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THE MEASUREMENTS OF VARIOUS ELECTRICAL QUANTITIES ARE MADE BY MEANS OF CALIBRATED INSTRUMENTS

UNITS OF MEASUREMENT AND SYMBOLS

VOL. 10 No. 4

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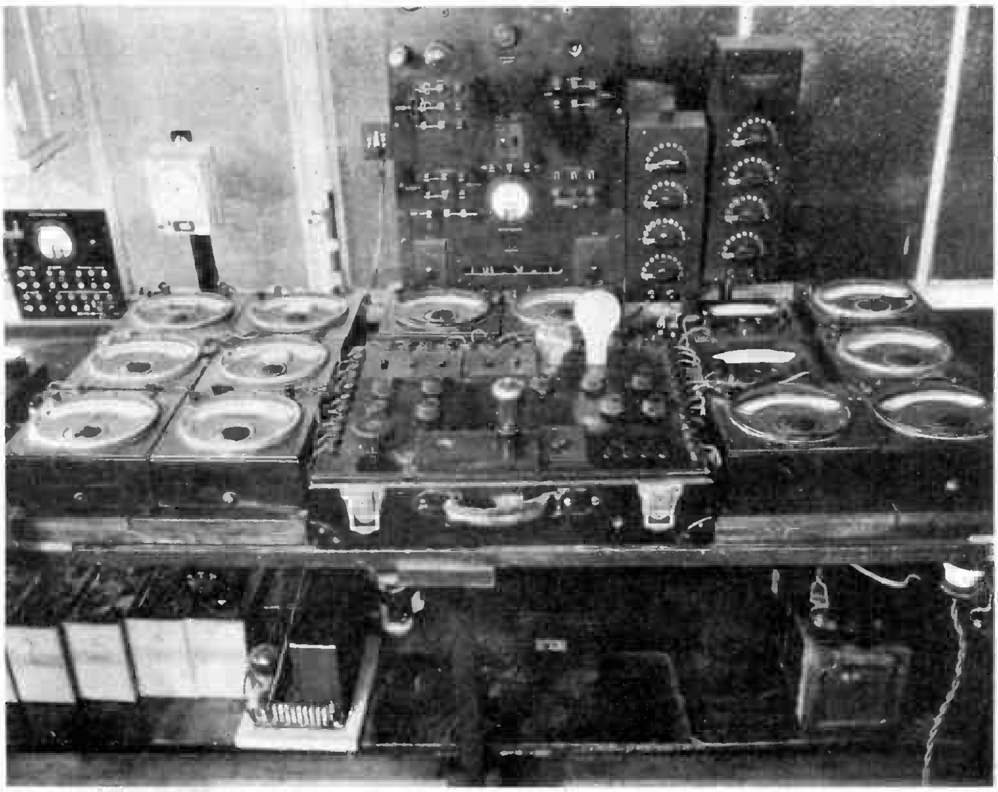

METERS ARE THE YARDSTICKS OF ELECTRICAL MEASUREMENTS

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ELECTRICAL UNITS AND TERMS

Many of our students have found it to their advantage at the beginning of their work to study the various electrical units in a single lesson although these units are again given along with their related subjects. It is with this idea in mind that we present this lesson. Everyone who studies electricity or one of its associated subjects, such as radio, television, sound motion pictures, aviation radio, and so on, should at least be familiar with the system which forms the basis of electrical computation as given below. The balance of this lesson consists of abbreviations, symbols and electrical units and terms in common use. If you review this work several times as you progress through your course it will be easy for you to understand and apply the various units and terms.

The three FUNDAMENTAL UNITS of measurement are:

(1) the centimeter, or unit of length,
(2) the gram, or unit of mass or weight,
(3) the second, or unit of time.

These three quantities are combined and expressed below in a simple relation known as the centimeter-gram-second, or C.G.S. system.

The C.G.S. unit of velocity is the kine, representing a distance of one centimeter covered in one second.
1 centimeter = 0.01 meter = 0.3937 inch.

$$\text{UNIT OF VELOCITY} = \text{cm/sec}$$

The C.G.S. unit of force is the dyne, representing the force required to move a mass of one gram one kine per second.
1 gram = 1/28th of an ounce.

$$\text{UNIT OF FORCE} = \frac{\text{gm cm/sec}}{\text{sec}}, \text{or } \frac{\text{gm cm}}{\text{sec}^2}$$

The C.G.S. unit of work or energy is the erg, representing the work accomplished by a force of one dyne working over a distance of one centimeter.

$$\text{UNIT OF WORK} = \text{dyne x cm, or } \frac{\text{gm cm}}{\text{sec}^2} \text{ x cm, or } \frac{\text{gm cm}^2}{\text{sec}^2}$$

DEFINITION OF ELECTRICAL UNITS AND TERMS

THE VOLT is the unit of electrical pressure. This pressure is known as "electromotive force" and, also, as "difference of potential." Electromotive force is abbreviated by letters (E.M.F.) or (e.m.f.).

<u>One volt is defined as that amount of electromotive force necessary to cause a current having an intensity of one ampere to flow through a circuit having a resistance of one ohm</u>.

In electrical practice you will hear references made to this unit by any one of the following names: Volt, Voltage, Electromotive Force, Pressure or Difference of Potential, all of which have the same meaning. The unit volt is denoted by the symbol (E).

In an electrical circuit we express the amount of the electromotive force as a certain number of volts. To illustrate the proper use of the terms "e.m.f." and "volts" let us consider the simple circuit drawn in Figure 1 where a 6 volt battery is connected to a 6 volt lamp. When speaking about the pressure in this circuit it would be the customary thing to say: "The e.m.f. of 6 volts, applied to this circuit by the battery, forces a certain amount of current through the filament of the lamp, thus causing it to light."

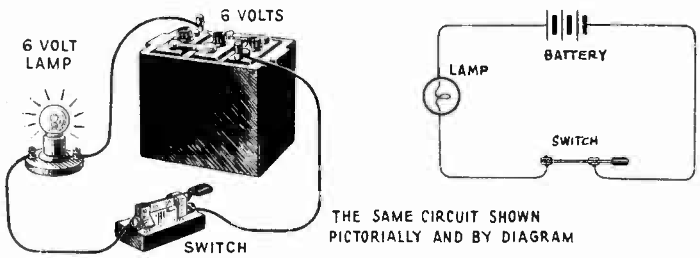


Figure 1

Electrical pressure is analogous to water pressure. To illustrate this let us suppose you connect up your garden hose to a faucet and open the valve. Providing there is water supply available in the mains we know that water will run through the hose. The <u>pressure</u> in the pipes was necessary in order to get this flow of water. Just how water pressure in pipes is obtained in our homes and buildings should be quite obvious to most anyone since there are practically only two sources; one source is the result of mechanical work done by a pumping machine of some type, while the other is the result of natural gravity provided by a head of water, or water supply originating at some level higher than the outlet where the hose is attached.

You will find that the water analogy is used to explain many phases of radio or electrical theory. It may be used to illustrate the action of a condenser or the action of a resistance or even the radiation of electromagnetic waves from a broadcasting station, but in no case is it more applicable than for illustrating the relation of pressure (E.M.F.) and the current which flows as a result of this pressure.

To point out the idea that pressure is always essential before a movement or motion of any kind can be produced we have shown a small tank partly filled with water in sketch (A) of Figure 2. Notice that to the bottom of the tank there has been connected a short pipe, bent into a U shape, the open end of which is arranged exactly level with the tank connection.

The valve acts in a manner similar to a switch in an electrical circuit in controlling the flow. If the valve in the pipe is closed the water pressure is not utilized although the pressure is always present by reason of the height and volume of water in the tank. But, if we open the valve, the pressure will immediately act and water will flow through the pipe and gush out at its open end. The flow will continue just so long as there is any water in the tank or any pressure. Finally when the tank is emptied it will be seen that the pipe still holds a quantity of water which does not flow out of the open end because both ends of the pipe are level, as shown in sketch (B). This result shows that while the water remaining in the pipe has a potential force due to its own weight, yet it cannot be made use of in this case. Thus, we see that it requires a difference of pressure level to obtain force by which the water may be made to flow even though water may be at hand. However, by merely bending the open end downward, as in (C), the water confined in the pipe will begin to flow out, since we have set up a condition where the force due to the weight of water is now acting. The higher the water level in the tank the greater will be the available pressure.

Although we can see the water we cannot see the "pressure." Nevertheless, it is easy to measure water pressure in pounds with a suitable pressure gauge. When we refer to pressure in the electrical sense, we also deal with an unseen force which may be generated in one of several ways. We know how to regulate the intensity of this

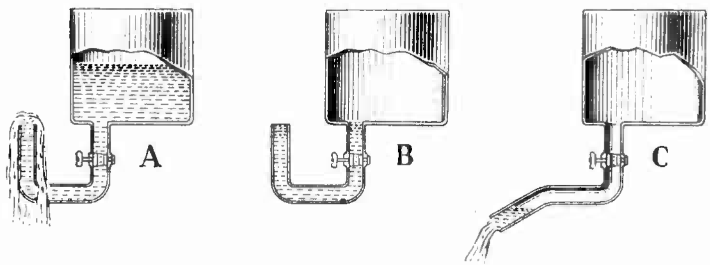


Figure 2

electrical pressure according to certain requirements so that it may be applied to a circuit to set up a flow of current. It is also easy to measure electrical pressure by means of a suitable instrument, called a "voltmeter." Two common sources of electrical pressure are batteries and generators.

THE AMPERE is the unit of electric current which represents a certain amount of current flowing at a given rate.

> One ampere is defined as the intensity (or strength, or value) of the current that will flow through a circuit whose resistance is one ohm, when the applied electromotive is one volt.

Another definition of the unit of current strength, based on the amount of chemical decomposition taking place in a given period of time, and stated in terms of quantity and rate of flow is, "One ampere is that steady flow of electric current which when passed through a standard solution of nitrate of silver in water will deposit silver at the rate of 0.001118 gram per second."

The quantity of electricity is measured by the unit "COULOMB." Although this unit is defined in a subsequent paragraph let us at this time show the relation between "coulomb" and "ampere" as follows: "When one coulomb of electricity passes a given point in a circuit, every second of time, one ampere of current is said to flow." Hence, if 2 coulombs of electricity pass a given point in a circuit per second the strength of the current is 2 amperes. In a given circuit, therefore, to find the total quantity of electricity expressed in coulombs we must take the product of the current in amperes and the length of time in seconds that the current flows. "Product" is the mathematical expression for the result of multiplication.
Note: The underlined definition of an ampere just given is the one that should be learned for our practical work.

Current is denoted by the symbol (I) and is measured by an instrument called an "ammeter." Small values of current are measured by a "milliammeter" or "microammeter."

Again refer to the drawing in Figure 2 to be sure that you have a clear understanding of the difference between "quantity" and "rate of flow." Water flowing through a pipe at the rate of a certain number of gallons per minute can be compared to coulombs passing through a circuit. In a water system "gallons" represents the quantity and "gallons per minute" the total amount for a given time, or rate of flow; whereas, in the electrical circuit "coulomb" is the quantity and "amperes" is the rate of flow of a given quantity.

An important point to be mentioned in this discussion is that throughout the whole length of the pipe there are oppositions set up which prevent a free movement of the water. These oppositions are due principally to friction by contact of the water with the inner walls of the pipe, bends in the pipe and the length and size, or cross section, of the pipe. In any of its forms, opposition must be met and overcome by the pressure before water flows and, of course, the oppositions will govern to some extent the amount of water that flows in a given time under a given pressure. It is easy to see that any opposition presented by the pipe itself will retard the water flow.

This opposition is comparable to that which is present at all times in electrical circuits because the wires or other metallic parts do not permit current to flow freely. The current must be forced to flow through the materials used to construct the circuit under pressure of the applied voltage. Each different kind of metal has its own specific resistance. For instance, current flows more readily through silver than through copper, and more readily through copper than iron. Thus, if we have two circuits consisting of the same length and cross-section of wire, and if one circuit uses copper wire and the other iron wire, and if exactly the same voltage is applied to both circuits it will be found, under these conditions, that about six times as much current will pass through the copper wire as compared to the iron wire circuit. This is because the relative resistance of copper is 1.075 as compared to 6.37 for iron. In the case of the electrical circuit this opposition of the material itself, which governs to a large extent the intensity of the current flow, is known as the "resistance."

For all practical purposes, copper wire is used because of its low resistance. Silver has a resistance lower than copper but its cost is prohibitive except for special purposes.

THE OHM is the electrical unit of resistance. Resistance is the natural opposition which all materials offer to the flow of current, and since this opposition is inherent in all matter it must be overcome by the electromotive force before current will flow.

One ohm is the resistance of an electrical circuit when an electromotive force of one volt is required to force a current of one ampere through it.

The following is a definition of the unit resistance based on a physical standard: One ohm is the amount of resistance offered to a steady flow of electric current by a column of mercury of uniform cross-section, 106.3 cm. long, 14.4521 grams in weight at a temperature of 32 degrees Fahrenheit, or 0 degrees Centigrade. (Note: One centimeter is a little less than a half inch. One ounce is equal to 28 grams.)

The ohm is denoted by the symbol (R) and is named after the German scientist George S. Ohm. He was responsible for recognizing the relation existing between the "voltage," "resistance" and "current" in all electrical circuits and formulating this relation into what is probably the most important and widely used law in electricity, known as "OHM'S LAW."

One megohm equals one million ohms.
One microhm equals 1/1,000,000th of an ohm.

THE COULOMB is the unit of electrical quantity used to express the total quantity of electric current passing through a circuit in a stated time.

One coulomb is the quantity of electricity that will flow in one second through a circuit having a resistance of one ohm when the applied e.m.f. is one volt.

We are now dealing with "quantity" in electricity in about the same way that ordinary standards, a pound or gallon for instance, are used to measure supplies such as sugar, milk, etc. Thus, if we wish to know the number of "coulombs" or "quantity of electricity" passing through a circuit in a given time we must multiply the number of amperes by the number of seconds the current continues to flow.

The following example shows how to apply this rule: Suppose the rate of current flow for a particular circuit is 8 amperes and the current continues to flow steadily for 4 seconds. The total quantity of electricity passed will be 8 x 4 or 32 ampere-seconds, or 32 coulombs of electricity. Also, if 2 amperes flow for 16 seconds we would have 32 ampere-seconds or 32 coulombs.

The unit "coulomb" is frequently applied in electrostatics with reference to placing an electrostatic charge on a condenser and in this usage it is defined as follows: "One coulomb is the quantity of electricity necessary to raise by one volt the difference of potential between the plates of a condenser whose capacitance is one farad."

The coulomb is denoted by the symbol (Q), and this unit is equal to one ampere-second. Mathematically expressed this statement takes the form of $Q = IS$.

THE HENRY is the unit of inductance. Inductance is a certain property possessed by every electrical circuit which establishes an electromagnetic field about its conductors and windings (coils) when current passes through it. Inductance is also applied to the peculiar property of all conductors and windings (coils) which tend to oppose any current change produced by a circuit within itself by virtue of the changing magnetism which is set up whenever current varies or tends to vary in strength. The effect is pronounced in any circuit in which the current is continually changing in intensity, as for example, in a circuit carrying pulsating direct current or alternating current. The net result of inductive effects is the generation of a second, or counter e.m.f. (C.E.M.F.) separate from the applied e.m.f. which causes the current to flow.

This property of "inductance" exists in all portions of an active circuit because the electromagnetic lines of force (flux) set up by the current will vary in magnitude according to every change in current intensity. These electromagnetic lines of force are continually acting upon the very wires (or conductors and coils) which comprise the circuit. The term "self-inductance" is commonly used to express this peculiar property exhibited by a circuit due to the action of its own magnetic lines upon itself. The tendency of a circuit to prevent changes in current intensity and spoken of as the "self-inductance" of a circuit, as just mentioned, represents one kind of opposition and it must not be confused with a circuit's "resistance."

Resistance is always present whether the current varies in strength or whether it flows steadily. However, "inductance effects" are not present in a circuit when a steady direct current flows, for in this case the magnetic lines are also steady and consequently do not act upon the conductors.

> A circuit is said to have an inductance of one henry when an electromotive force of one volt will be induced in the circuit by a current varying at the rate of one ampere per second.

The letter (L) is the symbol used to denote inductance.

THE FARAD is the unit of electrical capacity and is abbreviated "fd." This unit relates to the amount of charge that can be stored up in a condenser in electrostatic form under a given e.m.f. measured in volts.

> A condenser is said to have a capacitance of one farad if the potential difference between its plates will be raised one volt by a charge of one coulomb.

From this definition we see that a condenser, when connected in a circuit and supplied with voltage will store up a definite amount of electricity in static form.

The farad is considerably too large to be applied in practical work. We therefore have two sub-multiples of the unit in common use. They are:

Microfarad (abbreviated mfd. or µfd.)

Micro-microfarad (abbreviated mmfd. or µµfd.)

One microfarad is equal to one-millionth part of a farad.
One micro-microfarad is equal to one-millionth part of a farad again sub-divided into a million parts; that is to say, a micro-microfarad is one-millionth of one-millionth part of a farad. Pico-farad, although not an approved unit, is an expression sometimes used for micro-microfarad.

EXAMPLE. Either unit, microfarad or micro-microfarad, may be used to express a certain numerical value according to one's own preference. As a rule values in the order of 1000 mmfd. and higher are expressed in microfarads (mfd). Here are a few examples of how a value may be written in terms of either unit:

1 mmfd. = 0.000001 mfd.
250 mmfd. = 0.00025 mfd.
1000 mmfd. = 0.001 mfd.

A simple condenser is shown in Figure 3. It consists of a thin piece of suitable insulating material, such as mica, on either side of which is glued a sheet of tinfoil. The tinfoil sheets are called the "plates" and the mica the "dielectric." If two wires are connected from a source of voltage to the respective plates the e.m.f. thus provided will cause an electrostatic charge to be stored up by the mica. In Figure 5, the dry cell of 1.5 volts causes a difference of potential of 1.5 volts to be set up between plates "A" and "B" of the air type condensers; the electrostatic lines in this case are stored up in the air but in Figure 3 they are stored in the mica. The condensers in Figures 3 and 5 are called fixed condensers because no provision is made to alter their capacitances.

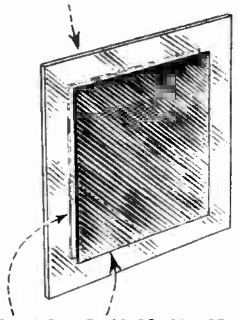


Figure 3

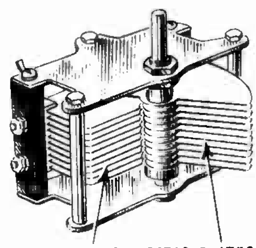


Figure 4

The multi-plate variable air type condenser in Figure 4 consists of a set of fixed and movable plates; this type is in general use in radio work for tuning purposes. The capacitance of this condenser is varied by rotating one set of plates, which acts to change the effective relationship between both sets of plates. The dielectric medium, which possesses the property of storing up electrostatic lines of force in a condenser of this kind, is the air which separates the plates. We will explain later how the particular kind of dielectric used, whether it be air, mica, paper or any other suitable material, has an important bearing upon the amount of charge the condenser will take on. The dielectric material also governs the amount of voltage that can be applied to the condenser without placing the insulating qualities of the dielectric under an excessive strain that would eventually result in a breakdown.

Capacity is designated in all of our writings and formulas by the letter (C).

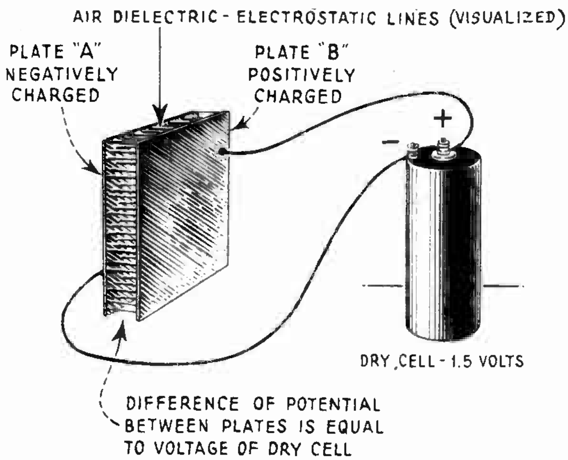


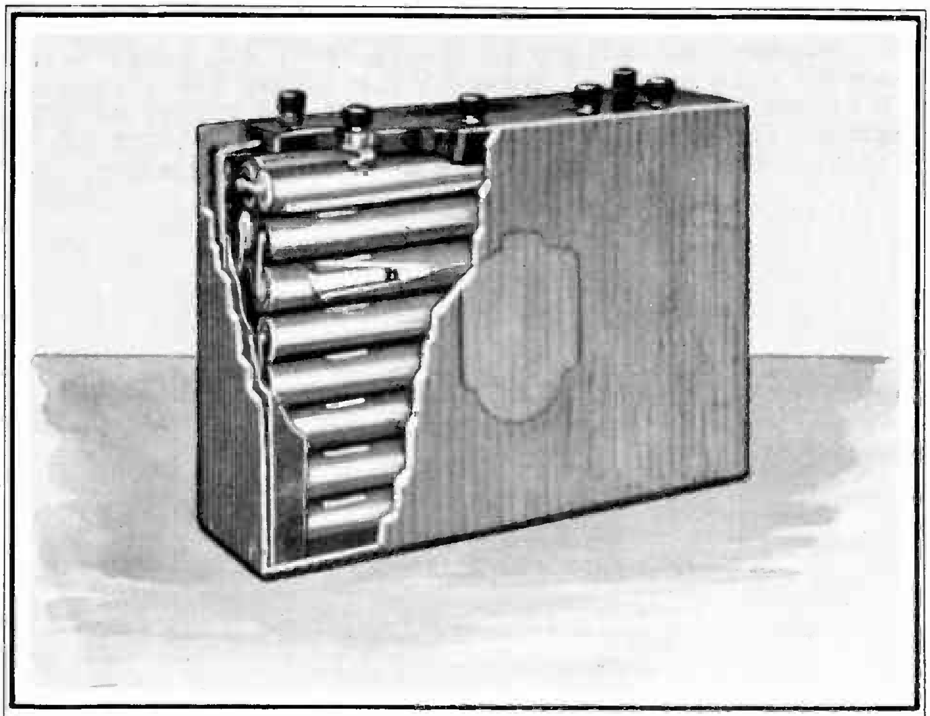
Figure 5

<u>ELECTRICAL WORK AND POWER</u>. In our radio subjects we deal considerably with work and power. Through experience we find that very often the terms, <u>force</u>, <u>power</u>, <u>energy</u> and <u>work</u> are not thoroughly understood by everyone. To avoid any confusion between these terms we will explain their meanings in the following paragraphs, also giving a practical example of their use.

There are different kinds of force that will produce work when properly directed. For instance, we apply muscular force whenever we exert ourselves in the performance of certain tasks. Also, we have mechanical force derived from various types of motors and engines which may be operated with compressed air, gas, water, steam, gasoline and so on. There is also chemical force and electrical force. Other examples of force could be cited, but electromotive force is the force most frequently dealt with in our work. It will be repeatedly mentioned that an electromotive force, when properly applied, will cause or tend to cause a flow of electrical current.

<u>FORCE</u>. Force is an unseen agent which acts to cause some change in the existing motion of a body, or mass, or it may cause a change in direction of motion, or it may in some cases alter the physical shape of the body acted upon.

At this time let us review a few of the possible conditions relating to force. If a body is at rest and force is applied, it will tend to set the body in motion; or if the body is already in motion a force may be applied in such a way as to cause the body to accelerate (move faster), or slow down, or perhaps come to a complete stop; or if a body is moving in a certain direction a force applied in some other direction will tend to cause the body to change its original course of direction.



A COMBINED "B" AND "C" BATTERY FOR AIRCRAFT RADIO

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P.O. 1166

VOL.10 No. 5

The e.m.f. across each series connection is 4.5 volts. In a parallel combination of cells the e.m.f. is the same across the component parts hence, the e.m.f. across the three groupings is 4.5 volts as marked on the diagram.

SERIES-PARALLEL COMBINATION. The circuit illustrated in Figure 16 consists of 12 cells connected in a series-parallel arrangement. Observe that there are three separate parallel groups each of which consists of 4 cells connected in parallel, and the three parallel groups are joined in series. Hence, a series-parallel combination is a series connection of a number of parallel arranged cells.

The e.m.f. across the battery in Figure 16 is 4.5 volts because the e.m.f. across each parallel group is 1.5 volts, i.e., the total e.m.f. of the 3 groups in series is their sum, or 4.5 volts, as marked on the diagram. Figure 17 is a diagram of the connections of "B" and "C" batteries for use in a sound-motion picture installation.

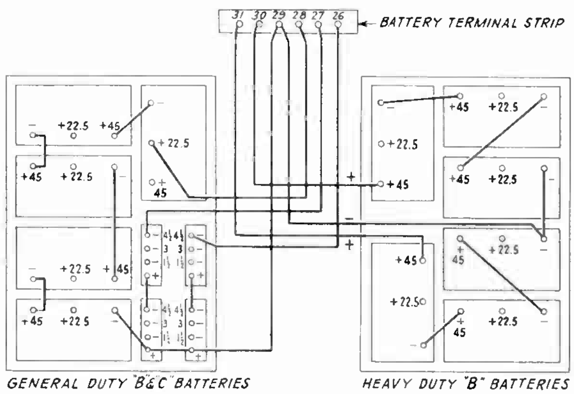

Figure 17

EXAMINATION QUESTIONS

1. What is a primary cell?
2. Name the materials used in some one type of primary cell.
3. (a) What determines the e.m.f. of a dry cell?
   (b) What determines the useful life of a primary cell?
4. (a) What is polarization?
   (b) How may polarization be reduced?
5. (a) What is meant by local action?
   (b) Do you know of any remedy for local action? Explain.
6. Can a primary cell be charged and used again like a storage cell? Why?
7. What is the difference between a cell and a battery?
8. (a) When would you use a series connection of cells?
   (b) What is the advantage of connecting cells in series?
   (c) How is the total e.m.f. of a series combination of cells computed?
9. (a) When would you use a parallel grouping of cells?
   (b) What is the advantage of a parallel connection of cells?
   (c) How is the total e.m.f. of a parallel combination of cells figured?
10. If you were given 15 dry cells and asked to connect them in a group which would supply a certain circuit with an e.m.f. of 4.5 volts, how would you do it? Draw a schematic diagram using symbols.

Figure 14 shows two parallel combinations of cells. The e.m.f. of the left-hand battery is 1.5 volts, which is the e.m.f. of any one of the cells. Likewise,the e.m.f. of the right-hand battery is 1.5 volts, or the e.m.f. of any cell in the group.

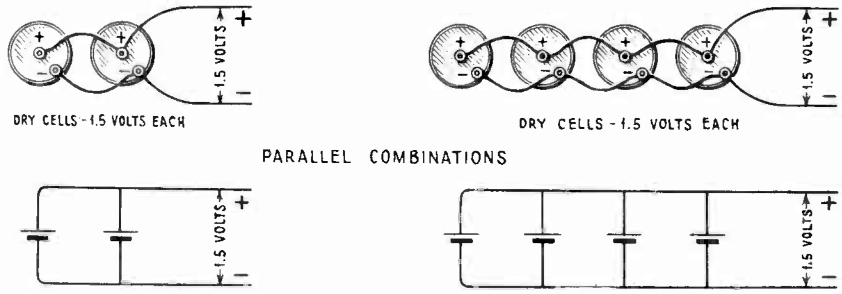

Figure 14

Hence, suppose the battery in Figure 13 consisting of 3 cells in parallel is connected to a circuit which is passing 2 amperes, then each cell of this group would contribute one-third of 2 amperes, or 0.66 ampere to the circuit. Thus, the load would be divided equally among the cells. If all of the cells were forced to pass 2 amperes steadily to energize such a circuit the cells would deteriorate very rapidly. In Figure 13 suppose the actual current passing through the bell is 0.15 ampere ; each cell then would furnish one-third of this amount, or $0.15 \div 3$ equals 0.05 ampere.

An <u>application of the parallel connection</u> may be easily understood by the following: Suppose we connect a small lamp to a single cell. The lamp will continue to remain lighted until the cell becomes exhausted which at the end of say, ten hours. If we connect another cell in parallel to the first and both are fresh cells, the lamp will remain lighted for twenty hours or twice as long as for one cell. With three lamps the lamp will remain lighted for thirty hours and so on. Each cell adds its current value to an adjacent cell with the additive current continually feeding the lamp as long as it is in the circuit. In any case, the voltage applied to the lamp would not be greater than that furnished by any single cell used.

<u>PARALLEL-SERIES COMBINATION</u>. The schematic diagram in Figure 15 shows 9 cells connected in a parallel-series arrangement. In this circuit we have three separate series groups each of which consists of 3 cells connected in series, and the three series groups are

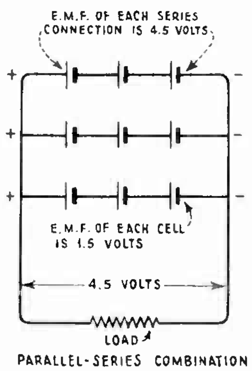

Figure 15

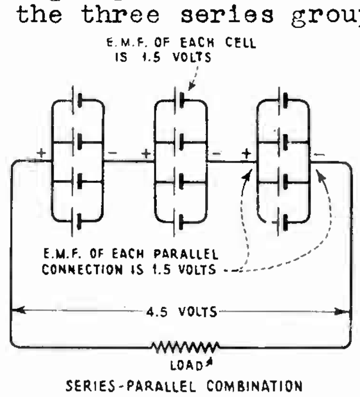

Figure 16

joined in parallel. The diagram shows that a parallel-series combination is a parallel connection of a number of series arranged cells.

From the foregoing explanations we learn that to find the resultant voltage, or e.m.f., of any number of cells connected in a series combination it is only necessary to multiply the voltage of any one of the cells, providing they are all alike, by the number of cells in the group. Also, to find the internal resistance of all of the cells taken together in a series combination we must multiply the internal resistance of one of the cells, providing they are all alike, by the number connected in the group.

PARALLEL COMBINATION. Figure 13 is a picture diagram of a parallel or multiple grouping of cells where the e.m.f. or voltage of the whole combination is only the e.m.f. of a single cell. The drawing shows that all of the negative terminals (—) are connected together and, therefore, we have but one lead coming from the negative side of the cells that is common to all of negatives. The positive terminals (+) are also all connected together which provides only one common lead coming from the positive side of the cells. Observe that the connecting wires are put on according to the following system: The zinc of cell 1 is joined to the zinc of cell 2; the zinc of cell 2 is joined to the zinc of cell 3; and from this point a lead is carried to the bell. Next we have the carbon of cell 1 joined to the carbon of cell 2; the carbon of cell 2 joined to the carbon of cell

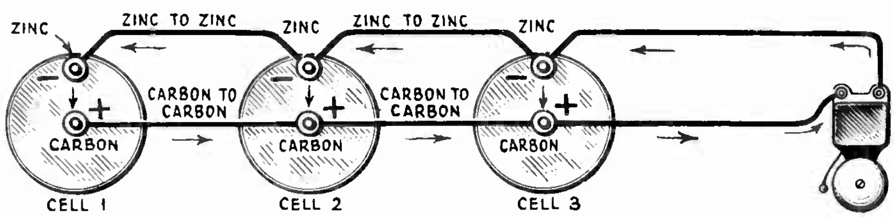

Figure 13

3; and then a second connection is carried from this point to the other terminal on the bell. Thus, we have completed the continuity of this parallel arrangement of cells. The path of the currents furnished by the individual cells and the total current flowing to the bell is represented by the arrows.

In this arrangement the internal resistance of the battery is reduced if cells are added to the group. For example, the internal resistance of the 3 cells in the battery in Figure 13 is one-third that of any single cell. If there are two cells in a parallel grouping the internal resistance is one-half that of either cell.

We learned in the first part of this lesson that the amount of zinc exposed to the action of the electrolyte determined the amount of current that would be delivered by the cell and that the voltage of all cells are exactly alike, relardless of their size, when the same combinations of materials are employed. Hence, in a parallel grouping of cells we have the effect of increasing the area of the plates since the zincs of all the cells are connected together; but we do not obtain an increase in the e.m.f. according to the consideration that certain combinations of materials give a known e.m.f. and the size, or area, of the materials has no influence on this voltage. The advantage of connecting cells in parallel is that each cell contributes an equal amount of the current delivered by the battery.

Example: Suppose we have a battery consisting of 12 cells, each rated at 1.5 volts, with the cells in series. What is the total voltage available? The answer is 12 x 1.5, or 18 volts. Example: If the internal resistance of each of the cells in a group of 12 connected in series is 0.5 ohm, what is the total internal resistance of the cells? The answer is 12 x 0.5 ohm , or 6 ohms.

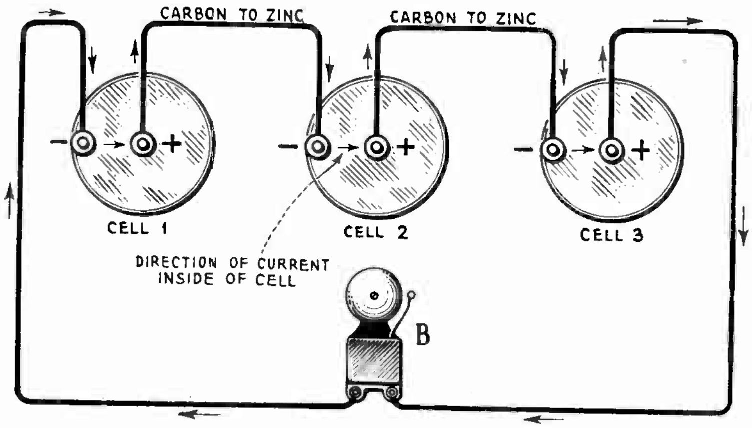

Figure 11

An illustration which clearly shows just how a series combination increases pressure is given by Figure 11. Assume that bell B requires a pressure of $4\frac{1}{2}$ volts before its clapper will move and strike the bell. With one cell in the circuit, the clapper would probably not move; with two cells connected in series to the bell the clapper may vibrate but not to its greatest extent; and with three cells connected in series, the clapper attains its maximum vibration. This increase of electrical pressure exists in every series circuit due to the fact that the voltage of every cell in the series group contributes its pressure additively and since a larger voltage is made available, a larger current can be forced through a given circuit to perform a certain amount of electrical work.

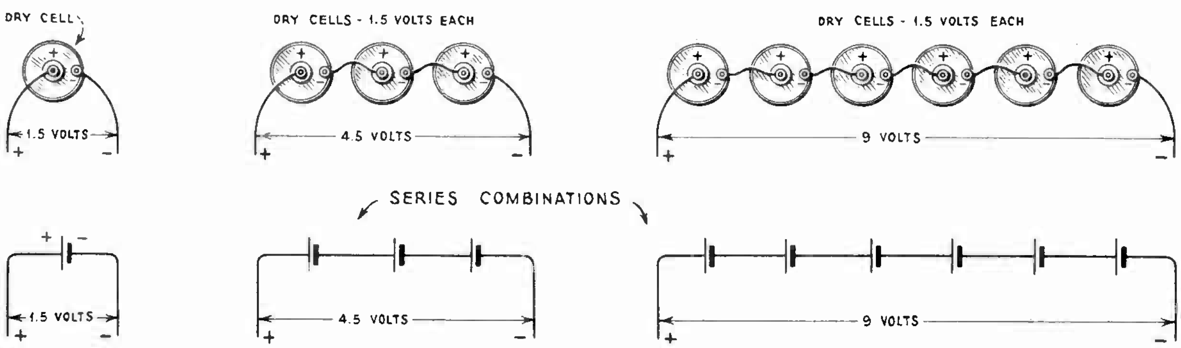

Figure 12

Figure 12 illustrates groupings of cells in series arrangements and is marked to show that the voltage of the cells is always additive in such a combination. The single cell at the left is shown to point out the relation between a cell and its symbol.

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that a dry cell has two terminals, one a positive and the other a negative. The small sketch to the right in Figure 8 is one way of drawing the top view of a cell and indicating the amount of electromotive force in volts that the cell is rated at, or in this case, the cell is seen to have a "terminal" e.m.f. of 1.5 volts. Instead of drawing a picture of a dry cell each time we desire to indicate one on a diagram we make use of the standard symbol as shown in your lesson on "Symbols." The long thin line represents the positive pole, whereas, the short heavy line represents the negative pole.

There are two ways in which the cells of a battery may be arranged to vary the current output of the cells; (1) by a series combination: and (2) by a parallel combination.

(1) By the series method the e.m.f. of the battery is increased because the single cells are connected in a way that permits the sum of all of their e.m.f.'s to be available. When cells are joined in series the internal resistance of the combination is equal to the sum of the internal resistances of the individual cells. In Figure 9 three cells are shown joined in series and connected to a bell.

(2) By the parallel method the e.m.f. of the battery will not be greater than that of a single cell but the internal resistance of the battery decreases with each addition in the number of cells used. Refer to Figure 10 showing three cells joined in parallel and the combination connected to a bell and controlled by a push button.

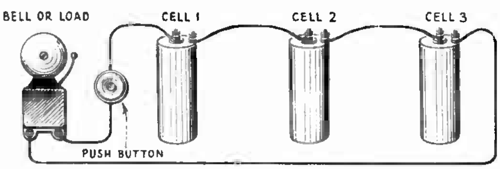

Figure 9

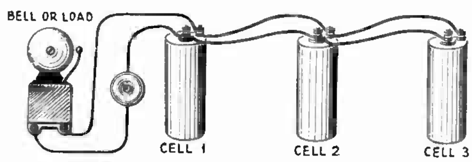

Figure 10

SERIES COMBINATION

Both Figures 9 and 10 are pictorial diagrams drawn to assist you in understanding just how the cells are actually connected. Notice that in the series combination in Figure 9 the connecting wires are put on according to the following system: The negative terminal post of cell 1 is joined to the positive of cell 2; the negative of cell 2 is joined to the positive of cell 3; the negative of cell 3 is joined to one terminal on the bell; the other bell terminal is joined to one terminal on the push button; the other terminal on the push button is connected to the positive terminal of cell 1. Thus, we have made a complete circuit, beginning at cell 1 and returning to it. In this arrangement the same amount of current that flows through one part of the circuit must also pass through all other parts since there is only one continuous circuit formed. Now refer to the diagram in Figure 11 which illustrates the circuit of Figure 9 in slightly different form. The purpose of Figure 11 is to show that when we connect two cells from positive to negative we are in reality connecting the carbon of one cell to the zinc of the adjoining cell. It is a simple matter to trace out the "continuity" of this circuit. The word "continuity" expresses just what we were doing, that is, tracing out a circuit from beginning to end to see that it is continuous and unbroken so that we may be sure that current will flow through all of its parts. The course of the current is shown by the arrows.

to keep a dry cell in a cool place whenever possible where the temperature is not much higher than 70° F.

A dry cell is a very convenient means for obtaining an electromotive force but it is adapted only for use on intermittent work such as, ringing door bells, telephone installations, or where the service demands only a small continuous current such as for supplying current to heat the filaments of small receiving type vacuum tubes in radio circuits, and other uses too numerous to mention.

Because of its low internal resistance a dry cell in good condition will deliver a current of about 18 to 30 amperes, or more, when measured on momentary short circuit by means of a low resistance ammeter. Short circuit tests should not be made often on the same cell as it places a heavy drain on the active materials. A voltage test can be made by using a good high-grade voltmeter with a low reading scale. The average e.m.f. of all new dry cells in good condition is about 1.5 or 1.6 volts. In certain classes of work after a cell has dropped to about 1 volt it is removed from active service and a new one is substituted. Also, if two or more cells are used in conjunction with one another their individual voltages should be measured frequently to ascertain whether they are nearly alike, or whether one cell is considerably lower than the rest in which event the operation of the circuit would be seriously impaired.

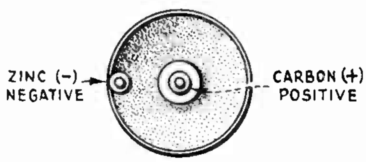

Figure 7

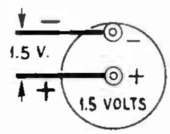

Figure 8

LECLANCHE CELL. The standard dry cell is practically a Leclanché cell made up in a different form — both employ similar materials in their construction. The Leclanché cell consists of two cylindrically shaped plates, one of zinc and one of carbon placed in a sal ammoniac solution, the carbon plate being corrugated in shape to form a porous cup in which the manganese dioxide and powdered coke are placed. When delivering current the sal ammoniac solution attacks the zinc and, as in the case of the simple dry cell, bubbles of hydrogen gas are liberated and collect on the surface of the carbon. The gas combines with the manganese dioxide and is removed, thus preventing polarization of the cell. A cell of this kind will keep in good working condition for years and practically the only attention it needs is an occasional filling with water and sometimes with a fresh supply of sal ammoniac.

METHOD OF CONNECTING CELLS

A top, or plan view, of a common dry cell is shown in Figure 7. The center terminal connects to the carbon rod and this terminal is called the "positive pole" of the cell; the (+) sign is used to denote positive polarity. We do not as a rule call this a "plus" sign in this work; we most generally say "positive" sign. The terminal at the outer edge of the cell connects to the zinc can, or shell, of the cell and this terminal is called the "negative pole"; the sign (—) is used to denote negative polarity. We do not call this a "minus" sign as a rule but rather a "negative" sign. Hence, we say

We will attempt to make the following explanation as easy to understand as possible although it is not necessary that you learn this explanation. When chemical action sets up in the cell each molecule of sulphuric acid separates into two oppositely charged parts; namely, positive ions which are the H_2 or hydrogen part of the acid, and negative ions which are the SO_4 or sulphuric part of the acid. The negative ions are made up of a certain number of negative electrons. Also, a portion of the zinc separates into electrons and positive ions with the latter uniting with the negative sulphate ions, the SO_4 mentioned above. But the electrons just made available by the zinc do not unite with other parts and, therefore, they move through the circuit. The repulsive force which electrons exert upon one another (this is because all electrons possess a negative charge of equal amount and have similar characteristics otherwise) causes them to move through the zinc electrode, and through the conductors forming the external circuit, and thence through the copper electrode and the action just described continues on so long as the cell is connected to the external circuit and the materials used in the cell are in good condition. (The external circuit consists of the connecting leads and the load as indicated by the resistance symbol.) The fact that each one of the two parts of the electrolyte go to opposite plates when it separates as stated above (that is, the H_2 positive ions go to the copper plate and the SO_4 negative charges go to the zinc plate) causes the respective plates to become charged electrically to positive and negative potentials. This results in the setting up of a difference of potential between the plates, or terminals, of the cell and the movement of the electrons through the external circuit in the direction from negative to positive.

The arrows in the drawing in Figure 6 are not to be associated with the movement of the electrons in the explanation just given. The arrows merely indicate the direction of current flow according to the usual convention or custom in practical use for many years. Note that the current arrows are in a direction in the external circuit from the positive to the negative electrode and in the internal circuit from the negative to the positive electrode.

CONSTRUCTION AND OPERATION OF THE COMMON DRY CELL. The interior view of a typical dry cell is plainly marked in Figure 2 to identify all of the parts that enter into its construction. Dry cells of this type are usually 6 inches high and $2\frac{1}{2}$ inches in diameter. The zinc cylindrical can is the negative electrode. The terms electrode and plate are used interchangeably. The zinc can holds the moist black paste into which is embedded a large carbon rod that forms the positive electrode, or plate. The paste usually consists of a mixture of ammonium chloride (or sal ammoniac, the chemical name of which is NH_4Cl), plaster of Paris, powdered coke, a small quantity of graphite, zinc chloride ($ZnCl_2$), and a depolarizing agent, such as manganese dioxide (MnO_2). Enough water is added to the electrolyte to moisten the absorbing paper which lines the zinc can and separates the zinc from the paste. After the paste and carbon rod are firmly packed in, the whole assembly is covered with sand and on top of this is placed a sealing compound to make the cell moisture proof and thus prevent evaporation.

The great advantage of this type of cell is that it can remain on open circuit for long periods without appreciably shortening its useful life. After a period of a year, or more, it will begin to deteriorate rapidly if unused and the drying out of the cell will be hastened if it is kept in a very warm atmosphere. It is always best

LOCAL ACTION. If a cell, like the one pictured in Figure 6, is left on open circuit (which means that there is no conductor of electricity connected to its respective plates) then there should be no chemical action occurring between the materials composing the cell. If the zinc plate is absolutely pure, (i.e., without foreign matter or impurities) an internal action cannot be set up and current cannot be produced by the cell's own materials. However, ordinary commercial zinc contains many foreign particles, such as carbon, tin, iron, and so on, and these small foreign particles act with the zinc to set up tiny electrical currents that flow in a short-circuit path as shown in Figure 5. This local action causes the zinc to be eaten away continuously and in time it will affect the normal output energy of the cell. To prevent this consumption of the zinc when the cell is not used to operate a circuit it is customary to rub a small quantity of mercury into the surface of the zinc. This process is called amalgamation. Amalgamation, therefore, stops local action when a cell is left on open circuit because the mercury does not combine with the carbon, or other foreign particles, but it does act chemically with the zinc to form zinc-mercury amalgam that works its way over the zinc plates and covers up the particles.

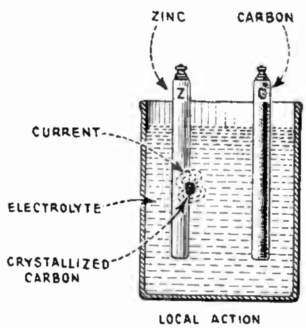

Figure 5

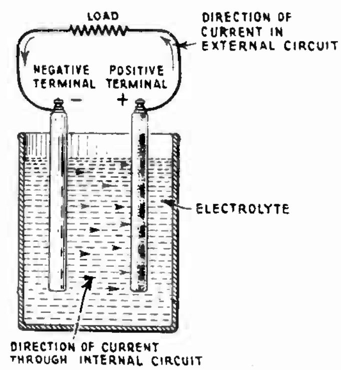

Figure 6

ACTION OF A SIMPLE PRIMARY CELL. Suppose the simple cell in Figure 6 is composed of a positive copper (Cu) electrode, a negative zinc (Zn) electrode, and diluted sulphuric acid. In this combination of materials the acid unites more readily with the zinc than with the copper. The chemical symbol for sulphuric acid is H_2SO_4 which denotes that a molecule of this liquid consists of two atoms of hydrogen, one atom of sulphur, and four atoms of oxygen.

The action is explained according to the "electron theory." The important thing to bear in mind is that atoms consist of an aggregation of electrons and if some of these electrons can be set free by chemical means the free electrons will move through the conductors forming the external circuit around the cell. As we have just stated the movement of current through the load circuit connected to the cell is simply a movement of electrons. Their direction of flow in the external circuit connected to a cell is from the negative terminal to the positive terminal of the cell. This is in accordance with the theory as explained in our lesson on "Static Electricity." It was stated that at a positively charged electrode there is a deficiency of electrons and at a negatively charged electrode there is a surplus of electrons.

by a sal ammoniac electrolyte solution. When a cell of this type is connected in a circuit and current flows the zinc is slowly dissolved, or eaten up, by the chemical action of the sal ammoniac (ammonium chloride). It is the combining of the electrolyte chemically with the zinc and the amount of the intensity of the action for this particular set of materials that makes the cell capable of developing an e.m.f. between its plates and, also, to furnish a given amount of current to a circuit for a given time.

While the chemical action goes on and current flows through the cell a quantity of fine bubbles of hydrogen gas are liberated which immediately form around the carbon. The bubbles collect very rapidly if the cell passes a current of high value continuously for any length of time and their presence on the positive carbon plate causes a very noticeable reduction in the current strength. Thus, we see that the hydrogen gas has a detrimental effect on the amount of electrical energy supplied by the cell. This weakening of the cell is called polarization and if allowed to continue the cell will cease functioning entirely.

The falling off of the current caused by the hydrogen gas is due to two conditions set up within the cell; first, the gas being a non-conductor of electricity acts as an insulator and increases the internal resistance of the cell and, therefore, actually tends to block the flow of current; secondly, the gas layer on the carbon reduces the amount of active surface material that the carbon can present to the electrolyte, that is to say, the gas acts to separate the carbon from the electrolyte. Moreover, if a cell of this kind is strongly polarized it sets up a small opposition e.m.f. because the character of the plates are altered inasmuch as the carbon plate virtually becomes a hydrogen plate. So far as the chemical action of the cell is concerned,it will behave as though it had zinc and hydrogen plates and not zinc and carbon. It has been mentioned before that different combinations of the materials of which a cell is composed will cause the e.m.f. produced between its plates to also change, hence, the e.m.f. of the cell is considerably lowered by the polarized condition.

Polarization is prevented in a cell when it is operated to give an intermittent current of average value for the particular type of cell in question. In the type already under consideration a strong oxidizing substance, such as manganese dioxide, is used for this purpose as it combines readily with the hydrogen and, therefore, removes the gas from around the carbon. It is to be understood that if an excessively large current is delivered steadily by the cell the chemical action between the oxidizing material and the hydrogen may be too slow to prevent polization and the cell will become inactive in a short time. However, if a cell when in this condition is disconnected from the circuit and permitted to remain on open circuit for a brief interval it will rapidly recuperate, or recover, which means that it will be restored to normal by the cleaning up of the hydrogen by the depolarizing agent. The carbon then is once more left free to act as a plate and conductor for the passage of current.

Have you ever noticed when using a pocket flashlight that the light suddenly became dim, but after allowing the switch to remain in the "off" position for a half minute or so the lamp when next lighted would glow with its former brightness? This dimming of the light was caused by the falling off of the current through the cell due to polarization. The same weakening effect is often noticed in the ringing of a door bell, or in the operation of a buzzer, especially when they are operated steadily for a time.

necessary to pass current again through the storage cell to restore the materials to their original condition. With intelligent care a storage cell will last for years since it only requires charging and the adding of water at periodic intervals to maintain it in a proper condition. The life of a dry cell, on the other hand, is a more or less fixed condition because it is governed by the rate at which the active material, zinc for instance, is consumed and this in turn depends upon the amount of electrical energy delivered by the cell. For the reasons just advanced a dry cell is called a primary cell and a storage cell is called a secondary cell. A lesson is devoted to storage batteries and storage cells later in our course. Primary cells are also known as galvanic cells.

Another important thing to mention is that a dry cell is not really dry as the name would lead most anyone to believe. The use of the word "dry" no doubt became popular owing to the fact that all of the materials in the cell are sealed up in a moisture-proof container without any outside evidence of a liquid solution in it like in a "wet" battery, for example. During the manufacture of a dry cell a certain amount of water is added to the materials and the liquid is therefore retained in the moist pasty filling which we could see if we broke open a good cell.

WHY AN ELECTROMOTIVE FORCE IS PRODUCED BY A DRY CELL. It is a known fact that there is always an e.m.f. of a certain number of volts set up between any two pieces of metal of dissimilar kind when immersed in a liquid. When certain combinations of materials are used, and the liquid is a chemical solution of a particular kind, e.m.f.'s as high as 2 volts and more can be obtained. The metal pieces referred to are called "plates" and the chemical solution the "electrolyte." The e.m.f. or voltage of a cell is determined solely by the kind of materials used for the plates and the nature of the electrolyte. The theory is that the electrolyte acts more readily on one material than the other and it is this chemical action that causes both plates to possess an electric potential, but because of their difference in character one plate will have a higher potential than the other. The higher potential plate is called the positive plate and the lower potential plate is the negative plate. The difference of potential is electrical pressure and it is capable of sending current through a circuit. The size of the plates, their actual surface area in contact with the electrolyte, or the amount of separation between plates have no bearing whatsoever on the voltage of the cell. However, these factors do have some effect on the internal resistance of the cell and this in turn will govern to some extent the amount of current that the cell will be capable of delivering.

Hence, if we have one very large cell and one very small cell and each one is made up of a similar combination of materials and electrolyte it will be found that the voltage reading taken between the plates will be alike for the two cells. This would prove our statement that only the materials and the electrolyte govern the e.m.f. or voltage across the plates. A cell consisting of a zinc plate and a copper plate immersed in a liquid of dilute sulphuric acid gives an e.m.f. of approximately 1 volt regardless of the size of the elements (elements means the materials). Another cell, however, having a different combination of materials, for instance, zinc for one plate, carbon for the other, and a sal ammoniac electrolyte, sets up an e.m.f. of approximately 1.5 volts between its plates.

POLARIZATION. To explain this term let us consider that we have a cell consisting of a zinc plate and a carbon plate being acted upon condition. Several cells may be connected to form a battery as follows: Suppose we have 3 cells of this type connected together to form a battery then the total e.m.f. at the terminals would be 3 x 1.5 or 4.5 volts. Again, suppose we had 30 cells of this kind connected to form a battery;then,the total e.m.f. available at the battery terminals would in this case be 30 x 1.5 or 45 volts. In many dry batteries there are connections taken from different cells in order to provide several different voltages from the same battery for convenience.

A battery consisting of three small dry cells connected together in series is shown in Figure 3. Notice that three terminals are supplied so that the e.m.f. (or voltage)of one or two cells may be used separately, or the voltage of three cells may be used by making connections to the outer two terminals. A dry battery containing thirty small cells compactly arranged in a container is shown in Figure 4; the e.m.f. at the outside two terminals is 45 volts. In this battery a tap taken between the 15th and 16th cells is brought to the center terminal on the top so that one-half of the total voltage, or 22½ volts, is available either between the first and second terminals, or between the second and third terminals.

The dry cell and batteries illustrated are typical of the kind found in widespread use for radio and electrical work. A battery similar to the one in Figure 3 is mostly used for a specific purpose in radio circuits to supply a negative voltage to the grids of vacuum tubes and it is, therefore, known as a "C" battery. The battery in Figure 4 is exactly the same as the one just mentioned so far as its principles of construction are concerned, except that it has more cells than the one in Figure 3. The larger battery in Figure 4 is employed principally to furnish the plate voltage to operate vacuum tubes in certain types of equipment and is known as a "B" battery. If several cells of the type shown in Figure 2 are used to furnish an e.m.f. to the filaments of vacuum tubes in receiving sets, to provide the heating current, the cells are then referred to as an "A" battery. Later on in your work you will become accustomed to using the terms "A," "B," and "C" for identifying batteries of any type according to their particular duty. It should now be clear that the terms battery and cell are not to be used interchangeably and, therefore, in your conversation and writing be careful to make the correct distinction between them. Say "cell" when you mean cell and "battery" when you mean battery.

DISTINCTION BETWEEN PRIMARY AND SECONDARY CELLS. There are two types of cells in general use, namely: dry cells and storage cells. A dry cell is one that depends for its operation upon the consumption of one of the materials by the chemical action of the solution on it when current flows through the cell and through the circuit to which it is connected. While current flows the material is gradually eaten up and in due time it will be entirely consumed,and as a result of this action the voltage (or e.m.f.) of the cell will drop so low that the cell becomes useless for all practical purposes. When this happens the cell must be discarded and replaced by a new one. A storage cell, on the other hand, is one that must first be charged by passing a current through it in a certain direction so that its materials will be put into the proper condition that will enable them to produce an electrical pressure. After the storage cell has been on circuit and delivers a certain amount of current in a stated time, its e.m.f. will fall below the proper working value because the chemical relations of the cell are then altered. Since the materials merely undergo a change and are not eaten away, as in a dry cell, it is only

In the case of the generator the electromotive force is obtained by making practical use of the laws of electromagnetic induction. According to the explanations in our preceding lesson on this subject one law stated that when a coil of wire is moved through a magnetic field an electromotive force is produced across the terminals of the coil; this is exactly the principle upon which the generator works since it is constructed to provide a strong magnetic field through which a number of coils are rotated by mechanical means and from these coils we are able to get an electromotive force, or electric power.

In the case of the battery, however, the electromotive force is obtained through the electrochemical action that occurs between the combination of materials that are used. We learn, therefore, that a generator transforms mechanical energy into electrical energy and a battery transforms chemical energy into electrical energy.

Hence, insofar as we are concerned at the present, a generator and a battery both produce similar results, that is, either one will provide an electromotive force. Of course, you will understand that many practical and economical considerations determine whether a generator or battery will be used to furnish power for the operation of certain types of equipment. In many of the modern radio broadcast, commercial telegraph, sound picture, television, and aviation radio installations it has been found necessary to employ both generators and batteries to obtain the best electrical results.

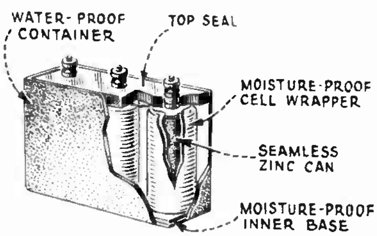

Figure 3

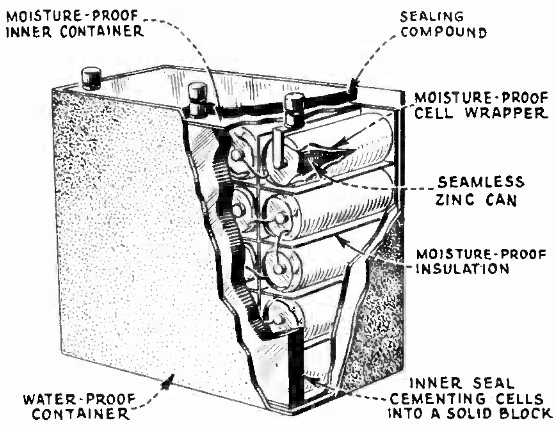

Figure 4

CLASSIFICATION OF BATTERIES AND CELLS. Let us first explain the distinction between the terms "battery" and "cell." A cell is a complete unit consisting of a chemical solution into which is placed two different kinds of materials which are not allowed to touch each other and from which an electromotive force can be obtained by the chemical action set up between the solution (electrolyte) and the materials. When two or more cells of similar kind are connected together in a combination that permits their individual e.m.f.'s to be utilized all at the same time, the whole combination is known as a "battery." Hence, a battery is a number of cells all functioning in conjunction with one another to provide a certain amount of electrical pressure, measured in volts, from its terminal binding posts.

A single cell of the dry cell type is shown in Figure 1, while its interior construction is pictured in the cross-sectional view in Figure 2. This cell has an e.m.f. of approximately 1.5 volts when in good

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PRIMARY CELLS

SOURCES OF ELECTRIC POWER. The principal sources of electric power that are utilized in practically every radio, sound picture, television, and aviation radio power installation, including recorders, reproducers, transmitters, receivers, auxiliary equipment and types of apparatus of unlimited varieties, are the electric generator and the electric battery. When we say source of electric power we mean a source of electromotive force. It is customary for some persons to think that a generator or battery stores up electricity and supplies current to any device to which it may be connected, but this is not a fact. A generator or battery merely furnishes an electromotive force (or pressure) which when applied to any device, or circuit, will set electrons in motion and cause them to flow through the device, or circuit. Always keep in mind that the movement of electrons through wires (and all conductors of electricity) is the so-called current flow. Now, since electrons already exist in the wires and other elements that form a circuit then it cannot be said

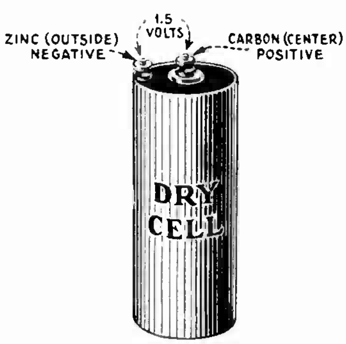

Figure 1

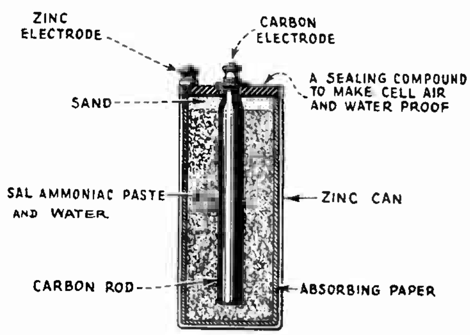

Figure 2

that a generator or battery supplies them; what the generator or battery does is to force these electrons to move through the wires from one place to another, that is, the electrons which constitute the current are forced to flow through a circuit by the e.m.f. (or pressure) applied to the circuit. Thus, it is evident that current will not flow in any circuit unless an electromotive force is applied to it from some source.

RESULTS OBTAINED FROM VARIOUS CELL COMBINATIONS

VOLTAGE - RESISTANCE - CURRENT

SERIES ARRANGEMENT OF CELLS

VOLTAGE......The total e.m.f. of a series combination of cells is the sum of the e.m.f.'s of the individual cells.

RESISTANCE...The combined resistance of cells in series is increased by adding cells. The total resistance is the sum of the internal resistances of the individual cells.

CURRENT......In practice cells are usually connected in series (to increase the e.m.f.) when the resistance of the load circuit (or external circuit) is high in order to obtain the proper current.

PARALLEL ARRANGEMENT OF CELLS

VOLTAGE......The total e.m.f. of a parallel combination of cells is equal only to the e.m.f. of any cell in the group providing they are of similar kind.

RESISTANCE...The combined resistance of cells in parallel is decreased by adding cells. The total internal resistance is equal to the internal resistance of one cell divided by the number of cells.

CURRENT......In practice cells are generally connected in parallel when the resistance of the load circuit is low so that each cell contributes its share of the total current in the circuit.