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## CELLS AND BATTERIES—POWER AND ENERGY

ASSIGNMENT 9

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# CELLS AND BATTERIES—POWER AND ENERGY

In circuits and drawings we have been dealing with in the preceding assignments, we have shown batteries and cells as the source of the emf, but no explanation of the operation of the batteries or cells has been given.

In this assignment we shall discuss a number of different types of cells and batteries and shall compare the characteristics of the various types. A group of cells and batteries is pictured in Figure 1. Note the variety of sizes, shapes, and terminal arrangements. (This is just a representative grouping and many other styles will be found.)

**The purpose of a cell, or battery, is to produce an emf, or voltage.** The emf so produced will cause electrons to flow through a closed circuit. Cells produce an emf by changing chemical energy into electrical energy.

It will be both interesting and useful to know something of the operation of batteries. Most electronic equipment is operated from the 110 volt alternating current supplied by the power companies, but transistorized radios and much specialized electronic equipment operate from batteries. Typical types of electronic and radio equipment operating from batteries are: Auto radios, two-way radio systems in police cars and taxicabs, receivers and transmitters on ships and in aircraft, and portable radio equipment of the armed forces, portable receivers for entertainment, radiation meters, traffic radar devices, and many others. Thus, it is necessary for a qualified electronics technician to understand the operating principles of cells and batteries.

## The Voltaic Cell

In the 18th century, an Italian physician (Galvaini) made a very crude form of electric cell. He discovered that two pieces of different metals touching the nerves of the leg of a freshly-skinned dead frog would cause muscular contractions, or jerks, provided the other ends of the metals were in contact. He thought this electrical effect was caused by the frog.

Another Italian (Volta) proved that it was possible to produce electrical effects apart from any living creature. We take this for granted now, but it was a very important discovery at the time. Volta built a simple electric cell consisting of two rods of different materials in a weak solution of sulphuric acid. The two rods he used were carbon and zinc. Such a cell is illustrated in Figure 2(A). The rods or plates used in cells are called the **plates** or **poles** of the cell, and the solution used is called the **electrolyte.**

When a copper wire is connected between the two rods, outside the cell, as shown in Figure 2(A), the wire will become warm due to the flow of electrons through the wire. If we had such a cell we could place a voltmeter across the two terminals of the cell and measure the voltage produced. This is shown in Figure 2(B). If we preferred, we could place an ammeter in series with the copper wire connecting the terminals of the cell, in order to measure the flow of current in the wire. The cell we have just discussed is called a "Voltaic Cell." The zinc rod is the **negative** plate of the cell, and the carbon rod is the **positive plate.**

In this cell, voltage is produced due to chemical action within the cell. The weak solution of sulphuric acid enters into a chemical reaction with the zinc plate. This action goes on at a slow rate if there is no complete circuit outside the cell, from the zinc to the carbon plate. When a complete circuit is established outside the cell, such as the copper wire between the two terminals in Figure 2(A), the chemical action increases, and the zinc plate will be "eaten" by the acid at a much faster rate. After this type of cell has been in operation for some time, the zinc plate will be "eaten away" by the acid, and will have to be replaced. Also, the acid solution will have to be replaced, since it has changed chemical composition and is no longer a weak solution of pure acid, but contains part of the zinc from the negative plate.

While this type of cell is not used in present day electronics installations, there are several actions which occur in it that also occur in modern cells, so we will discuss the action in this cell.

Let us trace the current path in the circuit of Figure 2(A). The current flows from the negative terminal of the cell, through the external circuit to the positive terminal of the cell, and **through the cell from the positive plate to the negative plate.** This current flow from the positive to negative pole **inside** the cell is actually carried out by the chemical action of the cell. There is some opposition offered by the electrolyte in conducting the current **inside** the cell, and this resistance is called the **internal resistance of the cell.** It is advantageous to have as low an internal resistance in a cell as possible.

If a Voltaic Cell is operated for any considerable length of time, bubbles of hydrogen gas collect on the carbon rod. This is illustrated in Figure 2(B). These hydrogen bubbles are produced by the chemical action taking place in the cell. Hydrogen is **not** a conductor of electricity, so when a sheath of hydrogen gas forms around the carbon plate, this plate becomes insulated from the electrolyte. More opposition is offered to the flow of current **through** the battery, or to state it another way, the **internal resistance** of the cell is increased. The result of increasing the internal resistance of a cell is that the output voltage will become lower. In Figure 2(B), the voltage output of the cell, as indicated by the voltmeter, would gradually decrease as the hydrogen bubbles form on the carbon plate. **The formation of hydrogen bubbles on the positive plate is called Polarization.**

Polarization is undesirable, since it increases internal resistance of the cell, and must be minimized if a cell is to be operated for a considerable length of time. It can be eliminated by adding a **depolarizer** to the cell. This depolarizer is a chemical which will not interfere with the chemical action taking place in the cell, but which will combine with the hydrogen bubbles and produce water. This removes the insulating sheath of hydrogen from the positive pole of the cell, and thereby reduces the internal resistance.

Another undesirable action which takes place in a cell is called **Local Action,** and results from impurities in the zinc plate. Zinc is one of the most difficult of metals to obtain in a **pure** state. Carbon is used in the process of purifying zinc, and some of this carbon remains in the form of tiny particles in the zinc plate. These small particles of carbon, the electrolyte, and the zinc pole set up small cells on the surface of the zinc plate. This is shown in Figure 2(A). The result of having these tiny cells on the surface of the zinc plate is that the zinc plate will be "eaten away" much more rapidly at these spots than on the remainder of the plate. This will require that the zinc plate and the electrolyte be replaced sooner than they would have if the zinc had been pure. No cheap method has been developed to eliminate local action.

**A cell is said to be charged** when the chemicals in it are in such a state that the cell is able to deliver its rated voltage and current to the external circuit.

There are two general types of cells. These are the **primary cell** and the **secondary cell.** The Voltaic Cell which we have discussed is one of the many primary cells. **A primary cell is a cell which cannot be recharged when it is once discharged.** When a Voltaic Cell is discharged it must be rebuilt. **A secondary cell may be recharged when it is discharged.** We shall discuss some secondary cells and methods of charging these later in this assignment.

When an external circuit is connected to a cell, the cell is said to be **discharging.** A cell is completely **discharged** when it produces no voltage across the terminals.

## The Dry Cell

A form of primary cell which is used very widely is the Dry Cell. The name Dry Cell is somewhat misleading because the cell is not dry, the chemicals being in the form of moist paste. Figure 3 shows the construction of a dry cell and several are pictured in Figure 1. The Dry Cell is the "old standard" in the field. These cells have been manufactured for more than 50 years, and—although superior cells have been developed, dry cells are still used very widely, particularly because they are the cheapest commercial cells available.

The negative plate of a dry cell is a zinc cylinder which forms the walls and bottom of the cell. The positive plate is a carbon rod placed in the center of the cylinder. The space between the carbon rod and the zinc container is filled with a paste of ammonium chloride, manganese dioxide, and powdered graphite. The top is covered with pitch or wax to prevent the loss of water by evaporation. A pin-hole in the pitch or wax permits the gas, which results from chemical action in the cell, to escape.

The ammonium chloride is the chemical which acts upon the zinc to supply the chemical energy which is converted into electrical energy. The manganese dioxide acts as the **depolarizer** to remove gas bubbles from the positive pole. The graphite is to reduce the **internal** resistance.

The emf of a new dry cell is about 1.5 volts. As the cell is discharged the output voltage will gradually decrease. In this cell the zinc is "eaten away" by the chemical action, and holes will usually be eaten through the zinc cylinder before the cell is completely discharged. Also the internal resistance of the cell increases greatly when the cell is partially discharged, due to the drying out of the paste electrolyte.

Dry cells are made in several sizes. The smallest practical cell, shown in Figure 1(M), is the "pen-lite" cell, which is about ½ inch in diameter and about 2 inches long. Another dry cell is the standard flashlight cell. It is 1¼ inches in diameter and 2½ inches long. The largest dry cell in use today is the #6 cell which is 2½ inches in diameter and 6 inches long. One of these is pictured in Figure 1(C). Each of these dry cells has an emf of 1.5 volts. The larger the cell, the greater the current it can deliver.

You may be wondering what the difference is between a cell and a battery. A battery is merely a group of cells connected together and usually placed in the same container. The cells may be connected in series, in parallel, or in series-parallel.

A type of battery which was once quite popular, and is still sometimes used in portable electronic equipment is the 45 volt "B" battery. The internal construction of such a battery is shown in Figure 4. In this battery, thirty small dry cells are connected in series. When the cells are connected in series, their voltages will add, so the full output voltage of this battery is 30 times 1.5 or 45 volts. On most of these batteries, there is a 22½ volt tap brought out to a terminal on the outside of the battery. This is shown in Figure 4. Sometimes the terminals are in the form of a receptacle, or socket, as in the case of the battery of Figure 1(D). Notice how the individual cells are connected together to form a battery. The positive terminal of the battery is connected to the positive pole of one of the cells. The negative pole of this cell is connected to the positive pole of the next cell. This continues for the entire thirty cells, and the negative pole of the last cell connects to the negative terminal of the battery. Check to see if you agree that the 22½ volt tap is actually 22½ volts more positive than the negative terminal of the battery.

Since the individual cells used in the 45 volt batteries are small, the maximum current that such a battery can provide is small. Twenty to 40 milliamperes is considered a reasonable current drain for these batteries. The large #6 dry cells can supply as much as 500 milliamperes or ½ ampere for a reasonable length of time.

We have seen how it is possible to connect a number of dry cells to get an increased voltage. Thirty 1½ volt dry cells connected in **series** produced a total voltage of 45 volts.

The total current which can be safely drawn from the **series** arrangement is the safe current of one of the individual cells, since the total current flows through each of the cells. In the 45 volt battery, each of the cells can safely supply 1½ volts at 40 **mA.**, which accounts for the fact that the entire battery can supply 45 volts at 40 **mA.**

It is possible to increase the current which can be safely supplied by cells by connecting them in **parallel.** This is shown in Figure 5(A). Four 1½ volt dry cells are connected in parallel. To do this, the negative terminals of all of the cells are connected together, and this is the negative terminal of the battery. The positive terminals of all of the cells are connected together and this is the positive terminal of the battery. The output voltage of the battery is equal to the output voltage of one of the cells, 1½ volts, but the total current drawn from the battery can be equal to the sum of the individual allowable currents of the cells. For example, if the four cells are #6 dry cells, which can supply 1½ volts at ½ ampere, then the battery can supply 1½ volts at 2 amperes. The reason for this is shown in schematic diagram Figure 5(B). Each cell is supplying its allowable current of ½ ampere, and the current through the resistor is the sum of the currents from each of the four cells, or 2 amperes.

Figure 6 shows a series-parallel arrangement, which is used when the battery current and voltage will be greater than that for each cell. Let us look at the row of cells nearest the resistor. These four cells are connected in series since the positive of the first is connected to the negative of the second, etc. The total voltage of this row of cells is, therefore, 4 times 1½ volts or 6 volts. If these are #6 dry cells, each may safely deliver ½ ampere, so this row can deliver 6 volts at ½ ampere. The other five rows of cells are identical with the row nearest the resistor. Each of these rows has 6 volts and can supply ½ ampere. These **rows** are connected in parallel. The battery voltage will be 6 volts, and the total current which may be drawn from this battery is the sum of the current which may be supplied by the individual rows, or 6 times ½ ampere or 3 amperes. Notice that the resistor in the diagram is called the **load.** This term is used very widely in electronics work. The resistor or other circuit component (it could be a coil) which is connected to the source of emf is called the load. In this case, our battery supplies 6 volts at 3 amperes to the load.

To summarize the connection of cells, we could say if cells are connected in **series, more voltage** is available and if cells are connected in **parallel, more current** is available.

Dry cells are **primary** cells, and the zinc containers are "eaten" away during their discharge so that they can not be recharged. When the output voltage drops below a satisfactory level, dry cells and batteries made from dry cells, must be discarded, and new batteries installed. As dry cells discharge, the internal resistance increases, and when the output voltage has fallen about 1/5 of the original voltage, the internal resistance of the cells become so high that the operation of the cell is unsatisfactory. Thus, a 45 volt battery should be replaced when the output voltage drops to about 36 volts. $45 - (1/5 \times 45) = 45 - 9 = 36$.

On the outside of most dry cells and batteries will be found a notation, telling by what date the battery should be placed in operation. This is because these batteries have a definite **shelf life**. If they are stored for too long a time they will become unsatisfactory. This is due mainly to the **local action** which takes place within the cell.

## The Alkaline Cell

Another type of cell which has proved quite popular for powering transistorized equipment, and other electronics units, is the Alkaline Cell. These cells deliver 1.5 volts as do the dry cells and have the same general appearance as the dry cells. (See Figure 1.) Their chief advantage over the dry cells is the fact that they maintain their peak power output over a much longer period of time. They will provide up to 10 times more service than a comparable size dry cell.

The alkaline cell has a negative electrode of zinc which has been amalgamated with mercury. The positive electrode is manganese dioxide, and the electrolyte is caustic solution (usually potassium hydroxide).

## The Mercury Cell

Mercury Cells and Mercury Batteries are manufactured in many sizes and shapes and, from the physical appearance, resemble the carbon-zinc dry cell. From the chemical composition viewpoint, however, the mercury cell is entirely different than the dry cell.

The case of the mercury cell is a zinc container which is often covered on the outside with some more durable metal such as chromium, or in some cases plastic, to prevent leakage. The center rod is a mixture of carbon and mercuric oxide. The electrolyte is in the form of a paste, the active ingredient of which is potassium hydroxide. The chemical reaction which occurs during discharge in this cell is entirely different than that of the dry cell and as a result the polarity is reverse of that of a dry cell—that is, the zinc case of the cell is the positive terminal and the center rod is the negative terminal of the cell. TERMINAL REVERSED

The output voltage of the mercury cell is slightly less than that of the dry cell, as it produces approximately 1.35 volts, or 1.4 volts depending upon the depolarizer used, compared to 1.5 volts for the dry cell. The chief advantage of the mercury cell is that, for the same size cell, it is capable of delivering its rated current for a longer period of time, even longer than the alkaline cell. Also, one of the smaller mercury cells will give the same service as a larger dry cell. Because of this space saving feature, these cells find wide application in hearing aids, transistorized radios, space probes, and other applications where size and space limitations are of particular importance. Other advantages of the mercury cell over the dry cell include longer shelf life, and lower and more uniform internal resistance during the entire useful life of the cell.

## Comparison of Commercial Primary Cells

Perhaps the most satisfactory way of comparing the commercially available primary cells is to summarize the information which has been given in the form of a chart. This will enable you to compare them at a glance.

Comparison Chart for Primary Cells

| TYPE OF CELL | VOLTAGE OUTPUT | COST | INTERNAL RESISTANCE | TOTAL ENERGY DELIVERED | PHYSICAL SIZE FOR RATED CURRENT |
|---|---|---|---|---|---|
| DRY CELL | 1.5V | CHEAPEST | HIGHEST | LOWEST | LARGEST |
| ALKALINE CELL | 1.5V | MEDIUM | MEDIUM | MEDIUM | MEDIUM |
| MERCURY CELL | 1.35V to 1.4V | HIGHEST | LOWEST | HIGHEST | SMALLEST |

## Lead–Acid Storage Cell

In the explanation on primary cells, we saw how electricity was produced by chemical action, and you will remember that the cells were made up with two plates and a chemical solution called the electrolyte.

When an electrical circuit is completed between the plates outside the cell, a chemical action "eats away" some of the parts, but it produces an emf which causes a current to flow in the circuit.

The lead-acid storage cell has two plates or sets of plates and an electrolyte, but it differs from the primary cell in that its plates are not eaten away during discharge, but are just changed to another chemical composition. After being discharged, this cell can be recharged by forcing an electric current through it in the opposite direction to the discharge current. This charging process changes the plates back to their original chemical composition, and the cell is ready to be used again. We shall deal with the charging process shortly, but let us examine the construction of the cell.

A typical storage battery is shown in Figure 7. This type of battery was used in automobiles for many years and consists of three lead-acid cells connected in series.

The positive plates of a lead-acid cell are composed of lead peroxide, and the negative plates are spongy lead. To secure more surface area, the plates of a lead-acid cell are actually several plates connected together. This may be seen in Figure 7. All of the positive plates of one cell are connected together, and all of the negative plates of one cell are connected together. These sets of positive and negative plates are sandwiched together, so that there is first a negative plate and then a positive plate, then a negative plate etc. The plates are held apart by pieces of insulating material called **separators**. Separators are made of rubber, glass rods, or corrugated wood. The electrolyte is a dilute or weak solution of sulphuric acid. When this cell is connected to a load and discharged, the chemical composition of both plates will change to lead sulphate, which is a chemical combination of **lead and sulphuric acid**. The electrolyte changes from sulphuric acid to water. **Neither** of the plates is "eaten away" by the acid. After this cell has been discharged, or partially discharged, it can be changed back to its original chemical composition by **forcing** current through the cell in the opposite direction to the discharge current. This is known as **charging** the cell, and is done by a **charger.**

When the cell has been charged, the positive plate is again lead peroxide, the negative plate is again spongy lead, and the electrolyte is a weak solution of sulphuric acid. Now we see why this type of battery is in such wide use. Its chemical action is **reversible.** Once it has been discharged, all that has to be done to recharge it is to connect it to a charger. This is much cheaper than replacing it with a new battery.

The voltage of a lead-acid cell is 2.1 volts. This voltage remains practically constant until the cell is almost completely discharged, at which time the voltage drops to zero. The amount of current which can be delivered by this cell gradually drops as the cell is discharged. Since the voltage is practically constant, when no current is being drawn, regardless of the state of charge, a voltmeter is of little value in checking a lead-acid cell.

A very simple method of checking the state of charge of a lead-acid cell is by checking the **specific gravity** of the electrolyte.

As you perhaps know, the same amount, or volume, of different liquids have different weights. For example, one gallon of sulphuric acid weighs more than one gallon of water, while one gallon of gasoline weighs less. We call this the specific gravity of the liquid, which means the ratio of its weight compared to the weight of an equal volume of water. Sulphuric acid weighs about twice as much as water, or 1.835 times as much, to be exact. As we mix the two for the electrolyte, the specific gravity of the solution will be somewhere between 1 and 1.835.

In the explanation of the lead cell, you remember, it was stated that when the cell was charged, the electrolyte was acid, and when the cell was discharged the electrolyte was water. In practical work, however, we never reach the condition of absolute discharge and no matter what state of charge the cell may have, there is always both acid and water in the electrolyte. As the cell charges, the chemical action takes place, and the amount of acid increases, giving us a very handy method of testing the state of charge of the battery.

It can be seen that we could pour out the electrolyte, weigh it and compare its weight to an equal amount of water. This would give us the specific gravity of the electrolyte, but, of course, such a method would not be convenient.

The handy way to check the specific gravity of the electrolyte is through the use of a hydrometer. The hydrometer is shown in a drawing in Figure 8. The hydrometer consists of a large glass tube that has a rubber bulb at the top, and a small rubber tube at the bottom. Inside the large glass tube is a little float, which is weighted at the lower end with shot and has a scale in the upper part of the tube. Since the float is made of glass, the scale may be placed on the inside of the small tube, and we can read it from the outside.

To use a hydrometer to measure the specific gravity of the electrolyte, the small rubber tube is placed in the electrolyte, and the bulb on top of the hydrometer is squeezed. When the rubber bulb is released, electrolyte will be drawn up into the large glass tube, and the float will float in the electrolyte. The more acid that is in the electrolyte, the heavier, or denser, it will be. The float will sink only as far as the density of the liquid will let it. The more dense the liquid, the less the float will sink in the liquid.

By properly marking the scale, we can read the specific gravity of the electrolyte directly from the scale. The point on the scale that comes level with the surface of the liquid shows the specific gravity.

The scale in the hydrometer used to check the specific gravity of the electrolyte in a lead-acid storage cell is marked off in graduations from 1300 to 1100. The number 1300 means a specific gravity of 1.3 and 1100 means 1.1, but as it is much easier to say eleven fifty or twelve hundred than one and fifteen hundredths, or one and two tenths, the decimal point is left out.

The range of this scale, 1.1 to 1.3 is much less than the 1 to 1.835 that we mentioned before, but it covers the ordinary working range of the cell. If the acid gets so strong that its specific gravity is over 1.3, it will injure the plates and separators. If it gets so weak that it is below 1.1, the chemical action is so slow that the cell is of no use. A specific gravity reading of 1300 is considered a full charge, and 1100 a complete discharge.

A battery should never be allowed to stand for a long period of time in a discharged condition, since it may be ruined. This is because the plates, which are lead sulphate when the cell is discharged, may become so hard that the charging process cannot be performed. When this has happened to a battery it is said to be **sulphated**.

The lead-acid battery is often called a **storage battery**. For years the storage batteries in cars consisted of three cells in series, as shown in Figure 7. (3 x 2.1V. per cell = 6.3V.) Since 1955 most car batteries contain 6 cells in series, producing 12.6 Volts.

The amount of electricity, or current, that a cell can produce is called its capacity. From the chemical actions just explained, it can be seen that the greater amount of active plate material we have, the more electrical energy the cell will be able to produce.

The capacity of a storage battery is measured by the amount of current in amperes multiplied by the time it is produced in hours. This makes the unit for measuring the capacity of a battery the Ampere-Hour.

However, this is not quite as simple as it sounds, for a cell that will deliver 10 amperes for 10 hours will not necessarily deliver 100 amperes for 1 hour. In general, the higher the current, or rate of discharge, the smaller the capacity will be. Since capacity is a variable factor, when the time of discharge is variable, the time for discharging is generally set at 8 hours. Thus, a 100 ampere-hour battery will deliver 12½ amperes for 8 hours, and a 300 ampere-hour battery will deliver 37½ amperes for 8 hours.

## The Edison Cell

Another secondary cell, or cell that can be charged, is the Edison Cell. This cell is rarely used in automobiles, because it is rather costly, but it is used in many commercial applications, since it will stand much abuse and has a very long life.

In this cell, the active materials are nickel peroxide for the positive plate and finely divided iron for the negative plate. The electrolyte is a 26 per cent solution of potassium hydroxide.

Like the lead-acid cell, the plates are assembled in groups, and plates are held apart by spacers. The container for these cells, or batteries is usually made of nickel-plated steel.

The chemical reactions which take place in this cell are very complex and have not been explained to the satisfaction of all chemists. The cell has an average voltage of 1.2 volts, which is lower than other lead-acid types, but it is not injured by discharging to zero voltage, by standing idle, or by over charging. The specific gravity of the electrolyte does not change during the charging and discharging processes. The state of charge of this battery should be determined by measuring its output voltage while it is delivering its rated current. The voltage of a fully charged Edison cell is 1.37 volts.

## The Nickel–Cadmium Cell

One of the latest to be developed is the Nickel-Cadmium Cell. The chemical arrangement of this cell is similar to the Edison cell except it uses cadmium instead of iron. These cells exhibit approximately the same characteristics as the Edison cell.

The chemical elements within the nickel-cadmium cells have been balanced so that the hydrogen and oxygen which are produced during charging are combined to form water, thereby replenishing the electrolyte which would otherwise be lost. This makes it possible for the cells to be produced in a sealed container and they are often manufactured in the same general shapes as dry cells. (See illustration (H) of Figure 1.) For this reason the small units are sometimes **incorrectly** called rechargeable dry cells. Because their characteristics are entirely different than dry cells, the nickel-cadmium cells should not be confused with dry cells. Nickel-cadmium cells find wide application in powering electric razors, electric tooth brushes, rechargeable flashlights, etc. Each individual nickel-cadmium cell delivers approximately 1.25 volts and they are often arranged in a series combination to form batteries which will deliver higher voltages. Note particularly that since these cells can be charged they are **secondary** cells.

## Charging Batteries

To charge a battery it is only necessary to connect the battery to a source of emf higher than the battery voltage. Thus, to charge a 12.6 volt storage battery, it should be connected to a source of emf of about 16 volts. The proper way of connecting a charger to a battery is shown in Figure 9. Since the voltage of the charger is higher than the battery voltage, it will force current **through the battery** from the negative terminal to the positive terminal. This current flow **through the battery** is in the opposite direction to the discharge current which, you will recall, flows from the positive to the negative plates. The flow of current from the negative to the positive plates in the storage cell reverses its chemical process, restoring the battery to its original charged state.

Few precautions need be observed in charging an Edison Cell or a nickel-cadmium cell since they are not affected by overcharging, too fast a charging rate, etc., but several precautions should be observed in charging a lead-acid battery.

As a lead-acid battery is charged, hydrogen gas bubbles up from the plates. Hydrogen is an explosive gas, so charging should be done in a well ventilated room.

The charging rate should be adjusted, by adjusting the charger voltage, so that only a small amount of bubbling occurs around the plates. The amount of bubbling is proportional to the amount of heat produced in the battery, since all chemical processes produce heat. If the charging rate is too high, too much heat will be produced in the battery, and the plates of the battery will warp and adjacent positive and negative plates are likely to touch together, ruining the battery. When a battery has reached a specific gravity of 1300, it should be disconnected from the charger, as overcharging a battery will cause the plate material to be washed away by the bubbling action of the electrolyte. Normally, a battery can be charged at a high rate when its charge is low, and the rate should be reduced as the battery approaches full charge. During charging, part of the water in the electrolyte will boil away. The level of the electrolyte should be brought up to slightly above the top of the plate by adding distilled water. Ordinary drinking water should not be added, since it contains a lot of chemicals.

Battery chargers may be motor driven generators, or they may be rectifier circuits which change the 110 volts a-c to the proper value of d-c voltage. In either case, provision is made for regulating the rate of charge.

## Power and Energy

Let us examine a few fundamental concepts of physics and apply them to electrical circuits.

In physics, **force** is defined as that which produces, or tends to produce motion. Thus, if we push an automobile, we are applying force to the automobile. In an electrical circuit, the **force** is the electromotive force, and is, of course, measured in volts. The emf is the **force** in an electrical circuit which produces motion of the free electrons, or current flow. **Current** is the **motion** in an electrical circuit. In physics, force produces **motion** against an opposing

**force,** such as friction or gravity. In an electrical circuit, the opposition is the **resistance** of the circuit.

**Work** is defined as the production of motion against an opposing force. **Power is a measure of the rate at which work is done.** Thus, if a certain amount of work is to be done, a large **powerful** motor would do the job more quickly than a small, less powerful motor. Power in electrical circuits is measured in **Watts.**

Another term which is used quite often in physics is **Energy. Energy is the ability to work.** One of the fundamental laws of nature is that energy can be neither created or destroyed, it can, however, be converted from one form to another. The batteries which we just studied did not create electrical energy. They changed chemical energy to electrical energy. In resistors, electrical energy is changed to heat energy. In an electric motor, electrical energy is converted into the energy of mechanical motion.

Electrical energy is measured in watt-hours. Before dealing with this term, let us take up the **watt.**

To repeat: The **watt** is the unit of electrical **power.**

There are three formulas which are used in finding the electrical power in an electrical circuit, or component of a circuit.

These formulas are:

(a) $P = E \times I$

(b) $P = I^2 \times R$

(c) $P = \frac{E^2}{R}$

P equals power in watts.
E equals the emf in volts
R equals the resistance in ohms.
I equals the current in amperes.

Formula (a) is used when we wish to know the power, with the voltage and the current known.

Let us apply this formula to the circuit shown in Figure 5(B) to find the amount of power being delivered by the battery. The voltage is 1½ volts, and the total current is 2 amperes. Putting these values in the formula we have:

$P = E \times I$

$P = 1\frac{1}{2} \times 2$

$P = 3$ watts

The total power being delivered by the battery (3 watts) is being supplied to the resistor. Since this power represents electrical energy, it cannot be destroyed. You are probably wondering what happens to it. The answer is that it is given off by the resistor in the form of heat. Electronics men generally say that this power is dissipated by the resistor. When a resistor carries current, it becomes warm. This is due to the power being dissipated in the resistor.

Resistors are rated according to the amount of power they can dissipate without overheating. In the circuit shown in Figure 5(B), the resistor would have to be at least a 3 watt resistor. If a smaller wattage rating than 3 watts is used in this case, the resistor will over-heat and be ruined.

Let us find the amount of power being delivered by each cell. Each cell has 1½ volts and is passing ½ ampere of current.

$P = E \times I$

$P = 1\frac{1}{2} \times \frac{1}{2}$

$P = \frac{3}{2} \times \frac{1}{2}$

$P = \frac{3}{4}$ watt (This is the power being delivered by **each** cell.)

In Figure 6, we see a 6 volt battery passing 3 amperes through a resistor. To find the amount of power being dissipated by the resistor, we apply the same formula:

$P = E \times I$

$P = 6 \times 3$

$P = 18$ watts

This same formula may be used to find the amount of heat given off by the resistor in Figure 10.

$P = E \times I$

$P = 45 \times .001$ (Note: 1 mA. was changed to .001, since the equation calls for amperes.)

$P = .045$ watt

Formula (b) is used when the current and the resistance are known, and the amount of power is desired. We can apply this formula to find the power dissipated by the 6 ohm resistor in Figure 11.

$P = I^2 \times R$

$P = (2)^2 \times 6$

$P = 4 \times 6$

$P = 24$ watts

Using this same formula, we could find the power dissipated by the resistor in Figure 12.

$P = I^2 \times R$

$P = (.003)^2 \times 2000$ (Note: Current is changed from 3 mA. to .003 amps)

$P = (3 \times 10^{-3}) \times (3 \times 10^{-3}) \times 2 \times 10^3$

$P = 9 \times 2 \times 10^{-6} \times 10^3$

$P = 18 \times 10^{-3}$

$P = .018$ watt

Formula (c) is used when the voltage and resistance are known.

Figure 13 shows such a problem. Substituting our known values in the equation, we can find the power dissipated.

$P = E^2/R$

$P = \frac{(20)^2}{200}$

$P = \frac{400}{200}$

$P = 2$ watts

Figure 14 presents a similar problem.

$P = E^2/R$

$$P = \frac{(100)^2}{10^6}$$

$$P = \frac{10^2 \times 10^2}{10^6} = \frac{10^4}{10^6} = 10^4 \times 10^{-6}$$

$P = 10^{-2}$ watts or .01 watt.

In Figure 15, it is desired to know the necessary wattage rating of each resistor. To solve this problem, we are going to have to apply Ohm's Law. First let us find the total resistance of the circuit. The two resistors are in series, so we will apply the series resistance formula:

$R_t = R_1 + R_2$

$R_t = 80{,}000 + 20{,}000$

$R_t = 100{,}000$ ohms. This is the total resistance of the two resistors.

Now to find the current flowing in the circuit, we use the Ohm's Law formula:

$I = E/R$

$$I = \frac{100}{100{,}000}$$

$$I = \frac{10^2}{10^5}$$

$I = 10^2 \times 10^{-5}$

$I = 10^{-3}$ or 1 mA.

The power dissipated by the 80–kΩ ohm resistor can be found by the formula:

$P = I^2 \times R$

$P = (.001)^2 \times 80{,}000$

$P = 10^{-3} \times 10^{-3} \times 8 \times 10^4$

$P = 10^{-6} \times 8 \times 10^4$

$P = 8 \times 10^{-2}$

$P = .08$ watt.

The power dissipated by the 20,000 ohm resistor is:

$P = I^2 \times R$

$P = (.001)^2 \times 20{,}000$

$P = 10^{-3} \times 10^{-3} \times 2 \times 10^4$

$P = 2 \times 10^{-2}$

$P = .02$ watt.

Figure 16 illustrates a typical electronics circuit. The milliampere meter indicates that there is a current of 5 mA. flowing through the 100,000 ohm resistor. How much power will be dissipated by the resistor?

$P = I^2 \times R$

$P = (.005)^2 \times 100{,}000$

$P = 5 \times 10^{-3} \times 5 \times 10^{-3} \times 10^5$

$P = 25 \times 10^{-6} \times 10^5$

$P = 25 \times 10^{-1}$

$P = 2.5$ watts.

In Figure 17, we see a circuit consisting of a 100 volt battery and three parallel resistors. Let us find the power dissipated in each resistor.

These resistors are connected in parallel; therefore, they have the same voltage across them. There is an emf of 100 volts across each resistor. Since we know the voltage across each resistor, and the ohmic value of each resistor, we can use the formula $P = \frac{E^2}{R}$ to find the power delivered to each resistor.

To find the power dissipated by the 200 ohm resistor:

$P = E^2/R$

$P = \frac{(100)^2}{200}$

$P = \frac{10^2 \times 10^2}{2 \times 10^2}$

$P = \frac{10^2 \times 10^2 \times 10^{-2}}{2}$

$P = \frac{10^2}{2}$

$P = \frac{100}{2}$

$P = 50$ watts.

To find the power dissipated in the 10,000 ohm resistor:

$P = E^2/R$

$P = \frac{(100)^2}{10{,}000}$

$P = \frac{10^2 \times 10^2}{10^4}$

$P = \frac{10^4}{10^4}$

$P = 1$ watt.

To find the power dissipated in the 1 megohm resistor:

$P = E^2/R$

$P = \frac{(100)^2}{10^6}$

$P = \frac{10^2 \times 10^2}{10^6}$

$P = \frac{10^4}{10^6}$

$P = 10^4 \times 10^{-6}$

$P = 10^{-2}$

$P = .01$ watt.

Would you have suspected that there would be such a big difference in the power dissipated (or amount of heat generated) by the three resistors in Figure 17?

To check the arithmetic in the example, apply Ohm's Law and find the current flowing in each resistor. Then apply the power formula $P = I^2 \times R$ to find the power dissipated in each resistor.

Suppose an electric iron were drawing 11 amperes from a 110 volt source. How much power would be drawn from the source? We know the voltage and current. We will use the formula P = E x I.

P = E x I

P = 110 x 11

P = 1210 watts or 1.21 kilowatts.

## Energy

As mentioned previously, watt-hour is the measure of electrical energy. One watt-hour of electrical energy is consumed when 1 watt of power continues in action for 1 hour. Similarly, 1000 watt-hours of energy is consumed when the power is 1000 watts and continues for 1 hour, or when 100 watts of power continues for 10 hours. We see that the amount of **energy depends on both power and time.**

If the iron in the preceding example were operated for one hour, then 1210 watt-hours of electrical energy has been supplied by the power company. The term kilowatt-hour is often used for large amounts of energy. 1210 watt-hours is equal to 1.21 kilowatt-hours, (abbreviated 1.21 kWh). If this same iron were operated for 5 hours, 5 x 1.21 or 6.05 kWh of energy would have to be supplied to it.

The consumer of electrical energy pays for the amount of energy used by his apparatus. If your home is served by a public utility company, you will find a kilowatt-hour meter near the fuse-box. This meter is read regularly by the utility company, and you are billed for the amount of electrical energy, in kWh, which was supplied to your home.

## Summary

All cells convert chemical energy into electrical energy. There are two general classifications of cells, these are Primary cells and Secondary cells.

Primary cells **cannot** be charged.

Secondary cells **can** be charged.

Voltaic cells, Dry cells, Alkaline cells, and Mercury cells are primary cells.

Lead-acid cells, Edison cells, and Nickel-cadmium cells are secondary cells.

Batteries are groups of cells.

Cells are connected in series to obtain higher voltage.

Cells are connected in parallel to obtain higher current.

Formation of hydrogen bubbles on the positive plate of a cell is called polarization.

The chemical put in cells to minimize polarization is called the depolarizer.

Local action in a cell results from impurities in the zinc.

Internal resistance is the name given the opposition offered by the electrolyte of a cell in carrying the current **inside of the cell.**

Power is the rate of doing work.

Power is measured in watts.

There are three formulas for finding power:

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

Energy is the ability to do work.

Energy is measured in watt-hours.

Energy can be converted from one form to another. For example, from chemical energy to electrical energy, as in batteries, or from electrical to heat as in an electric stove.

In this assignment, we have learned a great deal about batteries. There are two other widely used sources of d-c voltage; the d-c generator, and the rectifier, which changes a-c into d-c. These will be studied in detail in future assignments.

## "How To Pronounce . . ."

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

| | |
|---|---|
| dissipate | (DISS - ipp - ate) |
| electrolyte | (ell - EKK - troe - lite) |
| graphite | (GRAFF - ite) |
| hydrometer | (high - DROMM - ett - ur) |
| kilowatt | (KILL - owe - watt) |
| polarization | (pole - are - izz - A - shun) |
| radiation | (ray - dee - A - shun) |
| sulphuric | (sull - FEWER - ic) |
| voltaic | (voll - TAY - ic) |

ASSIGNMENT 9

# Test Questions

Use a multiple-choice answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer, except in cases where two answers are required, as indicated. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that answer (A) is correct for question No. 1, indicate your preference on the answer sheet as follows:

1. ~~(A)~~ (B) (C) (D)

**Submit your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.**

1. The outstanding difference between a primary cell and a secondary cell is:
   (A) A primary cell is one which can be recharged.
   (B) A secondary cell is one which can be recharged.
   (C) A secondary is recharged from a primary cell.
   (D) A primary cell is recharged from a secondary cell.

2. The difference between a cell and a battery is:
   (A) A cell consists of two or more batteries connected either in series or in parallel.
   (B) A battery consists of two or more cells connected either in series or in parallel.
   (C) A cell can always be recharged, when it becomes discharged, and a battery cannot.
   (D) A battery can always be recharged, when it becomes discharged, and a cell cannot.

3. If three dry cells are available, and you desire a voltage of 4.5 volts, you should connect them so that:
   (A) All three of the cells are in series.
   (B) All three of the cells are in parallel.
   (C) Two are in series, one in parallel.
   (D) Two are in parallel, one in series.

4. If you have a lead-acid cell with a specific gravity of 1300, it is:
   (A) Over-charged.
   (B) Fully charged.
   (C) Partially charged.
   (D) Completely discharged.

5. If, in charging a lead-acid storage battery, you observe that there are a great many bubbles rising around the plates, you should:
   (A) Increase the rate of charge.
   (B) Decrease the rate of charge.

(C) Add electrolyte solution.
(D) Add pure sulphuric acid.

6. Assuming you have two cells of the same physical size, and that one is a Dry cell and the other is a Mercury cell:—(check two)
   (A) The Mercury cell will have the longer shelf life.
   (B) The Dry cell will have the longer shelf life.
   (C) The Dry cell will deliver its rated current for a longer period of time.
   (D) The Mercury cell will deliver its rated current for a longer period of time.

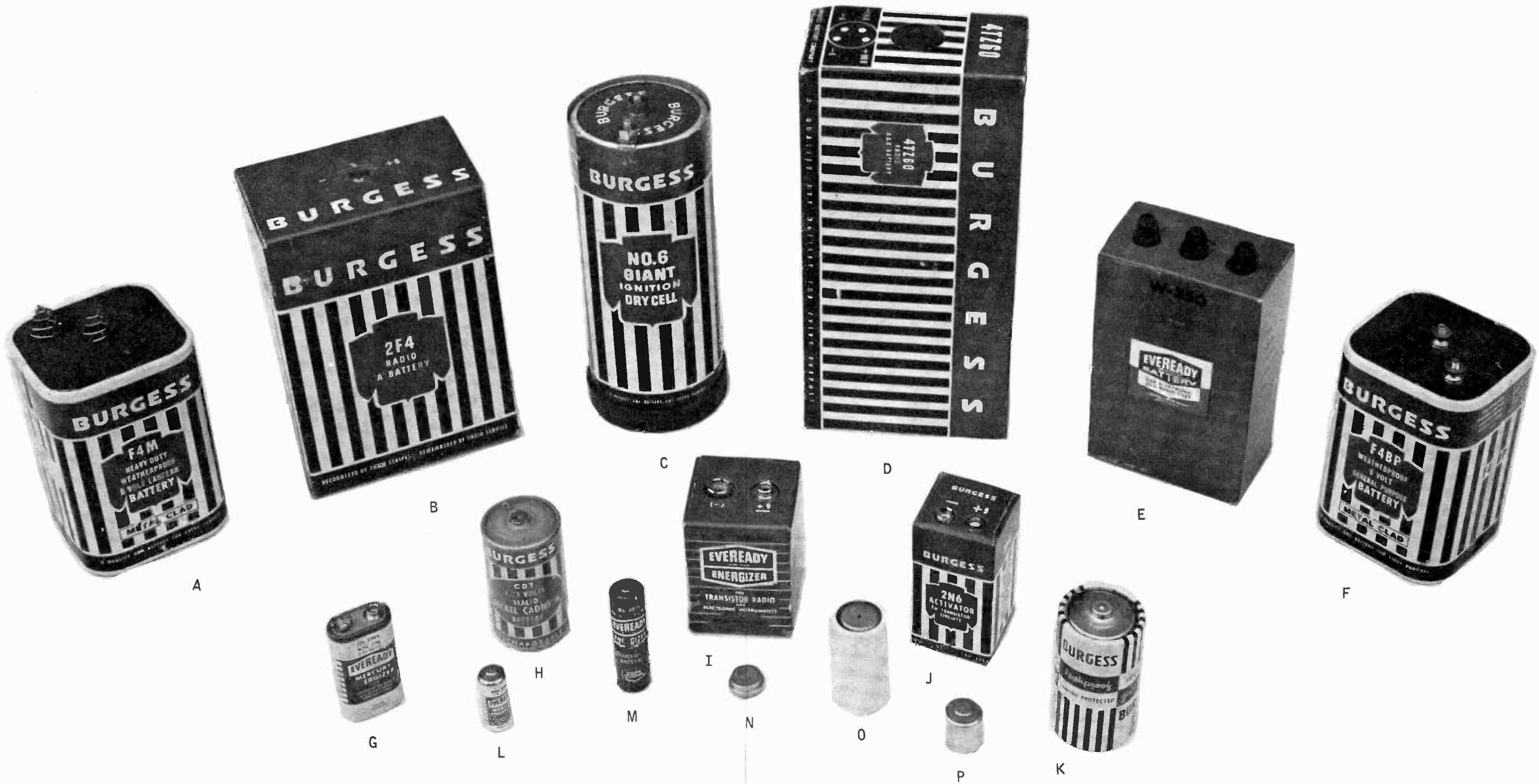
7. The unit of electrical power is:
   (A) Watt.
   (B) Volt.
   (C) Ampere.
   (D) Force.

8. An electric iron draws 20 amperes of current from a 100 volt source. The amount of energy which must be supplied by the utility company to operate this iron for 5 hours is:
   (A) 100 ampere-hours.
   (B) 10,000 ampere-hours.
   (C) 100 watt-hours.
   (D) 10 kilowatt-hours.

9. The energy which is supplied to a resistor carrying current is:
   (A) Completely destroyed.
   (B) Partially destroyed.
   (C) Stored in the resistor.
   (D) Dissipated in heat.

10. Three types of primary cells are:
   (A) Voltaic cell, dry cell, mercury cell.
   (B) Lead-acid cell, dry cell, alkaline cell.
   (C) Lead-acid cell, Edison cell, Nickel-cadmium cells.
   (D) Dry cell, Edison cell, alkaline cell.

CELLS AND BATTERIES




DRY CELLS-C,M

DRY CELL BATTERIES-A,B,D,E,F,I,J

ALKALINE CELL-K

MERCURY CELL-P

MERCURY-CELL BATTERIES-G,L

NICKEL-CADMIUM CELLS-H,N,O

FIGURE 1

## THE VOLTAIC CELL

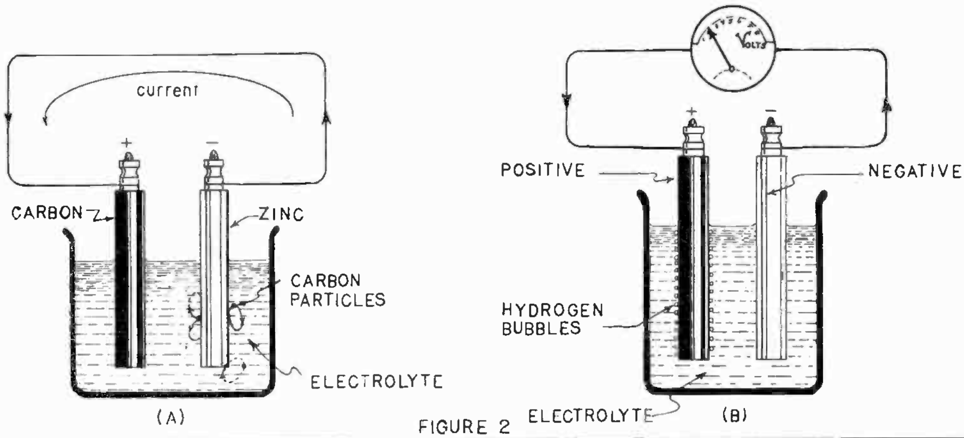



FIGURE 2

## THE DRY CELL

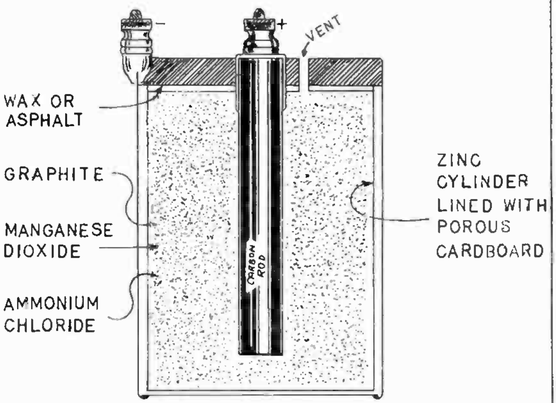



FIGURE 3

## A 45-VOLT BATTERY IS COMPOSED OF 30 CELLS IN SERIES

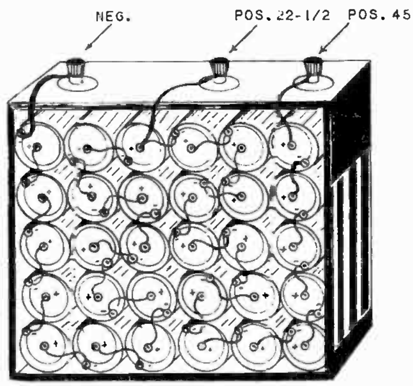



FIGURE 4

## CELLS CONNECTED IN PARALLEL FOR HIGHER CURRENT

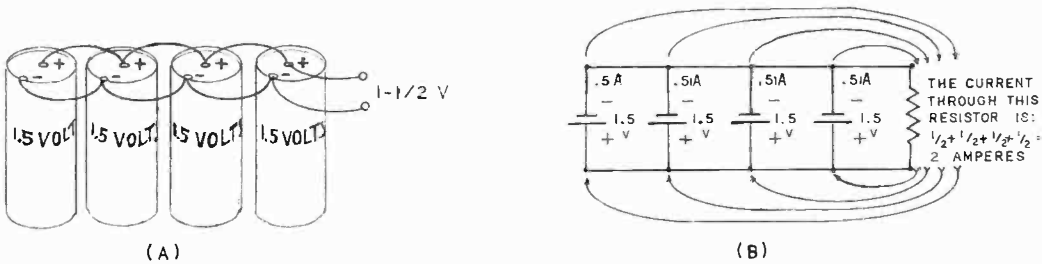



FIGURE 5

CELLS CONNECTED IN SERIES-PARALLEL ARRANGEMENT

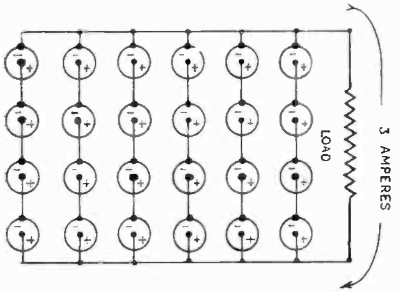



FIGURE 6

LEAD-ACID STORAGE BATTERY

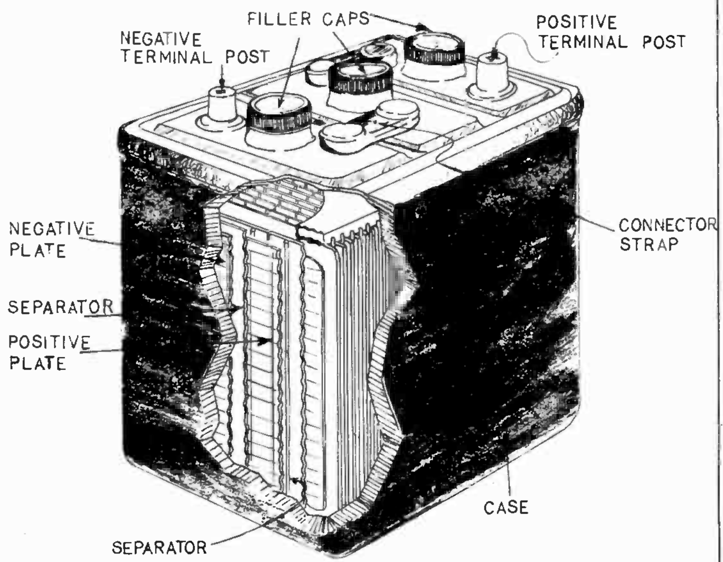



FIGURE 7

HYDROMETER

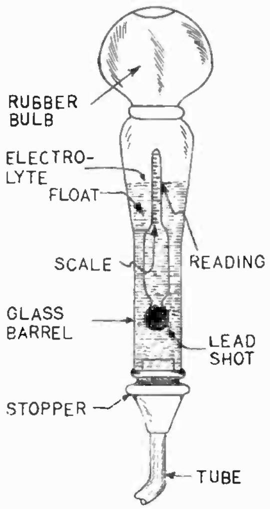



FIGURE 8

CHARGING A STORAGE BATTERY

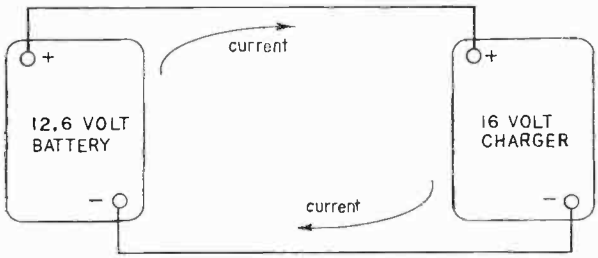



FIGURE 9

AN EXAMPLE CIRCUIT

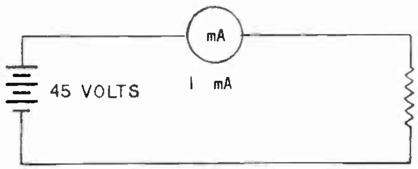



FIGURE 10

## MORE EXAMPLE CIRCUITS

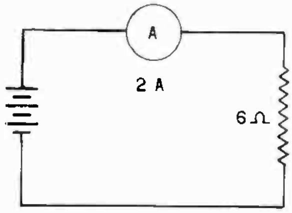



FIGURE 11

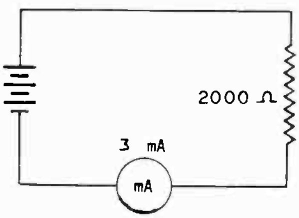



FIGURE 12

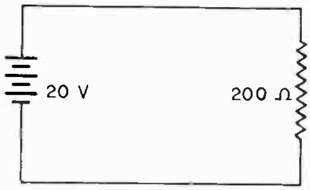



FIGURE 13

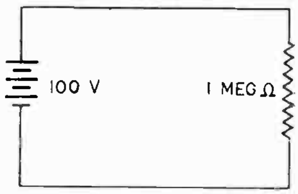



FIGURE 14

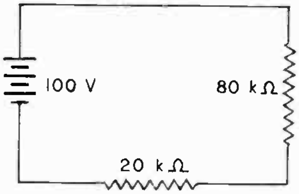



FIGURE 15

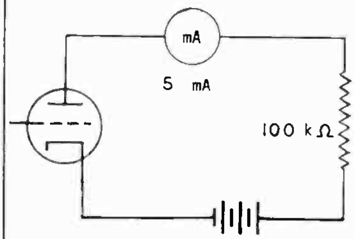



FIGURE 16

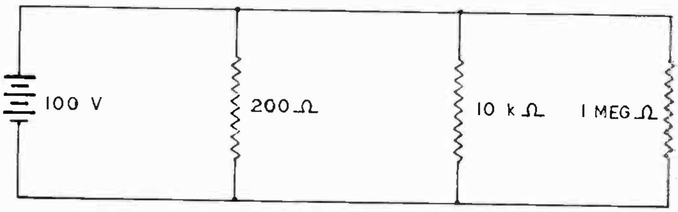



FIGURE 17