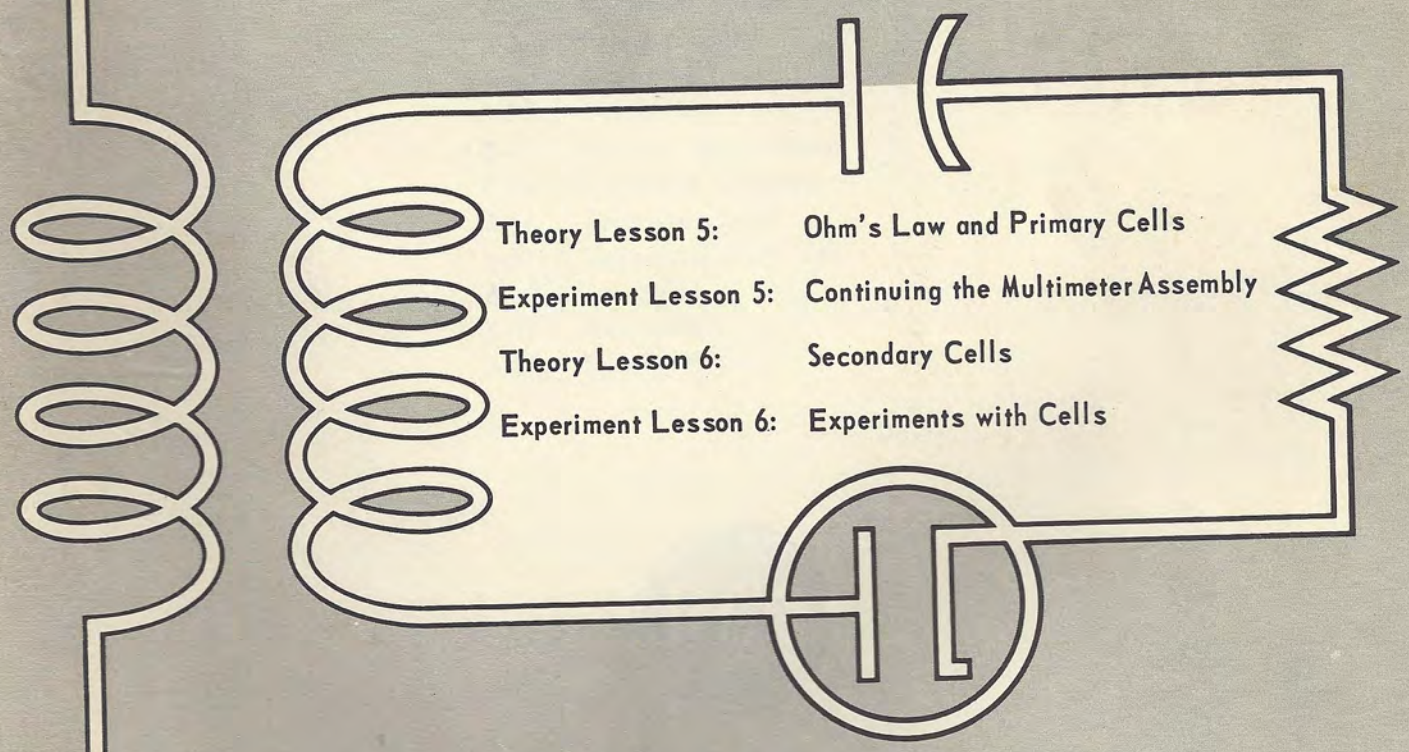
Study Group 3

ELECTRONIC FUNDAMENTALS



Theory Lesson 5: Ohm's Law and Primary Cells

Experiment Lesson 5: Continuing the Multimeter Assembly

Theory Lesson 6: Secondary Cells

Experiment Lesson 6: Experiments with Cells

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

New York, N. Y.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 5

OHM'S LAW AND PRIMARY CELLS

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RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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

Theory Lesson 5

INTRODUCTION

In the last lesson, we learned that when a difference in electric pressure exists between two points, and a conducting path connects them, an electric current will flow. We learned, too, that the flow of electrons is from the point of negative charge to the point of positive charge. Of course, if the flow is between two charged bodies, the current flow will stop as soon as the charge between the charged bodies becomes equal. When a conducting path connects the negative and positive terminals of a battery, however, the current flow is not momentary, but continues as long as the conducting path remains connected, or until the battery wears out or becomes discharged. Because this current always flows in the same direction, we call it *direct current.* There are other kinds of current, which will be discussed in another lesson.

5-1. BASIC ELECTRICAL UNITS

Just as we need units like ounces and pounds, inches and feet, and pints and quarts to measure many things we use daily, so do the electrician, the serviceman, and the engineer need units to measure electricity. Certain standard units have been adopted and are in use all over the world. No matter what country you visit, for instance, *volt* stands for the same amount of electrical pressure and *ampere* for the same rate of flow. Some of the more important units we must know something about are the *coulomb*, the *ampere*, the *volt*, the *ohm*, and the *watt*.

The *coulomb* is a unit of charge. Just as we measure gasoline by the gallon, we measure electrons by the coulomb. An electron is so very, very small an electrical charge that a tremendous number of electrons must flow in circuits to light lamps, operate radios, and run motors. The coulomb represents 6,240,000,000,000,000,000 electrons: that's 6.24 quintillion electrons. Remember that the coulomb is a unit of quantity. 6.24×10^{18}

The *ampere* is the unit that represents the rate of flow of electric current. An ampere of current is flowing when one coulomb of electricity passes any point in an electric circuit in one second. For instance, if 6.24 quintillion electrons flow through an electric lamp in one second, the rate of flow is one ampere. To understand the difference between coulombs and amperes, we might compare them to liquid measures. If you pour a gallon of water into a pail, you have a quantity of water. You don't care how fast the water goes into the pail. But if you are watering the lawn with a hose attached to a water tap, and someone asks you how much water you are using, you start figuring how many gallons per minute are coming out of the hose. The coulomb, like the gallon, is a measure of quantity. The ampere, like the gallons-per-minute, is a measure of rate of flow. (See Fig. 5-1.)

The *volt* is a measure of electrical pressure. It is the amount of pressure necessary to force one ampere through a circuit that has a resistance of one ohm. From now on, we'll speak of electrical pressure as *emf*, *potential difference*, or *voltage*.

The *ohm* is the unit of electrical resistance. Resistance opposes the flow of electric current. The *ohm* is the amount of resistance offered by a circuit when one ampere flows and the pressure across the circuit terminals is equal to one volt. The symbol for the ohm is the Greek letter Ω (omega). If there were such a thing as a perfect conductor, we would have a circuit

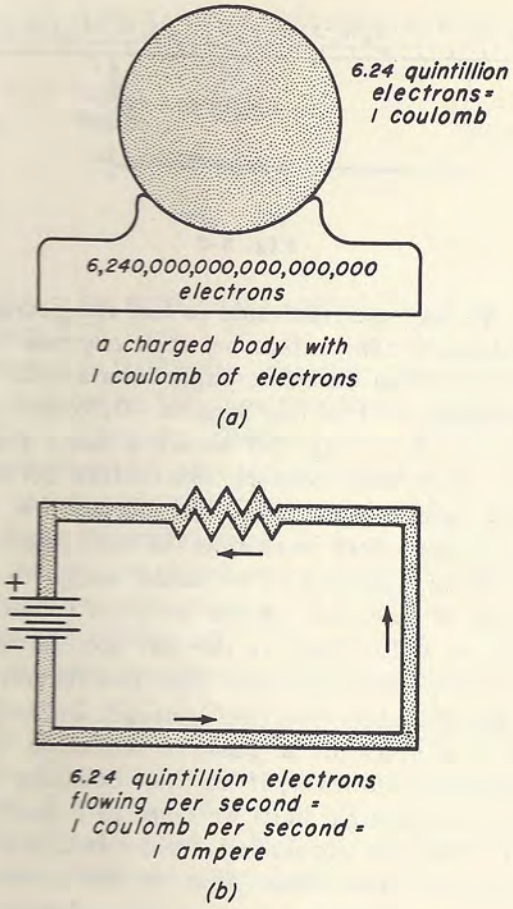


Fig. 5-1

without resistance. However, the perfect conductor does not exist, since even the best conducting materials offer some opposition (resistance) to the flow of current. There are three circuit properties or characteristics about which we are going to study quite a lot. They are: *resistance, inductance,* and *capacitance.* When we understand what happens when these properties are present in an electric circuit, we are well on the way to an understanding of radio principles.

The *watt* is the unit of measure of electrical *power.* Another word, *energy,* sometimes is mistakenly used instead of *power.* Let us see how they differ. *Energy* is the *ability to do work.* *Power* is the *rate of using energy,* or *energy per unit of time.* You might have an electric motor, with ample electrical energy to run it, but if you don't turn the switch no work is done and no power is consumed. The electrical unit of power, the *watt,* is defined as the rate at which energy is used when an emf of one volt causes one ampere to flow through a circuit.

5-2. VOLTAIC CELL

As you learned in the last lesson, we may obtain electricity in several ways. We may produce electricity by means of friction, by chemical action, by electromagnetic machines, by heating unlike metals that have been joined together, and in less common ways. This lesson is about the chemical methods of producing electricity.

Back in 1798, an Italian scientist, Alessandro Volta, discovered that, by placing a strip of zinc and a strip of copper in a jar containing dilute acetic acid (vinegar), as shown in Fig. 5-2, he could produce electricity. He found that a difference of electrical pressure existed between the zinc and the copper. He didn't know how much the pressure was because at that time there

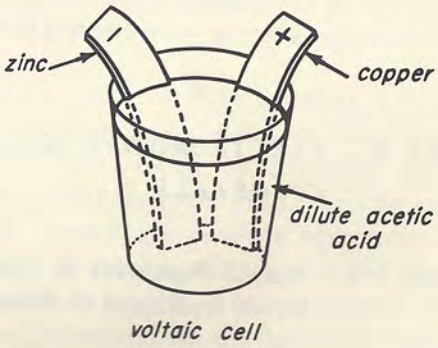


Fig. 5-2

were no electrical units with which to measure electricity. Later on, other men discovered the difference to be about 1.1 volts. As you might guess, the unit of electrical pres- is named after Volta.

One very important fact discovered by Volta was that electricity could be produced only between two unlike substances (usually metals). If, for instance, two copper or two zinc rods were placed in the fluid in the jar, no voltage was produced.

5-3. ELECTROMOTIVE SERIES OF METALS

Following Volta's experiments, other scientists learned that the amount of voltage produced by a cell made up of any two substances could be accurately predicted. Table A shows a table of some common substances and the electrical pressure that exists between them when they are placed in an alkaline, acid, or salt solution.

If you look at Table A, you will see that each substance is followed by a number that represents the difference in electrical pressure that exists between it and hydrogen. In electricity, radio, or chemistry, we say that hydrogen is used in this table as a *reference point* (a position from which things are counted). So, for this table, hydrogen is zero. Lead, tin, iron, etc. are negative with respect to hydrogen. Bismuth, copper, mercury, etc. are positive with respect to hydrogen. Any one of the substances shown in this table could have been used as the reference with all the differences in electrical pressure being counted from it, but hydrogen was chosen because it was convenient.

TABLE A – ELECTROMOTIVE SERIES OF METALS

Element	Normal Potential in Volts Using Hydrogen as Reference
Potassium	–2.92
Sodium	–2.71
Magnesium	–1.55
Zinc	–0.76
Iron	–0.44
Tin	–0.13
Lead	–0.12
Hydrogen	0.00
Bismuth	+0.20
Copper	+0.34
Mercury	+0.80
Silver	+0.80

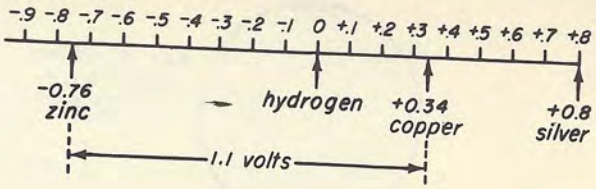


Fig. 5-3

We may use this table to find the potential difference that exists between any two substances from which we might form a cell. For example, we find that zinc is –0.76 and copper is +0.34. Fig. 5-3 shows a scale giving the electrical pressure that exists between zinc and copper. You will notice that the scale goes both ways from the zero reference point of hydrogen. The scale marks to the right of zero are shown as plus (positive) values while those to the left are shown as minus (negative) values. Zinc is 0.76 volts in a negative direction from hydrogen and copper is 0.34 volts in a positive direction from hydrogen. However, if we start counting from zinc to the right until we come to copper, we will find that copper is 1.1 volts in a positive direction from zinc. What we do is to add –0.76 and +0.34 without worrying about minus and plus signs and we get 1.1. This tells us the difference in voltage (electrical pressure) that exists between zinc and copper. Because copper is in a positive direction from zinc, it is the positive electrode of the cell, and zinc is the negative electrode of the cell.

However, if we make a cell with zinc and magnesium as the two electrodes, we can see in Fig. 5-4 that zinc is 0.76 volts in a minus direction from hydrogen and magnesium is 1.55 volts in a minus direction from hydrogen; the difference in pressure that exists between magnesium and zinc is the

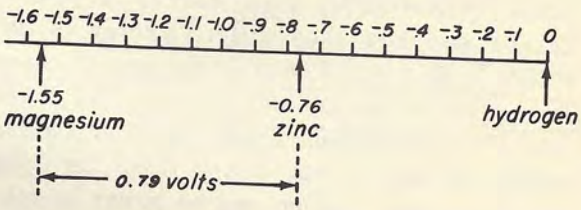


Fig. 5-4

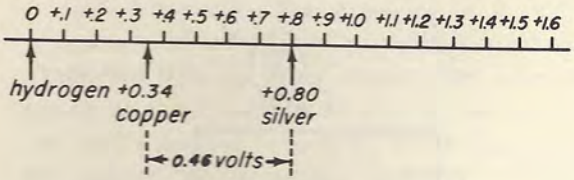


Fig. 5-5

difference between −1.55 and −0.76. By subtracting 0.76 from 1.55, we find that this difference is 0.79 volts. Because magnesium is in a negative direction from zinc, it is the negative electrode. Because zinc is in a positive direction with respect to magnesium, it is the positive electrode of a cell made from these two substances. So now we have a case where two substances, both of which are negative with respect to hydrogen, may be used to form a cell. The one that is the less negative becomes the positive electrode. In the same way, a cell might be made from copper and silver. As the scale in Fig. 5-5 shows, silver is 0.46 volts more positive than copper. A cell formed with copper as a negative electrode and silver as a positive electrode produces an emf of 0.46 volts.

From the electromotive series table, you can see that the emf produced by chemical action between two metals or other substances placed in an acid, alkaline, or salt solution of proper strength is determined by the metals used. The size of the cell, the amount of the metals, and the spacing of the metals does not affect the emf produced by chemical action.

5-4. CHEMICAL ACTION OF A CELL

You are probably interested in knowing how and why a cell produces electricity. The complete story is difficult to tell and, without a knowledge of chemistry, difficult to understand. In fact, even the people who make batteries cannot answer some of the questions we might ask about the chemical and electrical action in a cell. However, it is not necessary or particularly desirable that we, as servicemen, know more than a few basic facts about cells and batteries. For that reason, the following paragraphs do not attempt to go into the chemistry of a cell.

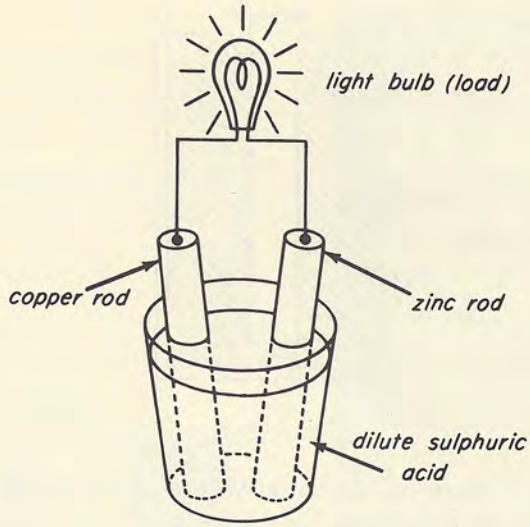


Fig. 5-6

Figure 5-6 shows a copper rod and a zinc rod in a jar containing sulphuric acid and water. The mixture of acid and water is called the electrolyte; without it there would be no cell action and no emf produced. The chemical action of the electrolyte upon the two metals produces a positive charge upon the copper rod and a negative charge upon the zinc rod.

When a small lamp is connected by wires to the upper ends of the copper and zinc rods, the electrical circuit is complete, because the wire, the lamp, the zinc, the electrolyte, and the copper all conduct electricity. The electrons of the negatively charged zinc rod are repelled by the other electrons on the zinc and attracted by the positive charge on the copper rod. Therefore, they move toward the copper through the connecting wires and the lamp – thus producing an electric current in the load circuit (outside the cell). This action continues until the circuit is broken by removing the lamp from the ends of the copper and zinc rods or until the zinc is eaten away by chemical action.

5-5. PRIMARY CELLS

Cells may be divided into two main classes: *primary* cells and *secondary* cells. By the term *primary* cell, we mean a unit that is consumed as it is used, while a

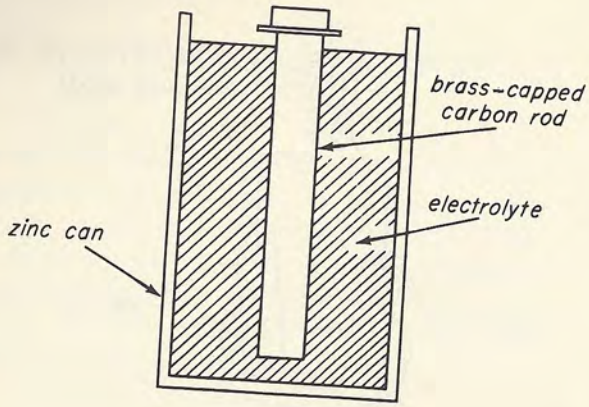


Fig. 5-7

secondary cell is usually defined as one that may be recharged when its electricity is used up.

Most primary cells used in this country are made from carbon and zinc and are called dry cells. This combination produces a cell that is normally rated at 1.5 volts, although some cells sometimes test a little higher.

Construction and Action of Carbon-Zinc Cell. As shown in Fig. 5-7, the container and negative electrode of a single carbon-zinc cell is made from zinc. The zinc is as free as possible from impurities. There is also a brass-capped carbon rod, which receives the positive charges and acts as the positive electrode. Between the carbon and zinc is the electrolyte, which is a paste made from ammonium chloride.

The action of the carbon-zinc cell is similar to that of the copper-zinc cell discussed before. The electrolyte acts upon the carbon and zinc to produce a positive charge on the carbon and a negative charge on the zinc.There is, however, another action not yet mentioned. While the cell is producing electricity, hydrogen bubbles gather on the carbon electrode, as shown in Fig. 5-8. When the carbon rod becomes coated with hydrogen bubbles, the flow of electricity slows down or stops completely, because the hydrogen acts to resist the chemical action between the carbon electrode and the electrolyte. When this happens, we say that the cell is *polarized.*

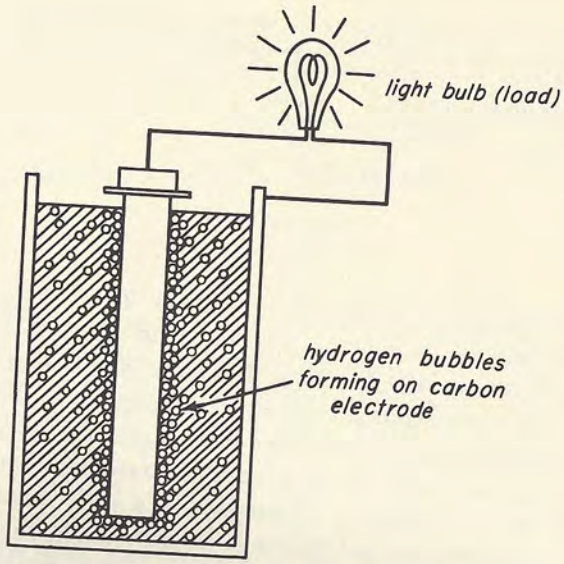


Fig. 5-8

Depolarizing Mix. It is necessary to add something to the cell that will get rid of the hydrogen bubbles as soon as they are formed on the carbon rod. So, in between the electrolyte and the carbon electrodes, as shown in Fig. 5-9, we insert a *depolarizing mix,* which contains a chemical called *manganese dioxide.* Some of the oxygen from this chemical combines with the hydrogen bubbles to form water, which leaves the carbon electrode free to gather more electrical charges, give up more electrons, and so remain positively charged.

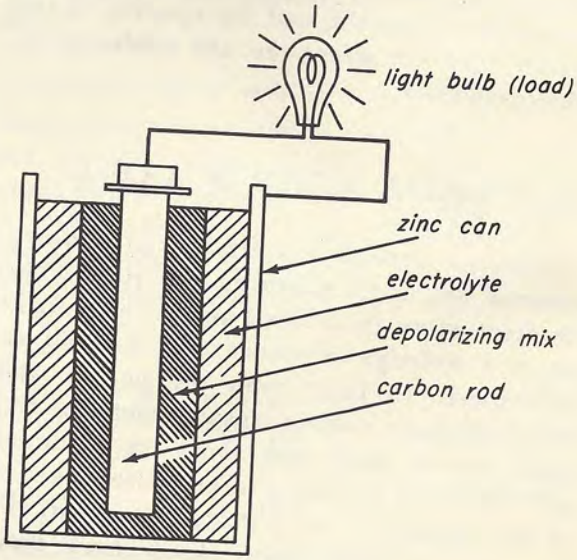


Fig. 5-9

Cell Capacity. The capacity of a cell is a measure of its ability to deliver electrical energy to a load. This means that when we speak of the capacity of a cell, we refer to the cell's ability to supply a certain amount of current, at a useful voltage, for some period of time. Each cell that is made today is designed for a certain load.

The ability of a cell to supply any desired amount of current is determined by the amount of surface area of each electrode that is exposed to the electrolyte and to the kinds and quantities of the materials that make up the depolarizing mix.

In the case of the carbon and zinc cell, the capacity of the cell is affected by the number of square inches of zinc and the number of square inches of carbon touched by the electrolyte. Therefore, none of the outside area of the zinc helps supply electricity, because it is not exposed to the electrolyte. Only that part of the inner surface of the zinc that actually touches the electrolyte can affect the capacity. In the same way, only the surface of the carbon electrode that is in actual contact with the electrolyte can affect the cell's capacity. The capacity of modern cells has been increased by mixing carbon in the depolarizing mix. This exposes a much larger area of carbon to the electrolyte.

There is no exact way of measuring the capacity of a cell. In other words, we cannot set an exact figure for the amount of electricity that may be obtained from a particular cell. There are many factors that determine how fast, and for how long a time, a cell can supply electrical power. Much depends upon the kind of service for which the cell is designed, and the kind of load that is connected to it. In general, under normal conditions, we can draw more current from a large cell than from a small cell. (There are exceptions to this rule.) Figure 5-10 shows the relative sizes of three types of cells. Also, some cells are made for continuous duty, while other cells are made to be used for short periods at a time. For that reason, we must know the kind of service for which the cell was designed.

Fig. 5-10

If we attempt to draw electricity from the cell at a rate greater or for a period longer than it was designed to deliver, the depolarizing agent cannot get rid of the hydrogen bubbles on the positive electrode as fast as they are formed. When this happens, the output voltage of the cell drops, and it does not rise again until the cell has "rested". You may have used a flashlight continuously at some time or other until the light grew very dim. Later on, you picked up the flashlight and found it working again. All that happened was that the cells were given time to depolarize.

On the other hand, if we draw electricity from a cell at a rate much slower than it was designed for, we may get less service out of the cell than it was designed to give. This is due to losses caused by the chemical actions that take place when a cell stands idle. For example, the *shelf life* (the period during which the cell can deliver from 80-95% of full capacity) of all but the very small dry cells (such as the pen-light size) is about two years. If we were to draw electricity from such a cell at so slow a rate that it was still in service after two years, some of the capacity of the cell would be lost in the chemical actions that naturally occur when a battery or cell stands idle.

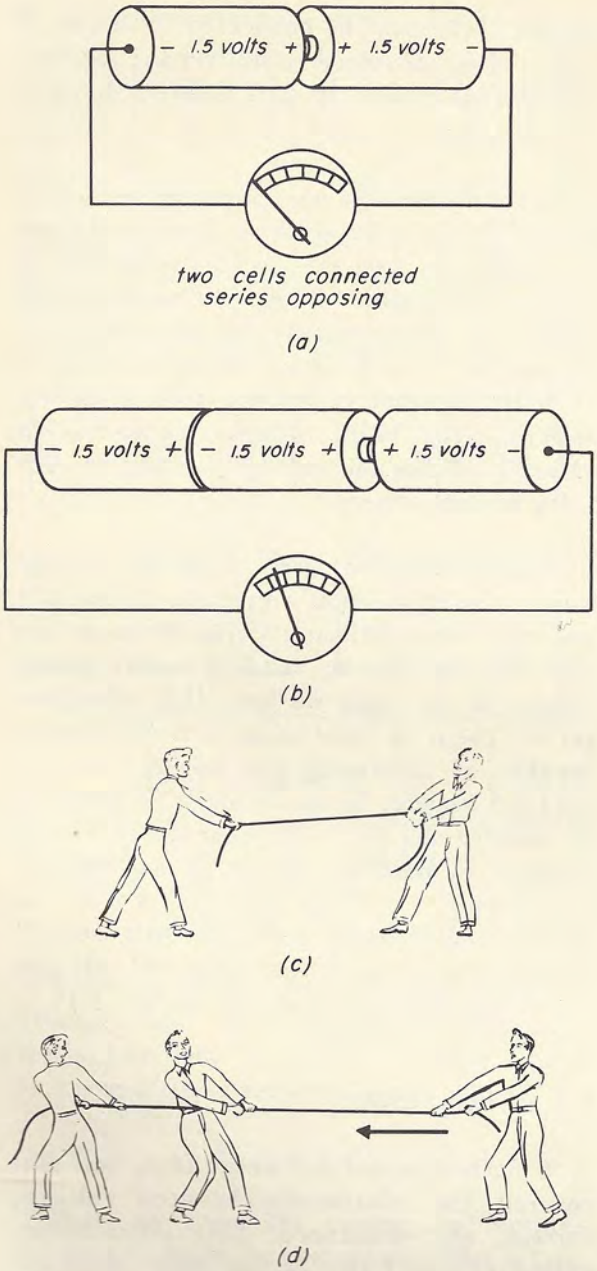


Fig. 5-12

the single cell. The resulting electrical pressure is the pressure of one cell exerted in the direction of the two cells.

If you have a 2-cell flashlight, try reversing one of the cells so that the negative terminal of one is connected to the negative terminal of the other. You will find that the flashlight will not light, because the voltage of one cell is cancelled by the voltage of the other cell in the opposite direction. So you can see that it is very important to connect

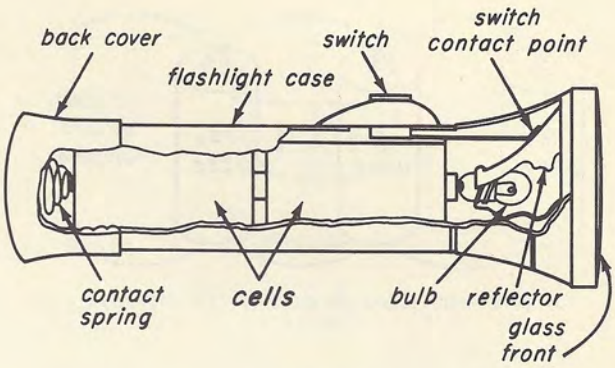


Fig. 5-13

cells in the proper way in order to get the voltage of one cell to add to the voltage of the next cell.

Carbon-zinc dry cells are connected together in series to form batteries of various voltages; many of these batteries are made specially for radio. However, one of the most common uses of dry cells connected in series is in 2-, 3-, or 5-cell flashlights. The 2-cell flashlight needs three volts to give maximum light; when we put cells in the flashlight case, we place them so that the positive electrode of one cell presses against one terminal of the flashlight bulb and the positive electrode of the second cell presses against the negative electrode of the first cell. This is shown in Fig. 5-13. The negative electrode of the second cell makes contact through the pressure spring, the metal case, and the switch to the other terminal of the bulb.

Cells Parallel Connected. When cells are connected in series to increase the voltage, there is no increase in the amount of current that may be drawn from the series over the amount of current that may be drawn from each individual cell. This means that if the cells are rated to deliver a quarter of an ampere continuously, this rate is not increased by connecting them in series. We can still draw only a quarter of an ampere safely. To increase the current-producing capacity, it is necessary to connect cells in parallel, as shown in Fig. 5-14*a*. For example, if one cell safely delivers a quarter of an ampere continuously, two cells in parallel will deliver half an ampere, and

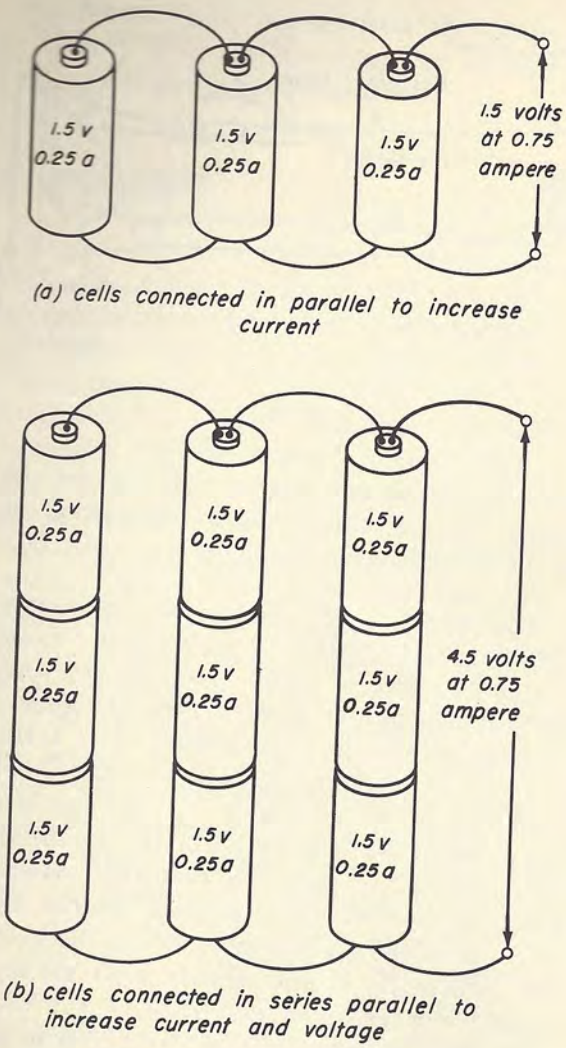


Fig. 5-14

so on. If we need to increase the voltage and the current at the same time, we must connect the cells together in series-parallel (to increase current-producing capacity), as shown in Figure 5-14*b*.

Let's try a few examples so we can see how to figure the number of cells needed to make a battery to supply a particular need. For example, suppose a 90-volt B-battery is needed for a portable radio and all we have is a supply of 1.5-volt cells. How many cells are needed and how must they be connected? To find the answer, we must find out how many times 1.5 volts goes into 90 volts. So we divide 90 by 1.5. We find that the answer is 60. So, 60 1.5-volt cells will be needed, and, because the voltage of one cell must add to the voltage of the next cell, all the cells must be connected in series. If each cell is designed to deliver 0.1 ampere, our 90-volt B-battery will deliver 90 volts at 0.1 ampere.

Let's try another one. Suppose we have a lot of 1.5-volt cells, each designed to deliver 0.1 ampere, and we need a 1.5-volt battery to deliver one ampere. The cells we have can supply the proper voltage, but not the proper current. So it will be necessary to connect 10 cells together (1 ampere divided by 0.1 ampere). The cells must be connected in parallel so that the battery will deliver 1.5 volts at one ampere.

Here's just one more. Suppose that we want to make a 6-volt battery to deliver 0.5 ampere, using the same cells. First we divide the voltage we need (6 volts) by the voltage of the cells we have (1.5 volts) and get 4. These 4 cells make a 6-volt battery capable of delivering 0.1 ampere. But we need 0.5 ampere. So we divide 0.5 ampere by 0.1 ampere and get 5. By connecting 5 cells together in parallel, we get a battery that will supply 1.5 volts and 0.5 ampere. To produce our battery then, we will need 5 strings of 4 cells, series connected, all tied together in parallel as shown in Fig. 5-15.

5-7. OHM'S LAW

A German scientist, George Ohm, first discovered the relationship between voltage, current, and resistance. This relationship, called Ohm's Law, is the most important principle in all electricity.

In any electrical circuit, the current in amperes is equal to the emf in volts divided by the resistance in ohms. When applying Ohm's Law to our work, we use the following abbreviations:

E = Volts

I = Amperes

R = Resistance in ohms

Ways to Write Ohm's Law. Thus, Ohm's

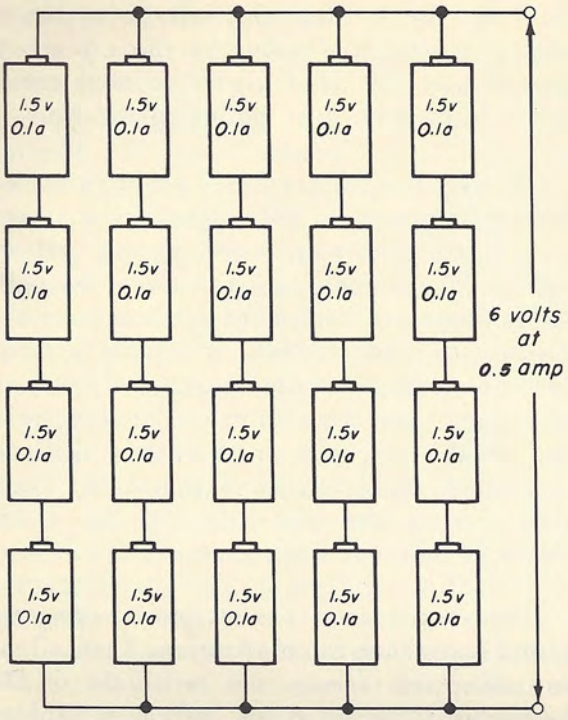


Fig. 5-15

Law may be written: Current equals the voltage divided by the resistance, or

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

When we know the current and the resistance, and want to know the voltage, Ohm's Law may be stated: Voltage equals the current times the resistance, or

$$E = (I \times R) = IR$$

When we know the current and voltage and want to know the resistance, Ohm's Law becomes: Resistance equals the voltage divided by the current, or

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

You can use the same little circle trick you used to solve wavelength and frequency problems to solve Ohm's Law problems. The circle to set up looks like the one in Fig. 5-16. You cover the term you want to find, and what remains is the answer. For example, to find E, you cover E in the circle and IR remains. Then you know that $E = IR$. Likewise, if you cover I, you can see that

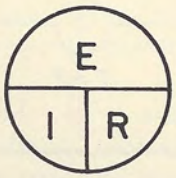


Fig. 5-16

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

and when you cover R, you see that

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

Application of Ohm's Law. Now that Ohm's Law has been stated, let us see how we can use it. Figure 5-17*a* shows a simple electrical circuit: a resistor connected across the terminals of a battery. The resistor has a resistance of 30 ohms and the battery has a voltage of 60 volts. To calculate how much current is flowing, we use the formula:

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

$$I = \frac{60}{30}$$

$$I = 2 \text{ amperes}$$

Suppose that we know the current to be 12 amperes and the resistance to be 10 ohms, as shown in *b* of the figure. We may find the voltage by:

$$E = I \times R$$

$$E = 12 \times 10$$

$$E = 120 \text{ volts}$$

If the current is 15 amperes and the voltage is 105 volts, as in *c* of the figure, we find the resistance as follows:

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

$$R = \frac{105}{15}$$

$$R = 7 \text{ ohms}$$

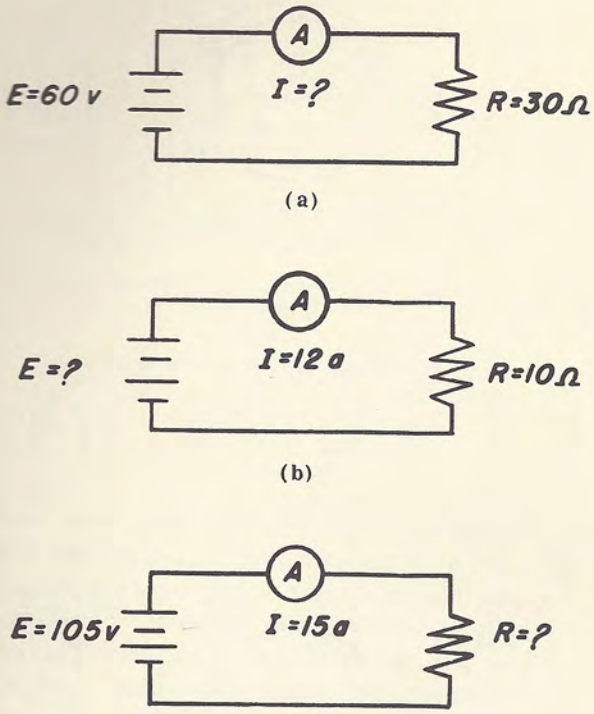


Fig. 5-17

5-8. INTERNAL RESISTANCE

Earlier in this lesson, it was said that resistance is the property of a circuit that opposes the flow of current in the circuit; that is, resistance tends to stop current from flowing. Even silver and copper, two of the very best conductors of electricity, offer some resistance to the flow of electricity. As we know, resistance is measured in ohms. According to Ohm's Law, the resistance can be found by dividing the voltage by the amount of current flowing in the circuit. A circuit part that is designed to offer resistance to electricity is called a *resistor.*

A cell or a battery has a property called *internal resistance.* This internal resistance is due to certain qualities of the cell or battery. The internal resistance of a dry cell, for instance, is due to the resistance of the electrolyte, polarization, and local action. In general the electrodes have practically no resistance, and the electrolyte, if it is fresh and of the proper strength, has very little resistance. However, the action of the electrolyte upon the electrodes is the major cause of internal resistance.

One example of the action causing internal resistance is polarization. When a load is connected across the terminals of the battery and current flows, hydrogen bubbles form on the positive electrode and slow down the chemical action of the battery. When the chemical action is slowed down, the battery cannot deliver as much voltage to the load. This is because some of the emf produced by chemical action is lost inside the battery. In other words, the internal resistance of the battery has been increased, and a greater portion of the emf is dropped across it.

Another cause of internal resistance is *local action,* caused by impurities in the substances used in making the battery. For

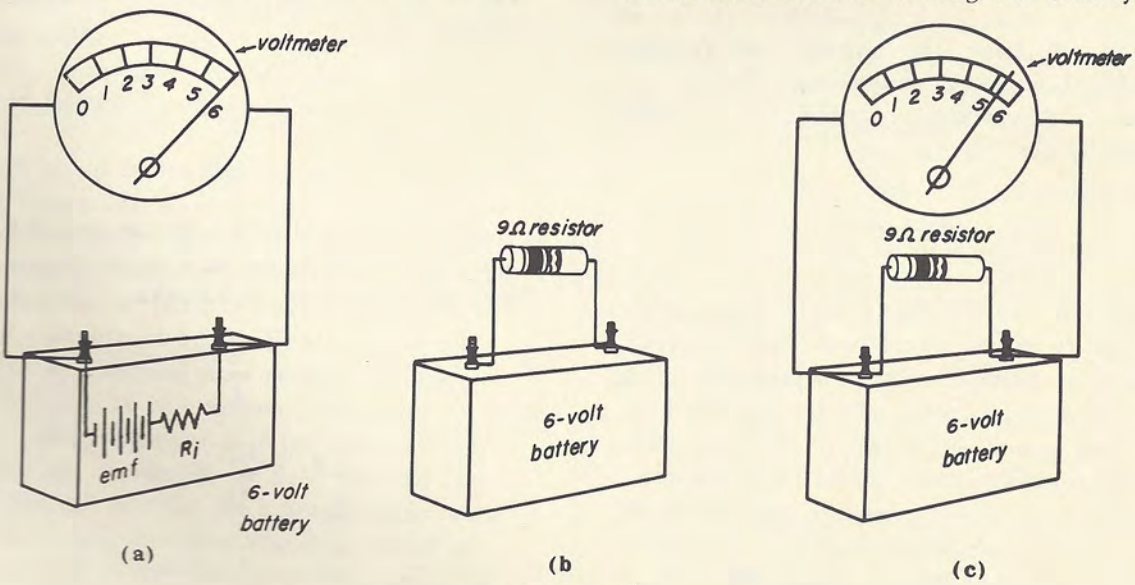


Fig. 5-18

Resistors in series divide voltage
current throughout series circuit is the same

example, if the zinc used in the zinc electrode is not pure – that is, if there are other substances mixed with it – the zinc and its impurities will cause local action. For instance, suppose another metal, such as copper, is mixed with the zinc. The copper and the zinc are unlike metals. Both are exposed to an electrolyte. As a result, they act as a very small electrical cell. Connected to each other, the electrodes of this cell are short-circuited, and the chemical action is continuous. The area where local action takes place does not contribute to the capacity of the cell. In other words, the internal resistance of the battery has been increased. A battery may be considered as if the emf and the internal resistance (R_i) were separate and in series as shown in Fig. 5-18*a*. A meter is connected across the terminals of a 6-volt battery. The meter reads 6 volts. This voltage is the *open-circuit voltage* of the battery; that is, the meter is measuring the voltage of the battery when no load is connected across it and, therefore, no current is being drawn. In Fig. 5-18*b*, a 9-ohm resistor is connected across the battery. This is to provide a load so that current can flow. When we measure the voltage across the battery terminals with the load connected across them, as shown in Fig. 5-18*c*, we are measuring the *closed-circuit voltage*, or *terminal voltage*. The terminal-voltage reading is 5.4 volts. This is 0.6 volt lower than the open-circuit voltage. The voltage has dropped 0.6 volt due to the internal resistance of the battery.

These measurements show us that terminal voltage is equal to the open circuit voltage less the voltage that is lost inside the cell due to internal resistance. The terminal voltage is the usable voltage of the cell. Naturally, it is best to keep internal resistance down so that terminal voltage will be as high as possible.

We can find the internal resistance of a cell for any particular load of a cell or battery. We must know what the load is so that we may know how much current is being taken from the cell or battery. As we know, when the load is very great and more current is drawn than the cell or battery is designed to deliver, polarization will occur faster and increase internal resistance.

The internal resistance may be found fairly accurately by subtracting the closed-circuit voltage from the open-circuit voltage and dividing the difference by the current flowing. Let's see why this is so. The open-circuit voltage is the emf developed by the battery. The closed-circuit voltage is the voltage at the terminal when a load, such as a 9-ohm resistor, is connected. The difference between these, of course, is the voltage drop inside the cell due to internal resistance. Ohm's Law tells us that the resistance of a resistor or of a part of a circuit may be found by dividing the voltage across the resistor SERIE or across that part of the circuit by the current flowing through the circuit. So, to find the internal resistance of a cell, we must also know how much current is flowing in the circuit when the load is connected. Then the internal resistance is found by dividing the voltage lost in the battery by the current flowing in the circuit.

For example, when we connected the meter to the 6-volt battery without a load, we measured the open-circuit voltage, which was 6-volts. When we read the meter after connecting the load, we found the closed-circuit voltage, which was 5.4 volts. The current in the circuit can be found by using Ohm's Law. The voltage across the resistor was 5.4 volts and the resistance of the resistor was 9 ohms. Therefore, the current flowing through the resistor and battery circuit is equal to 5.4 divided by 9. The answer is 0.6 ampere. The internal resistance equals the open-circuit voltage minus the closed-circuit voltage, divided by the current. This equals 6 minus 5.4 over 0.6. This equals 0.6 over 0.6, which equals 1 ohm. The internal resistance of the battery with a 9-ohm load resistor is equal to 1 ohm.

We can set up the problem we have just discussed in the following form.

$$\text{Internal resistance } (R_i) = \frac{\text{open circuit voltage} - \text{closed circuit voltage}}{\text{current}}$$

Current (I)

$$= \frac{\text{voltage across 9-ohm resistor (E)}}{9 \quad \text{(R)}}$$

$$= \frac{5.4}{9}$$

$$= 0.6 \text{ amp.}$$

$$\text{Internal Resistance } (R_i) = \frac{6 - 5.4}{0.6}$$

$$= \frac{0.6}{0.6}$$

$$= 1$$

In fresh cells made by leading battery manufacturers, the internal resistance of a cell is very, very small, provided the cell is not overloaded or otherwise abused.

5-9. LAYERBILT BATTERIES

The cells we have been studying about up until now have all been cylindrical in shape. When batteries are made from such cells, a lot of space is wasted, as you can see for yourself in Fig. 5-19. Actually, between the space used inside each cell and the space wasted between cells, only about fifty percent of the space occupied by such a battery contains useful electricity-making materials. In order to conserve space and to make smaller batteries do the work of larger ones, one manufacturer developed the the Layerbilt battery. Fig. 5-20*a* shows a cut-away view of a Layerbilt cell. It is a carbon-zinc cell like those we have been studying. However, instead of being cylindrical, each cell is square and flat, as shown in Fig. 5-20*b*. To form batteries, they are piled one on top of the other as shown in Fig. 5-20*c*. Two such stacks of 15 cells each are used to produce the familiar 45-volt B-battery used in so many portable battery-operated radios and shown in Fig. 5-20*d*.

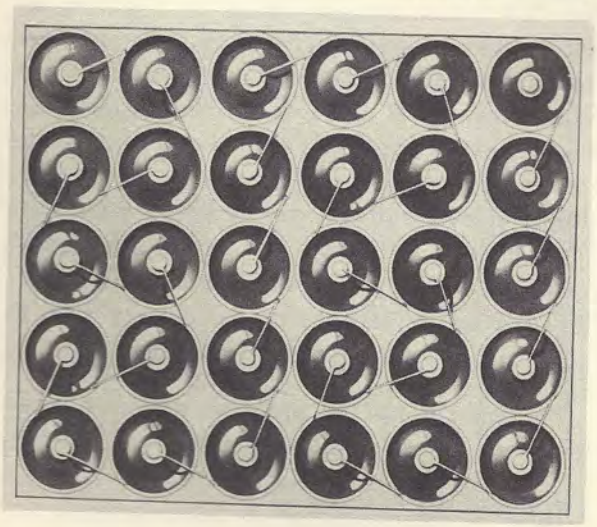
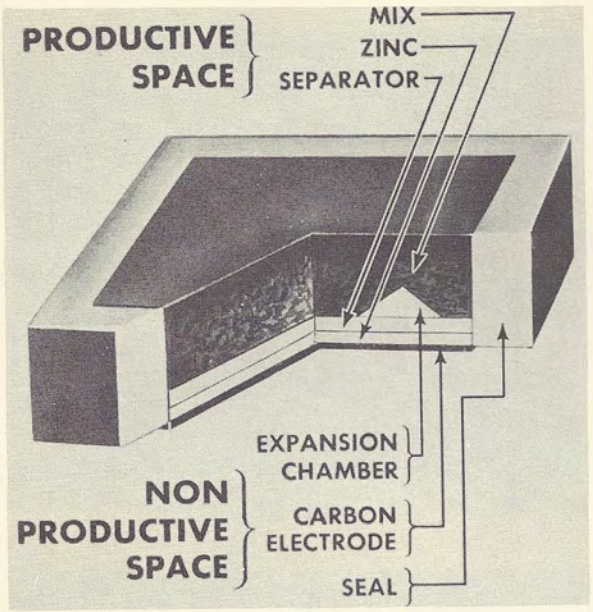


Fig. 5-19

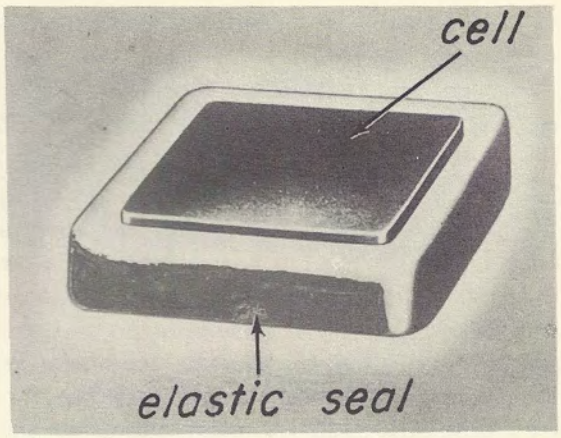
5-10. GRID-BIAS CELLS

Once in a while, in radio and television circuits, it is necessary to have a source of voltage just to act as a difference in potential. In such cases, no current is drawn. It is necessary that the cells that provide this voltage have long life with constant voltage have freedom from local action, and be small in size. Two types of cells of the same size and shape as the one shown in Fig. 5-21 have been used by radio manufacturers for many years. They are called *grid-bias* cells or, sometimes, *acorn* cells. One type has an outer container, shaped like an acorn and made of cadmium, that acts as the negative electrode. The electrolyte is an acid paste. The positive electrode is made of vanadium pentoxide, which is insulated from the cadmium container by an insulating grommet. The voltage developed by this cell is 1.04 volts. The other type of grid-bias cell is made in the same way, except that the container and negative electrode are made of zinc instead of cadmium. The voltage developed by this type of cell is 1.2 volts.

Grid-bias cells, used properly, maintain constant voltage for periods of from 5 to 10 years. Because they were not designed to provide current, care must be used to see that they are not accidentally shorted. Even testing one with a meter is not advisable; this tends to load the cell, and any readings obtained are likely to be inaccurate. However, these cells have the ability to return to approximately normal voltage after a momen-

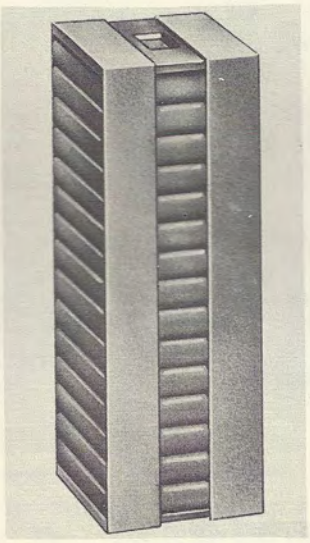


(a)

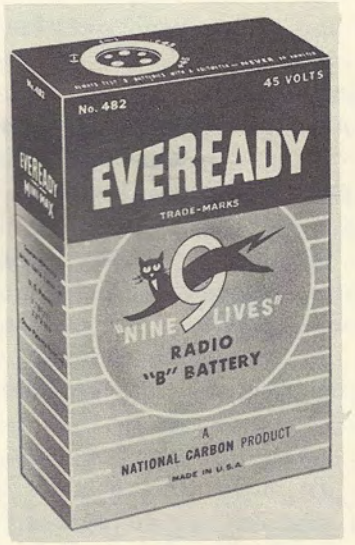


3 The elastic seal is shrunk around the entire assembly, protecting the cell against loss of moisture and preventing creepage of solution from one cell to the next.

(b)



(c)



(d)

Fig. 5-20

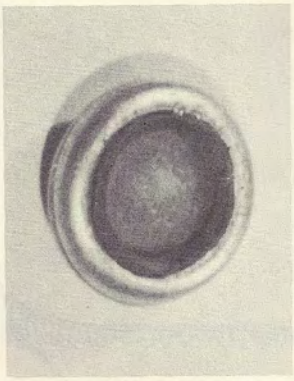


Fig. 5-21

tary short, which might easily occur while trouble shooting.

When more voltage is required than one cell can provide, cells may be connected in series to provide higher voltages. Special clip holders for these cells (shown in Fig. 5-22) are manufactured. Clip holders designed for two or more cells provide the connection between the cells.

5-11. MERCURY-OXIDE CELLS

Another type of cell, developed in recent years, is coming into common use. It is the

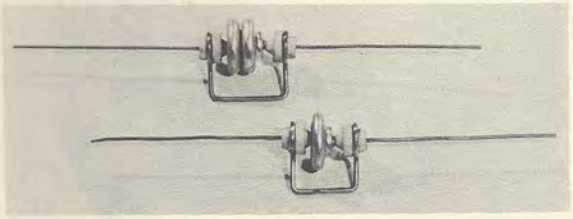


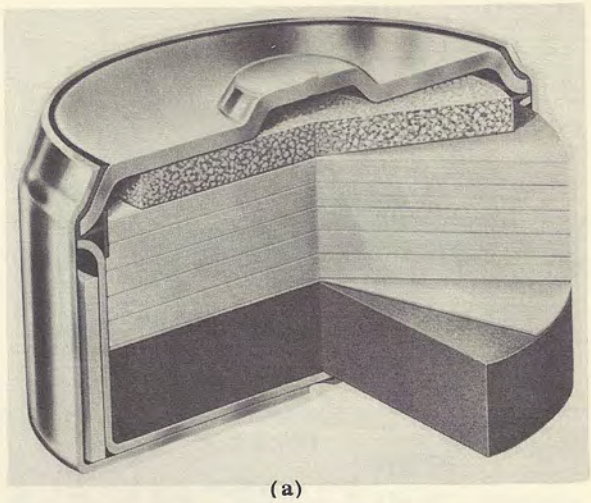
Fig. 5-22

mercury-oxide cell, shown in Fig. 5-23. Mercury-oxide cells, while costing more than the carbon-zinc cells have many advantages. First, they are considerably lighter and smaller than the standard cells (when cells of equal capacity are compared). In addition, they operate over a wide temperature range, the rated voltage of 1.34 volts remains constant during most of the cell's life, and they do not require periods of "rest". The type shown in Fig. 5-23*a* uses a button of compressed, amalgamated zinc powder attached to the nickel-steel top as the negative electrode. The electrolyte is a solution of potassium-hydroxide saturated with a zincate. The positive electrode, which connects with the nickel-steel outer case, is made of mercuric oxide and graphite. An insulating grommet separates the negative steel top from the positive steel case. The type shown in Fig. 5-23*b* uses the same materials, except that the negative electrode is made from a zinc foil. Thin sheets of zinc foil are corrugated (wrinkled) and wound around and around, as shown in Fig. 5-23*c*, with a strip of absorbent material that has been soaked in the electrolyte. In this way, a very great area of the zinc comes into contact with the electrolyte. This adds considerably to the capacity of the cell.

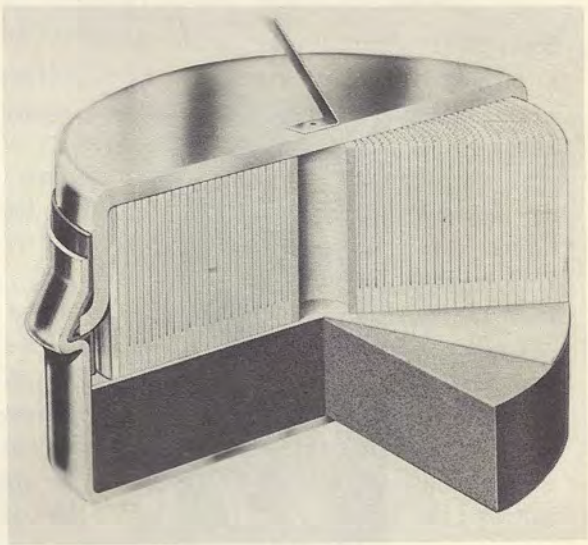
Mercury-oxide cells are used by the Armed Forces for "walkie-talkie" radios, for guided missles, and in other places where weight and size are important. In civilian production, at least one manufacturer uses them to power wrist-watches, and they are widely used by hearing-aid manufacturers.

5-12. AIR-CELL

This cell, while classed as a primary cell, cannot be called a dry cell. Even though



(a)



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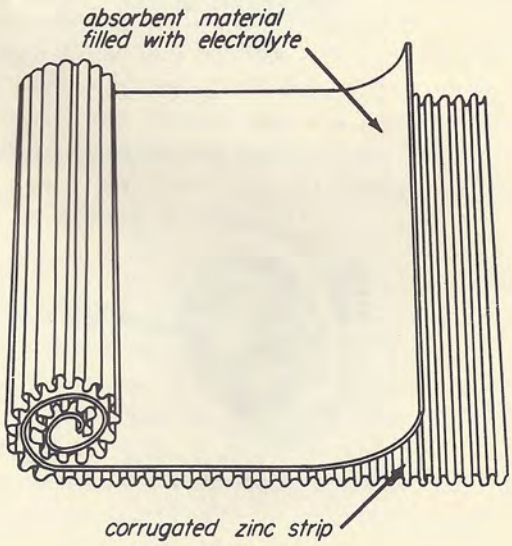


(c)

Fig. 5-23

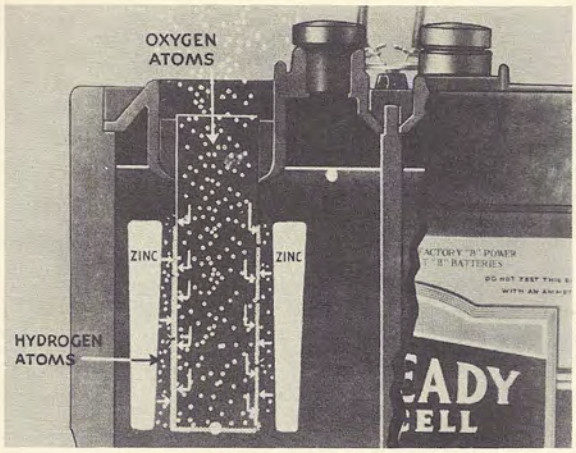


Fig. 5-24

it is shipped dry and kept dry until sold and put in use, the electrolyte, in a working cell, is decidedly wet. As shown in Fig. 5-24, the negative electrode is zinc. The electrolyte is a caustic alkaline solution of sodium hydroxide, and the positive electrode is porous carbon. (This means that the carbon has a lot of little holes in it.) This cell is put into service by adding ordinary drinking water to the level indicated by the manufacturer. It requires a well-ventilated room, because it draws oxygen from the air for depolarizing instead of using a depolarizing agent.

This cell is designed to give long life where the current drain is not more than 0.65 amperes. The voltage output is about 1.25 volts a cell. They are widely used for telephone switchboards, railway signals, and in radio stations.

5-13. TEMPERATURE

One condition that affects the output and the life of cells and batteries is temperature. Most batteries and cells are designed to operate at greatest efficiency at normal room temperature (70 °F). At temperatures of 100 °F and above, cells may deliver slightly higher voltages, but they wear out much faster. At very low temperatures, from 0 °F and below, the chemical action slows up greatly and cells do not deliver the power that they do at normal temperatures. One of the advantages of the mercury-oxide cell is that it can operate efficiently at higher and lower temperatures than the standard carbon-zinc cell.

5-14. STORING CELLS

Cells are best stored in a cool place, because this tends to slow up any chemical action that occurs while the cell is not in use. In a shop where batteries are kept for sale to customers, cells should be kept on one of the lower shelves (if there are several) because, as heat rises, the upper shelves are likely to be warmer. When a fresh supply of cells is received, be sure that the cells already in stock are placed in front of the shelf so that they may be sold before the fresh stock is put on sale. In ordering cells and batteries, do not order large quantities of unusual types of cells and batteries. Keep a low stock of those that sell slowly. Remember, very small cells, such as the pen-light size, have a short shelf life.

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 5

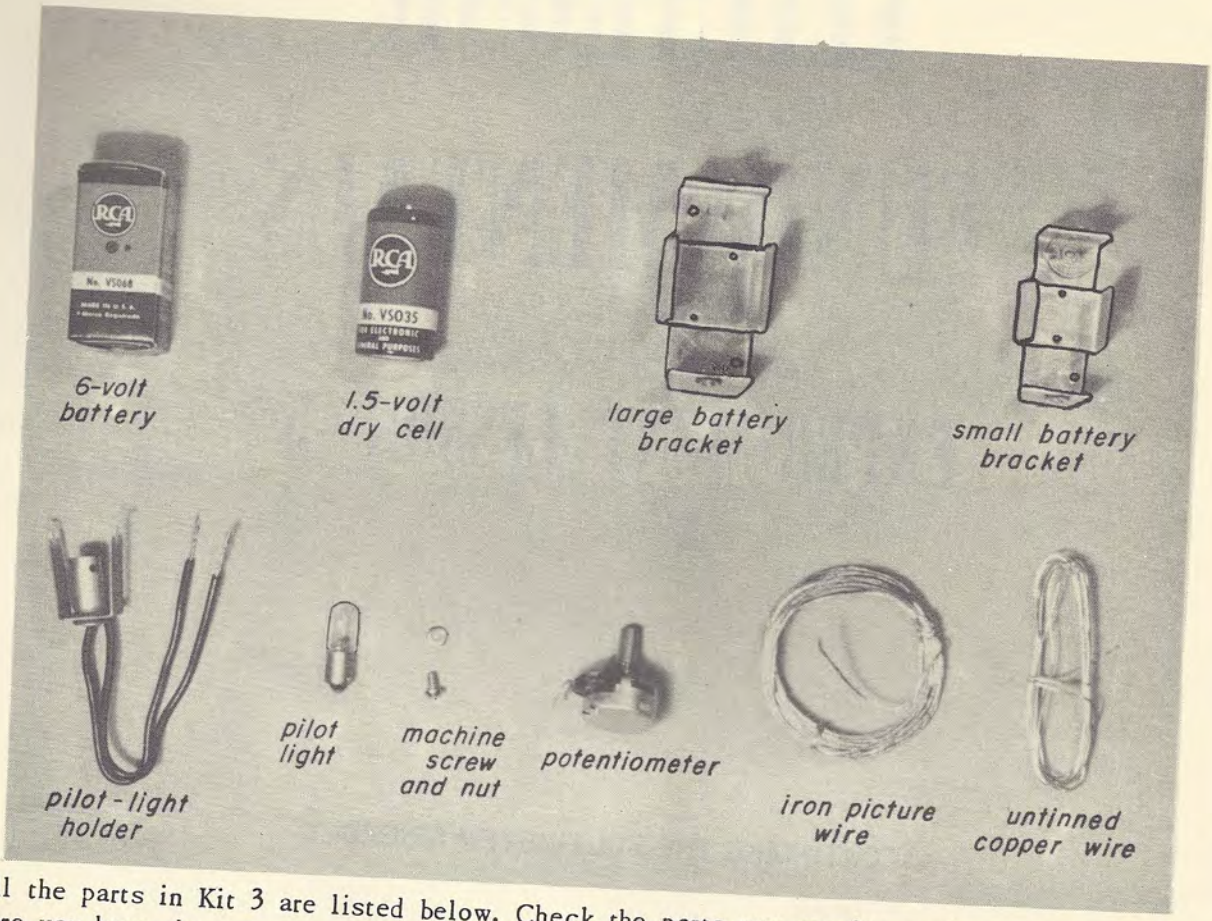
CONTINUING THE MULTIMETER ASSEMBLY

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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



All the parts in Kit 3 are listed below. Check the parts you receive against this list. Make sure you have the correct quantity of every item. If a part is either missing or defective upon arrival, request a replacement from Department R, Home Study School, RCA Institutes, Inc., 350 West 4th Street, New York 14, N.Y. *Your request must include your name and student number, the complete name and description of the part copied from the Item column below, the Quantity missing or defective, and the reason you are asking for a new part.*

KIT 3

BILL OF MATERIALS

Quantity	Item
1	Battery, 6 volts
1	Dry cell, type C, 1.5 volts
3	Dry cell, type D, 1.5 volts
1	Pilot light
1	Large battery bracket
1	Small battery bracket
1	Pilot-light holder
2	Potentiometer, 30 k-ohms, with 1 flat washer and 1 nut
1	Resistor, 110 k-ohms, ½ watt, 5% Brn Brn Yell Gold
1	Resistor, 22 k-ohms, ½ watt, 5% Red Red Oran Gold
1	Resistor, 17.9 k-ohms, ½ watt, 1%
1	Resistor, 1,500 ohms, ½ watt, 5% Brn Grn Red Gold
1	Resistor, 91 ohms, ½ watt, 5% White Brn Black Gold
1	Resistor, 15 ohms, ½ watt, 5% Brn Grn Black Gold
1	Resistor, 9.1 ohms, ½ watt, 5% White Brn Gold Gold
1	Resistor, 1 ohm, ½ watt, 5% Brn Black Gold Gold
2	Machine screws, 6-32 x 5/16"
2	Hex nuts
3'	Bare copper wire, solid untinned
3'	Iron picture wire, stranded
5'	Hook-up wire, stranded tinned

If you get a part slightly different from a part described in this list, the substitute part will not interfere electrically or mechanically with your experiments or equipment.

Experiment Lesson 5

OBJECT

To continue the assembly of your multimeter with the parts received in Kit 3.

METHOD

As in Experiment Lesson 3, the wiring you perform in this lesson is planned in a series of steps. By following the instructions and performing the steps in order, you will avoid making errors. Be sure to solder connections when soldering is called for and to make only a simple connection without soldering when so instructed. Before each step, check and double-check the instructions and the picture diagrams so that your multimeter may be wired correctly.

EQUIPMENT NEEDED

Soldering Iron

Cloth for keeping soldering tip clean

Solder

Long-nose pliers

Diagonal cutting pliers

Adjustable crescent wrench, or a one half inch open-end or box wrench

Fine-blade screwdriver

CHECK KIT

Carefully unpack the parts sent to you in Kit 3. Check them against the packing list as directed on page 2.

After checking the parts, place the pilot light, pilot-light socket, and the three 1.5-volt D cells away where you can find them for the next Experiment Lesson.

INFORMATION

Two potentiometers are included in Kit 3 (P_1 and P_2). A complete definition and explanation of *potentiometers* is given in Theory Lesson 7. When you are ready to study Lesson 7, you will be better prepared to understand the differences between resistors, variable resistors, and potentiometers. However, for now, it can be said that a potentiometer is a resistor with a sliding arm, as shown in Fig. 5-1. Both potentiometers are exactly alike, so it does not matter which becomes P_1 and which P_2. Later in this lesson, you will fasten these two potentiometers back to back. At that time, you will receive instructions for doing so. Where tinned bare wire is called for, use a piece of solid pushback wire, with the insulation removed.

CHECK YOUR WORK

Before you start to work, re-check the wiring and connections made in Experiment Lesson 3. If you haven't looked at these first steps recently, you may now be able to find an error more easily than you could have when you had just completed the work. Remember that no extra care you take now is wasted, because you are laying the foundation for the good workmanship that is expected of successful, reputable radio and television serviceman. When you are sure that no error has been made in the

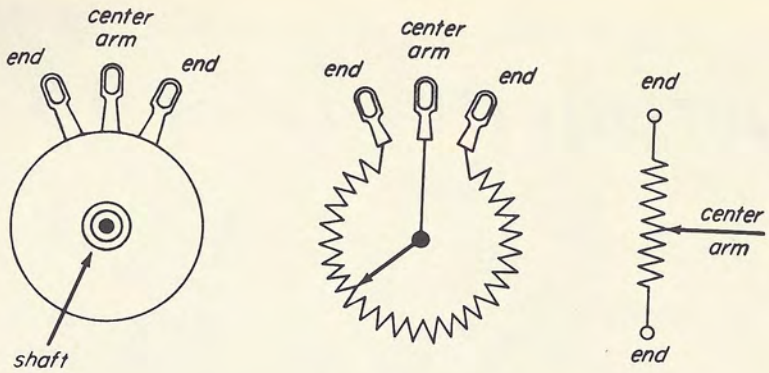


Fig. 5-1

previous work, proceed with the following preparation.

PREPARATION

1. Carefully examine the picture diagrams in Fig. 5-2 and see just where the parts go and how they look when properly wired.

2. Examine the schematic diagram shown in Fig. 5-3 to see the electrical connections to be made in this lesson. You will notice that the work already done is shown by light lines and the work to be done in this lesson is shown by heavy, dark lines. In this way, you can see how the wiring you are now going to do fits in with the wiring completed in Experiment Lesson 3.

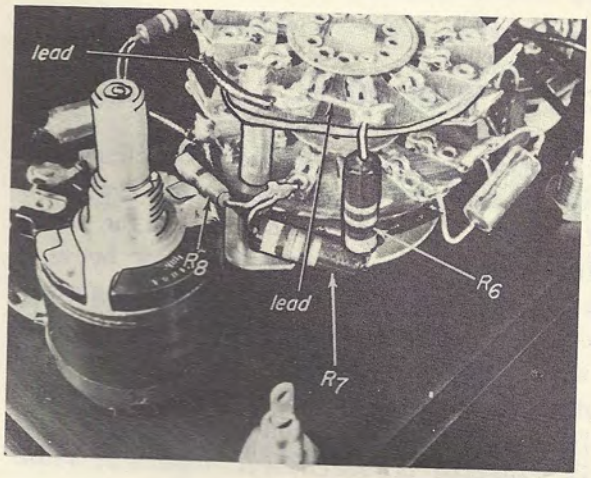
3. Make sure that your soldering iron tip is clean. Then plug in your iron to an electric-power outlet so that it will be ready for use when you need it.

4. Clear your bench or table and arrange your tools for easy use.

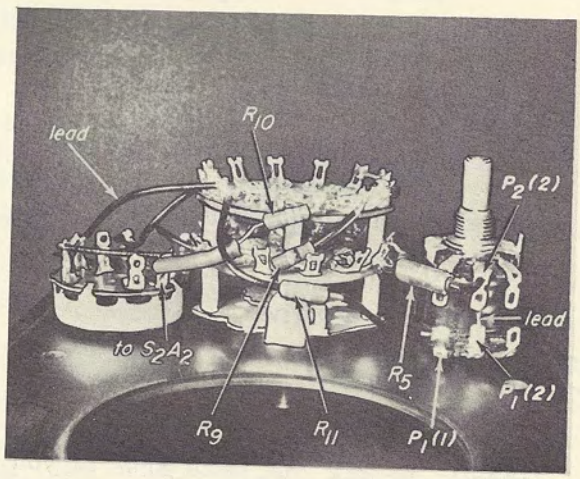
Note: Remember that the instruction to connect means to make a good tight connection, without soldering, and the instruction to solder means to make a good tight connection and then solder.

JOB 5-1

To mount resistor R_6 on RANGE selector switch S_1.



(a)



(b)

Fig. 5-2

Procedure.

Step 1. Remove 1 inch of lead from each end of the 1-ohm resistor, R_6.

Step 2. Connect one end of the resistor to S_1B_5 and connect the other end to S_1A_5 (on the deck above).

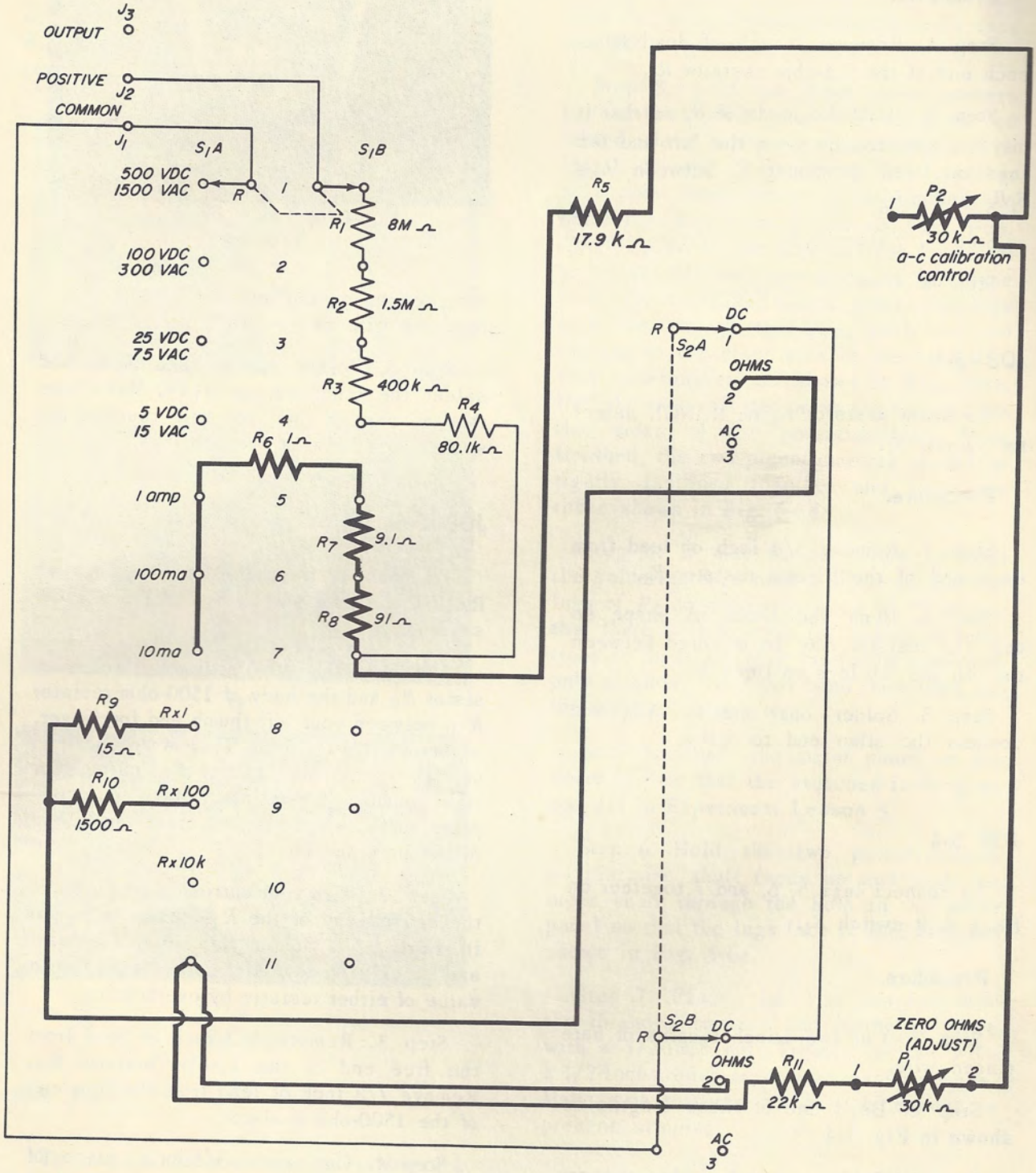


Fig. 5-3

JOB 5-2

To mount resistor R_7 on switch S_1.

Procedure.

Step 1. Remove 1 inch of lead from each end of the 9.1-ohm resistor R_7.

Step 2. Bend the leads of R_7 so that it may be mounted between the 5th and 6th lugs on Deck *B*. Mount R_7 between lugs S_1B_5 and S_1B_6.

Step 3. Solder S_1B_5.

Step 4. Connect S_1B_6.

JOB 5-3

To mount resistor R_8 on RANGE selector switch S_1.

Procedure.

Step 1. Remove 3/4 inch of lead from each end of the 91-ohm resistor R_8.

Step 2. Bend the leads in shape so that the resistor may be mounted between the 6th and 7th lugs on Deck *B*.

Step 3. Solder one end to S_1B_6 and connect the other end to S_1B_7.

JOB 5-4

To connect lugs 5, 6, and 7 together on Deck *A* of switch S_1.

Procedure.

Step 1. Cut two 1-inch lengths of bare tinned wire.

Step 2. Bend one of these lengths as shown in Fig. 5-4.

Step 3. Solder one end of this connector to S_1A_5. Connect the other end to S_1A_6.

Step 4. Cut 1/2 inch of spaghetti and slip it over the other 1-inch piece of wire.

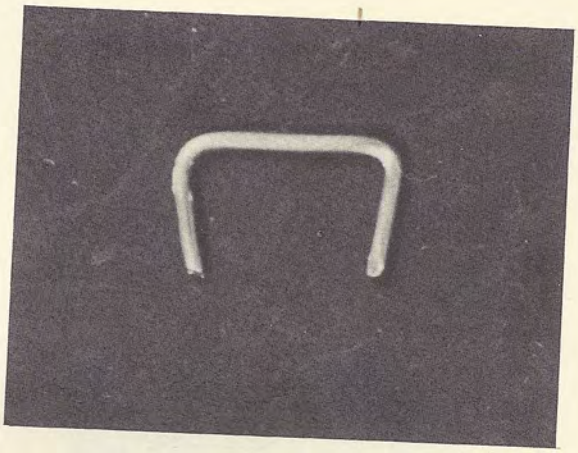


Fig. 5-4

After centering the spaghetti on the wire, bend the wire as you did the first length.

Step 5. Solder one end to S_1A_6 and solder the other end to S_1A_7. Make sure that no part of the bare wire touches the spacer post between the two lugs.

JOB 5-5

To mount resistors R_9 and R_{10} between RANGE selector switch S_1 and FUNCTION switch S_2.

Step 1. Grasp the body of 15-ohm resistor R_9 and the body of 1500-ohm resistor R_{10} between your left thumb and forefinger, as shown in Fig. 5-5*a*. Then wrap one lead of R_{10} around one lead of R_9, using your right thumb and forefinger. Make four complete turns, each of them tight and close to the previous one.

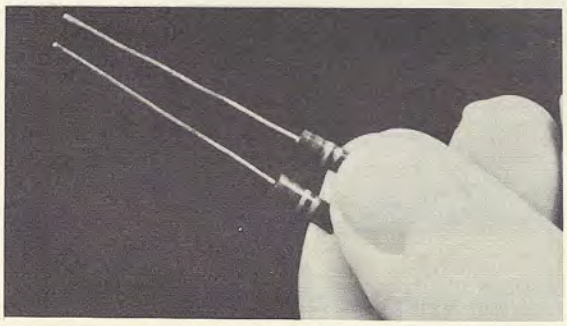
Step 2. With your cutting pliers, remove the unused end of the R_{10} lead, as shown in Fig. 5-5*b*. Solder this joint carefully and quickly so that you do not change the value of either resistor by overheating.

Step 3. Remove 1/2 inch of lead from the free end of the 15-ohm resistor R_9. Remove 7/8 inch of lead from the free end of the 1500-ohm resistor.

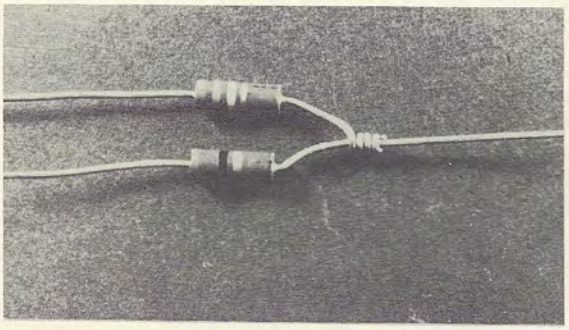
Step 4. Cut one 3/4-inch piece of spaghetti and slip it over the free end of resistor R_9. Slip this end into the lug of S_1A_8. At the same time, slip the free end of R_{10} into S_1A_9. When you have made a

good tight connection to each of these lugs, solder R_9 to S_1A_8 and R_{10} to S_1A_9 as shown in Figure 5-5*c*.

Step 5. Cut one 1-1/4-inch length of spaghetti and slip it over the joint lead of R_9 and R_{10}. Connect (but do not solder) this lead to S_2A_2.



(a)



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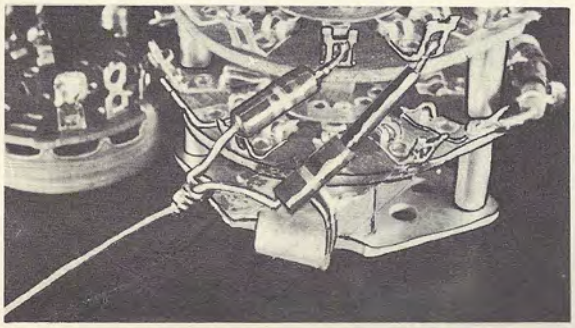


(c)

Fig. 5-5

JOB 5-6

To prepare and mount the potentiometers P_1 and P_2 on the meter panel.

Procedure.

Step 1. Place the two potentiometers, P_1 and P_2, back-to-back, as shown in Fig. 5-6*a*. See that the lugs of each potentiometer are located as shown.

Step 2. Cut a 3-1/2 inch length of tape from the roll of plastic electrician's tape that you received in Kit 1.

Step 3. Hold the two potentiometers back-to-back with your left hand as you fasten them together with a 3-1/2 inch length of tape. Start taping them together at a point immediately to one side of the soldering lugs, as shown in Fig. 5-6*b*. Carefully press the tape against the metal sides of the potentiometers as you tape them together. When you reach the lugs with the end of the tape, push the end through to the other side of the lugs with your screwdriver, as shown in Fig. 5-6*c*. Pull the tape taut and press the end against the sides of the potentiometers. When finished, the two potentiometers should be tightly fastened together and look like those shown in Fig. 5-6*d*.

Step 4. It may be necessary to bend the soldering lugs back a little so that the lugs of P_1 do not touch those of P_2 and so that there will be room for making connections to them. Be very careful to bend them only slightly, for if you bend them back too far they may break off.

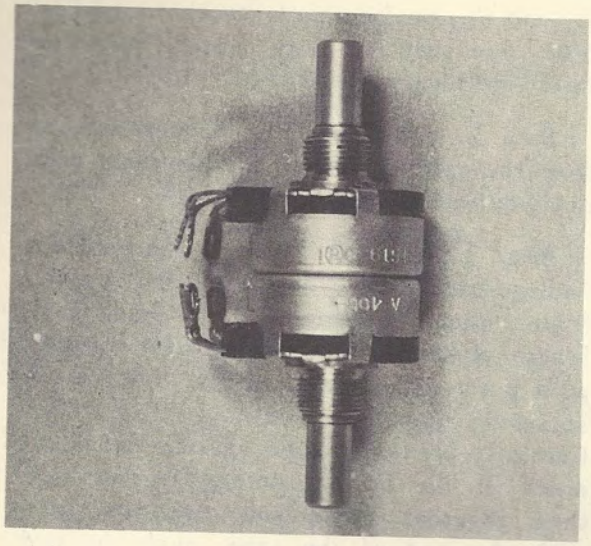
Step 5. Place the meter panel on the meter box so that the switches face up as you did in Experiment Lesson 3.

Step 6. Hold the two potentiometers so that one shaft faces up and push the other shaft through the hole in the meter panel so that the lugs face in the direction shown in Fig. 5-6*e*.

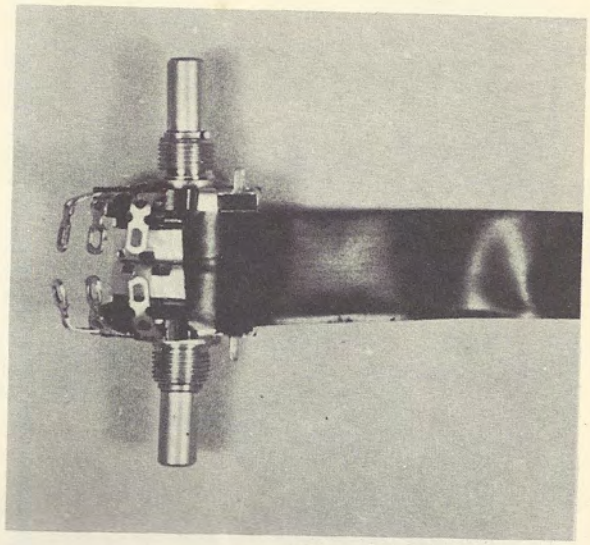
Step 7. Place the flat washer over the threaded bushing and fasten in place with a 1/2-inch nut. Tighten the nut with a 1/2-inch wrench or with a crescent wrench. Make sure that the nut is tight enough to prevent slipping.

JOB 5-7

To mount resistor R_{11} between potentiometer P_1 and switch S_1, as shown in Fig. 5-7.



(a)



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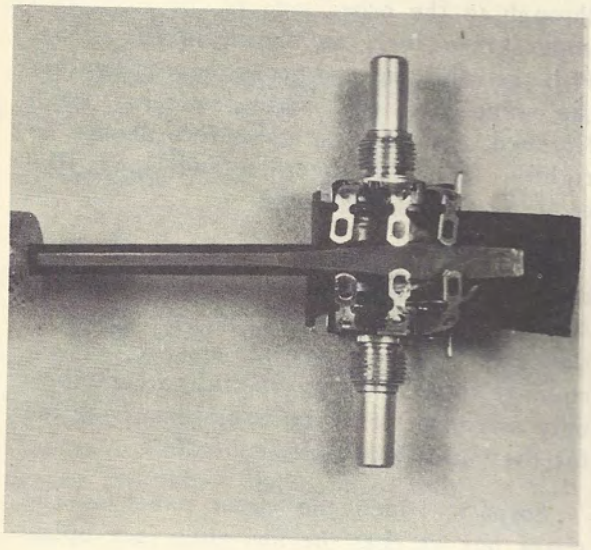

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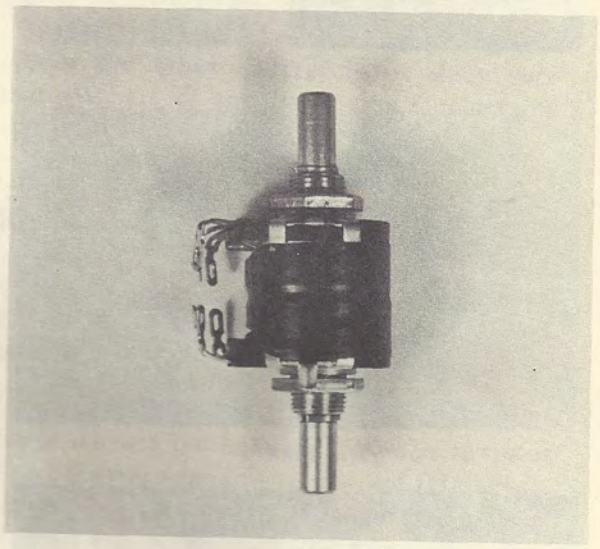

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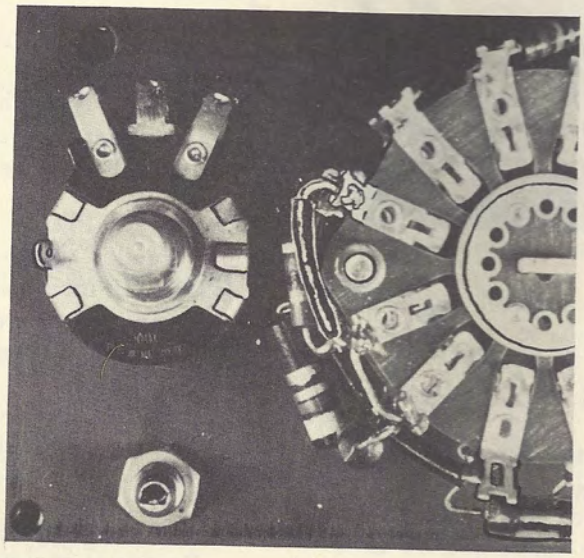

(e)

Fig. 5-6

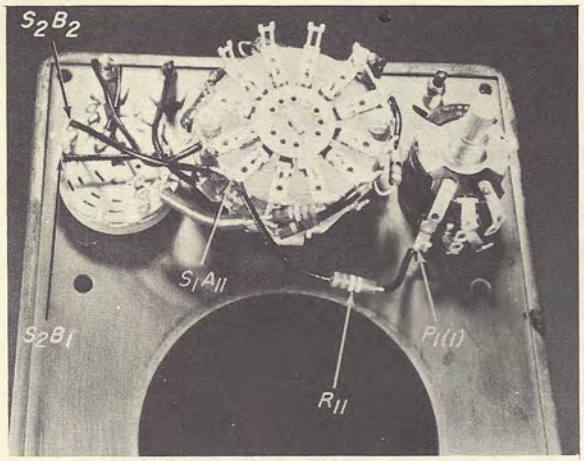

Fig. 5-7

Procedure.

Step 1. Cut two 1-1/4-inch lengths of spaghetti. Slip one length over each end of the 22 k-ohm resistor R_{11}.

Step 2. Solder one end of R_{11} to terminal 1 of potentiometer P_1. Connect the other end to S_1A_{11}, as shown in Fig. 5-7.

Because the adjustable stop was placed on the RANGE selector switch S_1 so that only the first ten positions can be used, terminals S_1A_{11} and S_1B_{11} are not used as part of switch S_1. Therefore, in connecting one end of resistor R_{11} to S_1A_{11}, you are making use of the lug as a convenient place to tie two circuits together. The leads of resistor R_{11} are not long enough to reach all the way from potentiometer P_1 to FUNCTION switch S_2. So lug 11 on Deck *A* comes in handy, because, to complete the circuit, you now can connect a wire lead between this lug and switch S_2.

JOB 5-8

To connect S_1A_{11} to S_2B_2.

Procedure.

Step 1. Cut one 2-1/2 inch length of hook-up wire. Remove 1/4 inch of insulation from each end.

Step 2. Solder one end of this lead to S_1A_{11} and solder the other end to S_2B_2, as shown in Fig. 5-7.

JOB 5-9

To mount R_5 between RANGE selector switch S_1 and potentiometer P_2.

Procedure.

Step 1. Remove 3/4-inch of lead from each end of the 17.9 k-ohm resistor R_5.

Step 2. Cut two 1/2-inch lengths of spaghetti. Slip one length over each end of resistor R_5.

Step 3. Connect one end of this resistor to terminal 2 of potentiometer P_2, as shown in Fig. 5-8.

Step 4. Solder the other end of this resistor to S_1B_7.

JOB 5-10

To make a connection between potentiometer P_1 and potentiometer P_2.

Step 1. Cut 1 inch of bare tinned wire.

Step 2. Connect one end of this lead to terminal 2 of potentiometer P_2, as shown in Fig. 5-9.

Step 3. Solder the other end of the lead to terminal 2 of potentiometer P_1.

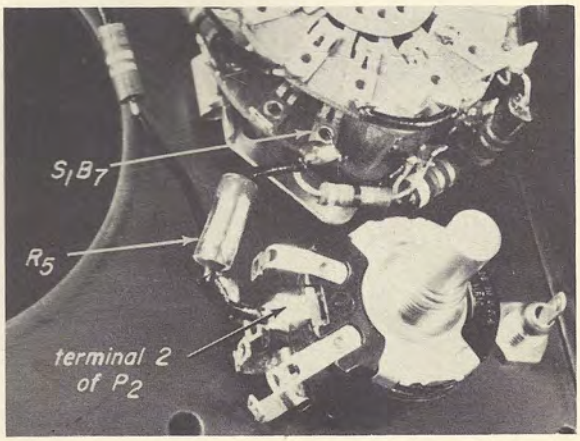

Fig. 5-8

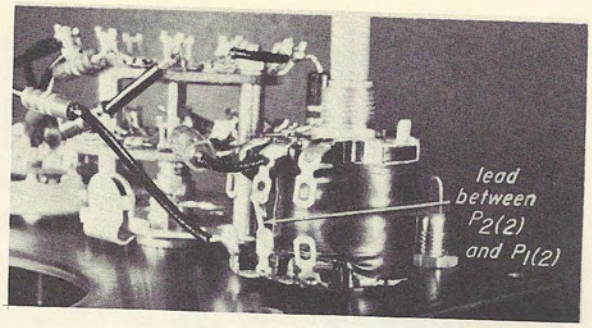

Fig. 5-9

CHECK YOUR WORK

With the connection made in Step 3 of Job 5-10, your multimeter is ready for the installation of the meter movement that will be sent to you in Kit 4. As soon as you are ready for Experiment Lesson 7, you can install the movement, make two connections, and put the meter to work measuring voltage and current.

Before you put your work aside, check the wiring very carefully.

1. See that the seven resistors you have wired in this lesson are of the values called for and that they are connected exactly according to the instructions.

2. Make sure that no bare wire touches any other bare wire or metal surface, except where instructions call for two or more wires to be connected to the same terminal.

3. Check the soldering; see that it is well done, with no excess solder or cold-soldered joints. Be very sure that no bits of solder dropped among the switch contacts while you were soldering.

ELECTRONIC FUNDAMENTALS

THEORY LESSON 6

SECONDARY CELLS

6-1. Lead-Acid Storage Battery
6-2. Specific Gravity
6-3. Capacity Ratings
6-4. New Lead-Acid Batteries
6-5. Batteries in Service
6-6. General Rules for Charging
6-7. Charging Methods
6-8. Overcharging
6-9. Charging Primary Batteries
6-10. Efficiency
6-11. Edison Alkaline Cell
6-12. Nickel-Cadmium Cell
6-13. Storing Storage Batteries

RCA INSTITUTES, INC.

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HOME STUDY SCHOOL

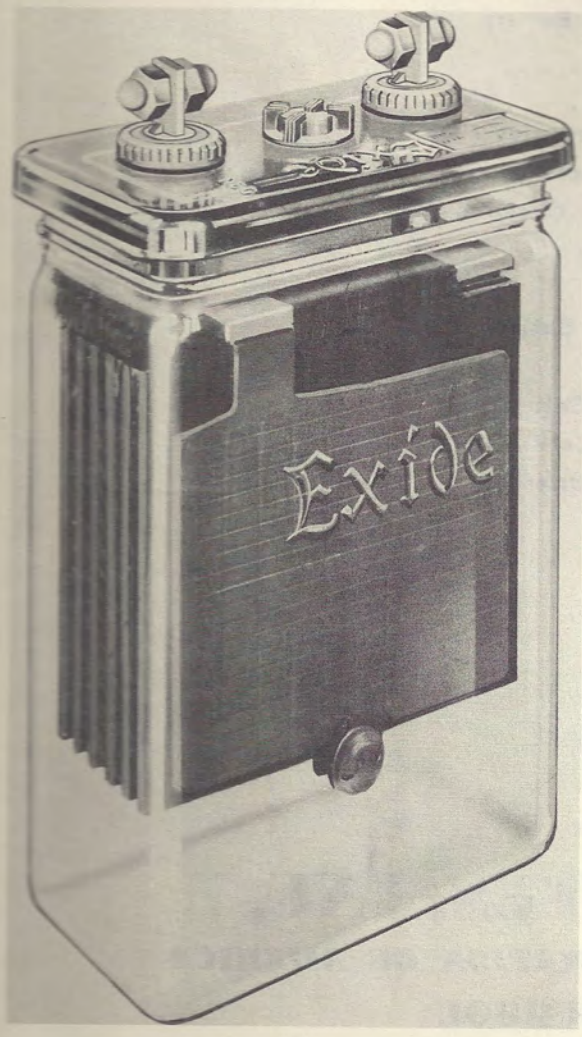
350 West 4th Street, New York 14, N. Y.

Theory Lesson 6

INTRODUCTION

In the last lesson, a *secondary cell* was partly defined as one that may be recharged when its electricity is used up. A more complete explanation follows: A secondary cell is a device that produces electricity by chemical action. When the emf produced by such a cell falls below a useful level, the chemical action can be reversed and the emf can be brought back to its original level. This is done by sending an electric current through the cell in a direction opposite to the direction in which current flows as the cell is discharged. This action is called *charging*. When a cell receives its first charge, it is said to be *charged*. When it is charged again, we usually say it is *recharged*. The same cell may be used over and over again, so long as it remains in good condition, is used properly, and is recharged when necessary. Secondary cells are often called storage cells, since they have the effect of storing electricity until needed. Like primary cells, storage cells may be connected together to form batteries. We call these batteries *storage batteries*. The most common form of storage batteries used in this country are the 6-volt and 12-volt automobile battery. Figure 6-1 shows a cell and a battery. A 6-volt battery contains three 2-volt cells; a 12-volt battery contains six 2-volt cells.

Like the primary cell, the storage cell is made up of two unlike substances and an



(a)

(b)

Fig. 6-1

electrolyte. In this country, the commonest storage cell is the lead-acid cell. This cell is made up of two kinds of lead in a solution of sulphuric acid and water. It was stated in the last lesson that the electrodes of a cell must be of different substances. Yet, in a lead-acid cell, both electrodes are made from lead. The reason it is possible to produce a lead-acid cell is that the two kinds of lead have different characteristics and different potentials in the electrochemical series of metals. The positive electrode is made from lead peroxide, which is normally dark brown in color. The negative electrode is made from a gray, spongy lead. Both electrodes are highly porous (which means that they are full of pores or tiny holes). These small pores make it possible for the electrolyte to soak into the electrode and increase the capacity of the cell.

6-1. LEAD-ACID STORAGE BATTERY

A fully charged lead-acid cell produces an open-circuit voltage of about 2.2 volts. Under load, the voltage may drop to 2.0 volts or less. Some portable radios and other portable equipment are powered by such cells. In general, however, there is a need for a greater voltage, so cells are connected together in series to produce batteries.

Batteries of many sizes and many cells are made for all kinds of uses, but the 6-volt battery is familiar to most of us. Let us see how one is made. Figure 6-2 shows a cutaway view of a 6-volt storage battery, with each part identified. The parts that chemically produce electricity are the negative plates, the positive plates, and the electrolyte (which is not shown). Each plate of a modern lead-acid cell is built up by filling a metal *grid* or framework with lead peroxide (for the positive plates) or spongy lead (for the negative plates). Grids are made from an alloy of lead and antimony. The antimony adds strength to the lead, so that each grid may support the weight of the materials it is filled with. Figure 6-3*a* shows a grid partly filled with lead peroxide, and Fig. 6-3*b* shows a complete negative plate made from a grid filled with spongy lead.

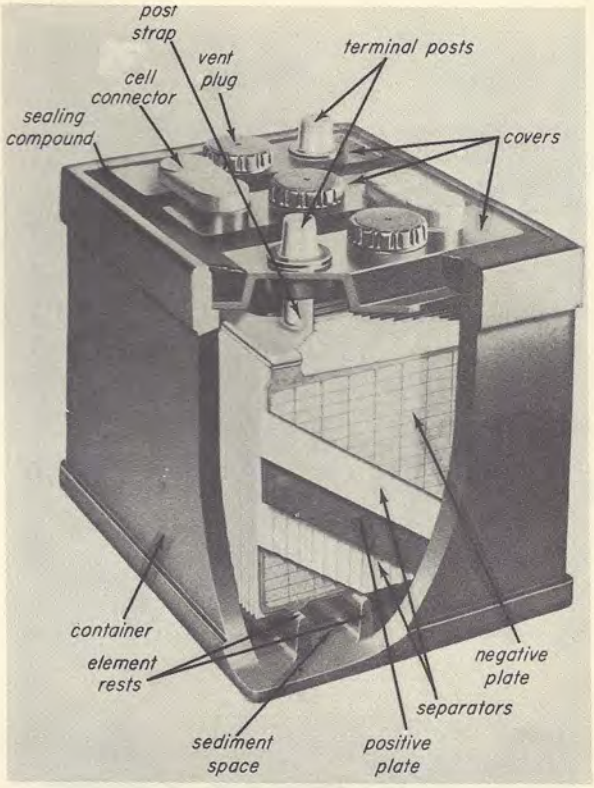
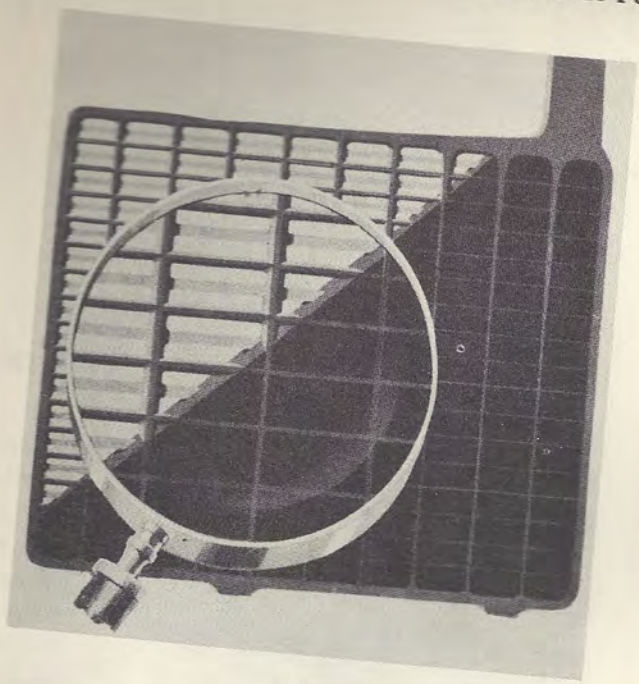


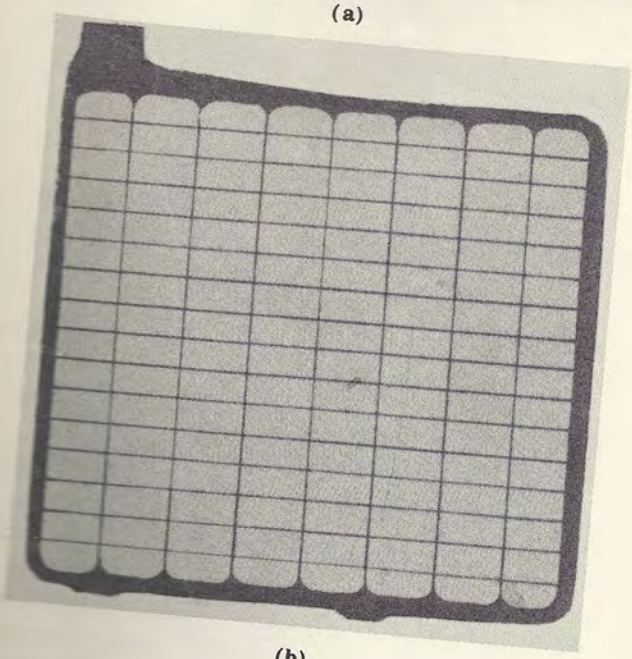
Fig. 6-2

To make cells of large capacity, several positive plates are welded together to form a positive element, and several negative plates are welded together to form a *negative element.* One of the ways in which storage batteries are rated is by the number of plates in each cell. Because the negative plates are on the outside of the positive plates, there is always one more negative plate than positive plate. Therefore, there is always an odd number of plates in a cell. For example, a thirteen-plate battery is made up of cells, each having six positive (lead peroxide) plates and seven negative (spongy lead) plates, while a twenty-one plate battery has ten positive plates and eleven negative plates in each cell. The plates of the positive and negative elements are interleaved, as shown in Fig. 6-4*a*.

Separators. To prevent a positive plate from touching a negative plate, a *separator* is slipped between each positive and negative plate. Separators are thin, non-conducting strips of porous wood, fiber, glass fiber, or rubber. No matter what they are made of,



(a)

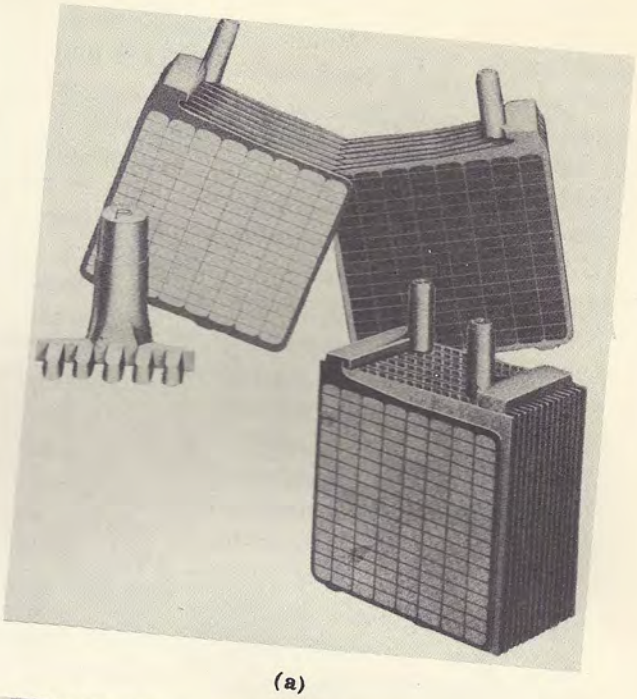


(b)

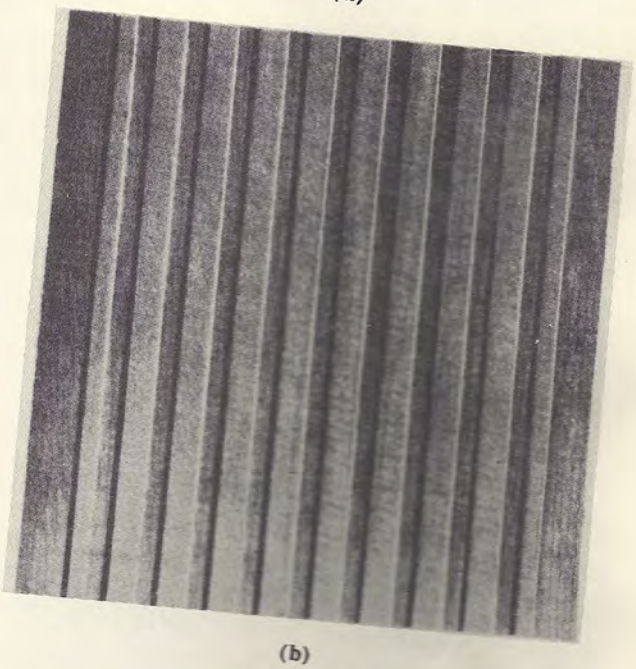
Fig. 6-3

separators must be non-conductors and porous enough to permit the passage of the electrolyte. Figure 6-4*b* shows a wood separator with grooves cut in one side. This side faces a positive plate. The function of the grooves is to permit a better flow of electrolyte within the cell.

Battery Container. The assembled cells are placed in a glass or hard-rubber container. As shown in Fig. 6-5, each cell compartment is separated from the next compartment



(a)



(b)

Fig. 6-4

by a wall of the same material the case is made from. Molded rests or bridges for the cell element to rest on are at the bottom of each cell compartment. While discharging, or charging, or being subjected to a vibration, particles may flake or chip off the plates of a cell and settle at the bottom of the container. If the plates rested on the bottom of the case, the cell would be shorted. For this reason, the plates of the cell rest on the bridges, and room is left at the bottom to receive this loosened material. Each cell of a portable

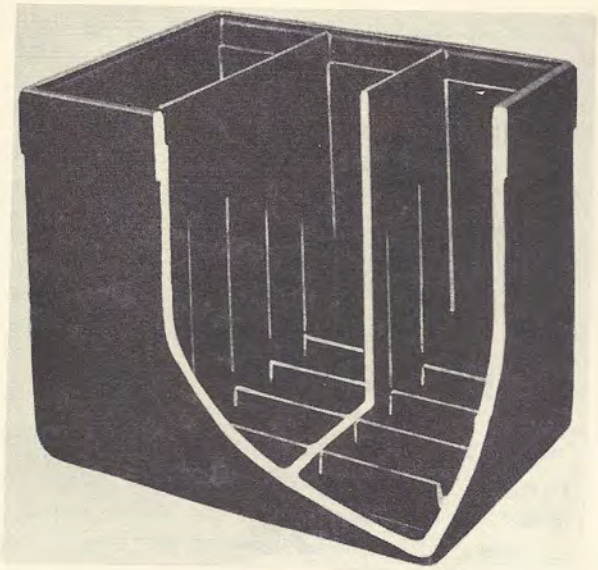


Fig. 6-5

battery, such as the kind used in automobiles, is covered with a hard rubber cover, as shown in Fig. 6-6. The hole at each end is slipped over the terminal post of a cell. The center hole is threaded to receive a cap, which may be removed for servicing the cell.

The cells are connected together by *cell connectors*, shown in Fig. 6-7*a*, which are made from lead or an alloy of lead and antimony. They must be heavy enough to carry a high current, such as that required of an automobile battery when starting the car. The negative and positive battery terminals are tapered, as shown in Fig. 6-7*b*, so as to receive any standard battery clamp. The positive terminal is always slightly larger than the negative terminal in order to prevent making battery connections in reverse. The individual cell covers are sealed to the battery case with a compound of a blown-oil asphalt or other tarry product. This sealing is necessary to prevent any accidental leakage of the acid solution. In this way, no

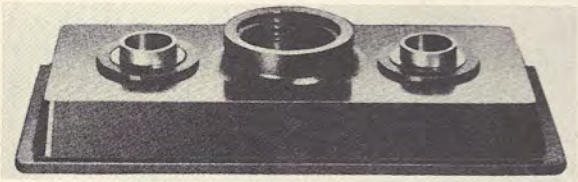


Fig. 6-6

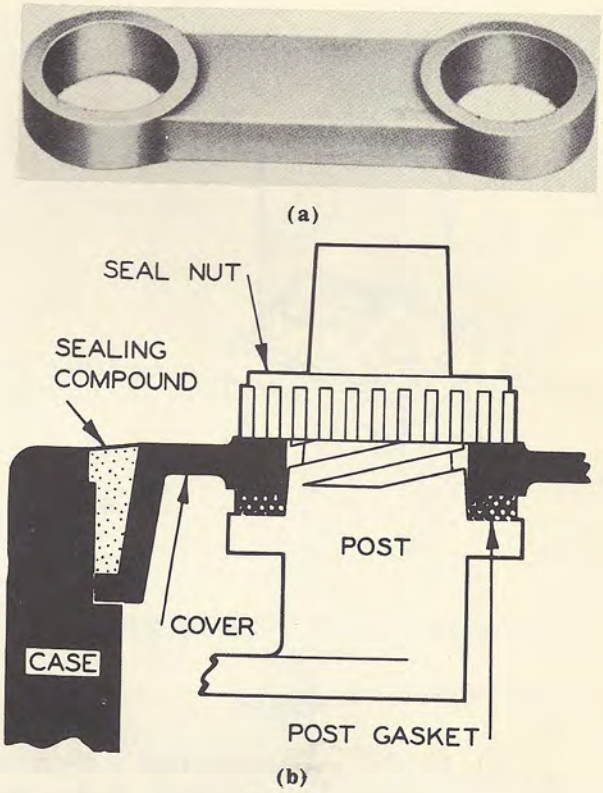
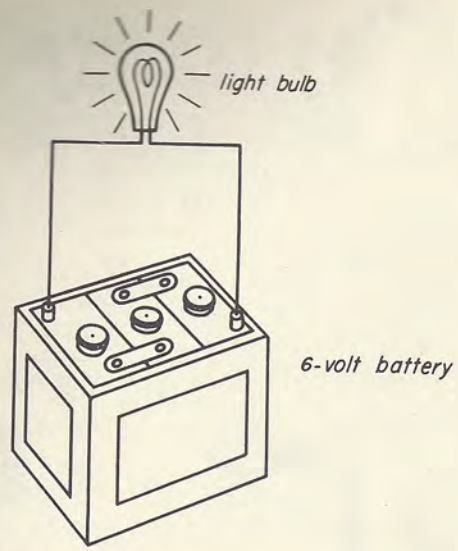


Fig. 6-7

acid is allowed to spill on and possibly destroy other surfaces.

Electrolyte. The electrolyte used in the lead-acid cell is a mixture of sulphuric acid and water. The electrolyte of a fully charged cell contains about 27%, by volume, of pure sulphuric acid. The other 73% is pure water. Most battery manufacturers suggest that only distilled water be used because, in many parts of the country, water contains chemical substances that may affect the chemical action of the cell or battery.

Chemical Action. The chemical action of the lead-acid cell is similar to the action of a primary cell. It is not important that we know all of the chemical changes that take place. It is sufficient if we understand that chemical action between the lead peroxide, the electrolyte, and the spongy lead can produce electricity, as shown in Fig. 6-8. However, we should know about some of the chemical changes that occur. As the cell is discharged in use, both the positive electrode (lead peroxide) and the negative electrode (spongy lead) combine with the sulphur-



Electricity produced by chemical action lights bulb

Fig. 6-8

ic acid of the electrolyte to form a chemical substance called lead sulphate. In the language of battery men, the plates become sulphated. In producing this change, sulphuric acid is taken from the electrolyte. As a result, the electrolyte becomes weaker and weaker as the battery discharges. As more and more of the surface of each plate becomes sulphated, less and less electricity is produced. If the battery were to be completely discharged, the surface of each electrode would be entirely lead sulphate, and very little acid would remain in the electrolyte. For two reasons, therefore, no further electricity could be produced. First and most important, if two electrodes are made from the same substance, there is no potential difference between them. So, even if the electrolyte were full-strength, no emf could be produced. The second reason is that even if the electrodes were in their original condition, the electrolyte would be so weak that no effective emf could be produced.

In good practice, no battery or cell is ever permitted to become fully discharged. Either a cell is kept charged as it is used or it is recharged when the output voltage reaches a certain level. In recharging, an electric current is applied to the terminals of the cell and passes through the cell in a direction opposite to that of the discharging current. This reverses the chemical action, and the sulphate is returned from the positive and negative electrodes to the electrolyte. This makes the positive plate once again lead peroxide, makes the negative plate spongy lead, and restores the electrolyte to its full strength.

6-2. SPECIFIC GRAVITY

We have seen that, as the battery discharges, the electrolyte loses sulphuric acid. So, one way to test the condition of a storage cell is to find out how much sulphuric acid remains in the electrolyte. At first glance, this might seem difficult to do, and it would be except for the fact that sulphuric acid is heavier than water. A pint of pure sulphuric acid weighs 1.835 times as much as a pint of water. We use water as a standard for measuring the relative weights of equal volumes of all kinds of substances. This relative weight we call *specific gravity*, and because water is used as the standard, we say that it has a specific gravity of 1. Because sulphuric acid weighs 1.835 times as much as water, it is said to have a specific gravity of 1.835.

Of course, the electrolyte used in lead-acid cells is not pure sulphuric acid, but a mixture of acid and water. By measuring, we find that the specific gravity of a fully charged lead-acid cell is about 1.280. Table A shows the approximate specific gravity of the electrolyte for different states of charge at a temperature of 80° F.

TABLE A – SPECIFIC GRAVITY AND CHARGE AT 80° F

Specific Gravity	State of Charge
1.280	100%
1.250	75%
1.220	50%
1.190	25%
1.130	0%

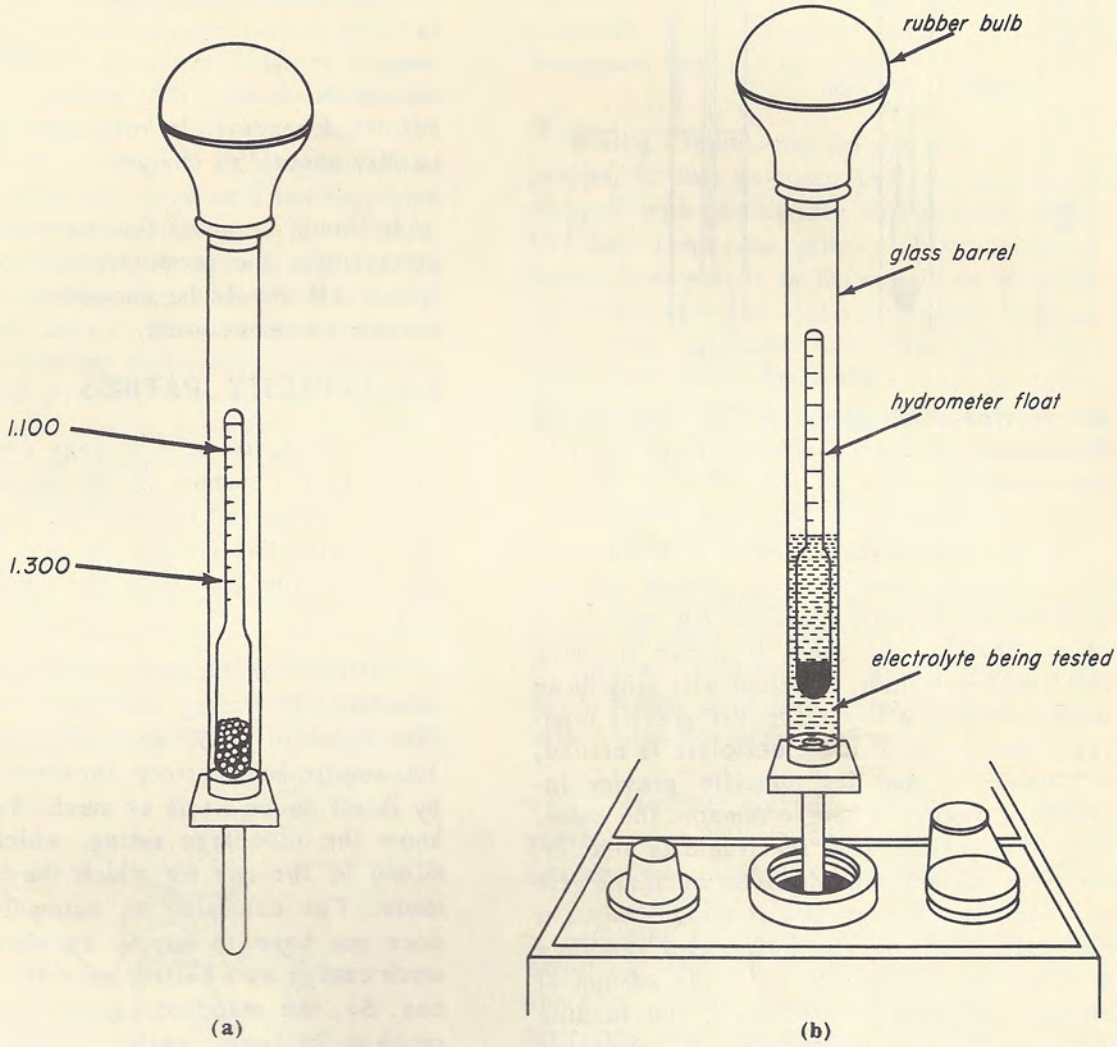


Fig. 6-9

Hydrometer. We measure the specific gravity of the electrolyte with a hydrometer. This instrument, shown in Fig. 6-9*a*, has a weighted float with a glass stem marked off like a thermometer. Instead of indicating temperature, however, it shows specific gravity. This float is enclosed in a glass tube with a flexible hose attached to the bottom and a rubber bulb at the top.

To test the specific gravity of a cell, the vent cap is removed from the top of the cell. Then the hydrometer is used, as shown in Fig. 6-9*b*, and enough of the electrolyte is sucked up into the hydrometer so that the float floats freely. To take a reading, your eye must be at the level of the fluid in the hydrometer. In this position, note the specific gravity as marked on the stem of the float. Typical readings are shown in Fig. 6-10*a* and *b*.

Note that the lighter the liquid the more the float sinks down. When the liquid is heavier (higher specific gravity) the *less* the float sinks down. Thus the lower specific gravity numbers are nearer the top of the float.

After the reading is taken for one cell, the electrolyte is returned to the cell. In the case of a battery, test each cell, one at a time. Always be sure to return the electrolyte to the cell from which it was taken.

Temperature and Hydrometer Readings. Most hydrometers made for testing lead-acid cells are accurately marked for an electrolyte temperature of 80 degrees F. When temper-

6-4. NEW LEAD-ACID BATTERIES

New batteries are quite frequently shipped "dry". That means that the electrolyte is shipped separately and must be added to the battery before placing it in service. When filling the cells of a lead-acid battery, care must be taken not to spill any of the electrolyte, because the sulphuric acid will damage clothing and other surfaces on which it spills. It is a good idea to use a rubber or glass funnel when pouring electrolyte into the cell, as shown in Fig. 6-11. Never use a metal funnel or a metal container for the electrolyte, because the sulphuric acid will eat away the metal. When pouring electrolyte into a cell, do not let the level rise above the line indicated by the manufacturer. If there is no level indicator, the proper level is about ¼ to ½ inch above the top of the plates. After pouring electrolyte into a new cell, recheck the level in about fifteen minutes; then add enough electrolyte to make up for the amount absorbed by the plates and separators. If possible, let the batteries stand for 8 to 10 hours and readjust the level.

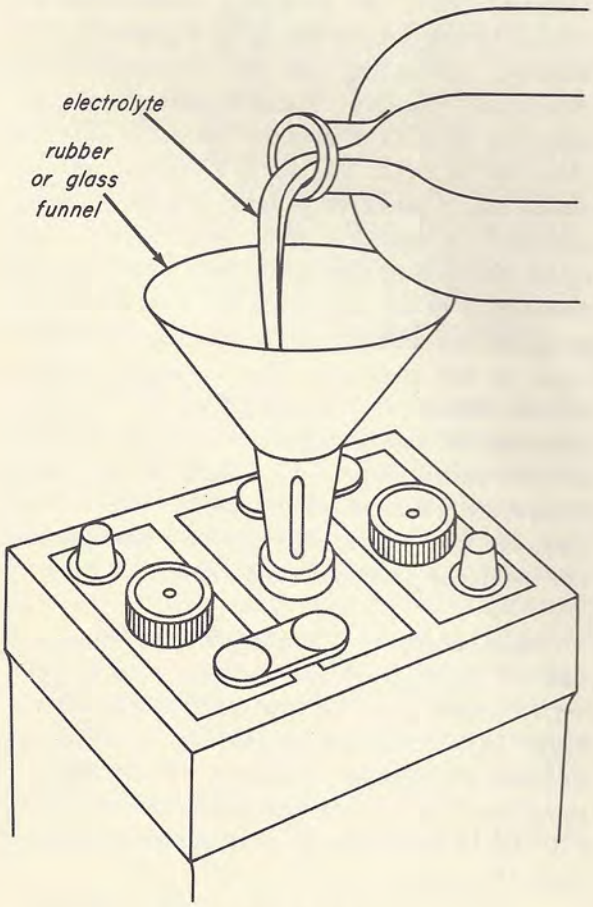


Fig. 6-11

Mixing Electrolyte. In the previous paragraphs, it was assumed that the electrolyte shipped with the battery was properly mixed and had a specific gravity of 1.280. Sometimes, however, it is necessary to mix your own electrolyte. If electrolyte must be made from pure sulphuric acid (specific gravity 1.835) and water, great care must be taken. Pure sulphuric acid burns and blisters the skin. For that reason, it is a very good idea to wear a rubber apron, rubber gloves, and goggles for your protection when handling pure sulphuric acid.

Warning: Never pour water into acid. If you do, acid will spatter around you, just as grease spatters in a hot frying pan. Always pour *acid into water*, stirring gently with a glass or rubber rod.

To produce electrolyte with a specific gravity of 1.280, slowly mix one part acid into two and one-half parts distilled water.

Charging New Lead-Acid Batteries. New batteries, whether shipped wet or dry, need charging before being placed in service. Batteries that are shipped wet are already charged. However, a light finishing or "boosting" charge, at a low rate, is recommended. Batteries shipped dry must be fully charged before placing in service.

After charging a new battery, we may find that the electrolyte has a specific gravity greater than 1.280. In such cases, it is necessary to add sufficient distilled water to bring the specific gravity down to the proper level. It may be necessary to draw off some of the electrolyte to make room for water. However, any dilution of the electrolyte should be done slowly, with frequent testing, so that the electrolyte does not fall below the proper level.

6-5. BATTERIES IN SERVICE

Batteries in service should never be per-

mitted to become completely discharged. The specific gravity of the electrolyte should never be permitted to fall below 1.150. In addition, batteries should never be permitted to remain discharged for any length of time. Some battery manufacturers recommend recharging when the specific gravity reaches 1.175 or 1.200.

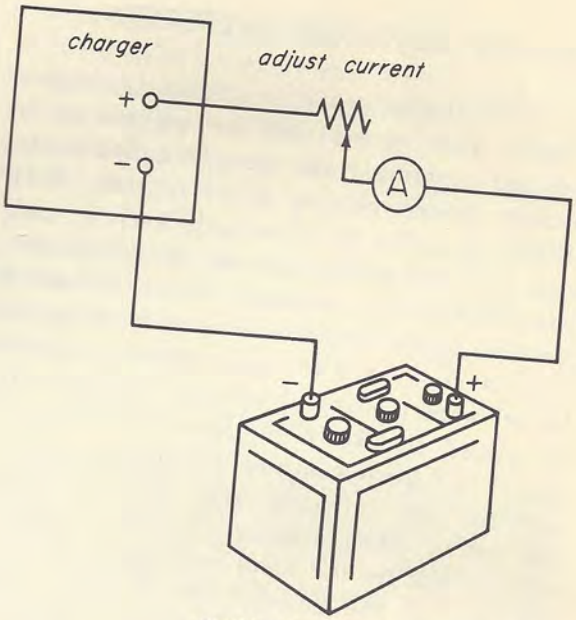
6-6. GENERAL RULES FOR CHARGING

Batteries should be charged in a well-ventilated room. While charging, lead-acid cells and batteries give off oxygen and hydrogen. So, no matches, lighted cigarettes or cigars, or sparks of any kind should be permitted near a charging battery. Keep vent caps screwed tightly on cells. This will prevent spattering of acid from the cells during charging. Before placing a battery on charge, clean all dirt and corrosion from the terminals. See that the vent hole in each vent cap is open and clear of dirt and grease. Make sure that the electrolyte of each cell is at the proper level. If not, add sufficient distilled water to bring it to the proper level. Battery manufacturers urge you not to add acid, any other type of electrolyte, or any battery "dope". Just add water to the proper level.

6-7. CHARGING METHODS

No matter which method of charging is used, batteries are charged by placing direct current of the proper voltage and polarity across the terminals of the battery. A battery is considered to be fully charged when all cells are bubbling freely and no change in voltage or hydrometer readings is observed during four successive hourly readings. There are several methods of charging in use. These are *constant-current* charging, *constant-voltage* charging, *high-rate* charging, and *trickle* charging.

Constant-Current Charging. The oldest and most used charging method is the constant-current method. As shown in Fig. 6-12, the positive terminal of the charger is connected to the positive terminal of the battery



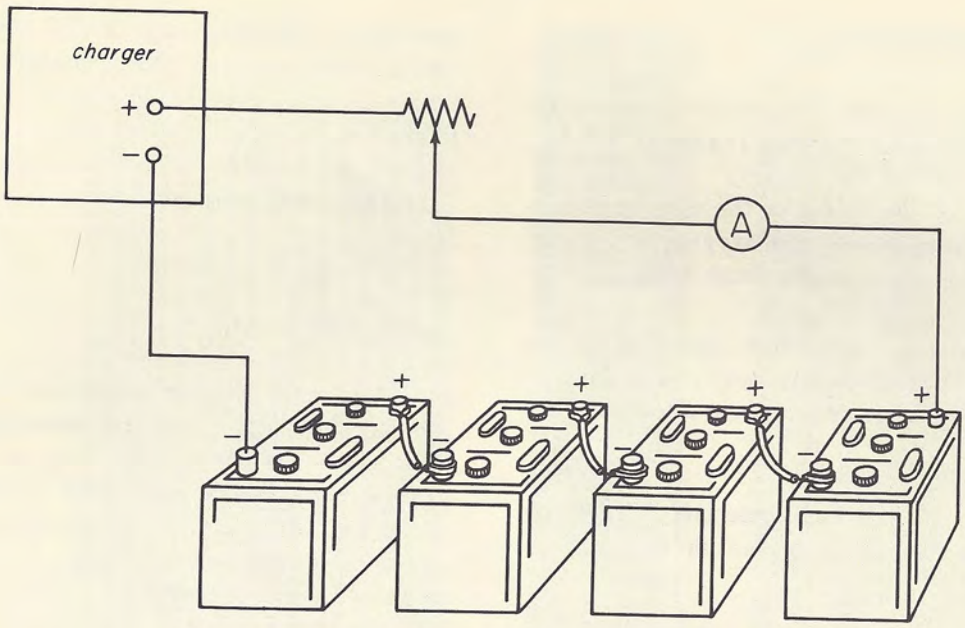
constant-current charging

Fig. 6-12

and the negative terminal of the charger is connected to the negative terminal of the battery. Then, the charging resistor is adjusted to the proper charging current for the battery. According to the Association of American Battery Manufacturers, a safe charging rate is 1 ampere for each positive plate in a cell. So, in a 13-plate battery, which has 6 positive plates, a safe charging current is 6 amperes. If several batteries are to be charged at the same time, they may be connected in series, with the positive electrode of one connected to the negative electrode of the next one. The positive terminal of the series is connected to the positive terminal of the charger or voltage source, as shown in Fig. 6-13. When several batteries are charged at the same time in this way, the charging rate is the rate suitable for the smallest battery in the line.

When charging a battery by the constant-current method, it is necessary to keep a watch to see that the charging rate is not too high. This condition is usually indicated by excessive gassing (bubbling of the electrolyte) and by electrolyte temperatures over 110°F. In such cases, it is necessary to reduce the charge rate.

Constant-Voltage Charging. When batteries are not badly sulphated or are not too



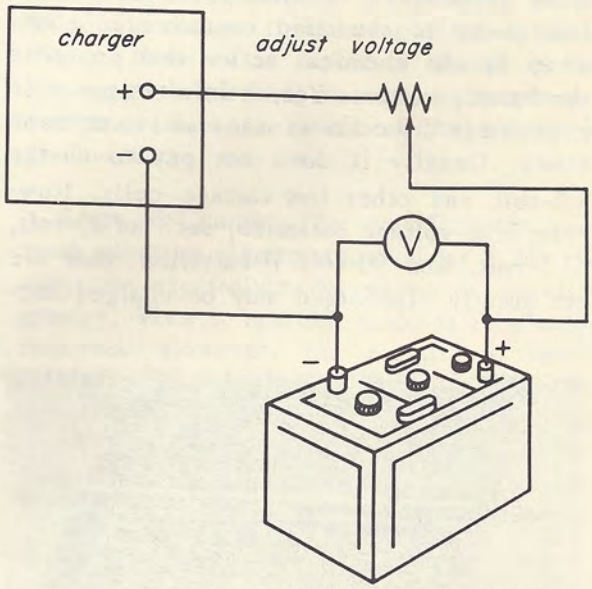
constant—current charging of batteries connected in series

Fig. 6-13

greatly discharged, the time required for charging may be reduced by using the constant-voltage method. Apply a source of d.c. equal to 2.5 volts per cell. The charging current, at the start, is very high. As the cell becomes charged, the current rate reduces; by the time the cell is completely charged, the current has tapered off to a very small quantity. For that reason, this is sometimes called a *taper* charge. Figure 6-14 shows one arrangement of batteries being charged by the constant voltage method.

High-Rate Charging. Since the war, high-rate chargers have become increasingly popular. If a battery is not badly discharged or over-sulphated, as long as the electrolyte temperature does not rise above 125°F, and there is no excessive bubbling, an occasional high-rate charge does no material damage to a battery. Great care must be used, however, to follow the instructions for operating a high-rate charger. Otherwise this charge can cause great damage to batteries. Batteries shipped dry should not be charged by this method, since, in such batteries, the temperature should not be allowed to exceed 110°F.

Trickle Charging. Trickle charging is really a form of constant-voltage charging, except that it is applied continuously with a low charging current. The charging current is usually 1% or 2% of the ampere-hour rating of the battery. The storage cells used in some makes of 3-way portable radios use a trickle-charging circuit to charge the cell whenever the radio is connected to an electric power line. A typical circuit of this type is shown in the Service Practices booklet on portable radios.



constant-voltage charging

Fig. 6-14

6-8. OVERCHARGING

Care must be taken to avoid overcharging a battery for the following reasons:

1. Some of the water of the electrolyte is changed into hydrogen and oxygen, and these gases escape through the vent hole.

2. The loss of water increases the strength of the acid, which may cause damage to the negative plates and to wood or fibre separators.

3. Positive plates sometimes warp or buckle from overcharging, as shown in Fig. 6-15.

4. High internal heat frequently results from overcharging. This increases the rate of corrosion and may soften the sealing compound used in assembling the battery.

5. Excessive amounts of sediment form at the bottom of each cell.

6-9. CHARGING PRIMARY BATTERIES

In the lesson on primary batteries, it was stated that such batteries tend to consume themselves in discharging. It is true that some of the zinc container is eaten away by the chemical action that produces the battery current. Yet, it is often possible to recharge dry cells as many as two or three times. Usually it does not pay to charge 1.5-volt and other low-voltage cells. However, high-voltage batteries, such as 45-volt, 67.5-volt, and 90-volt B-batteries that are not greatly discharged may be charged successfully. In fact, some 3-way portables are made that recharge the B-battery when the radio is connected to an electric power line. This is discussed further in a Service Practices booklet on how to service battery and three-way portables.

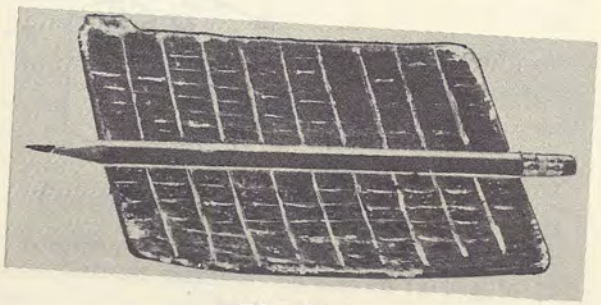


Fig. 6-15

6-10. EFFICIENCY

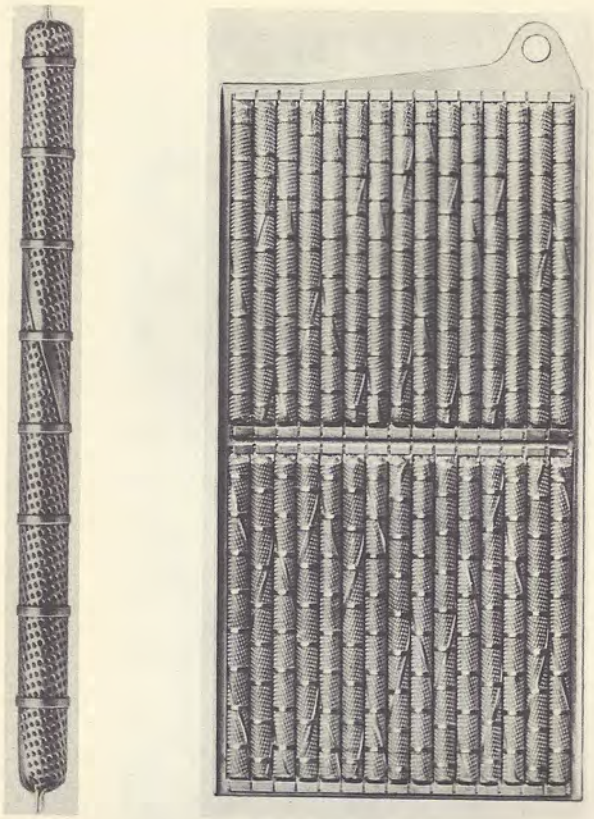
The converting of electrical energy into chemical energy, as in charging storage batteries, is never 100-percent efficient. There are always losses of energy due to heat and local action. In discharging a battery, there are similar losses in the conversion of chemical energy into electrical energy and in overcoming the internal resistance of the battery. However, while there is some loss in efficiency, the portability and convenience of batteries make them indispensible for many types of equipment.

6-11. EDISON ALKALINE CELL

The Edison alkaline cell is a storage cell that has widespread use in telephone central offices, railway signalling, and communication on railroad trains and in battery-operated trucks. Although Edison cells originally cost more than lead-acid cells, their long life and lighter weight frequently make them more economical to use over long periods of time.

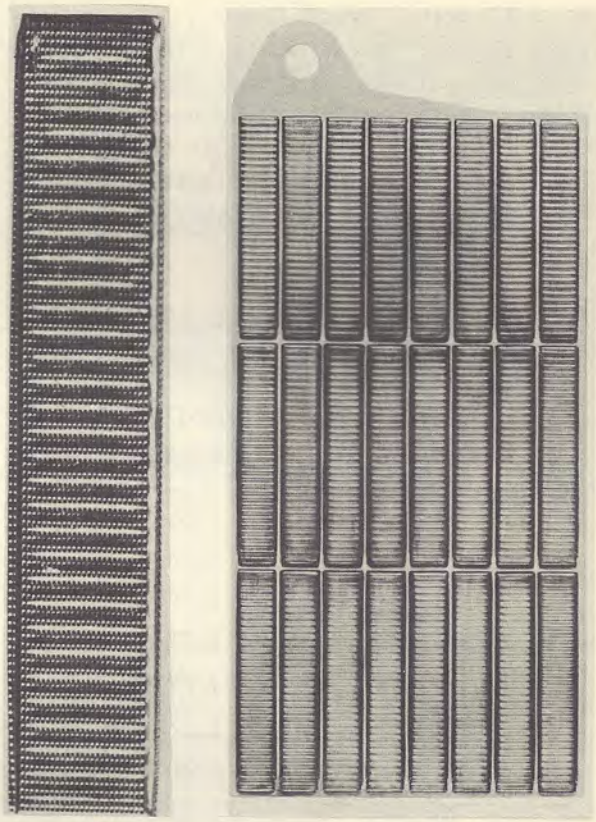
Positive Plates. The positive plates of an Edison cell, as shown in Fig. 6-16*a*, are made from nickel-plated steel tubes filled with 315 layers of nickel flakes, with a layer of nickel hydroxide between each layer of flake nickel. These tubes are normally 1/4 or 3/16 of an inch in diameter and usually 4.5 inches in length. The tubes are punched with many small holes and reinforced with eight nickel-plated rings. They are then mounted on a nickel-plated steel grid, as shown in Fig. 6-16*b*.

Negative Plates. The negative plates are made from rectangular nickel-plated steel containers known as *pockets*. Each of these is punched with many fine holes and



(a) (b)

Fig. 6-16



(a) (b)

Fig. 6-17

filled with ferrous oxide (iron oxide) mixed with a little yellow oxide of mercury. The negative pockets are mounted on a nickel-plated steel grid to form the negative plate. Figure 6-17 shows a single negative pocket and an assembled negative plate.

The Electrolyte. The electrolyte is potassium hydroxide, and a small amount of lithium hydroxide, in water. The cells have nickel-plated steel terminal posts, specially tapered to fit the connectors made to join one cell to another. The cells are mounted in a case made from nickel-plated sheet steel. As shown in Fig. 6-18, the positive plates are mounted on a steel rod, evenly spaced by washers between each plate. The negative plates are assembled in the same way. Then the negative plates and the positive plates are interleaved, as shown in Fig. 6-18.

Chemical Action. Studies have been made of the chemical action that takes place in a charging and discharging nickel-iron storage cell (another name for Edison cell). However, exactly what happens is not yet completely understood. It is known that in discharging, oxygen is liberated by the positive plate and added to the negative plate. In charging, the action is reversed, with the oxygen leaving the negative plate and being absorbed by the positive plate. It is also known that during discharge and charge there is no important change in the electrolyte. For that reason, a hydrometer does not show the state of the charge or discharge.

State of Charge. The specific gravity of fresh alkaline electrolyte is about 1.230. In use, the electrolyte decreases in specific gravity. When it reaches 1.160 it is usually renewed. However, the electrolyte needs this renewal only two or three times during the life of the battery. The electrolyte is renewed by replacing the old electrolyte with fresh renewal electrolyte made especially for this purpose.

To determine the state of charge, it is necessary to measure the closed-circuit voltage of the cell under normal load. Freshly charged, the output of an average Edison cell

is 1.47 volts, which drops to about 1.42 volts in about six hours even if the cell is not used in the meantime. The terminal voltage of a completely discharged Edison cell is about 1.13 volts. Table B shows approximate closed-circuit voltage readings of an Edison cell in discharging.

TABLE B – EDISON CELL VOLTAGES DURING DISCHARGE

Percent Discharge	Closed-Circuit Voltage
0	1.42
10	1.32
20	1.27
30	1.25
40	1.23
50	1.22
60	1.21
70	1.20
80	1.19
90	1.17
100	1.13

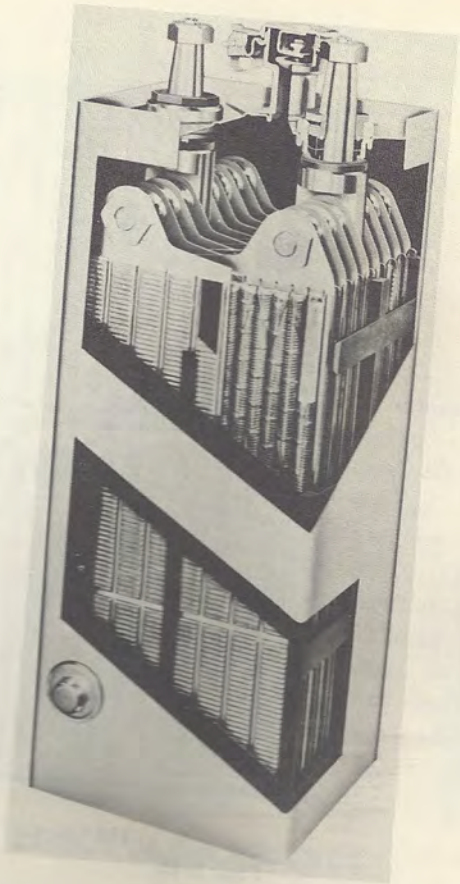


Fig. 6-18

Charging Edison Cells. For best results, the temperature of the electrolyte before charging should be between 70° and 80°F. If charged while the electrolyte is at a higher temperature, the capacity of the cell may be reduced during the next discharge period. Because the temperature of Edison cells rises considerably during discharging, as well as during charging, it may be necessary to let the cell cool off before charging. Edison cells are best charged by the constant-voltage method. The manufacturer's directions must be followed carefully when charging.

6-12. NICKEL-CADMIUM CELL

The nickel-cadmium cell is very much like the nickel-iron cell, except that the negative electrode is usually cadmium or a mixture of cadmium and iron. Figure 6-19 shows a cut-away view of a nickel-cadmium cell. The electrolyte used is potassium hydroxide with a normal specific gravity of 1.210.

The open-circuit voltage of a nickel-cadmium cell is about 1.3 volts. When loaded so that it discharges at the normal rate suggested by the manufacturer, the closed circuit voltage is approximately 1.2 volts, until it is about 75-percent discharged. Some nickel-cadmium cells are considered discharged when the closed-circuit voltage reaches 1.1 volts and, in other cells, when the voltage reaches 1.0 volts. For charging rates, follow the manufacturer's instructions.

Nickel-cadmium batteries are much more common in Europe, where they have been manufactured and used for many years. They are used for train lighting, mine lamps, in trucks and tractors, for communication systems, and to start marine engines. They have long life, are very rugged in construction, and require little attention.

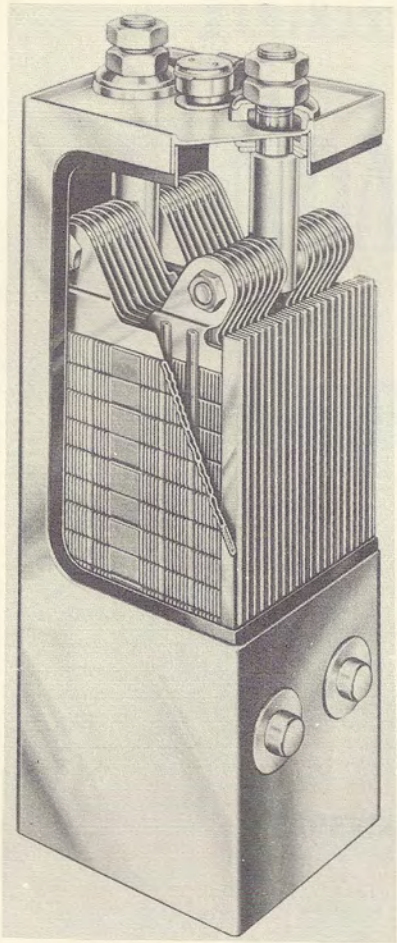


Fig. 6-19

6-13. STORING STORAGE BATTERIES

New lead-acid batteries that have been shipped dry may be stored for an indefinite period of time so long as the vent caps remain sealed and are not removed. Batteries that are received fully charged and ready for service should be stored in a cool place

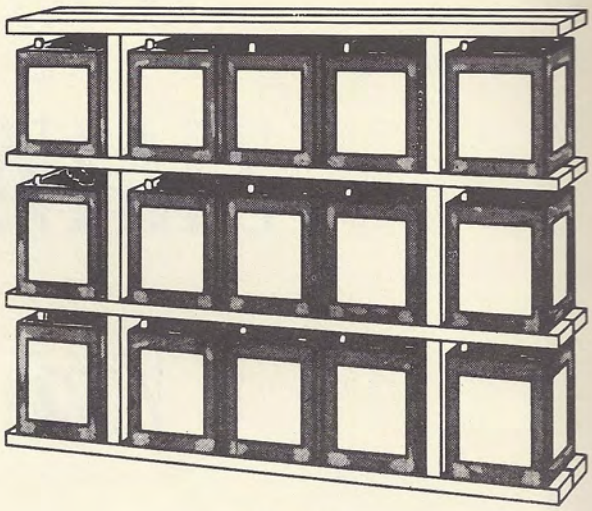


Fig. 6-20

with plenty of ventilation. They may be placed on shelves, as shown in Fig. 6-20. Sufficient room should be allowed for connecting a charger to the terminals. While standing idle in storage, lead-acid batteries slowly discharge. At 100-degrees F, an idle lead-acid cell discharges six times as fast as it does at 50-degrees F. So, every so often lead-acid batteries need a booster charge to bring the specific gravity of the electrolyte up to a normal figure.

Batteries that have been in use should be recharged before being stored, and should be inspected about every two weeks. Never store a discharged battery.

Nickel-iron and nickel-cadmium batteries should be stored in a well-ventilated, cool place. However, the amount of self-discharge is so small that they require very little attention.

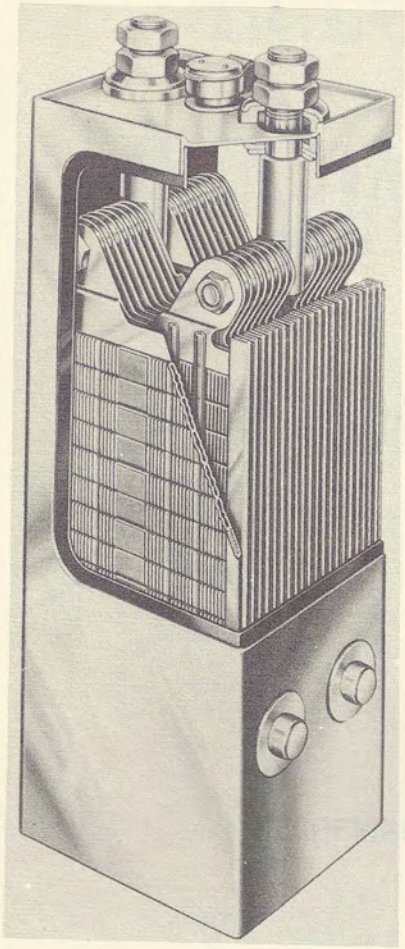


Fig. 6-19

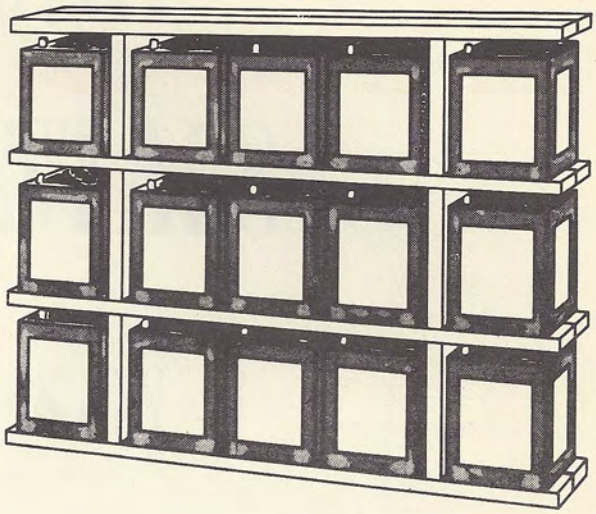


Fig. 6-20

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ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 6

EXPERIMENTS WITH CELLS

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA

HOME STUDY SCHOOL

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

Experiment Lesson 6

OBJECT

The object of the experiments in this lesson is to confirm the following statements made in Theory Lesson 5:

1. Carbon-zinc dry cells are connected together in series to form batteries of various voltages.

2. When cells are connected in *series aiding*, the voltage of each cell adds to the next voltage.

3. It is possible to connect cells so that they don't aid.

4. Electrical pressure or emf exists between some common substances when they are placed in an alkaline, acid, or salt solution.

5. The emf produced by chemical action between two metals or other substances placed in an acid, alkaline, or salt solution of proper strength is determined by the metals used.

6. The emf produced by chemical action is not affected by the size of the cell, the amount of metal, and the spacing of the metals.

PREPARATION

In order to prepare for these experiments, read and study Theory Lesson 5. When you are sure that you understand the information given in Theory Lesson 5, proceed with the experiments given in this lesson. If you have trouble understanding some point in an experiment, stop what you are doing and read Theory Lesson 5 again until the point is cleared up and you find the answer to your problem.

INFORMATION

The experiments in the first part of this lesson are best performed where the lighting in the room is not too bright to keep you from observing the brightness level of a small flashlight bulb. Bright lights in the room should be turned off; medium to low lighting should be used. The equipment needed to perform this experiment probably can be found in your own home, making it unnecessary to buy anything.

PART ONE

OBJECT

The object of the first part of this lesson is to:

1. Test the total potential across a battery made up of 1.5-volt dry cells that are connected in *series aiding*.

2. Test the total potential across a battery made up of 1.5-volt dry cells that are connected in *series opposing*.

3. Test the total potential across a battery made up of 1.5-volt dry cells that are connected as a combination of both *series aiding* and *series opposing*.

4. Test the potential across a battery made up of dry cells that are connected in parallel.

In each of the following experiments, you will use your sense of sight and sense of taste to observe the strength of the total battery voltage. You will use your sense of sight by observing the brightness of a small, low-voltage lamp; you will also judge the potential strength by means of taste sensa-

tions. For example, if two conductors that carry a low d-c potential are placed on the tongue, the tongue will receive a certain taste sensation. If the voltage is reduced, the taste sensation will not be as strong.

Caution: Never place conductors or wires in the mouth unless you are sure that the potential is obtained from battery cells and does not exceed 3 volts.

In future lessons, you will use a meter for testing and will have no further use for this method.

EQUIPMENT NEEDED

One 6-volt pilot-light bulb
One pilot light socket
Three 1.5-volt dry cells
One 6-foot length of pushback wire
Soldering iron
Solder
Cutting pliers
Fine sandpaper
Clean cloth

PREPARATION OF PARTS

In order that different methods of connecting the individual cells may be used, it will be necessary to solder separate wires to the positive and negative terminals of the three 1.5-volt dry cells. Connect the wires as follows:

1. Using the cutting pliers, cut six 4-inch lengths of pushback wire.

2. Push back the insulation for 1/2 inch from each end of each of the 6 leads.

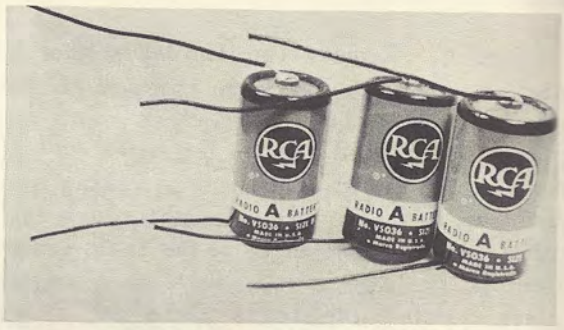
3. Lightly clean the top surface of the brass positive terminal of each of the 1.5-volt cells with the sandpaper.

4. Solder a lead to the brass positive terminal of each cell, as shown in Fig. 6-1*a*.

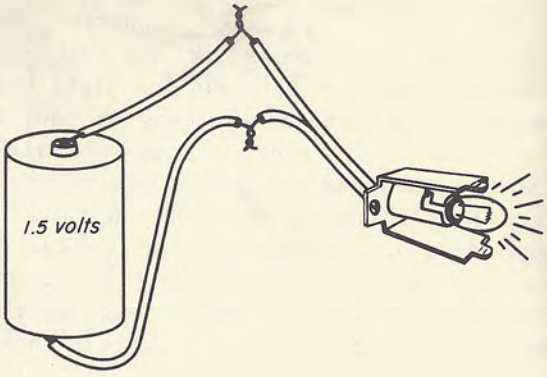
5. Clean a small spot on the zinc bottom of each cell.

6. Solder a lead to the clean spot on the bottom of the zinc casing of each cell. Your finished work should look like Fig. 6-1*b*.

(a)



(b)



Pilot light connected to 1.5 v cell

(c)

Fig. 6-1

Caution: Do not allow the two exposed leads of a cell to touch each other. If you do, the cell will become short-circuited and discharge in a short time.

EXPERIMENT 6-1

To test one dry cell using pilot-light and socket.

Procedure.

Step 1. Insert the 6-volt pilot-light bulb in its socket.

Step 2. Holding one lead of one of the dry cells in each hand, carefully contact the two terminals of the pilot-light socket with the bared ends of the two leads, as shown in Fig. 6-1*c*.

Step 3. Observe the brightness of the pilot-light bulb.

Step 4. Remove the two leads from the socket terminals. Wipe the exposed ends of of the two leads with a clean cloth and place the exposed ends of the wires on your tongue, as shown in Fig. 6-2, making sure that the two bare wires do not touch each other. Note the strength of the taste sensation as the two wires touch your tongue. After holding the leads there for a few seconds, remove them from your mouth.

Discussion. When you connected the pilot light bulb across the dry cell, you observed that the bulb did not light very brightly. In fact, it was easy to look at the glowing filament without eyestrain. This was because the bulb is made to produce full brightness only when 6 volts is applied to its terminals. The voltage of the cell was very small—only 1.5 volts. This voltage could not force enough current through the bulb to cause it to light brightly.

You noticed, too, that the taste sensation received by your tongue was not too strong. The 1.5 volts of the cell was not enough to produce much sensation.

Fig. 6-2

EXPERIMENT 6-2

To observe, by sight and taste, the effects of increasing the voltage.

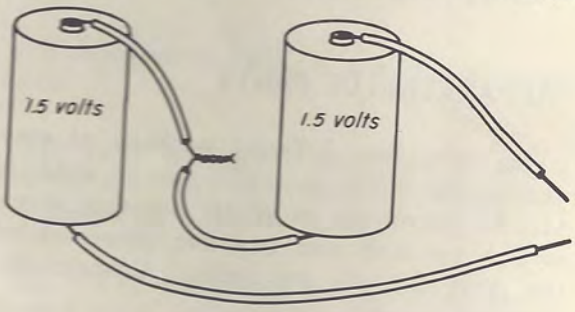
Procedure.

Step 1. To obtain a total potential of 3-volts, connect two of the 1.5-volt dry cells in *series aiding*, as shown in Fig. 6-3*a*.

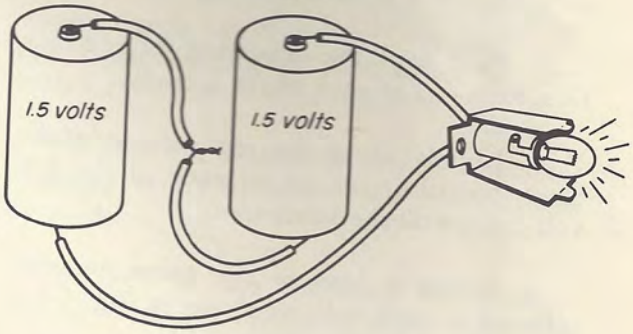
Step 2. Connect the two series-connected cells to the pilot-light socket, as shown in Fig. 6-3*b*.

Step 3. Observe the brightness of the bulb. Notice how much brighter it glows with a potential of 3 volts than when a potential of only 1.5 volts was used.

Step 4. Remove the two leads from the



two cells connected series aiding
(a)



two cells connected in series aiding across the pilot light
(b)

Fig. 6-3

socket and wipe their ends clean. Place the two leads on your tongue. The taste will seem stronger and more salty than the taste you experienced when a potential of 1.5 volts was used. Remove the two wires from the tongue.

Discussion. When the bulb was placed across the two series-aiding cells, it was easy to see that the electrical potential or voltage had increased over that obtained by using only one dry cell. The filament of the bulb glowed brightly, showing that the doubled electrical pressure forced more current through the resistance of the filament. Stated more simply, the increased voltage simply caused a greater electron movement through the filament wire. The filament wire, being a poor conductor of current, became hot and glowed even when only 1.5 volts was used; it became *hotter* and glowed brighter when 3 volts was used. The increased heat and light were due to the increased quantity of electrons forced through the thin, high-resistance filament wire.

The tongue, as we now realize, is sensitive to differences in electrical current flow. The increased voltage, due to two series-aiding cells, produced more current flow through the moist tongue; the taste sensation informed you that you could actually taste the greater force of the two cells.

EXPERIMENT 6-3

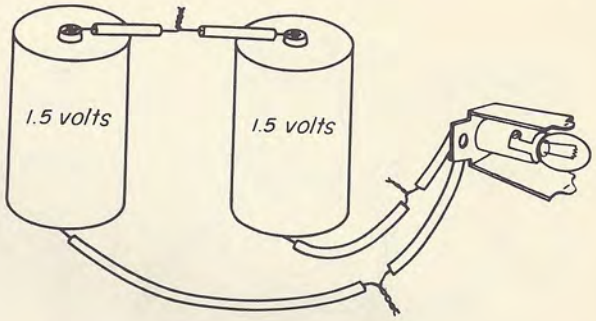
To connect two cells in series opposing and observe the effects by sight and taste.

Procedure.

Step 1. Connect two 1.5-volt cells in *series opposing,* as shown in Fig. 6-4.

Step 2. Connect the terminals of this series to the pilot-light socket and observe the filament of the bulb. Does it glow?

Step 3. Remove the leads from the socket and test the potential of the series with your tongue, as before. Is there any taste sensation? Does it have the sensation of one or two cells?



two cells connected in series opposing across pilot light, light does not light

Fig. 6-4

Discussion. You probably found that the bulb did not glow at all and that the only taste sensation was that of two plain wires connected to nothing. This was because an electrical tug-of-war was taking place. The electrical pressure (voltage) of the first cell equaled the pressure of the second cell, and, because the pressures were in opposite directions, they balanced each other. This caused the voltage of the first cell to cancel the voltage of the second cell, resulting in no voltage at all at the terminals of the series.

EXPERIMENT 6-4

To observe the effects of connecting two cells so as to *oppose* the potential of a third cell.

Procedure.

Step 1. Connect the three cells as shown in Fig. 6-5, with cells *2* and *3* aiding and opposing cell *1*. Connect the terminals of this series to the terminals of the pilot-light socket.

Step 2. Observe the glow of the heated filament. Make a mental comparison between the brightness obtained now and when a single cell was used.

Step 3. Remove the leads from the socket and test the series with your tongue. Is the taste sensation greater than that of a 3-volt battery, or is it more like that of a single cell?

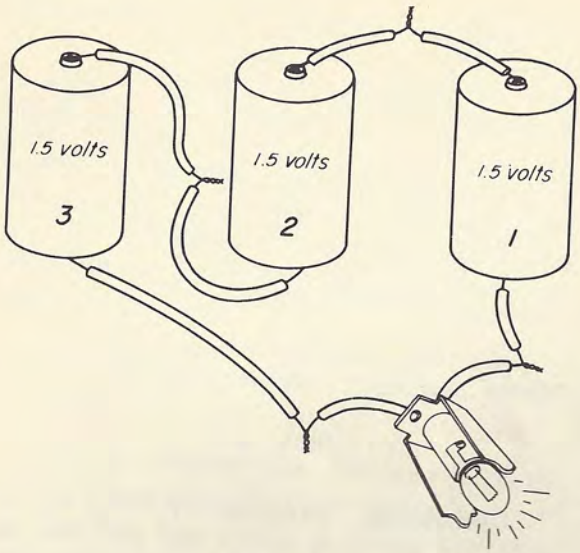


Fig. 6-5

Discussion. In this experiment, another electrical tug-of-war was taking place. Cell *1* and cell *2* balanced each other out by acting as though they were pulling on opposite ends of a rope; in this manner, they *opposed* each other. Cell *3*, not having another cell to oppose, was free to exert its 1.5 volts of electrical pressure and force current to flow through the circuit. The circuit behaved as though cells *1* and *2* were not there, and cell *3* was acting alone. The potential of cell *1* cancelled the potential of cell *2*, leaving a potential of cell *3* to do the work.

EXPERIMENT 6-5

To connect two cells in parallel and observe the results by sight and taste.

Procedure.

Step 1. Connect two cells in parallel, as shown in Fig. 6-6, making sure that the polarities (+ and –) are as shown.

Step 2. Connect the cells to the pilot-light socket and observe the glow. Is it like the glow that you observed when one cell or when two cells were connected in series?

Step 3. Remove the leads from the socket and test the voltage with your tongue. Does it taste like 1.5 volts or like 3 volts?

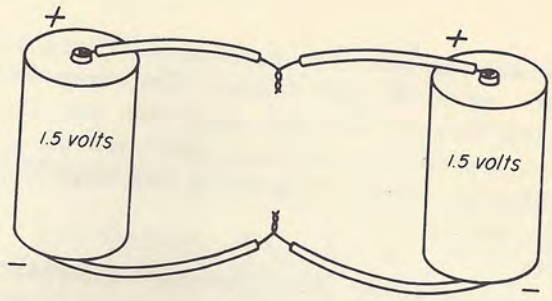


Fig. 6-6

Discussion. In this experiment, you observed that the two parallel-connected cells had the same electrical pressure as a single 1.5-volt cell. In other words, if one cell had been disconnected completely and removed from the circuit, leaving only one cell, the lamp would have had the same brilliance and the taste sensation would have been the same. Why bother connecting two cells in parallel, when one cell delivers the same voltage? The reason is simply this: Each cell in a parallel-connected circuit shares the current flowing through the load; this means that they last longer and will not discharge as quickly as a single cell.

In all of the preceding experiments, you used dry cells, which have a potential of 1.5 volts d.c. You learned in Theory Lesson 5 that the positive electrode of such a cell is made of carbon, the negative electrode is made of zinc, and the electrolyte is ammonium chloride in paste form.

In the experiments that follow, you will make your own battery cells by using two dissimilar metals in a home-made electrolyte.

PART TWO

OBJECT

The object of this part of the lesson is to:

1. Construct three home-made cells.

2. Use the sense of taste to determine if an emf is present.

3. Attempt to force current through the

high internal resistance of the cells so as to light a pilot-light bulb.

4. Determine if a potential can be developed across two electrodes made of the same metals.

5. See if the potentials of a cell can be affected by changing the make-up of a cell, by changing the quantity of electrolyte, or by changing the size and spacing of the metals used for the electrodes.

PREPARATION

Review Theory Lesson 5 so that you will be prepared to perform the following experiments. Since you are going to assemble three cells, you should become familiar with the part of Theory Lesson 5 that explains the action of different metals in an electrolyte solution.

These experiments are best performed on a kitchen table or worktable located where accidental spilling of liquid will not do much damage. However, since all of the materials used are common substances found in your home, no special precautions need be taken.

EQUIPMENT NEEDED

Three water tumblers
Eight ounces of cider vinegar
Three feet of stranded iron picture-hanging wire
Three feet of bare copper wire (not tinned)
Pilot-light bulb and socket (used in Part One)
Cutting pliers
Six inches of adhesive tape or cellophane tape

ASSEMBLY OF CELLS

Three cells will be assembled, each using an acid (vinegar) as the electrolyte. The electrodes will consist of copper (+) and iron (−). Assemble the cells in the following steps:

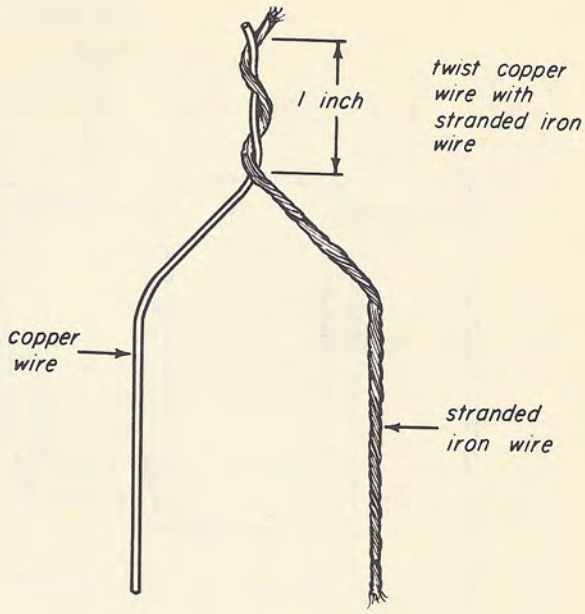


Fig. 6-7

Step 1. Cut three 6-inch lengths of copper wire and three 6-inch lengths of iron wire.

Step 2. Make up two pairs of joined electrodes by tightly twisting together a copper wire with an iron wire for a distance of one inch, as shown in Fig. 6-7.

Step 3. Place the two pairs of joined electrodes and the remaining single copper and iron electrodes in the glass tumblers in the arrangement shown in Fig. 6-8. Arrange the electrodes and the spacing between the glass tumblers so that each electrode is about 1/4 inch from the bottom of the glass.

Step 4. Fasten each electrode to the top edge of the glass, using six 1-inch strips of cellophane or adhesive tape, one strip for each electrode.

Step 5. Carefully pour an equal quantity of cider vinegar into each glass, allowing each glass to become about one-third full.

Step6. Wrap the bare end of the single copper-wire electrode around one of the 3-foot test leads, by twisting them together, as shown in Fig. 6-8. In the same way, connect the other 3-foot test lead to the single iron-wire electrode.

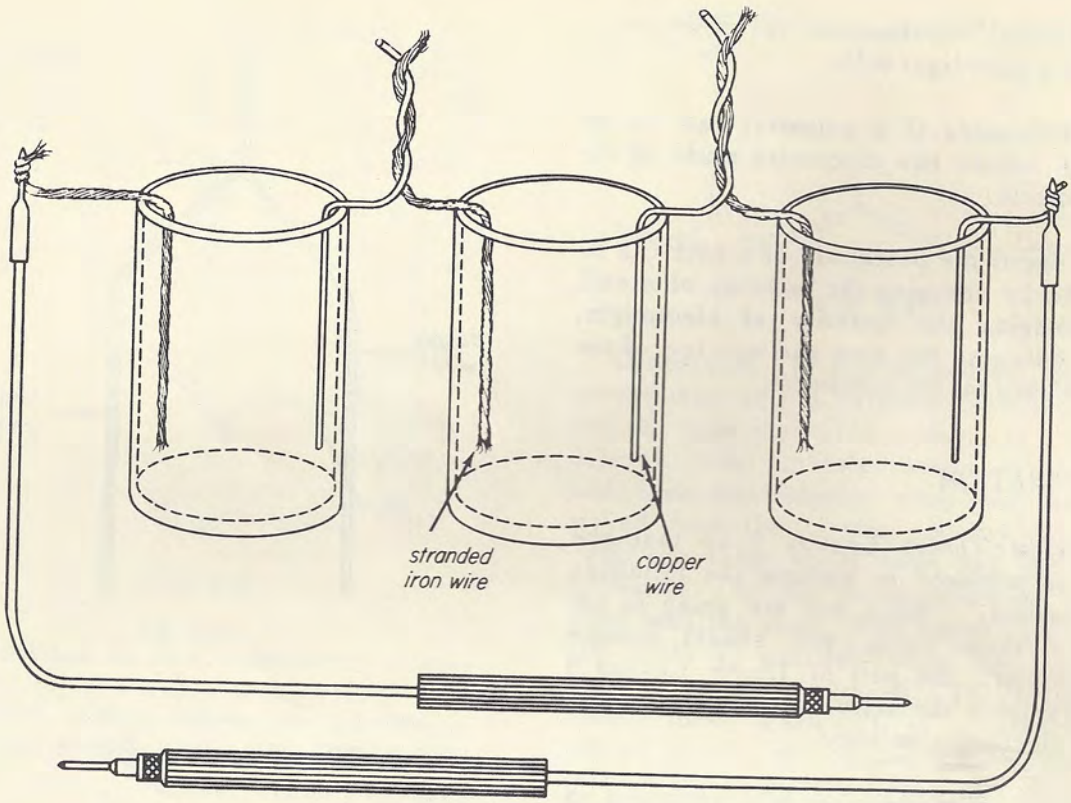


Fig. 6-8

EXPERIMENT 6-6

To test the potential of three home-made cells.

Procedure.

Step 1. Wipe the free ends of the two 3-foot leads with a clean cloth and place the exposed ends of the wires on your tongue as in the other experiments.

Step 2. Note the strength of the taste sensation and compare it with the taste sensation of the series-connected dry cells. Try to guess the value of emf produced in the experiments in Part One of this Lesson. Remove the test leads from your mouth.

Step 3. Connect the 3-foot leads to the two terminals of the pilot-light socket. Do not be surprised if the bulb does not light or even glow faintly. This will be explained in the discussion that follows.

Discussion. Your taste sensation told you, in Step 2, that a voltage was present. This proved that electrical pressure existed when unlike metals were placed in an acid. Since the three copper-iron cells were connected in series-aiding, the total emf across the ends of the 3-foot test leads was three times the value of the voltage of one of the copper-iron cells. The total potential across the three home-made cells is equal to about the same voltage as a single 1.5-volt dry cell. In other words, the potential of each of your home-made copper-iron cells is equal to about 0.5 volt under load. Your tongue was the load. If the total emf of the three cells is 1.5 volts, why did the pilot-light bulb fail to glow when it was placed across the three series-connected cells in Step 3? The answer is that the internal resistance of each of the home-made cells is very high and does not pass enough current to heat the filament. The resistance of the filament is very low compared with the total internal resistance of the battery. When the battery resistance and the filament resistance are combined, the voltage divides; practically *all* of the battery potential is across its own internal resistance, and very little voltage remains

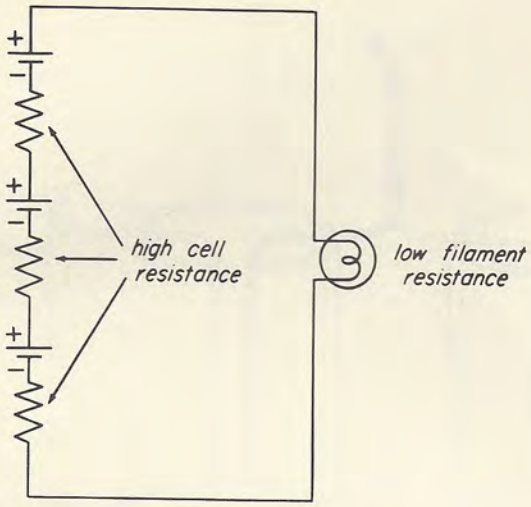


Fig. 6-9

to operate the bulb. (See Fig. 6-9.) Although a voltage-dividing action took place when the high resistance circuit of your tongue was in series with the high resistance of the battery, both *loads* showed high resistance. Therefore, part of the battery voltage remained across the wires resting on your tongue, allowing enough current to flow to arouse the sensitive sense of taste.

You might ask why the emf produced by each of the home-made copper-iron cells is only about 0.5 volt? The Electrochemical Series Table in Theory Lesson 5 shows that the emf should be about 0.78 volt. The answer is that the vinegar used as the electrolyte is a very weak form of acetic acid. If a strong solution had been used, a greater emf would have been produced. In addition, the capacity of each cell was very small because the area of the electrodes exposed to the electrolyte was very small. So, when a load (the bulb or tongue) was applied to the terminals, the current drawn exceeded the capacity of the cells. Therefore, the positive electrode became polarized, and the internal resistance increased. As a result, very little power was delivered to the load.

EXPERIMENT 6-7

To reduce the quantity of electrolyte in order to observe the effect on the emf produced.

Procedure.

Step 1. Carefully pour most of the electrolyte from each glass into a glass jar, allowing enough electrolyte to remain in the three glass tumblers to immerse the bottom of each of the six electrodes for 1/2 inch.

Step 2. Use the taste test to discover whether the battery potential has been lowered due to the reduction in the amount of electrolyte.

Discussion. The sensation of taste told you that the battery potential remained about the same as when the original quantity of electrolyte was used. It is not the *amount* of electrolyte that determines the strength of the generated emf, but the strength or *type* of electrolyte used.

EXPERIMENT 6-8

To find what effect distance between the copper and iron electrodes has on the voltage of the cells.

Procedure.

Step 1. Repeat the taste test of Experiment 6-7, Step 2, and try to remember the amount of sensation your tongue receives.

Step 2. Bend all of the copper- and iron-electrode wires in the three glass tumblers so that there is only about 1/4 inch between each pair. Make sure that the electrodes do not touch each other. This arrangement is shown in Fig. 6-10.

Step 3. Determine again, by means of the taste test, whether the battery potential has changed due to the difference in spacing between the electrodes.

Discussion. Your sense of taste told you that the potential strength of the cells remained the same, even though the spacing between the electrodes was changed. Of course, if you had carelessly allowed an iron electrode and a copper electrode in one of the cells to touch, the cell would have been shorted out of the circuit, and

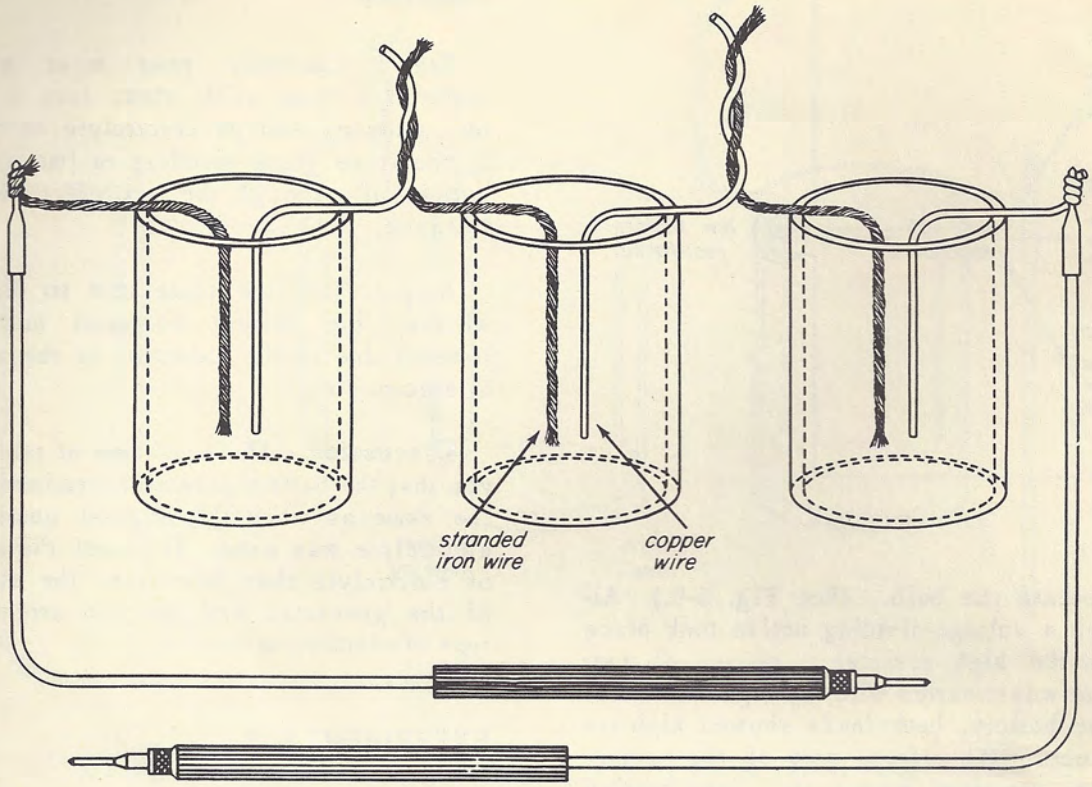


Fig. 6-10

the potential strength of the battery would have been decreased to two-thirds of its original total value.

EXPERIMENT 6-9

To learn what effect the use of electrodes made of the same metal has on the emf produced.

Procedure.

Step 1. Remove the three copper-wire electrodes from the three cells and replace them with iron-wire electrodes. The three cells should now have iron-wire electrodes only.

Step 2. Repeat the taste test and try to detect any signs of voltage.

Discussion. Your taste sensations informed you that no potential was present. This proved that, in order to produce an emf, it is necessary to place *different* metals in an electrolyte solution. The iron wire used for one of the electrodes is just as negative with respect to hydrogen as the other electrode made of iron wire. Since *both* iron-wire electrodes are equally negative, zero potential exists between them.