get a gain of 100 or more. When we say that an amplifier has a gain of 100, we mean that the signal at the output is 100 times that at the input.

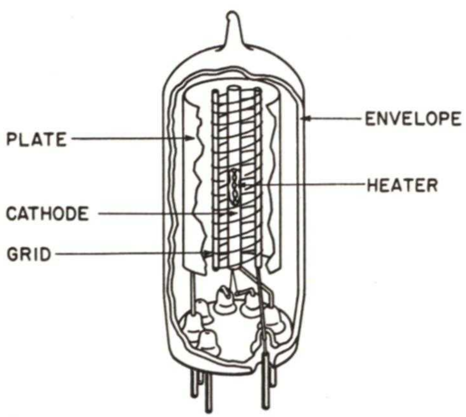


FIG. 31. Cut-away view of a typical vacuum tube.

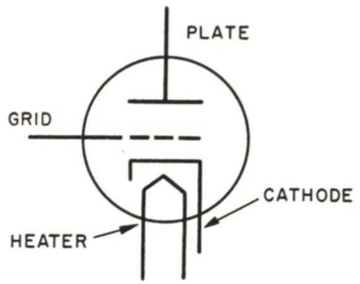


FIG. 32. Schematic symbol of a triode tube with a cathode and a heater.

In Fig. 30, the three batteries are labeled A, B, and C. In the early days of radio, the battery used to heat the filament of the tube was called the "A" battery. The battery used to supply the voltage for the plate of the tube was called the "B" battery, and the voltage applied to the grid was obtained from a battery called the "C" battery. These names have been used ever since then, particularly the naming of the "B" battery for the plate voltage supply, even though batteries are seldom used to supply power except in portable equipment. In modern electronic equipment you will often see the plate voltage supply marked "B+" and "B—", even though the voltage is obtained from a source other than a battery.

Modern Tubes. One of the big disadvantages of tubes using a filament is that a dc voltage must be applied to the filament to heat it. It is much more convenient to heat the filament with ac instead of dc. To overcome this disadvantage, many modern tubes are made with a cathode instead of a filament. The cathode is simply a small hollow cylinder that has been coated with a material that will readily give off electrons when it is heated. The cathode is heated by a heater placed inside it. The heater is heated by ac applied to it from a transformer and it gets red hot. The heater in turn heats the cathode to red heat and the cathode gives off the electrons that make the vacuum tube operate. The construction of a tube of this type is shown in Fig. 31, and the schematic symbol for a triode tube using a cathode and a heater is shown in Fig. 32. This tube is still called a triode, because the heater serves only to heat the cathode. It does not enter into the operation of the tube in any way. In fact, the heater connections are often omitted on diagrams to simplify them. The heater is often called the filament because it resembles the filament we have already described; but remember that when there is a separate cathode, the only purpose of the heater is to heat the cathode.

TRANSISTORS

Transistors are made out of materials called *semi-conductors.* Remember that a *conductor* is a material that will conduct or pass the flow of electric current. An *insulator* is the material that will not normally pass an electric current. A *semi-conductor* is a material that is neither a good *conductor* nor a good *insulator.*

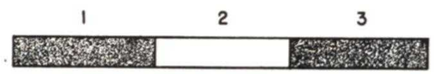


FIG. 33. A triode transistor made of three pieces of germanium. The germanium in the pieces marked 1 and 3 has been mixed with a small amount of one chemical; the germanium in the section marked 2 has been mixed with another.

Germanium is the semi-conductor used in making transistors. A typical transistor is made up of three pieces of germanium. These three pieces are arranged as shown in Fig. 33. Each piece of germanium has been mixed with small quantities of another chemical. The pieces marked 1 and 3 have been mixed with the same chemical, and the piece marked 2 has been mixed with small quantities of another chemical.

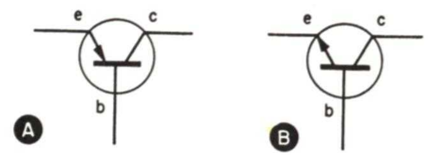


FIG. 34. Schematic symbols for two different types of three-element transistors. The emitter is marked e, the base b, and the collector c.

Since the transistor is made up of three pieces of germanium, it is often called a triode, just as the vacuum tube with a cathode, a grid, and a plate is called a triode. The elements in a transistor are called the emitter, the base, and the collector. The schematic symbols for transistors are shown in Fig. 34. The lead with the arrow on it and marked with the letter e, is the emitter, the long straight line marked b is the base, and the other lead marked c is the collector. The two different types of symbols are for the two different types of transistors. Their operation is somewhat different, but they can be used to accomplish the same thing.

A simplified version of a transistor amplifier is shown in Fig. 35. Here the weak input signal is applied between the emitter and the base, and the stronger output signal is picked up between the base and the collector. Although the method of operation of a transistor differs considerably from that of a vacuum tube, the end result is the same. You can feed a weak

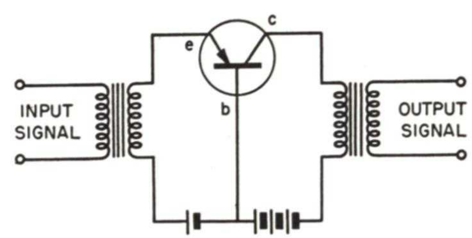


FIG. 35. A simplified transistor amplifier.

signal into the input and obtain a much stronger signal in the output.

The transistor offers several advantages over the vacuum tube. It is much smaller than a vacuum tube and it is much more rugged than a vacuum tube. It also generates much less heat than a vacuum tube and so can be used in small spaces. However, the vacuum tube is easier to make than the transistor, it is cheaper, and in general is a more flexible device than the transistor.

SUMMARY

We have covered a great deal of information in this section on components. This is simply to introduce you to these components. We do not expect you to remember all the details we have covered, but you should get used to speaking about these parts, and get some idea of their uses and how they operate. Later on we will study each of these components in more detail, and also many more parts. For the present, simply concentrate on getting a general idea of how these devices work. You should know what a diode tube and a triode tube are and how current flows through these tubes. You should have a general idea of how a triode tube amplifies a signal. We have not attempted to describe the operation of transistors, but you should be able to recognize them on schematic diagrams. You should also know the schematic symbols for all the other parts described in this section.

Answering the Questions

On the last page of this lesson you will find ten questions. These questions are designed to help you learn the important points in this lesson. We do not want you to try to memorize the lesson or answer the questions from memory.

When you are ready to answer the questions, read over the first question carefully, make sure you understand the question and then mentally see if you can answer the question. Next, go to the section of the lesson where the answer is given, and read over that section of the lesson again. Make sure that you completely understand the answer to the question. Then, close the book and write out the answer. Do not copy the answer from the book, but rather try to write the answer in your own words. If you find that you cannot answer the question, it shows that you need to study some more.

Many of the questions can be answered by a single word or by one or two words. Make your answers as brief and as direct as possible. Make sure that your answer actually answers the question asked. In some questions you will be asked to draw a schematic diagram or part of a diagram. Be sure you check these diagrams over carefully before you send in your answers for grading, because it is easy to make a mistake in drawing schematics.

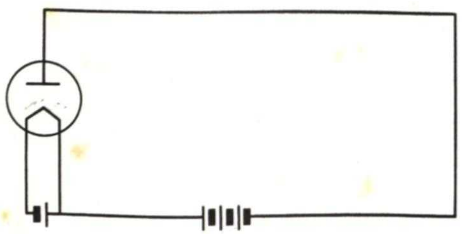
Lesson Questions

Be sure to number your Answer Sheet 1B.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time, or you may run out of lessons before new ones can reach you.

1. Two small balls of unknown material that are suspended near each other by threads are charged by being rubbed with a silk cloth. The balls then repel each other. Which *one* of the following statements do you know to be *incorrect*?
   (1) The balls both have a negative charge on them.
   (2) The balls both have a positive charge on them.
   (3) One ball has a positive charge, the other a negative charge.
2. Which does a negatively charged body have, a *shortage* or a *surplus* of electrons?
3. Draw a schematic diagram of a wire connected between the two terminals of a flashlight cell. Mark the polarity of the battery terminals and show by means of arrows the direction in which current will flow.
4. If we double the voltage applied to a circuit, what will happen to the current?
5. If you find that when you bring 2 poles of a magnet together they *attract* each other, which *one* of the following statements is true?
   (1) The two poles must both be north poles.
   (2) The two poles must both be south poles.
   (3) One pole must be a north pole and the other a south pole.
6. If a permanent magnet is held motionless inside a coil, will a voltage be induced in the coil?
7. How many flashlight cells would you have to connect in series to get 7.5 volts?
8. Will current flow from the filament to the plate in the circuit shown at the right? Explain your answer.



9. Draw a schematic diagram of a transformer-coupled triode amplifier. Mark the polarity of all batteries used.
10. Draw the schematic symbol for a triode transistor and label each element with its full name.

HOW TO DEVELOP CONFIDENCE

Self-confidence—an active faith in your own power to accomplish whatever you try to do—is a personal asset which can do big things for you.

One thing which builds self-confidence is a successful experience. Each lesson completed with a passing grade is a successful experience which will build up confidence in you.

Little successes are contagious. Once you get a taste of success, you'll find yourself doing something successful every day. And before you realize it, your little successes will have built up to that big success you've been dreaming of. So—get the habit of success as fast as possible. Resolve to study *every day*, even if only for a few minutes.

Another confidence builder is a deep, firm faith in *yourself*—in your ability to get ahead. If you do believe in yourself and you are willing to back up this faith with good hard studying, you can safely leave the final result to itself. With complete confidence, you can look forward to an early success in electronics.

Act as if you could not possibly fail, and you will succeed!

J. E. Smith