PRIMARY BATTERIES

Training Pamphlet No. 7

PREPARED IN THE OFFICE OF THE
CHIEF SIGNAL OFFICER

June, 1922

UNITED STATES OF AMERICA
WAR OFFICE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1923

WAR DEPARTMENT
Document No. 1112
Office of The Adjutant General

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WAR DEPARTMENT,
WASHINGTON, *June 30, 1922.*

The following publication, entitled "Primary Batteries," Training Pamphlet No. 7, is published for the information and guidance of all concerned.

[A. G. 062.1 (6-21-22).]

BY ORDER OF THE SECRETARY OF WAR:

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PRIMARY BATTERIES.

SECTION I.

DEFINITIONS AND USES.

1. **Definitions.**—A battery is an apparatus for converting *chemical energy* directly into *electrical energy.* In practical language, this simply means that a battery is a source of a current of electricity which is generated as a result of chemical action. This definition includes both primary and secondary (or storage) batteries, and the essential difference between the two is briefly as follows: When a primary battery is exhausted, it can be renewed only by renewing its parts or chemicals, whereas a storage battery can be renewed simply by charging with a current of electricity from some suitable external source. In other words, a *primary battery is not reversible; a storage battery is reversible.* Only primary batteries are described in this pamphlet, and these may be classified in various ways, depending on their uses and characteristics, such as: "Open-circuit" and "closed-circuit" cells; "wet" and "dry" cells; "two-fluid" and "one-fluid" cells; etc.

In general, a battery consists of a number of cells, which may be connected in an electrical circuit in different ways, depending on the use to which they are to be put. The cell is thus the unit in a battery. The simplest cell, as shown in Figure 1, consists of a glass jar partly filled with dilute sulphuric acid, and containing *two different metals,* as zinc and copper. If the metals are pure there is no visible action or effect of any sort, unless connected by an external conductor or wire. If they are so connected a current of electricity will flow, there being a complete electrical circuit consisting of the (1) *external circuit* of the connecting wire and any apparatus connecting with it, and the (2) *internal circuit* of the two plates and the acid. This current may make itself manifest in several ways: In the external circuit by heating the wire; and by magnetic effects such as deflecting the magnetic needle of a mariner's compass which is brought near the wire; and in the internal circuit by the formation of bubbles of gas on the copper plate; eating away of the zinc; heating the acid; etc.

2. **Uses.**—In general, a primary battery is used as a source of an electric current whenever it is desired to deliver a limited amount of

current at a limited voltage without any mechanical action, and when a storage battery can not be used because there is no source of electricity to charge it. It is to be contrasted with a dynamo or generator which, driven by a prime mover, as a steam turbine, can deliver an almost unlimited amount of current at almost any voltage. In some cases the choice between a primary battery, a secondary battery, and a small dynamo may depend on such matters as location, cost, available room, weight, attention of an operator, etc. Thus a primary battery would certainly be used as a source of current in an isolated location, but would *not* be used in an industrial center or a large city. The advantage of a primary battery lies in part, at least, in the fact that it is self-contained, needs little or no attention for long periods, is easy to replace, etc.

There are a great number of uses to which primary batteries are put, and in some cases they fill a want that can not be supplied by any other convenient means. Among their many uses in supplying current are the following: (1) Portable flashlights; (2) spark coils for ignition purposes in gasoline engines; (3) telegraph relays and sounders on isolated lines; (4) telephone transmitter in local battery sets; (5) detector-testing buzzer in radio receiving sets; (6) plate circuits in vacuum tube portable transmitting and receiving radio sets; (7) master clocks; (8) bells and gongs; (9) projectors; (10) signal lights; (11) intercommunicating systems; (12) annunciators; etc.

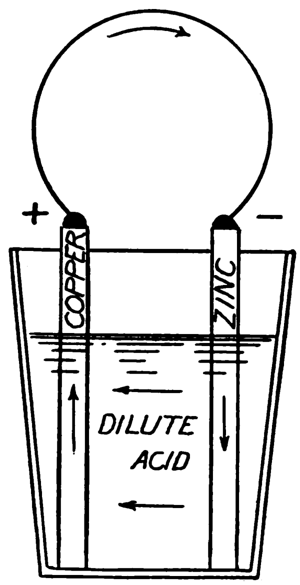


FIG. 1.—Simple cell.

SECTION II.

THEORY OF SIMPLE VOLTAIC CELL.

3. **Component parts.**—The simple form of primary cell described in Section I is sometimes called a "voltaic" or "galvanic" cell, after the names of two early workers in electricity, Volta and Galvani. The *component parts* of a simple voltaic cell, as well as other forms of primary batteries, have been given certain names and may be de-

fined as follows: The liquid in which the two different metals are immersed is called the "electrolyte," which may be: (*a*) An acid, as sulphuric acid, dilute with water; (*b*) a salt or other chemical, as sal ammoniac (ammonium chloride) dissolved in water; etc. In some types of cells the electrolyte or chemical is also known by a trade name such as "electropoin"; in other cells as "chromac"; etc. The two different metals are called "electrodes," one being an "anode" and the other a "cathode," which may be copper, zinc, carbon, etc. The electrolyte and the electrodes are contained in a vessel called a "battery jar," "can," or "container." These may be round, square, or conical, and made of *glass*, *enameled steel*, *zinc*, etc., depending on the type of cell. Certain jars are made of a special "*heat-resisting*" glass, so called because they are not easily cracked by the heat which is developed when the chemicals for the electrolyte are first mixed in them.

4. **Seat of voltage and contact difference of potential.**—The seat of the voltage of a cell is considered to be at the *surfaces* of the two electrodes which are in contact with the electrolyte. For this reason it is sometimes called the "contact electromotive force." The value of the electromotive force will differ with different metals as the electrodes, and with different liquids as the electrolyte, as will be seen from the following abridged table of experimental values,

Contact differences of potentials.

Electrode metal.	Electrolyte.	
	Sulphuric acid.	Hydrochloric acid.
Zinc	−0.62	−0.54
Copper	+0.46	+0.35
Silver	+0.73	+0.57

in which the potentials are referred to that of the electrolyte as a reference point or a zero of potential. Thus zinc in sulphuric acid has a potential of 0.62 volts *below* that of the acid; and copper in the same acid has a potential of 0.46 volts *above* that of the acid. Hence the total difference of potential between the two metals in sulphuric acid is 0.62 plus 0.46 or 1.08 volts, which is the voltage of such a cell.

The above table shows that the *voltage* of a cell depends on the kind or nature of the materials of which it is made and not on the amount of the materials. In other words, the *voltage is independent of the size of the cell.* This is a most important fact, to which reference will be made in later parts of the pamphlet.

Although in theory many different combinations of electrodes and electrolytes can be selected from a table of contact differences of potential, yet as a result of long practical experience only a comparatively small number of types of primary cells have been found to be useful and their voltage generally lies between 1 and 2 volts. These cells are described in later sections.

5. **Chemical actions; formation of ions.**—When the external electrical circuit is completed by a wire and the current begins to flow, there is no observable change in the wire itself, but there are *chemical changes* taking place in the electrolyte at and near the surfaces of the electrodes, and one of the electrodes begins to combine chemically with the electrolyte. As a result of the chemical action it is found that the electrolyte is partly decomposed into electrically charged groups of atoms, called "ions." Some of these carry a *positive* charge and are known as "anions," and the others carry a *negative* charge and are known as "cathions." At the time of the formation of the ions the two electrodes are also electrically charged, the one with a positive charge being called the "anode" and the other with a negative charge the "cathode."

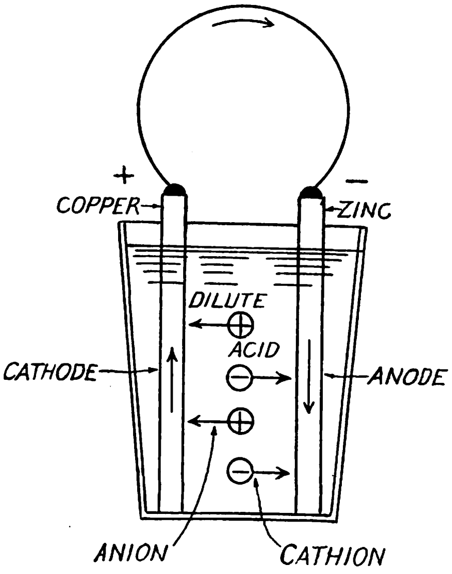


Fig. 2.—Cell with positive and negative ions.

6. **Movement of anions and cathions.** — According to well-known laws of electricity, two bodies charged with the *same* kind of electricity, both being positive or both being negative, will repel each other. Similarly two bodies charged with *opposite* kinds of electricity will attract each other. Inasmuch as the ions are comparatively free to move in the electrolyte, the anions (positive charges) will move to the cathode (negative electrode); and the cathions (negative charges) will move to the anode (positive electrode). Thus it is seen that the flow of current in the internal circuit of the electrolyte consists essentially of the movement of ions of opposite signs in two opposite directions. It is to be noted, however, that *in effect* the movement of positive ions in one direction is the same as the movement of negative ions in the opposite direction, in that one electrode becomes positive and at the same time the other becomes negative, and thus the effect of the movements of the two kinds of ions is additive.

The following is a brief example of the decomposition of the electrolyte and the movement of the ions in the simple voltaic cell. The chemical formula for sulphuric acid is H_2SO_4, which is decomposed into H_2 ions which are positively charged and may be indicated thus: $H_2\oplus$; and SO_4 ions, which are negatively charged and may be indicated $SO_4\ominus$. At the same time the copper becomes negatively charged and the zinc positively charged. The copper attracts the positive H_2 ions (anions) which appear on the copper plate as hydrogen gas. The zinc, whose chemical formula is Zn, attracts the negative SO_4 ions (cathions) and combines with them chemically to form $ZnSO_4$, which remains dissolved in the electrolyte. This is indicated in Figure 2, where the positive ions are moving to the cathode (negative electrode) and the negative ions are moving to the anode (positive electrode).

The chemical actions and the movements of the ions in other types of cells are much more complicated and in certain cells are not yet completely understood.

7. **Local action and amalgamation.**—If the zinc electrode of a simple cell is chemically pure, there is no chemical action when the external circuit is open. In almost all cases, however, the zinc is not pure and as a result it is noted that gas bubbles are continually forming on its surface and that the zinc gradually wastes away, even when the cell is not being used. This is called "local action." It is due to small impurities, such as particles of other metals, etc., embedded in the zinc. These impurities, being in the electrolyte, together with the zinc form a *small closed local cell* that thus wastes the zinc. It has been found that this action can be remedied by cleaning the surface of the zinc with sandpaper and then with dilute sulphuric acid, and afterwards rubbing mercury over it until the surface is coated with the mercury. The coating is an alloy of mercury and zinc and is called an "amalgam." The amalgam does not affect the activity of the zinc as an electrode in the cell, as it is continually dissolving in the mercury, where it is acted upon by the acid as before. The impurities apparently come to the surface of the amalgam and then drop to the bottom of the jar. This treatment of the zinc to prevent local action is called "amalgamation." The term is applied only to the zinc as found in certain types of open-circuit cells. In a few cases the zinc is cast with a mixture of a small amount of mercury so that it is thereby partially amalgamated and may not need any further amalgamation when put into service.

8. **Polarization and depolarizers.**—After a simple cell has been furnishing current for some time, it will be found that a considerable number of hydrogen bubbles will accumulate on the copper electrode and that the voltage and hence the current, as measured by suitable instruments, will gradually decrease. In this condition the cell is said to be *polarized* or in a condition of *polarization*. The diminished

voltage is due to the presence of the hydrogen gas on the copper. This gas produces several effects, thus, (1) as it is a poor conductor of the electric current, it introduces a high resistance in the internal circuit of the cell; (2) as it reduces the area of the electrode in contact with the electrolyte, it still further increases the resistance; and (3) finally, as it is in effect an additional electrode with a small contact difference of potential opposing that of the cell itself, it reduces the voltage. The total result of these various effects is to cause a reduction in voltage at the terminals of the cell and hence a reduction in current through the circuit. If the bubbles are removed by mechanical means, as shaking or scraping them off from the copper, the cell will deliver the same voltage and current as before for a short time. But polarization will start again, with the same result of decreased voltage and current. In other words, this simple cell is not a practical one on account of its constant tendency to polarize. The polarization of a cell can in general be removed or prevented by suitable means, which will differ in the various types of cells as follows: (1) Chemical means; (2) constructional means; and (3) mechanical means.

The most common method is the *chemical* one in which one electrode is either immersed in a solution of suitable chemicals or is surrounded by suitable solid chemicals. These have a strong attraction for hydrogen and combine chemically with it or the other products of the polarization and thus remove them from the electrodes or prevent their deposition on the electrodes. Some of these depolarizers are: Nitric acid, black oxide of copper, dioxide of manganese as in the dry cell, etc. The *constructional* method is also a chemical one and consists in the use of a depolarizing solution which is separated from the electrolyte in the battery jar by a porous cup. The cup allows the current to flow through its walls and the necessary chemical actions to take place, but keeps the depolarizer from mixing freely with the electrolyte. Some of these depolarizers are: Bichromate of soda; bichromate of potash, as in the Fuller cell, etc. In special cases the porous cup may be omitted, as in the gravity cell, where the two solutions are kept apart by other means. When a cell has both a liquid electrolyte and depolarizer it is sometimes called a "two-fluid" cell, and when only a liquid electrolyte, a "single-fluid" cell. The *mechanical* method consists in scraping the bubbles off the electrode or shaking them off by keeping the electrode in motion. Obviously this is not a practical method and cells that would require this treatment are used only in experimental work.

In some types of cells the depolarizer not only largely prevents polarization when the current is flowing, but also to a certain extent continues the depolarization when it is not supplying current, and thus helps the cell to recover its voltage. This is often the case in dry cells.

In an ideal cell there would be no local action and no polarization, and hence no need of amalgamation and depolarizers.

SECTION III.

INTERNAL CIRCUIT OF A CELL.

9. **Positive and negative terminals.**—From a suitable table of contact differences of potential (see par. 4) it is possible to tell which electrode of a cell has a potential above that of the electrolyte and which one a potential below that of the electrolyte. The electrode whose potential is *above* that of the electrolyte is called the *positive terminal* or *pole* of the cell, and similarly the electrode whose potential is *below* that of the electrolyte is called the *negative terminal* or *pole* of the cell. In practical cases, however, the positive and negative terminals or poles are identified by means of a suitable electrical testing instrument, such as a voltmeter. The terminals or binding posts of this instrument are marked "Plus" or +, and "Negative" or −, and if the corresponding poles of a cell are connected to them by a pair of insulated wires, the needle of the voltmeter will be deflected in a correct direction over its scale of volts. Under these conditions the terminal of the cell connected to the positive binding post is positive, and the one connected to the negative post is negative. If the needle should be deflected in the wrong direction, the wires should be reversed at either the voltmeter or the cell, and then as before the terminal connected to the positive post is positive, etc.

Referring to Figures 1 and 2, it will be noted that the *positive pole* or *terminal* of the cell is the *negative electrode* (cathode) and similarly the negative pole or terminal is the *positive electrode* (anode). Although from some points of view this may seem to be contradictory, yet it must be remembered that the signs of the electrodes are generally used in considering the theory and internal structure of the cell, whereas the signs of the poles or terminals are used in practical work and refer to the external circuit. However, if the internal and external circuits are considered *each with its own polarity*, the current will always flow from positive to negative and will be in the same sense or direction in the complete circuit. Thus, in the circuit inside the cell, the current will flow from the anode (positive plate) through the electrolyte to the cathode (negative plate); and in the circuit outside the cell, from the positive pole or terminal through the external resistance to the negative pole or terminal.

10. **Marking of terminals.**—It is not usual to mark the polarity of the terminals of primary cells; although it is almost the invariable practice to do so in the case of secondary (or storage) cells. The reason for this probably lies in the fact that the terminals of a primary cell are so obviously different, as copper and zinc, carbon and zinc, etc., that they can be immediately recognized, whereas in the case of a storage cell there may be no *apparent* difference between the terminals. However, when several *dry cells* are assembled and sealed as a unit in a case or container, the polarity is usually marked by plus and minus marks, or by a red wire for the positive terminal and a black wire for the negative. In all practical cells in common use to-day where zinc is one of the electrodes it is the negative terminal and the other electrode is the positive terminal.

11. **Open-circuit and closed-circuit voltage.**—In theory the voltage of a cell can be determined from a table of contact differences of potential and when so obtained is called the "open-circuit" voltage, because the external circuit is *open* and not closed as it would be when the cell is delivering current. In actual work, however, the open-circuit voltage is measured at the terminals of the cell by a voltmeter, which because of its high resistance draws so small a current to deflect its needle that the cell is *practically on open circuit.*

When, however, the external circuit of a cell is closed through a wire or an electrical device, while the voltage is being measured, it will be noticed that the reading of the voltmeter is invariably decreased, thus showing that the voltage of the cell at its terminals has been reduced. The voltage when thus delivering current is called the "closed-circuit" voltage. The cause of the difference between the open and closed circuit voltages lies in the fact that a cell has an *internal resistance.*

12. **Internal drop in voltage.**—The effect of the internal resistance can be explained by the application of Ohm's law, which when applied to the complete electrical circuit is $I=\frac{E}{R}$ where E is the open-circuit voltage; R is the *total* resistance in circuit and I is the resulting current. Considering the total resistance as consisting of two parts, the *internal* part, r, inside the cell; and the *external* part, R, in the outside circuit; then Ohm's law can be written as follows: $I=\frac{E}{r+R}$ or $E=(I\times r)+(I\times R)$. This states in effect that the voltage, E, may be considered as being used in two parts of the circuit, one part, $I\times r$ volts, in the resistance, r, *inside the cell;* and the other, $I\times R$ volts, in the resistance, R, *outside the cell.* The $(I\times r)$ part is called the

"internal drop in voltage" or "lost volts" because it occurs within the cell; and the $(I \times R)$ part is called the "external drop in voltage" or the "closed-circuit voltage" because it occurs in the external circuit and is the voltage at the terminals of the cell when the external circuit is closed and the cell is supplying current to it. If the formula is rewritten as follows, $(I \times R) = E - (I \times r)$ it is seen that the closed-circuit voltage is equal to the open-circuit voltage minus the internal drop in voltage. In other words, the closed-circuit voltage is always less than the open-circuit voltage. It must be noted that both the internal drop in volts and the closed-circuit volts depend on the values of the current and resistance. Other things being equal, the larger the current, I, the larger will be the internal drop $(I \times r)$ and the less will be the closed-circuit volts $(I \times R)$; and conversely the smaller the current, the less will be the internal drop and the larger will be the closed-circuit volts, until at zero current the closed-circuit volts become the same as the open-circuit volts. Similarly the smaller the internal resistance, r, the smaller will be the internal drop and the larger will be the closed-circuit voltage until at zero resistance the closed-circuit volts become the same as the open-circuit volts; and conversely the larger the internal resistance, the larger will be the internal drop and the smaller will be the closed-circuit voltage. In an ideal cell there would be no internal resistance, no internal drop in voltage, and the open and closed circuit voltages would be the same for all values of the current.

13. **Internal resistance.**—The internal resistance of a cell differs greatly with the type of cell, and in any one type is not strictly constant but depends on many factors, such as size of the electrodes, their distance apart, character of the electrolyte, age of the cell, etc. The effect of these different factors can be explained as follows. In general the larger the electrodes, the smaller will be their resistance, and conversely the smaller the electrodes, the larger will be their resistance. The larger the electrodes, the greater will be the area of the cross section of the electrolyte between them and hence the smaller will be its resistance; and conversely the smaller the electrodes, the smaller will be the cross section of the electrolyte and hence the larger will be its resistance. The farther apart the electrodes, the longer will be the path of the current in the electrolyte and hence the larger its resistance; and conversely the closer the electrodes together, the shorter the path and the smaller will be its resistance. The resistance of the electrolyte depends largely on the materials from which it is made, on its chemical condition, its length of service in the cell, and other factors of similar nature. In general the resistance is comparatively low in a new cell and increases with use. Thus in a new dry cell it may be as low as 0.05 ohm; in an old one as high

as 100 ohms or more; and in a new wet cell as high as 3 ohms, and with increasing resistance as the cell continues in service.

13 *a*. **Example of internal drop in voltage.**—The following numerical examples will illustrate the principles of the internal drop in voltage and the measurement of the internal resistance. If the open-circuit voltage of a cell, E, is 1.450 volts; its internal resistance, r, is 0.25 ohm; and the external resistance, R, 21.7 ohms; what is the internal drop in voltage? In this case Ohm's law is $1=\frac{E}{r+R}=\frac{1.450}{0.25+21.7}=0.06606$ or 0.0661 amperes nearly. The internal drop is $I\times r=0.0661\times 0.25=0.016(52)$ or 0.017 volts nearly. Therefore the voltage at the terminals of the cell is $1.450-0.017=1.433$ volts, when delivering a current of 0.0661 ampere. If the external resistance were reduced so that the current were doubled (0.1322 ampere) then the internal drop would be doubled because $(I\times r)$ is doubled, and the voltage at the terminals of the cell is $1.450-0.33=1.417$ volts when delivering a current of 0.1322 ampere.

13 *b*. **Example of internal resistance.**—The formula $(I\times r)=E-(I\times R)$ can be rewritten as follows: $r=\frac{E-(I\times R)}{I}$ where as before E is the open-circuit volts; $I\times R$ the closed-circuit volts; and I is the current. As in the previous example, let E be 1.450 volts; $I=0.066(06)$ ampere; $I\times R=1.433(5)$ volts; and $E-I\times R=0.016(52)$. What is the internal resistance?

From the formula $r=\frac{1.450-1.433(5)}{0.066(06)}=0.25$ ohms nearly. The formula for the internal resistance can be written in many other ways, but they are all equivalent to the one given above.

SECTION IV.

EXTERNAL CIRCUITS OF CELLS.

14. **Definitions.**—Some of the terms used in battery and similar circuits will be defined for convenience in use in later paragraphs.

The length of time expressed, for example, in days, weeks, or months during which a cell can supply a useful amount of current is sometimes called the "life" or "hours of service" of the cell. In general this can be determined only by an actual test under service conditions. Thus, a Fuller cell will furnish current for a telegraph circuit for about three months and its life is therefore three months.

If the current which a cell supplies is small, as in telephone work, it is said to be in "light" service or duty; and similarly, when the current is large, as in ignition work for gasoline engines, it is in "heavy" service or duty.

In some cases cells are rated from the point of view of their capacity or ability to furnish a certain current for a certain length of time. This is expressed in "ampere-hours," being the product of the current in amperes by the time in hours. Thus, if a cell furnishes half an ampere continuously for one week, the ampere-hours would be $\frac{7\times 24}{2}$ or 84. It is, however, more usual to rate storage (or secondary) cells in ampere-hours than it is primary cells.

15. **Cells in parallel.**—From the preceding section it is evident that the current delivered by a cell depends upon resistances in both the internal and external circuits; and further that the current delivered by a battery or combination of cells depends upon many combinations of resistances and voltages. The most common, as well as the most useful, combinations can be illustrated by means of two simple voltaic cells as follows: If (1) zinc terminals of the two cells are connected together with a short wire; (2) the copper terminals are likewise connected; (3) the wire between the zincs is connected to one terminal of the external resistance R; and (4) the wire between the coppers is connected to the other terminal, as shown in Figure 3, then the two cells are said to be connected "in parallel" or "in multiple." In effect, the zinc electrode of one cell is doubled in area and likewise the copper electrode is doubled. Under these conditions the two cells may be considered as one large cell whose *voltage*

is that of *one* cell but whose internal resistance is reduced to *half* that of *one cell* because the two internal resistances are connected in parallel or in multiple. In this case Ohm's law becomes $I = \frac{E}{\frac{r}{2} + R}$ where E, r and R are respectively the open circuit voltage; the internal resistance of one cell; and the external resistance.

If the number of equal cells, all connected in parallel, is further increased, the voltage will still be that of *one cell,* but the internal resistance of the combination will be much decreased; in fact it will be decreased as many times as there are cells of equal size in parallel. Thus, if there are *n* cells in parallel where n is any whole number, the internal resistance of the n cells will be $\frac{r}{n(p)}$ ohms, where the letter (p) is added to the n to indicate the parallel connection. If these cells are connected to an external resistance, R, as before, the current will be $I = \frac{E}{\frac{r}{n(p)} + R}$.

16. **Advantage of cells in parallel; large currents.**—From a consideration of the last formula it is evident that if the external resistance, R, is large compared with $\frac{r}{n(p)}$, there will be only a very small increase in current as more cells are added in parallel. This is because R remains large and only the small part, $\frac{r}{n(p)}$, is decreased. On the other hand if R is small compared with $\frac{r}{n(p)}$, the quantity $\frac{r}{n(p)}$ should also be made small if possible, as a decrease in it will considerably increase the current. In general, cells should be connected in parallel when it is desired to send a large current through a small external resistance. The combination of cells to send a *maximum current* through an external resistance will be given in a later paragraph. (See par. 25.)

16 *a*. **Examples.**—The following numerical examples will illustrate the use of cells in parallel in high and low resistance circuits. In the first case let the external circuit resistance be 1,000 ohms, and let there be a single cell of 1.45 volts on open circuit, and with an internal resistance of 0.25 ohm; then the current will be $I = \frac{1.45}{0.25 + 1{,}000}$ $= 0.00145$ ampere approximately. If there are 10 cells all similar to the single cell and connected in parallel, then the E will be 1.45; $\frac{r}{n\ (p)}$ will be 0.025 ohm; and the current will be $I = \frac{1.45}{.025 + 1{,}000}$ $= 0.00145$ ampere, approximately, or about the same as before. Finally,

if the number of cells in parallel is increased almost without limit, the internal resistance of the combination will be reduced almost to zero, but the current will be only very slightly increased. In other words, increasing the number of cells in parallel when the external resistance is high gives only a very small increase in current.

16 *b*. **Examples.**—In the second case let the external resistance be 0.1 ohms and there be a single cell similar to the above, then the current will be $I=\frac{1.45}{0.25+0.1}=4.14$ amperes. If there are 10 cells in parallel, then the current will be $I=\frac{1.45}{0.025+0.1}=11.6$ amperes. Finally, if the number of cells in parallel is increased almost without limit, the current will be increased to nearly 14.5 amperes. In other words, increasing the number of cells in parallel when the external resistance is low gives a large increase in current.

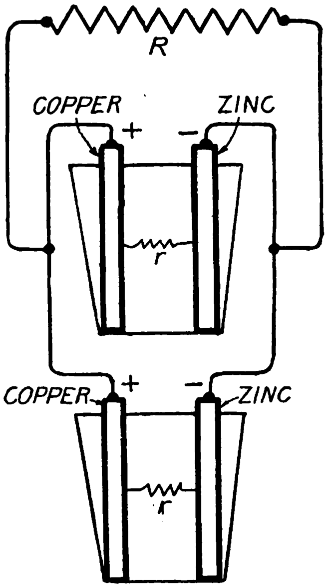


FIG. 3.—Two cells in parallel.

17. **Advantage of cells in parallel; long life.**—In many cases there is an advantage of connecting cells in parallel as it serves to lengthen their life. In light service the life in general is long, but in heavy service it is much shorter. In explanation it may be stated that when the current delivered by a cell is excessive, or as it is sometimes expressed, when the "drain" is excessive, the exhaustion of the chemicals is also excessive and their life is very much shortened.

In heavy service a battery of cells can be used in either of two ways: (1) By connecting the cells singly into circuit, one after the other, replacing each one as it fails after a comparatively short time, until all have been used up; or (2) by connecting them all in parallel and using them until they all fail. In the former case each cell must supply the full current as long as it is in circuit; whereas in the latter case each cell will supply only its fractional part of the whole current. Practical experience has shown that a given number of cells will last longer if used in the latter method. The following example will illustrate this point: If a given large current is to be delivered, two cells in parallel will last 40 per cent longer than two cells used singly, one after the other. Similarly, three cells in parallel will last 60 per cent longer than when used singly, one after the other. Thus, if one cell will last 5 days, two in succession will last 10 days; but if they were connected in parallel, they would last 14 days. Similarly, 3 cells in succession will last 15 days; but if they are connected in parallel, they will last 24 days. Thus, for large currents, cells should be connected in parallel in order to obtain long service with a minimum number of cells.

18. **Effect of size of cell.**—As has been stated, when several cells are connected in parallel, the internal resistance of the combination is decreased, but the voltage remains unchanged. The result is essentially the same as though the cells were replaced by a *single* large sized cell with the same kind of electrolyte and electrodes but with a smaller internal resistance. The increase in size *may* increase the current in the circuit, because of a decrease in resistance in the internal part of the circuit, but in any case it will *increase the life* of the cell, because of the increase in the amount of the chemicals or "active materials," as they are sometimes called. In other words, the larger the amount of the chemicals, the greater is the amount of the chemical energy, and hence the greater is the electrical energy and the ampere hours. Thus, a large cell can supply a certain current for a *longer time* than a small one; or it can supply a *larger* current than a small cell for a given length of time.

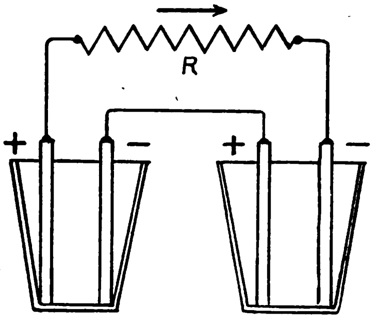


FIG. 4.—Two cells in series.

The effect of the size of a cell can be illustrated as follows: A single drop of acid with the smallest size or piece of zinc and copper wires as the electrodes will give the same *voltage* as the largest size of cell of the same materials which has ever been made; but the *current* which the latter would deliver might be a thousand times greater than the former, and probably this current would be delivered for a thousand times longer interval of time. Thus the voltage of a cell, being a *contact* voltage, is independent of the dimensions and weight of the cell, but the current and life are dependent on the size, etc., being greater as the cell is larger, and smaller as the cell is smaller.

19. **Cells in series.**—If (1) the zinc terminal of one cell is connected to one terminal of an external resistance, R; (2) the copper terminal of the same cell is connected to the zinc terminal of a second cell; (3) and if the copper terminal of this cell is connected to the other terminal of the external resistance, as shown in Figure 4, the two cells are then said to be connected "in series." In this case it is evident that the size of the electrodes of each cell, the voltage of each cell, etc., remain unchanged, but as the voltage of both cells is applied in the same sense or direction in the complete circuit, the two voltages must be added together to give the total voltage. In a similar way,

as the current must flow through the internal resistances of both cells, the two resistances must be added together to give the total internal resistance. Thus, if E and r are, as before, respectively the open-circuit voltage and internal resistance of one cell, the total voltage is $2 \times E$ and the internal resistance $2 \times r$. When connected to the external resistance, R, the current will be $I = \frac{2E}{2r + R.}$.

If the number of equal cells, all connected in series, is increased, both the volts and the internal resistance will be increased by as many times as there are cells in series. Thus if there are n cells, where n is any whole number, the total volts is $n(s) \times E$ where the letter (s) is added to indicate the *series* connection, and the total internal resistance is $n(s) \times r$. If these cells are connected in series with an external resistance, R, as before, the current will be $I = \frac{n(s) \times E}{n(s) \times r + R}$.

20. **Advantage of cells in series; high voltage.**—From a consideration of the last formula it is evident that if the external resistance, R, is large compared with $n(s) \times r$, there will be a large increase in current as the number of cells is increased. This is because the total volts, $n(s) \times E$, increases rapidly as cells are added, whereas the total resistance $n(s) \times r + R$ increases only very slowly. On the other hand, if R is small compared with $n(s) \times r$, there will be only a very slight increase in the current as the number of cells is increased. This is because both the total voltage and total internal resistance increase at about the same rate. Thus, cells should be used in series when it is desired to send a large current through a large resistance.

20 *a*. **Example.**—The following numerical examples will illustrate the use of cells in series in high and low resistance circuits. In the first case let the external resistance be 1,000 ohms, and let there be 10 cells, each of 1.45 volts on open circuit and with an internal resistance of 0.25 ohm. If all are connected in series, the voltage $n(s) \times E$ will be 14.5 volts; the internal resistance $n(s) \times r$, 2.5 ohms, and the current will be $I = \frac{14.5}{2.5 + 1{,}000} = 0.0145$ ampere. If the number of cells in series is increased to 20, the current will be increased to 0.0289 ampere, and if the number is still further increased, the current will continue to increase nearly as fast as the number of cells increases. In other words, increasing the number of cells in series when the external resistance is large compared with the internal resistance gives continually increasing current.

20 *b*. **Example.**—In the second case let the external resistance be 0.1 ohm, then the current will be $I = \frac{14.5}{2.5 + 0.1} = 5.58$ amperes. If the number of cells in series were doubled, the current would be in-

creased to only 5.69 amperes. In other words, increasing the number of cells in series when the external resistance is low compared with the internal resistance gives only a very small increase in current.

21. **Conventional symbol for a cell.**—It has been found convenient to have a symbol to indicate a cell and its polarities in the various battery connections described in paragraphs 15–20 above. There are many different conventional symbols in use, but the one adopted in this pamphlet is shown in Figure 5–a, where the short, thick line is the positive terminal, and the long thin line is the negative terminal. This same symbol may be used for any primary or secondary cell. Cells in parallel, as described in paragraphs 16–17, are shown in Figure 5–b, in which all the positive terminals are connected together as one large common positive terminal, and similarly all the negative terminals are connected together as one large negative terminal. Cells in series, as described in paragraphs 19–20, are shown in Figure 5–c, in which the positive terminal of the first cell is connected to one terminal of the external resistance, and the negative terminal of this cell is connected to the positive terminal of the second cell; the negative terminal of the second cell is connected to the positive terminal of the third cell, etc.

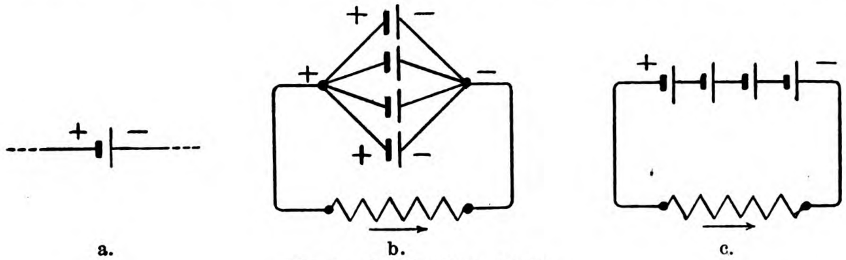


FIG. 5.—Combinations of cells.

22. **Cells in series-parallel.**—With some values of internal and external resistances, a simple series or parallel connection of several cells may not give as large a current as is possible to obtain from the given number of cells. In this case, some combination of the two types may be used, such as that shown in Figure 6–a or 6–b, which is called a "series-parallel" connection. In the first case, Figure 6–a, the two cells in the left-hand group are connected in parallel, as are the two in the right-hand group, and these two groups are connected in series. This is one of the simplest of series-parallel connection. The resulting voltage and internal resistance can be obtained as follows: The left-hand group has, by paragraph 15, an open-circuit voltage and an internal resistance respectively of E and $\frac{r}{2}$; likewise the right-hand group has the same voltage and resistance, E and $\frac{r}{2}$; and hence two groups in series have, by paragraph 19, a combined or

resultant open-circuit voltage of 2 × E, and an internal resistance of $\frac{r}{2}+\frac{r}{2}=r$. Thus, this series-parallel combination of four cells has the advantage of having the voltage of two cells in series with the internal resistance of only one cell. In the second case, Figure 6–b, four cells are arranged in another simple series-parallel connection. The two cells in the top group are in series and the resulting voltage and internal resistance are respectively 2 × E and 2 × r. The two cells in the bottom group are also in series and have the same voltage and resistance. As the two groups are in parallel the voltage is that of one group, 2 × E, but the resistance is one-half that of either group or $\frac{1}{2} \times 2 \times r$, or r. Hence this series-parallel combination of four cells has the same resultant voltage and resistance as that of the other four cells.

Any practical series-parallel connection can, in general, be reduced to the equivalent of either Figure 6–a or 6–b. Thus, if there are n (p) cells in parallel in one group, the voltage is E and the internal resistance is $\frac{r}{n(p)}$, and if there are n (s) of these groups in series, the voltage will be n (s) × E and the internal resistance n (s) $\times \frac{r}{n(p)}$. Hence the formula $I=\frac{n(s)\times E}{\frac{n(s)\times r}{n(p)}+R}$. Similarly, if there are n (s) sells in series in one group, the voltage will be n (s) × E and the resistance n(s) × r; and if there are n (p) of these groups in parallel, the voltage will be n(s) × E and the resistance $\frac{n(s)\times r}{n(p)}$. Hence the formula is the same as above.

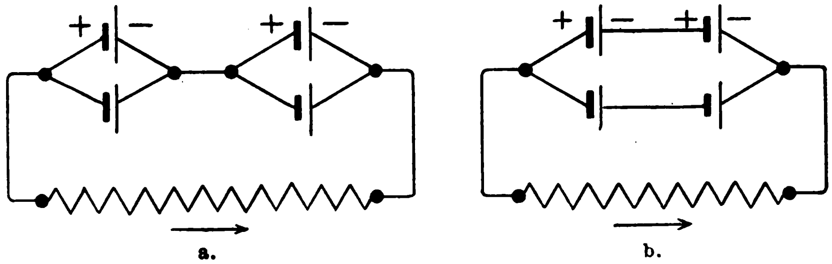


FIG. 6.—Cells in series-parallel.

23. **Advantage of cells in series-parallel.**—The principal advantage of cells connected in series-parallel lies in the great number of combinations of available voltages, internal resistances, etc. The most useful combination is probably that described in paragraph 25 for obtaining a maximum current through a given external resistance.

23 *a*. **Example.**—The following numerical example will illustrate the result of using cells in series-parallel connection. Let there be 12

cells each of 1.01 volts on open circuit and of 2.99 ohms internal resistance and let them be connected in 3 groups in parallel with 4 cells in series in each group. What is the current when the external resistance is 4.00 ohms? In the notation of the formula above, n(s) is 4; hence $n(s) \times E$ is 4.04; n(p) is 3; hence $\frac{n(s) \times r}{n(p)}$ is $\frac{4 \times r}{3}$ or 3.987. Hence $I = \frac{4.04}{3.987 + 4.00} = 0.506$ ampere.

24. **Maximum current; single cell.**—From the formula $I = \frac{E}{r + R}$, it will be seen that with any single cell of open-circuit voltage, E, and internal resistance, r, the maximum current that can possibly be obtained will be when R is zero and then $I = \frac{E}{r}$. In this case, however, the cell is short-circuited so that the current is used *wholly within the cell* and none is available for useful work in any electrical device. Evidently this current can not be measured. When, however, the cell is short-circuited through a *very low resistance* current-measuring instrument, as an ammeter which with its lead wires has a resistance of say only 0.01 ohm, the current will be the maximum current that can be measured, and this is called the "short-circuit current." This current is sometimes used in making certain tests of dry cells as described in later sections of the pamphlet.

25. **Maximum current from a given number of cells.**—The maximum current that can be supplied through a given external resistance, R, depends principally on the number of cells available and also on their open-circuit voltage and internal resistance. If a given number of cells is available, the maximum current will be obtained when the resulting internal resistance of the combination of cells is *most nearly equal* to the external resistance. In some cases this will indicate that cells in series should be used; in other cases cells in parallel; and in the general case cells in series-parallel.

25 *a*. **Examples.**—If there are 10 cells available, each of open-circuit voltage, $E = 1.45$ volts; and internal resistance, $r = 0.25$ ohm; what connection should be used to give the maximum current through an external resistance of 1,000 ohms? Evidently the total internal resistance can *not* be made equal to the external resistance, R, and the nearest approach to it will be with all cells in series. In this case $I = \frac{n(s) \times E}{n(s) \times r + R} = \frac{14.5}{2.5 + 1000} = 0.0144$ ampere, or 14.4 milliamperes. If all the cells had been connected in parallel, the current would have been only 1.45 milliamperes.

25 *b*. If there are 10 cells as in example *a* above, what connection should be made to give the maximum current through an external

resistance 0.02 ohm? On account of the low external resistance, cells must evidently be used in parallel. If all cells are connected in parallel, the resulting voltage is 1.45 volts and the internal resistance 0.025 ohm. Therefore $I=\cfrac{E}{\cfrac{r+R}{n(p)}}=\frac{1.45}{0.025+0.020}=32.2$. If the 10 cells had been connected in series, the current would have been only 5.75 amperes.

25 *c*. If there are 10 cells, as in examples *a* and *b* above, what connection should be used to give the maximum current through an external resistance of 0.1 ohm? The external resistance is less than that of one cell and possibly all cells should be connected in parallel, or else in a series-parallel connection. If all cells are in parallel, the voltage is 1.45 volts, the internal resistance 0.025 ohm, and the current will be 11.6 amperes. If a series-parallel combination is used, such as five cells in series in one group, connected in parallel with the other five cells in series in another group, the total voltage is $5\times1.45=7.25$ volts; the internal resistance $\frac{1}{2}\times5\times0.25$ or 0.625 ohm; and the current will be 10.0 amperes. Another series-parallel combination would be five cells in parallel in one group connected in series with another group of five cells also in parallel, in which the total voltage is $2\times1.45=2.90$ volts; the internal resistance 0.1 ohm, which is the same as the external resistance, and the current will be 14.5 amperes. As stated in paragraph 25, this is the *maximum* current that can be obtained from these cells in the given resistance.

26. **Maximum current from any number of cells.**—If the number of cells is *not limited*, the statements of paragraph 25 do not necessarily apply. In general, the current through a *large* external resistance will increase as the number of cells in series is increased. Similarly, the current through a *small* resistance will increase as the number of cells in parallel is increased. In actual practice, however, the least number of cells, each at its normal current, is used that will supply the necessary current.

26 *a*. **Example.**—In the first case let the external resistance be 1,000 ohms and let there be 10 cells in series, each with an open-circuit voltage of 1.45 volts; an internal resistance of 0.25 ohm; then the current will be 0.0145 ampere, as in paragraph 20 *a*. If the number of cells is increased to 20 and then to 30, the current would be increased to 0.0289 and 0.043 amperes, etc.

26 *b*. **Example.**—In the second case let the external resistance be 0.02 ohm and let the same 10 cells be connected in parallel. Then the current would be 32.3 amperes, as in paragraph 25 *b*. If the number of cells in parallel is increased to 20 and then to 30, the current will be increased to 44.6 and 51.2 amperes, etc.

27. **Electrical power of a cell.**—In the previous paragraphs there have been given the values of currents which different combinations of cells can send through various external resistances. Although in many cases the number of amperes which the cells can furnish may be the only information that is desired, yet the true estimate of the value of the cell is not in the current but in the electrical power which it can supply to a circuit. This may be measured in either of two equivalent ways, both of which will give the same numerical answer and are based on Ohm's law, as follows: (1) The product of the volts at the terminals of the circuit by the current in amperes in the circuit; and (2) the product of the square of the current in amperes in the circuit by the resistance in ohms of the circuit. Both of these products give the "electrical power," the practical unit of which is the "watt." Thus the electrical power $=$ watts $= W = E \times I$; or watts $= I^2R$. These formulas apply either to the whole circuit or to any part of it, but in each case E, I, and R must all belong to the *same* part of the circuit.

When these formulas are applied to a *complete* circuit, E is the open-circuit voltage; R is the *total* resistance in circuit, including the internal resistance of the cells; and W is the *total* watts. Thus, total watts $= W = E \times I$, or $W = I^2\ (R + r)$. The total watts may be considered as used in two parts of the circuit—(1) in the cell, and (2) in the external circuit. The part of the power consumed inside the cell is called the "internal power or watts," and that in the external circuit the "external power or watts." When the formulas are applied to the part of the circuit inside the cell, E is the open-circuit voltage; r is the internal resistance; and W is the internal watts. Thus, internal watts $= W = E \times I = I^2 \times r$. When the formulas are applied to the external circuit, E is the closed-circuit voltage; R is the external resistance; and W is the external watts, Thus, external watts $= W = E \times I = I^2 \times R$. If the cell is short-circuited, the whole power is represented by the internal watts. In this case, E is the open-circuit voltage, I is the short-circuit current, r the internal resistance, and the total watts $=$ internal watts $= W = E \times I = I^2 \times r$. This can be rewritten by Ohm's law to include only the constants of the cell itself. $W = I^2 \times r = \frac{E^2}{r^2} \times r = \frac{E^2}{r}$. Inasmuch as $\frac{E^2}{r}$ represents the total power which the cell can supply, it is evident that the number of external watts can never be as large as $\frac{E^2}{r}$, and that in general the number will be much less. The external power or watts is obviously the only part which is available for any useful purpose.

27 *a*. **Example.**—Referring to the example in paragraph 13 *a*, where the open-circuit voltage, $E = 1.45$ volts; the internal resistance, $r = 0.25$ ohm; the external resistance, $R = 21.7$ ohms; and the cur-

rent, $I = 0.06606$ ampere; the total watts in the complete circuit are $W = E \times I = 1.45 \times 0.06606 = 0.0958$ watt; or $W = I^2 \times (R + r) = \frac{2}{0.06606} \times 21.95 = 0.0958$ watt as before.

27 *b*. **Example.**—The internal watts are $W = E \times I$ or $W = I^2 \times r$, where now E is the internal drop $= 0.01652$ volt; $I = 0.06606$ ampere as before; and r is the internal resistance $= 0.25$ ohm. Thus $W = E \times I = 0.01652 \times 0.06606 = 0.0011$ watt approximately. $W = I^2 \times r = \frac{2}{0.06606} \times 0.25 = 0.0011$ watt as before.

27 *c*. **Example.**—The external watts are $W = E \times I$ or $W = I^2 \times R$, where E is the closed-circuit voltage $= 1.433$ volts; $I = 0.06606$ ampere; and R is the external resistance $= 21.7$ ohms. Thus $W = E \times I = 1.433 \times 0.06606 = 0.0947$ watt. $W = I^2 \times R = \frac{2}{0.06606} \times 21.7 = 0.0947$ watt as before. Evidently the sum of the internal and external watts in *b* and *c* should be equal to the total watts in *a*. Thus $0.0011 + 0.0947 = 0.0958$ watt.

28. **Maximum power from a given number of cells.**—The conditions for supplying the maximum power to an external circuit depend on the internal and external resistances. It is found to be the same as in paragraph 25 for the maximum current; that is, when the internal resistance is equal to the external resistance.

28 *a*. **Example.**—Using the figures in the example of paragraph 25 *c* of 10 cells, each of open-circuit voltage 1.45 volts; internal resistance 0.25 ohm; external resistance 0.1 ohm; connected in parallel, series-parallel, etc., the watts in the external resistance may be computed as follows: (1) With the 10 cells in parallel and a current of 11.6 amperes, $W = I^2 \times R = \frac{2}{11.6} \times 0.1 = 13.4$ watts; (2) with the 10 cells in series-parallel, 5 in series in one group connected in parallel with the other 5 in series in the other group; and with a current of 10 amperes, $W = I^2 \times R = \frac{2}{10} \times 0.1 = 10$ watts; (3) with the 10 cells in series-parallel, 2 groups in series each of 5 cells in parallel, and a maximum current of 14.5 amperes, $W = I^2 \times R = \frac{2}{14.5} \times 0.1 = 21.02$ watts; and (4) with the 10 cells in series and a current of 5.57 amperes, $W = I^2 \times R = \frac{2}{5.57} \times 0.1 = 3.11$ watts. Thus it is seen that the maximum electrical power or watts will be furnished by a given number of cells to an external resistance when their internal resistance is equal to the external resistance.

29. **Maximum power from any number of cells.**—If the number of cells is *not limited*, the statements of paragraph 28 do not necessarily

apply. In general, the power supplied to a large resistance will increase as the number of cells in series is increased, and that supplied to a low resistance will increase as the number of cells in parallel is increased.

30. **Efficiency of a cell or battery.**—From the preceding paragraphs, it is evident that only a part of the electrical power of a cell is available for *useful* work. Thus, as in other electrical devices, the efficiency can be expressed as follows:

Efficiency in per cent $= \frac{\text{useful work}}{\text{total work}} \times 100 = \frac{\text{external watts}}{\text{total watts}} \times 100 = \frac{I^2R}{I^2r + I^2R} \times 100 = \frac{R}{r+R} \times 100$. It is to be noted that the smaller the internal resistance the higher will be the efficiency, and vice versa; the larger the internal resistance the lower *the efficiency.*

In an ideal cell the internal resistance and the internal watts are zero, and hence the electrical efficiency would be 100 per cent.

The efficiency thus defined is a purely *electrical efficiency* and hence takes no account of the efficiency of the *chemical* processes in the electrolyte, etc.

30 *a*. **Example.**—Referring to the example in paragraph 27 *a*, where the open-circuit voltage of a cell, E, is 1.45 volts; the internal resistance, r, is 0.25 ohm; the external resistance, R, is 21.7 ohms, the current, I, is 0.06606 ampere, etc., the efficiency may be computed as follows:

Efficiency $= \frac{R}{r+R} \times 100 = \frac{21.7}{0.25 + 21.7} \times 100 = 99$ per cent under the given conditions.

This may be confirmed by using the internal and external watts as follows:

Efficiency $= \frac{\text{external watts}}{\text{total watts}} \times 100 = \frac{0.0947}{0.0958} \times 100 = 99$ per cent as before.

30 *b*. **Example.**—If this same cell had been used with an external resistance of 0.25 ohm, the current would have been greater, $I = 2.90$ amperes, but the efficiency lower, as follows: $\frac{0.25}{0.25 + 0.25}$ or 50 per cent. This is due to the fact that a greater proportion of the watts has been used in the internal circuit, and less in the external circuit.

30 *c*. **Example.**—Similarly, referring to the example in paragraph 23 *a* with a battery of 12 cells, each of open-circuit voltage of 1.01 volts and internal resistance of 2.99 ohms, connected in 3 groups in parallel with 4 cells in series in each group, with a combined internal resistance of 3.987 ohms, and an external resistance of 4 ohms, the efficiency is $\frac{4.00}{3.987 + 4.00} \times 100 = 50$ per cent approximately under the given conditions.

SECTION V.

CARE OF BATTERIES.

31. **Types of cells, wet and dry, open circuit and closed circuit.**—All types of primary cells need a certain amount of care and attention which will vary with the kind of cells. The various cells may be divided into two classes, depending on the character of the electrolyte. The presence of the liquid or electrolyte in certain older types of cells led them to become known as "wet" cells. In contrast to these the most common type today is the "dry" cell, which is so called because there is *apparently* no liquid or electrolyte. Part, at least, of the care of a battery depends on the character of the electrolyte.

The various cells may also be divided into two other classes, depending on the nature of the service which they render. Some types of cells can be used to supply a large current for a comparatively short time and at infrequent intervals without serious polarization until the chemicals are exhausted. As the circuit is *open* during most of the life of the cell, these are called "open-circuit" cells. Other types can be used to supply a small current nearly continuously without serious polarization until the chemicals are exhausted. As the circuit is *closed* during most of the life of the cell, these are called "closed-circuit" cells. Part of the care of a battery depends on the choice of the type of cell for the circuits to which it is to supply current.

32. **General care of all types.**—All cells need a certain amount of care and attention both before and after being put into service

While in storage dry cells and the chemicals for wet cells should be kept dry, clean, and at a temperature of ordinary living conditions. Moisture and dirt may cause corrosion and bad contacts at the terminals of the cells, leakage and short-circuits on the cells, and also a deterioration or spoiling of many of the chemicals. These actions are hastened at high temperature but retarded at low temperature. Care must be taken that at low temperatures the dry cells are not frozen, as they are unserviceable in that condition, and when thawed out may not be able to give their normal current. Care must also be taken that the liquids do not freeze, as they may break their bottles or containers. However, the freezing point of most of the liquids is lower than that of water (32° F. or 0° C.). Under correct conditions of storage there is little or no deterioration of the chemicals, but a certain unavoidable deterioration of dry cells. (See par. 34.)

When cells are installed, they should be put in as dry and clean a place as possible and where the temperature is that of ordinary living conditions, for the same reasons as stated above. When a large number of cells are to be used, as on a long telegraph line, they should be installed in trays, racks, or tables where they are accessible for convenient inspection and renewal of any cell or its parts.

When put into service care should be taken that the cells are adapted to the work in question. Thus, for continuous duty a closed-circuit cell should be used, and for intermittent duty an open-circuit cell. A cell should be used at not more than its normal current, and if a larger current must be supplied either a larger cell of greater ampere-hour capacity should be used or else a number of cells should be connected in parallel so that each is supplying only its normal current. (See pars. 17 and 18.) The voltages, currents, etc., can be determined by the aid of the formulas in the preceding section. In some cases cells are used for testing purposes in shop work and care must be taken not to short-circuit them by laying pieces of wire, tools, etc., across the terminals or lead wires.

33. **Care of wet cells.**—The care of a wet cell begins with the care of the chemicals used in preparation of the electrolyte and the depolarizer. In some cells the electrolyte is an alkali dissolved in water, or an acid diluted with water. Many of the alkalies, such as caustic soda, sal ammoniac, etc., deteriorate rapidly when exposed to air and moisture, and for this reason they must be kept while in storage in *air-tight* cans or containers. The alkalies and acids, both before and after their mixture with water, are *very corrosive*, and for this reason they must be kept in containers that do *not leak*, do not have cork stoppers, etc. Preferably both should be kept in glass carboys or bottles with glass stoppers. An acid must never be kept in a metal container. An acid or alkali may temporarily be kept or mixed in a glazed porcelain vessel. As both acids and alkalies will burn holes in wood, clothing, etc., and cause dangerous flesh burns or wounds, they must be handled with the greatest care. If any is spilled, it should be washed off with a great excess of water. If the necessary means are available, an acid burn may be neutralized with a mild alkali, and vice versa, an alkali burn may be neutralized with a mild acid; after which, in both cases, it should be washed with a great excess of water.

In making up the electrolyte, distilled water or rain water should be used if possible, but if it is not available, ordinary tap water may be used, but this should be free from lime and salts of iron.

Care must be taken never to use a cracked battery jar or container, as the electrolyte is certain to leak out and put the cell out of commission. If such a cell were in series in a battery, the whole circuit would be opened and made inoperative. In contrast with the electrolyte, the electrodes need no special care except to see that they are not broken and that the terminal wires make good electrical contact with them.

In general, cells should be assembled as near as convenient to their place of installation so as to avoid transportation and the possible danger of spilling the electrolyte. The loss of any considerable amount of it will tend to increase the internal resistance because of the decreased area of the cross section of the electrolyte. (See par. 13.) It is most important that wet cells be installed in as clean a place as possible so that no dirt, impurities, or pieces of metal can get into the electrolyte where they will certainly injure or short-circuit the cell. Further, the cells should not be installed in a very hot place, as the evaporation of the water of the electrolyte may cause a certain loss of the electrolyte and hence an increase in internal resistance. In many cells a cover is provided for the battery jar, and when so provided it should always be kept in place, as it will not only keep out the dirt, etc., but will also reduce the evaporation of the electrolyte.

The special instructions and precautions for the various cells, as mixing the electrolyte, assembly of the component parts, details of the use in service, renewal of parts, etc., will be given in the description of the various cells in later sections of the pamphlet.

34. **Care of dry cells.**—As dry cells are supplied completely assembled, the first part of their care pertains to the conditions of storage. All cells will deteriorate to a certain extent in storage, due to local chemical action within the cell and on the zinc can. There is no method of preventing this, but the effects can be reduced to a minimum by keeping the cells in storage at ordinary temperatures for the minimum length of time. In general, the deterioration is more rapid in the case of small cells and at the higher temperatures. Thus, if a small sized low grade of cell is kept in storage under average conditions for a few months, it may be nearly useless when withdrawn for service. On the other hand, a large sized high grade of cell may often be kept in storage for six months and yet give nearly as good service as when new.

Although the best practice would be to obtain a supply of cells from the manufacturer as they are needed and issue them immediately afterwards, yet this is not always possible, and generally cells must be kept for a certain length of time in storage. In order to tell the age of the cells, the date of manufacture is generally stamped on the cardboard case or carton. When cells are withdrawn for issue the *oldest* in storage should be withdrawn *first*, as by this order of supply and withdrawal no cells will be issued which have deteriorated to any serious extent.

Dry cells should be installed in a clean and dry place and where the temperature is that of ordinary living conditions. They should be kept free from dirt and moisture to avoid short circuits, etc., and in general have the same care as wet cells. Individual cells are contained in a cardboard case or carton which serves principally to insulate the zinc can, which is one of the terminals of the cell, but also to a certain extent to protect the zinc against mechanical injury. The carton should not be removed from the cell in ordinary use.

The special instructions and precautions for the various cells, details of use in service, etc., will be given in the descriptions of the various cells in later sections of the pamphlet.

35. **Care of reserve cell.**—This is a special form of dry cell, sometimes called a "desiccated" cell because as manufactured the interior of the cell is *dry*. On account of the absence of water there is little or no possibility of wasteful chemical action taking place in the cell in storage, and in this respect it has the advantage of not deteriorating like an ordinary cell. The principal care of this cell thus lies in its being kept clean and dry in storage.

36. **Maintenance.**—All cells should be inspected at certain regular intervals so as to be able to detect and remedy any approaching failure of a cell and thus insure continuity of service. The inspection should obviously be made at intervals shorter than the life of the cell. Thus if the life of a Fuller cell is three months, the inspection should be made monthly. Where there are a large number of cells, a routine test should be made and a suitable record kept on inspection forms or blanks. The inspection should make certain that (1) there are plenty of renewals for component parts always on hand and in good condition; (2) the cells are clean, dry, and free from short circuits; (3) there is no composition or bad contact at the terminals or binding posts of the cells, as this may introduce a high resistance into circuit or even cause an open circuit; (4) in the case of dry cells, the zinc can or container is not corroded and the cardboard carton is dry, as otherwise this may form a leakage path and ground the cell; (5) in the case of wet cells, (*a*) the jar is not cracked, as this will allow the electrolyte to leak away and either ground or open circuit the cell; (*b*) the electrolyte is at the correct level in the battery jar, as otherwise if too low it will seriously increase the internal resistance of the cell and in the case of the Gravity cell may even open the circuit; (*c*) the electrolyte is in good condition, as shown by its color, clearness, etc.; (*d*) the electrodes are in good condition and without holes in them or otherwise eaten away, etc. Exceptional care in inspection must be taken in the tropics, where high temperature and excessive moisture tend to hasten corrosion, deterioration, etc.

The *special* care that each type of cell may need is given in later sections of the pamphlet.

37. **Special tests with voltmeter and hydrometer.**—In a few cases where the special means are available, the condition of cells may be determined by measuring the *voltage* with a voltmeter, and the *specific gravity* of the electrolyte with a hydrometer. Both of these measures *must* be made on storage (or secondary) cells in order to take proper care of them, but they are not usually made on primary cells.

The *open-circuit voltage* of a cell is not always a certain test of its condition. Thus if the voltage is normal, the cell may be (1) in good condition; or (2) in poor condition, but still able to deliver the very small current necessary to operate the voltmeter. The closed-circuit voltage is a more certain test. Thus if, when the cell is put into circuit, the closed-circuit voltage drops below its normal value, the cell is in poor condition; but if both the open-circuit and closed-circuit voltages are normal, the cell is in good condition.

The *specific gravity* of the electrolyte of some types of cells is a certain test of their condition. Thus in the case of the Gravity cell, the specific gravity of the sulphate of zinc solution should be about 1.15. If it is too high, as 1.20, crystals of sulphate of zinc will soon be deposited on the jar and a leakage path to ground may be formed; and if it is too low, as 1.05, the internal resistance is too high.

Inasmuch as the condition of a cell is generally well shown by an inspection of its electrolyte and electrodes, as described in later sections of the pamphlet, the Signal Corps does not issue voltmeters and hydrometers for use with primary cells.

SECTION VI.

WET CELLS; GRAVITY—SIGNAL CORPS TYPE BA-12.

38. **Advantages and disadvantages of wet cells.**—Wet cells have certain advantages and disadvantages. A striking advantage is the possibility of the renewal of a cell by the renewal of its parts as they waste away. Thus an electrode can be easily replaced; a depolarizer

or an electrolyte can be strengthened, etc., none of these being possible in the case of a dry cell. There are certain disadvantages that can not be avoided. Thus glass battery jars are easily broken; the cells are not conveniently transportable on account of the danger of spilling of the electrolyte, which is generally corrosive; there is a continual evaporation of the electrolyte, etc. In spite of the disadvantages of wet cells, they are more useful in many cases than any other means of generating an electric current. Thus the component parts of a complete battery of wet cells can be shipped to any destination, stored away almost indefinitely, and then the cells assembled when needed and put into commission almost immediately.

39. **Useful types of wet cells.**—A great many different types of wet cells have been devised in the past, but as the result of long practical experience probably less than a dozen types have been found sufficiently useful to be manufactured to-day. Among the best known are the following cells: Bunsen, Daniell (also known as "Bluestone," "Crowfoot," or "Gravity"), Edison-Lalande; Edison, Fuller, Leclanche, etc.

These cells may be divided into the various types mentioned in the previous sections. Thus the Leclanche is an *open-circuit cell;* and the Bunsen, Daniell, Edison-Lalande, Edison, and Fuller are *closed-circuit cells.* The Edison-Lalande, Edison, and Leclanche are *single-fluid* cells; and the Bunsen, Daniell, and Fuller are *two-fluid* cells. The Bunsen, Daniell, and Fuller use a liquid depolarizer; and the Leclanche, Edison-Lalande, and Edison a solid depolarizer; etc.

At the present time there are only three types, Gravity, Edison, and Fuller, in use in the Signal Corps, and some of these are gradually being replaced by dry cells or storage batteries. The essential constants of these cells are given in the following table:

Types of cells.

Name of cell.	Positive pole or terminal.	Negative pole or terminal.	Electrolyte.	Depolarizer.	Open circuit volts.	Internal resistance in ohms.
Gravity	Copper	Zinc	Sulphate of zinc	Sulphate of copper.	1.00 to 1.07	2.5 to 3.0
Edison	do	do	Caustic soda	Oxide of copper	0.95	0.1 to 0.3
Fuller	Carbon	do	Sulphuric acid	Bichromate of potassium.	2.0	0.5

They are described in detail in the following paragraph:

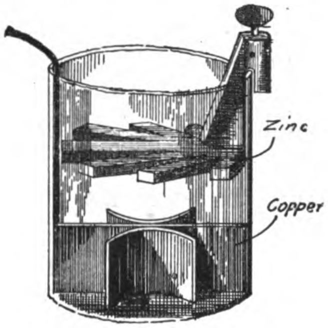
40. **Gravity cell, type BA-12; general description.**—This is a special form of the Daniell cell which in the early designs was provided with a porous cup to contain the electrolyte and keep it from mixing with the depolarizing solution. In the Gravity type the solutions are kept apart by other means, as described in paragraph 43. The cell is shown assembled in Figure 7. It is often known as the

"Crowfoot" or "Bluestones," the significance of these terms being given in paragraph 41. It is a closed-circuit, two-fluid cell, with a liquid depolarizer. The cell has an open circuit voltage of between 1 and 1.07 volts and an internal resistance of between 2.5 and 3 ohms. It is used by the Signal Corps on telegraph lines in Alaska and in the United States where a small but nearly constant current is required. Its life is from four weeks to six months, depending on the amount of current which it must supply.

41. **BA-12; component parts.**—The essential component parts are the battery jar, copper electrode, zinc electrode, and sulphate of copper for the depolarizer.

The *battery jar* is of annealed flint glass, 5 inches in inside diameter by 7 inches deep. The top edges are dipped in hot melted paraffin to prevent leakage as described in paragraph 45.

The *copper electrode* is made up of thin copper strips riveted together in the form of a star as shown in Figure 7. The advantage of this construction is that it gives a large area in contact with the liquid. Thin copper can be used, as a part of the chemical action in the electrolyte is to dissolve the zinc and deposit copper on the copper electrode. The copper must be kept in the *bottom* of the jar. A heavily insulated rubber-covered copper wire is riveted to one of the strips, long enough to reach well above the electrolyte and outside the jar so as to serve as one terminal of the cell. The insulation is to confine the action on the copper to the star strips at the bottom of the cell and also to prevent other chemical actions to be described later in the top of the cell. The *copper* with its connecting wire is the *positive pole or terminal* of the cell.



GRAVITY CELL

FIG. 7.

The wire to the strip copper should be of copper and should be riveted and not soldered to the strip. Similarly the copper strips should be riveted together and not soldered. This precaution is necessary in both cases, as otherwise there will be local battery action at the soldered points, due to the presence of two different metals—copper and solder—in a conducting liquid. (See pars. 1 and 3.) If the rubber insulation on the wire is faulty, it should be replaced by a new well-insulated piece. In an emergency, however, a glass or hard-rubber tube may be slipped over the wire, taking care that it extends as an unbroken piece from the coppers to above the top of the cell.

The zinc electrode is made in a special form of cast zinc with a heavy hook or lug to support it from the top edge of the jar and with a spread-out construction so as to give a large area in contact with the liquid. On account of its shape the zinc is sometimes called a "crowfoot," and a cell a "crowfoot" cell. It weighs about 1¾ pounds and is held between 1½ and 2½ inches above the tops of the copper strips. A binding post is provided on top of the hook for connection to the external circuit. The zinc with its post is the *negative pole* or *terminal* of the cell. The zinc is not amalgamated, as the cell, being of the closed-circuit type, does not stand idle for long periods, and hence there is no wastage of the zinc on this account.

The *electrolyte* is a solution of *sulphate of zinc* which is formed by chemical action *after* the assembly and use of the cell, and for this reason it will be described in a later paragraph. (See par. 43.)

The depolarizer is a solution of the (blue) crystals of *sulphate* of copper or copper sulphate, also known commercially as "blue vitriol" or "bluestones;" hence the cell is sometimes known as the "bluestone" cell. The crystals should be free from dirt, iron, and other impurities and of fairly uniform size. No very fine crystals or dust should be used. About 3 pounds of bluestones are needed for each cell.

42. **To set up BA–12.**—Be sure that the battery jar is clean and dry. Spread out the copper strips evenly and put them in the bottom of the battery jar. Bring the insulated wire straight up along the side of the jar. Spread the 3 pounds of bluestones uniformly over the bottom of the jar; they should nearly cover the copper strips. Hang the zinc in place with the hook on the opposite side of the jar from the insulated wire. Fill the jar with distilled water or rain water until it is about 1 inch above the crowfoot part of the zinc. Do not stir the water or try to dissolve the crystals. Pour paraffin or lubricating oil, preferably the former, over the surface of the water until there is a layer not more than ¼ inch deep. The oil must be of such grade as not to dissolve the rubber insulation on the wire from the copper strips.

Short circuit the cell by connecting the free end of the insulated wire to the zinc binding post by a short piece of copper wire. Allow the cell to stand in this condition for several days, or at least until a part of the bluestones has dissolved, the lower part of the solution has become blue at least to above the tops of the copper strips but not up to the zincs, and the upper part is clear. The cell is then ready for use.

43. **Chemical actions and formation of the electrolyte.**—The principal chemical actions that are effective in forming the electrolyte and preventing polarization may be briefly described as follows: When the short-circuit current begins to flow, there is at the bottom of the jar the copper electrode, Cu, in a solution of sulphate of

copper, $CuSO_4$, and at the top a zinc electrode, Zn, in water, H_2O. The hydrogen ion, H_2, moves toward the copper electrode (see par. 6) but does not reach it, for on entering the sulphate of copper it combines with the SO_4 ion to form H_2SO_4, sulphuric acid, and frees the Cu ion, which proceeds to the copper electrode and is there deposited as a copper plating. The sulphuric acid H_2SO_4 then attacks the zinc (see par. 6) to form a sulphate of zinc, $ZnSO_4$, and frees the hydrogen, H_2, which moves toward the copper, etc., as before. Thus there are the following solutions or liquids: Water, sulphuric acid, sulphate of zinc, and sulphate of copper. The sulphate of copper is the *heavier* and is the blue solution in the bottom of the jar; the sulphate of zinc with dilute sulphuric acid is the *lighter* and is the clear solution at the top of the jar. When the cell is in good condition, there is a distinct line separating the two liquids. As the successful operation of the cell depends on keeping the liquids apart, the cell must not be shaken after it is set up.

The *electrolyte* is thus seen to be the sulphate of zinc solution and the *depolarizer* the sulphate of copper solution.

The formation and separation of the liquids thus depends on the continual flow of the current and therefore the cell is a typical closed-circuit cell. As the separation of the liquids depends on the *difference in weight*, or on the pull of gravity, the cell is generally called the "*Gravity*" cell.

44. **Creeping of salts.**—As the cell continues in service, the (blue) sulphate of copper solution tends to grow weaker and the (clear) sulphate of zinc solution to grow stronger. The latter soon becomes a saturated solution; that is, no more sulphate of zinc can be formed and kept dissolved in the solution and the excess appears as white crystals of sulphate of zinc on the zinc and the jar. These tend to increase and "creep" up on the zinc and its connecting wire and the sides of the jar. As they carry a certain amount of sulphuric acid from the solution, they are quite corrosive. The action at the zinc terminal is to cause bad contacts at the binding post and an eating away of the copper wire to the external circuit. Similarly, as the crystals are conducting, the action on the jar is to cause a leakage path over the surface of the glass and a serious loss in insulation, particularly if there are many cells in series. The creeping of the salts is probably the most serious fault of the Gravity cell.

45. **Remedy for creeping.**—There are several remedies for creeping, depending on the part of the cell to be treated, as follows: Jar, zinc electrode, and the sulphate of zinc solution. Inasmuch as the trouble originates with the liquid the correct procedure is to treat it first, as follows: Draw off part of the sulphate of zinc solution with a battery syringe or a bent glass tube used as a siphon and replace by

water. This serves to dilute the solution below saturation and will prevent creeping until it is again saturated, after which it must be again repeated.

The use of paraffin on the edges of the jar and the oil on the surface of the liquid tend to reduce the creeping both on the jar and on the zinc. The presence of the oil also reduces the evaporation of the water in the sulphate of zinc solution and thus reduces the tendency for the solution to become saturated. The zinc can be freed from the salts only by cleaning with sand, etc., as described in the following paragraph.

46. **Care and maintenance.**—The condition of a cell in service is shown by its general appearance, and the necessary care and maintenance includes attention to the following points: (1) The cell should be kept on a closed circuit for part, say 60 per cent, or all the time; (2) there should be an excess of undissolved bluestone crystals in the bottom of the jar; (3) the bottom solution should be of a clear blue color, to above the tops of the copper strips but below the zinc, and there should be a distinct line separating the two solutions; (4) the sulphate of zinc solution should be above the top of the zinc; (5) there should be a layer of oil on top of the sulphate of zinc solution; (6) there should be no sign of "creeping" of the sulphate of zinc crystals on the jar, etc.; and (7) the zinc should not be badly eaten away.

If the cell is kept too long on open circuit, the two solutions tend to mix and the sulphate of copper comes in contact with the zinc electrode where it is decomposed. A fine deposit of oxide of copper is deposited on the zinc which looks more or less like black mud. Under the circumstances the zinc must be cleaned with sand as described in a later paragraph and the cell put on a closed circuit.

After the cell has been in use for some time the sulphate of copper solution tends to grow weaker and the blue color to fade to a brownish color. Crystals of sulphate of copper should then be added until the blue line is again above the tops of the copper strips but below the zinc. When adding the crystals, care must be taken that they do not fall on the zinc but drop to the bottom of the jar. In some cases long dark masses form on the lower parts of the zinc. These should be removed with a stick and the zinc cleaned if necessary. After a while the sulphate of zinc solution becomes so saturated that "creeping" occurs, as described in paragraph 44. This should be remedied as described in paragraph 45.

47. **Cleaning and renewing a cell.**—Cells should be cleaned at regular intervals, which will depend on the amount of current that they have been supplying. This will vary from three weeks to three months or more. The zinc should be carefully removed from the cell so as not to disturb the solutions and cleaned immediately

thereafter, as otherwise the deposits will harden on the zinc on exposure to air and their removal will be difficult. The zinc should be washed off with plenty of water, and as some of the oil will probably cling to it, the zinc should be scoured with sand and wet cotton waste or other similar means. Also it may be necessary to scrape away part of the zinc with a knife so as to get a clean fresh surface.

Next, pour or siphon off the sulphate of zinc solution into another jar. Remove the copper strips and clean them if necessary. Then pour or siphon off the sulphate of copper solution, taking care not to disturb the sediment in the bottom of the jar. Throw away the sediment, clean out the jar, and dry it carefully before being put into service again.

Reassemble the component parts as described in paragraph 42. If necessary add water to the sulphate of zinc solution to bring it over the top of the crowfoot. If more than half the sulphate of zinc would have to be replaced by water, it may be preferable to make up a solution of sulphate of zinc crystals in water and add it instead of water. This makes the internal resistance low enough so that the cell may begin to deliver current immediately, without waiting to be short-circuited, etc. In some cases the necessary amount of the sulphate of zinc solution may be obtained by drawing off a small amount of it from each of several other cells in the battery, taking care to replace it by water. If, however, the cell has been in use for a long time it may be best to make a fresh solution as when setting up the cell for the first time, but it must be remembered that under these conditions the cell must stand short-circuited for 24 hours or more. If the zinc is badly eaten away, it should be replaced by new zinc. The copper strip rarely needs to be replaced.

48. **Setting up a cell in a hurry.**—In some cases it may be necessary to obtain a current quickly from a gravity cell, that is, when there is no time to allow it to stand short-circuited. Although it is not the best practice to do so, the cell may be put into service immediately as follows: Assemble the copper, bluestones, and the zinc as described in paragraph 42, and then add a tablespoonful of common salt to the water before putting it into the cell. This procedure is not recommended, as it tends to make the cell dirty and to shorten its life.

49. **Note on specific gravity of the electrolyte.**—Under ordinary conditions the preceding information is all that is usually necessary to set up the gravity cell. Under some *special* conditions it may be desirable to test the specific gravity or density of the sulphate of zinc solution. This can be done with a hydrometer in the same way that the specific gravity of the storage battery solution is measured. There are two systems or scales of units in use; one, the specific gravity, and the other the Baumé scale. The former is in more

general use in this country and is gradually replacing the other. A few corresponding points on the two scales are given in the table for convenient reference.

Density or specific gravity scales.

Specific gravity.	Baumé.
1.00	0
1.04	5
1.07	10
1.12	15
1.16	20
1.20	25

The correct specific gravity or density of the sulphate of zinc solution is about 1.16 (20 on the Baumé scale). When it falls below 1.04 (5 on the Baumé scale) the solution is too dilute, and more bluestones should be added to the copper solution and the cell short-circuited until the specific gravity rises to its correct value. Similarly when the specific gravity is above 1.20, or 25 on the Baumé scale, the solution is too dense and water must be added until the specific gravity drops to its correct value.

Hydrometers are no longer issued by the Signal Corps for use with gravity cells.

SECTION VII.

EDISON CELLS; SIGNAL CORPS TYPES BA-14 AND BA-24.

50. **BA-14 and BA-24; general description.**—These are Edison cells of commercial type generally known as "Edison primary cells" so as to distinguish them from the Edison secondary or storage cells. They are a development, with minor improvements, of earlier types known as the Edison-Lalande and Edison-BSCo cells. They are closed-circuit, single-fluid cells, with a solid depolarizer, and are of 200 ampere-hour capacity. The cells have an open-circuit voltage of about 0.95 volt, and an internal resistance of between 0.1 and 0.3 ohm. They are used in the Signal Corps for meteorological work, etc. Their life is from six weeks to six months, depending on the amount of current which they must supply.

51. **Component parts.**—The principal component parts for the two types are the same, although differing slightly in detail, as follows: The battery jar and cover; oxide of copper electrode; double zinc electrode; caustic soda for the electrolyte; and oil for use on top of the electrolyte. The essential differences in the two types will be given at length in the description of the cells.

The *battery jars* are of different shapes and materials, each with its advantages and disadvantages. Both are provided with porcelain covers to keep out the dirt and reduce the evaporation of the water of the electrolyte. The covers also serve as a convenient means for mounting the electrodes which are attached to the under side.

The *oxide of copper electrode* is a plate 4 inches by 3½ inches by $\frac{7}{16}$ inch thick composed largely of the black oxide of copper made up of copper turnings or filings, which, with some sort of a binder, have been formed by great pressure into the desired shape. The plate is often briefly called the "oxide" plate. As oxide of copper is not an electrical conductor, its surface has been copper plated with a very thin layer of copper so as to give a low internal resistance when the cell is first set up. After the cell begins to deliver current the process is continued as a part of the chemical actions in the cell as described in paragraph 52. The plate is fastened centrally on the under side of the cover with one or two copper-plated bolts, which extend through the cover and are provided with a binding post. The *oxide of copper plate* with its post is the *positive terminal* or *post* of the cell.

The *zinc electrode* is in the form of two plates of zinc, each 4 inches by 3½ inches by ⅛ inch thick connected together above the top of the oxide plate. They are fastened one on each side of the oxide plate either by bolts through the cover or by an insulated bolt through the oxide plate. In the former case one of the bolts is provided with a binding post and in the latter case an insulated wire from the bolt extends through a hole in the cover. The plates have been amalgamated in the process of manufacture so as to prevent local action. The *zinc plates* and their post or wire is the *negative terminal* or *pole* of the *cell.*

The *electrolyte* is a solution of caustic soda dissolved in water.

The *depolarizer* is the oxide of copper plate whose action is described in paragraph 52. This plate thus serves a double purpose—as an electrode and as the depolarizer.

The *oil* is a heavy mineral oil to cover the electrolyte and thus prevent the evaporation of water of the electrolyte. It is of a selected grade that is not attacked by the caustic soda.

52. **Chemical actions of electrolyte and depolarizer.**—The chemical action in both types is the same and is essentially as follows: The sodium ion, Na, in the caustic soda solution whose formula is $NaOH$,

moves toward the copper electrode with its depolarizer of oxide of copper, whose formula is CuO. The sodium has a strong attraction for the oxygen, O, of the CuO, combines with it and leaves the copper, Cu, as a deposit on the oxide of copper electrode. At the same time the OH ions in the NaOH move toward the zinc, Zn, and attack it. The sodium, the oxygen from the CuO, and the zinc unite to form a (double) salt of sodium and zinc, Na_2ZnO_2 that remains dissolved in the electrolyte and water, H_2O. Thus the zinc is gradually eaten away and the oxide of copper is converted into metallic copper. The cell will evidently be exhausted either when the zinc is eaten away or the oxide of copper is converted into copper.

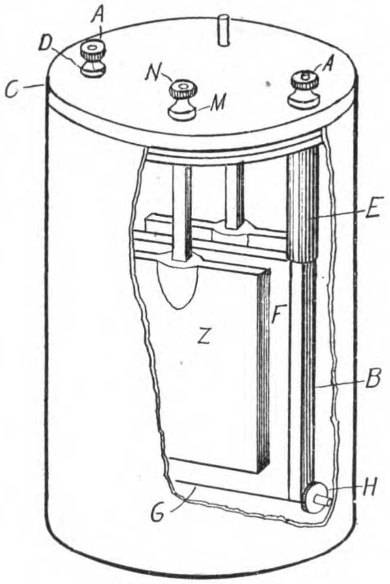


FIG. 8.—Edison cell.

53. **Mixing of the electrolyte.**—The method of mixing the electrolyte is the same for both types of cells, and is as follows: Be sure that the battery jar is clean and dry. Fill the jar to within about 1½ inches of the top with distilled water or rain water. If neither is available use ordinary tap water, but this should be free from salts of iron, lime, copper, or sulphur. Add one can of caustic soda, about 1¼ pounds, which must have been kept in an air-tight can, *slowly* to the water. Considerable heat will be developed and in the case of glass jars the soda must be very slowly added even though they are made of the special "heat-resisting" glass, in order to avoid breaking them. Stir the solution constantly with a glass rod or a wooden stick until all of the soda is dissolved. The entire contents should not be added at once as some of the soda may solidify in the bottom of the jar. Take care not to splash the solution as it will burn the skin and clothing. If any has been splashed it can be removed by quickly washing with an excess of water and wiping it off with a piece of rag or paper. In order to protect the hands from the action of the solution, lard or an animal or vegetable oil may be applied to them before mixing the electrolyte.

If the cell is not to be used for three hours or more the solution should be allowed to cool before immersing the electrodes. If, however, it *must* be used immediately, the electrodes may be immersed while the solution is still hot. In either case all of the soda must *dissolve* before immersing the electrodes.

54. BA–14; assembly of electrodes and setting up of cell.—This is the Edison commercial Type No. 207 which replaces the former Type V. It is shown assembled in Figure 8.

The *battery jar* is cylindrical and of enameled steel, with an inside diameter of 5 inches and a depth of 7½ inches. The steel construction has the advantage that the jar is unbreakable in transportation and can not be cracked by the heat which is developed in mixing the electrolyte. It has the disadvantage of not being transparent and thus not permitting an inspection of the condition of the plates and the height of the electrolyte without removing the cover. In most cases, however, this is not a serious disadvantage.

The battery jar of the earlier Type V was of steel and conical in shape, being larger in diameter at the top than at the bottom. This design permitted the jars to be "nested," one partly inside the other, in a very compact pile or stack, so that the bulk in storage and shipment was much less than with the other types. Although the manufacture of this type of jar has been stopped, yet it has so many advantages for the Signal Corps that it may come into use again.

Two types of *electrodes* may be used with this cell and the method of assembly will depend on the type which has been supplied. In the earlier form there were many small parts such as frame, screws, washers, nuts, etc., which had to be fitted together before the electrodes could be attached to the cover. The earlier form is no longer being manufactured, but this type will be issued until the supply on hand is exhausted, after which only the later type will be furnished. In the later form both electrodes are completely assembled at the factory as a single unit by means of specially fitted parts and they can be attached almost immediately to the cover.

The following method applies to the *earlier* type of electrodes where the letters are those of Figure 8 and it is assumed that all of the necessary parts have been provided. Although Figure 8 illustrates the essential features of both types, yet the details are those of the earlier type which is shown, as the assembly is somewhat more complicated than the later type. Unscrew the thumb nut, N, and the jamb nut, M, from the screw on the bridge between the double zinc plates. Pass the screw from below through one of the holes in the cover and the steady pin on the other end of the bridge through the other hole. Replace the leather washer and the jamb nut, M. Tighten the nut until the zinc plates are firmly clamped on the under side of the cover. Then screw on the thumb nut, N. Unscrew the thumb nuts, A, and the jamb nut, D, from the screws on the two side pieces, B, of the copper frame, but leave the flat leather washers in position on the screws. Pass the screws from below through the holes in the cover; replace the jamb nut, D, on one of the screws and one of the thumb nuts, A, on the other screw. Tighten both until the side frames are firmly clamped on the under side of the cover. Replace the other thumb nuts, A, on the screw with the jamb nut, D. Slip the two hard rubber insulating tubes, E, over the two side pieces, B. The purpose of this insulation is to protect the side pieces from the action of the electrolyte and to confine it to the oxide plate. Slide the oxide plate, F, far enough into the frame so that the copper bolt, G, can be passed just underneath it and through the slots in the bottom of the side pieces, B. Tighten the nut, H, and the plate will then be firmly clamped on the under side of the cover. If the assembly is correctly made, the three plates will be nearly parallel; the oxide plate will be half way between the two zinc plates, and it will be separated from both by three-eighths to one-half inch. Neither zinc plate should touch the oxide plate, as the cell will be short-circuited thereby. The surface of the plate should be of a bright copper or brick red color which it will hold indefinitely if kept in its *original wrapper* in a *dry place* until ready for use. It will, however, soon tarnish or oxidize if wet or exposed to damp air, and for this reason the wrapper must not be removed until the cell is to be set up. If the surface is badly tarnished the cell will not behave properly when connected into circuit and for this reason the plate should be treated after the cell has been set up, as follows: Connect the cell to an external resistance and allow the normal current, say 1 ampere, to flow until the plate acquires the copper color. This may be continued for half an hour if necessary. If, however, the cell must be used immediately, the plate can be quickly treated by short-circuiting the cell by connecting the wire from the zinc plate to the binding post of the copper plate for periods of three minutes with intervals of five minutes between each short circuit until the plate acquires the correct color. The cover is provided with a rubber gasket ring which makes the cell nearly splash tight. The cover will fit easier into place by wetting the rubber. Put on the cover, making certain that it is seated into place. Then either remove the cover and note the height of the electrolyte as shown by the wetting of insulating tubes, E, or tip the cover slightly and note the height. When first installed the top edge of the oxide plate should be not less than 1 inch below the surface of the electrolyte. If it is less than this, add water until the height is correct. Put the cover nearly back into place and then pour the oil slowly on top of the electrolyte, taking care that the plates are kept under the electrolyte. If for any reason the oil had been poured onto the electrolyte *before* the plates were immersed, they should be soaked in water and while still wet the cover with the plates should be put back into place. This wetting of the plates will prevent the oil from adhering to it. The cell is now ready to be put into circuit. The connection to the copper plate is made between the thumb nut, A, and the jamb nut, D, on one end of the copper frame; and that to the zinc plate between the thumb nut, N, and the jamb nut, M, on the screw from the bridge between the zinc plates.

The following method of assembly applies to the *later* type of electrodes which are now being supplied. The oxide and the two zinc plates are assembled in a single unit by the manufacturer as follows: The oxide plate is held in a frame somewhat similar to that described in the first part of this paragraph, except that the top of the frame is bent upward and shaped like a yoke. This is provided with a long suspension bolt extending upward through the cover, which serves as part of the binding post for the copper plate. The surface of the plate should be of a bright copper color as stated in the first part of this paragraph, otherwise the plate must be treated as previously described. The two zinc plates are held in place, one on each side of the oxide plate, by a bolt through an opening in the top of the oxide plate. The bolt is insulated from the oxide plate by two porcelain bushings, which also serve as spacers to keep the zincs at the required distance from the oxide plate. At the bottom corners four corks are inserted to keep the plates from bending during shipment. An insulated wire extends upward from one end of the bolt and serves as a terminal for the two zinc plates. The electrodes should be fastened to the cover as follows: Unscrew the two wing nuts and remove the brass washer under them. Screw the large round thin copper nut down until it is firmly seated on top of the yoke. Straighten out the insulated wire until it is parallel with the bolt on the yoke. Pass the wire from the underside through the smaller hole in the cover and the bolt on the yoke through the larger central hole. Put the brass washer on the copper bolt and screw one wing nut hard down on the washer, thus clamping the assembled plates firmly on the underside of the cover. Screw on the other wing nut. Remove the corks from between the zinc and oxide plates, which should be nearly parallel, with the oxide plate halfway between the two zinc plates; and also the wrapper from the oxide plate. Neither zinc plate should touch the oxide plate, as the cell will be short-circuited thereby. Put on the cover, see that the electrolyte is at the correct height, the oil poured on the electrolyte, etc., as described in the first part of this paragraph. The connection to the copper plate is made under the upper winged nut and that to the zinc plates at the wire.

55. **BA–14; care and maintenance.**—The cells need only a small amount of attention during their life. They should be examined at least once a month, and in hot climates more often, to make certain that the electrolyte is always above the tops of the plates and that the plates are in good condition. Although the cell is a closed-circuit cell, yet it can remain on open circuit for a long time without appreciable deterioration. This cell does not need cleaning, as does

the type BA–12, but requires renewals as described in the following paragraph:

56. **BA–14; renewal of cell.**—The tests for the need of the renewal of the cell are (1) the failure to deliver current, and (2) the condition of the plates. The method of renewal will depend on the type of electrodes with which the cell has been provided. In the case of the *earlier* form, the following method applies: Immediately after taking off the cover of the battery jar, the caustic soda should be thoroughly washed off the plates before they are handled. If the zinc plates are eaten through in any place, they should be thrown away. The method of disassembly and the reassembly of the new zincs will be obvious from paragraph 54. The oxide plate should be tested as follows: Pick into the body of the plate with a sharp-pointed penknife. If there is a layer of black (oxide of copper) in the interior of the plate, there is some life left, the amount depending upon the thickness of this layer, and the plate should be continued in use. If, on the other hand, it is red throughout the whole mass, it is completely exhausted and should be thrown away. When renewing the oxide plate it may be desirable to brighten up the metal parts with emery paper if they are corroded, and particularly the inside grooves of the frames where contact is made with the oxide plate. This may be easily done by wrapping a small piece of emery paper around a stick which will just fit into the grooves or by immersing the metal in a dilute solution of one part of sulphuric acid and four parts of water and then carefully rinsing them in clear water to remove all traces of the acid. These precautions are necessary to insure good electrical conditions and a low internal resistance. The method of disassembly and reassembly of the oxide plate will be obvious from paragraph 54. If the condition of the zinc and oxide plates is such that both should be thrown away, the caustic soda should also be thrown away, but all other parts can be used again. The caustic soda must be carefully poured out, so as to avoid splashing. (See par. 53.) The renewal of the cell with new caustic soda, zinc, and oxide plates will be obvious from paragraph 54.

In the latter form of electrodes the following method applies: Immediately after taking off the cover of the jar, the caustic soda should be thoroughly washed off the plates before they are handled. If a hole has been eaten through either zinc plate, the two zincs are nearly wasted away, the oxide of copper plate has been converted into metallic copper, and the electrolyte is exhausted; in other words, these chemicals are exhausted and should be thrown away. This test for renewal is based on the design and construction of the zinc plates which have a small test area, called a panel, near the bottom.

When a panel first begins to be eaten through, the cell is approaching exhaustion, say 75 per cent exhausted, and its parts should be renewed as soon as convenient. When the panels are completely eaten through, the parts should be renewed *immediately*. The method of disassembly and reassembly of new electrodes, the mixing of a new electrolyte, etc., will be obvious from paragraph 54.

The completely exhausted condition of a cell when the panels have been eaten through is clearly shown in Figure 9 by the closed-circuit voltage curve of a 200 ampere-hour cell such as types BA–14 and BA–24. It is to be noted that the voltage drops off very rapidly after about 240 ampere-hours' service.

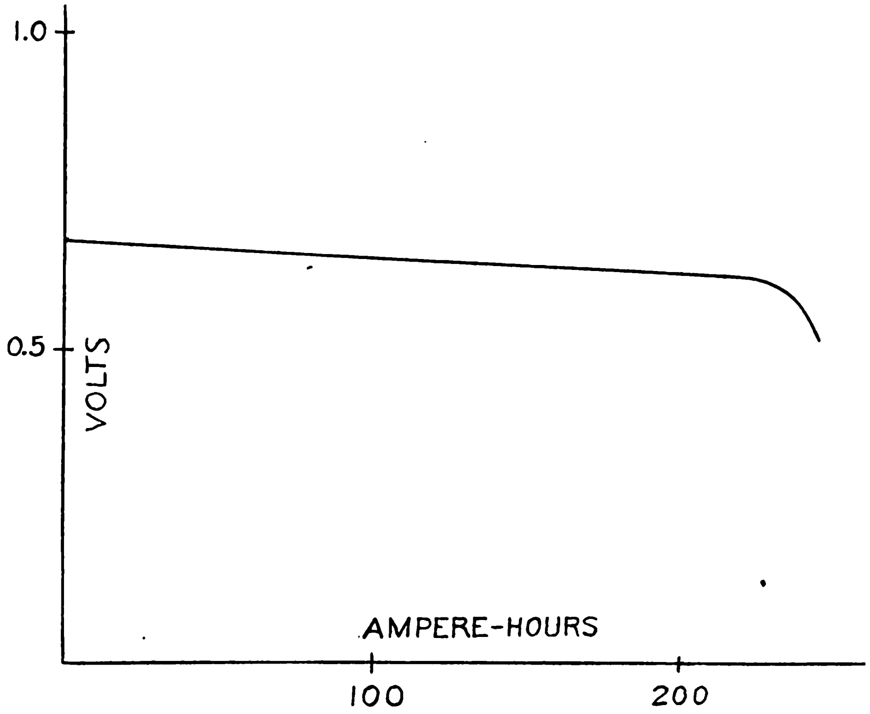


FIG. 9.—Test of Edison cell.

57. **BA–24; assembly of electrodes and setting up of cell.**—This is the Edison commercial type No. 202, similar in many respects to BA–14 or Edison No. 207. Both are of the same 200 ampere-hour capacity and are interchangeable as to voltage, service, etc., and as to some but not all of the component parts.

The *battery jar* is rectangular and of "heat-resisting" glass, with inside dimensions $2\frac{7}{8}$ by $5\frac{1}{4}$ by 9 inches high. The glass has the advantage of permitting an inspection of the height of the electrolyte and the condition of the plates without the necessity of removing the cover, but has the disadvantage that it is easily breakable. This may be a serious disadvantage in the case of shipments to distant points where the freight must be handled several times. The cover is not provided with a rubber gasket as the cell is not designed to be splash-tight.

The *electrolyte* should be mixed as described for BA–14 in paragraph 53, taking special care to add the caustic soda *very slowly* to the water so as not to crack the battery jar. The cans of caustic soda and the battery oil for BA–14 and BA–24 are interchangeable.

Only one type of *electrodes* is furnished, being one of the later and completely assembled type, as for BA–14, described in the last part of paragraph 54. The electrodes of BA–14 and BA–24 are thus interchangeable.

The method of *setting up* the cell is also the same as for BA–14, as described in the last part of paragraph 54.

58. **BA–24; care, maintenance, and renewal of cell.**—These are the same as for BA–14, as described in paragraph 55 and the last part of paragraph 56.

SECTION VIII.

FULLER CELL; SIGNAL CORPS TYPE BA–13.

59. **General description.**—This is a closed-circuit two-fluid cell with a liquid depolarizer. It is sometimes called a "bichromate" cell because bichromate of potassium is used as the depolarizer. It has an open-circuit voltage of about 2 volts, an internal resistance of between 0.2 and 0.5 ohms, and a life of about three months. It is shown assembled in Figure 10. The cell has been used in the Signal Corps to supply the transmitter or talking current in a local battery telephone system. Such systems are generally used in isolated places where storage cells can not be used on account of the lack of suitable means of charging them. Apparently only a few cells of this type are now being manufactured, and on account of the difficulty of obtaining renewals the cells are going out of use in the Signal Corps.

These cells have been used by telephone companies for many years in local battery telephone systems to which they are well adapted on account of the comparatively high voltage and low internal resistance. With the rapid increase of the common battery system with its storage battery and with the gradual replacement of the Fuller cells by the Edison primary cells in the remaining local battery systems, the Fuller cell is going out of use in the commercial field.

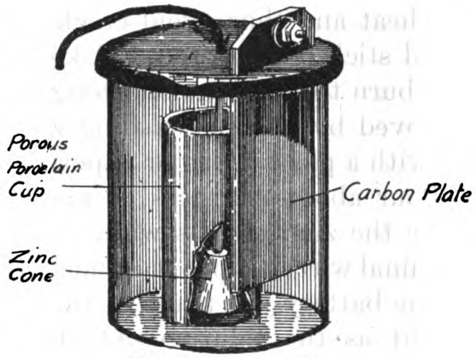
60. **Component parts.**—The principal component parts are as follows: The battery jar and cover; carbon electrode; zinc electrode; porous cup; weak solution of common salt for the electrolyte; can of "chromac" for the depolarizer; and mercury for the amalgamation of the zinc.

The *battery jar* is cylindrical and of glass, with an internal diameter of 6 inches and a depth of 8 inches. The cover is of wood and painted with asphaltum, "P. B.," or other insulating paint to protect it from corrosion and to preserve its insulating properties.

The *carbon electrode* is a thin plate of carbon, 4 by 9 by $\frac{1}{4}$ inch thick, held in place in a slot in the battery jar cover by a shoulder which keeps the plate at a fixed distance from the bottom of the jar. Generally the shoulder and the top of the plate are coated with paraffin to prevent the corrosion of the terminals. Connection to the carbon is made at a binding post through the shoulder of the plate. The *carbon plate* and its *binding post* is the *positive terminal* or *pole* of the cell.

The *zinc electrode* is a cone-shaped casting of about 1 pound weight, with a wire extending above the top of the cell. The *zinc* with its wire is the *negative terminal* or *pole* of the cell.

The *porous cup* is cylindrical with an internal diameter of 3 inches and a depth of $7\frac{1}{4}$ inches. It stands in the battery jar and holds the electrolyte, the zinc electrode, and the mercury. It is porous enough to allow the current to flow through it, but dense enough to prevent the electrolyte from mixing freely with the depolarizer.



FULLER CELL

FIG. 10.

The *electrolyte* is water to which about a tablespoonful of ordinary table salt is added so as to increase its conductivity and thus lower the internal resistance of the cell.

The *depolarizer* is a solution of bichromate of potassium made by dissolving the "chromac" in water. "Chromac" is a mixture of bichromate of potassium, sulphuric acid, etc., and hence is very corrosive. It must be kept in an air-tight can and in a cool place, otherwise it may eat through the can.

The *mercury* is for the amalgamation of the zinc to prevent local battery action while the cell is standing idle.

61. **Chemical actions of electrolyte and depolarizer.**—The chemical actions are somewhat complicated, much more so than in the Gravity or Edison cells, and for this reason only an outline will be given.

Some of the acid from the depolarizing solution will diffuse through the porous cup and attack the zinc anode, freeing ions of hydrogen and forming a soluble salt of zinc that remains dissolved in the electrolyte. The hydrogen ions move toward the carbon cathode, passing through the porous cup and entering the depolarizing solution. There are other actions occurring in the depolarizer by which ions of oxygen are freed and certain soluble salts are formed. The hydrogen from the anode combines with the oxygen from the depolarizer to form water and thus is prevented from collecting on the cathode. It is to be noted that the carbon takes no part in the chemical actions but serves simply as a convenient conductor or terminal for the cell.

62. **Mixing depolarizer and electrolyte; setting up of cell.**—Pour about 2 quarts of water into the battery jar and add a 1-pound can of "chromac" *slowly* to the water. As considerable heat is developed, it is best to keep the battery jar in a larger pail of water to carry off the heat and thus avoid cracking the jar. Stir the solution with a wood stick or glass rod. Take care not to splash the solution as it will burn the skin and clothing. If any has been splashed, it can be removed by quickly washing with an excess of water and wiping it off with a piece of rag or paper.

Pour about 2 ounces of mercury into the porous cup. Amalgamate the zinc and its wire. (See par. 7.) Straighten out the zinc terminal wire and put the zinc in the cup. Put the cup in the center of the battery jar, pouring water into the cup until it is of the same height as the solution outside. Add a tablespoonful of ordinary table salt to the water.

Pass the zinc terminal wire from the underside through the hole in the center of the cover. Put the cover in place on the jar. Put the carbon plate through the slot in the cover, allowing it to rest on its shoulder on top of the cover. The cell is now ready to be put into circuit. The connection to the carbon plate is made at its binding post and that to the zinc at its wire.

In the above method the chemicals for the depolarizer are supplied in a dry form as a matter of convenience to avoid the necessity of shipping and handling sulphuric acid which is very corrosive. However, the depolarizing solution can be made up by using water, bichromate of potassium or of sodium, and sulphuric acid in certain proportions, and this solution is then known as "electropoion." There are also other forms of the Fuller cell in which (*a*) the carbon electrode is a cylinder nearly inclosing the porous cup; (*b*) a long zinc electrode is used, etc. The details of making the depolarizing solution and of the various types of Fuller cells will not be given, as the cell is going out of use in the Signal Corps.

63. **Care and maintenance.**—The cell needs only a small amount of attention during its life. It should be examined at least once a month, and in hot climates more often, to make certain that the two solutions are at about the same level, and to add water as necessary. Although the cell is of the closed-circuit type, yet it can remain on open circuit for a long time without appreciable deterioration because of the amalgamation of the zinc.

64. **Renewal of cell.**—The tests for the renewal of the cell are (1) the failure to deliver current; (2) the condition of the depolarizer; and (3) the condition of the zinc electrode. Generally the first to need renewal is the depolarizing solution which after some weeks of use turns to a muddy bluish color and should then be thrown away. Immediately after taking off the cover of the battery jar, the acid should be thoroughly washed off the electrodes before they are handled. The depolarizer must be carefully poured away so as to avoid splashing on account of its corrosive nature. The mercury should be saved and used repeatedly, adding a small amount each time if necessary. The carbon electrode lasts indefinitely (see par. 61) but at each renewal should be soaked in warm water. If for any reason the electrolyte is renewed at the same time as the depolarizer, the porous cup should also be soaked in warm water. The purpose of soaking these parts is to dissolve away any impurities that may be clinging to the surfaces or contained in the walls of the cup—both of which would tend to increase the internal resistance of the cell. Fresh depolarizer should then be mixed and the cell reassembled as described in paragraph 62.

When the zinc has become badly eaten, it should be thrown away. Generally one zinc will last for several renewals of the depolarizer. The new zinc should be amalgamated, mercury poured in the porous cup, etc., as previously described.

SECTION IX.

DRY CELLS.

65. **General description.**—The dry cell is a development of the Leclanche cell in which the electrolyte has been made unspillable by the use of absorbent materials in the cell which hold the electrolyte in the form of a jelly or paste. Thus the dry cell is really *not dry* but is sufficiently wet to behave electrically like a wet cell. Although the dry cell is one of the most recent forms of primary cells, yet it is more generally used than all the older types together. They are manufactured by the millions every year in the United States.

The dry cell is an open-circuit, single-fluid cell with a solid depolarizer. It has an open-circuit voltage of between 1.5 and 1.65 volts and an internal resistance and life that will depend entirely on the size of the cell, its condition, etc. They are used in the Signal Corps to supply current for local battery telephone systems; field and camp telephones; field buzzer; signal lights; plate circuits for vacuum tube receiving set, etc.

66. **Advantages and disadvantages.**—Dry cells have certain advantages and disadvantages. Thus they have the following advantages over all other types of primary cells: (1) They can be used in almost any position; (2) they are supplied completely assembled and ready to be connected into circuit; and (3) they are practically unbreakable. They have, however, the following disadvantages: (1) There is a certain unavoidable deterioration with age and (2) no part of the cell is renewable when it is exhausted. In spite of these apparent disadvantages they are the simplest and most useful device for generating a current of electricity.

It is interesting to note that usually an exhausted cell may be *temporarily* renewed by drilling holes in the sealing compound and pouring in as much water as it can absorb. This method may be useful in an emergency. Care must be taken not to short-circuit the cell by an excess of water on top of the sealing compound between the carbon and the zinc can.

67. **General construction.**—The construction of a dry cell may be explained by reference to the *Leclanche* cell, of which it is a special form. This cell consists of a glass battery jar containing a solution of ammonium chloride, generally called "sal ammoniac," dissolved in water as the electrolyte, in which there is a rod of zinc as one electrode and a porous cup containing a carbon plate as the other electrode, which is closely packed in powdered carbon and manganese dioxide, the latter of which is the depolarizer. The *zinc* rod is provided with a binding post and is the *negative terminal* or *pole* of the cell. The *carbon* plate is likewise provided with a binding post and is the *positive terminal* or *pole*.

In the *dry cell* the glass jar is replaced by a zinc can which serves both as the battery jar and as the zinc electrode. The sal ammoniac is contained in an absorbent material such as flour, starch, etc., which differs with different manufacturers and is generally a trade secret. The porous cup is replaced by a paper lining to the zinc can, or a cloth bag, in which is contained a carbon rod as the other electrode, packed in powdered carbon and manganese dioxide as before.

Since the *zinc* is eaten away as a necessary part of the chemical actions of the cell and as the life of the cell depends in part at least on the amount of the zinc, it should have (1) not less than a certain minimum thickness—generally about 0.02 or 0.018 inches; (2) be free from mechanical defects, such as cracks, holes, etc., which would allow the liquid contents to leak out and the interior of the cell to dry up; and (3) free from particles of other metals, which with the zinc would cause local battery action. The carbon rod should be of low resistance, particularly in cells intended for heavy currents, as otherwise this internal resistance may seriously reduce the current. It must also make good contact with the powdered carbon and manganese dioxide, especially in cells which are used in the plate circuits of vacuum-tube receiving sets, in order to avoid noises in the telephone receivers due to changing and irregular contacts. Owing to the conductivity of the powder, it must be kept from contact with the zinc, as otherwise the cell would be short-circuited internally. To prevent this, either of two types of construction has been used: (1) The zinc is lined on the inside with a *paper lining* or (2) the manganese and carbon are contained in a *cloth bag*. The paper or cloth becomes saturated with the sal-ammoniac solution and is porous or of large enough mesh to allow the current to flow through, but of sufficiently fine mesh to keep the cell free from an internal short circuit. The paper-lined type is the most common in the United States and the bag type in Europe. Other things being equal, the bag type probably gives the longer life to the cell. The cell is sealed at the top by a *sealing compound* which prevents the evaporation of the water of the electrolyte and also serves to insulate the terminals of the cell. This should have no cold flow at the higher temperatures nor should it crack at lower temperatures. The zinc can is covered with a *paper tube* or *carton* impregnated with paraffin which insulates the zinc and the cell as a whole. The *carbon* rod is generally provided with a binding post or clip and is the *positive terminal* or *pole* of the cell. The *zinc* can is provided with a binding post and is the *negative terminal* or *pole*.

A cross sectional view of a dry and reserve type of cell is shown in Figure 11.

In some types of batteries several cells are connected in series by soldered strips and sealed in a carton with the two end terminals free. The polarity is then marked "plus" and "minus," or a *red* wire is used at the *positive* terminal, and a *black* wire at the *negative* terminal.

68. **Special construction; "reserve" cell.**—This cell is essentially the same as those previously described except that it is really *dry* and is inoperative as it is supplied. The carbon electrode is hollow and water must be added through a hole in the top which then runs down and saturates the inside of the cell, and thus forms the electrolyte, after which it behaves as an ordinary dry cell with an open-circuit voltage of about 1.5 volts. It requires some time for the cell to absorb all the necessary water, which must be added every half hour or so until no more can be retained. The electrolyte is prevented from spilling by a cork stopper fitted to the hole in the carbon. It is probable that its ampere-hour capacity is not as great as that of the standard type of the same size. It is, however, a most useful cell, as it does not deteriorate in storage. (See pars. 34 and 35.)

69. **Special construction; "chloride of silver" cell.**—This cell differs from the ordinary dry cell in several minor details, the principal one of which is in the use of chloride of silver as the depolarizing material, from which the cell takes its name. The can is made of zinc, which is also one electrode and terminal, and the other electrode is silver. The open-circuit voltage is 1 volt. Although they are made only in the smaller sizes, the life is rather long for the size of the cell. They have been used in the Signal Corps for operating the buzzer of the decremeter (SCR–87), but will be gradually replaced by one of the standard sizes of the ordinary dry cells.

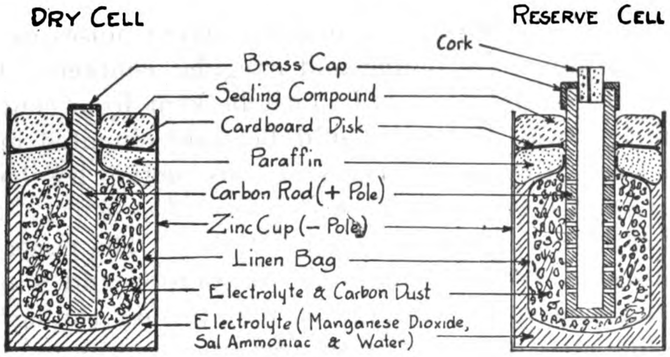


FIG. 11.—Cross sections of dry cells.

70. **Chemical actions of electrolyte and depolarizer.**—The chemical actions are somewhat obscure and only an outline will be given. The sal-ammoniac solution will attack the zinc anode, freeing ions of hydrogen and forming salts of zinc. The hydrogen ions move toward the carbon cathode, passing through the paper lining or cloth and entering the depolarizer. Part of the hydrogen ions combine with the oxygen of the depolarizer to form water and thus are prevented from collecting on the cathode.

71. **Shelf life and deterioration.**—The purchase and supply of dry cells often involves keeping them for a certain length of time in storage. During this time there is some unavoidable deterioration, and the length of time, say in months, that they may be kept without serious deterioration is called the "shelf life." This will differ greatly with the make, size, etc., of the cell and on the method of testing for deterioration as described in the following paragraphs.

72. **Mechanical tests of dry cells.**—These tests consist in the examination of (1) the zinc can to see that it is not eaten away and that there are no holes, tears, etc., in it; (2) the sealing compound to make certain that it adheres both to the can and the carbon, and that it has no cracks, both these tests being necessary to insure that the water of the electrolyte can not evaporate; and (3) the binding posts to see that they make good contact with the electrodes, particularly with the carbon.

73. **Electrical tests of dry cells.**—These tests consist of measures of the open-circuit voltage and the short-circuit current for the purpose of indicating the condition of the cells. In some cases these readings give definite information of value and in others they are quite useless. Thus some cells are designed for light and nearly continuous duty, and others for heavy intermittent duty. Repeated measures of the short-circuit current on the former type will seriously injure the cells and will not certainly indicate their ability to deliver a small current for a long time. In other words a cell should be tested in as nearly as possible the same manner as it is to be used.

The open-circuit voltage alone may not be a sufficient test of the condition of a cell. Thus if it is much below 1.45 volts, the cell is certainly faulty and should be rejected; but if it is 1.5 or more, it may or may not be in good condition. In explanation it may be stated that measures of voltage require only a very small current and a cell may be in good enough condition to supply this current during the time of measurement, but still not be in good enough condition to supply its rated current for any considerable length of time.

The initial short-circuit current is a sufficient test of the condition of a cell, but is not necessarily a test for the life of a cell. Thus if the current is at least equal to the average value for the particular size and type under test, it is in good condition; but if it is much below the average value, the cell is certainly faulty and should be rejected. This initial short-circuit current will differ greatly with the size, type, make, etc., of cell and for this reason different types *can not* be fairly compared by means of these readings. The practice of using the short-circuit current as a universal test for the condition and excellence of *different* makes of cells has often led to the choice of a cell whose only virtue was in a large *initial* short-circuit current. Thus in Figure 12 there are shown the short-circuit amperes of two cells of the same size out of different makes. It is to be noted that cell A gives initially a current of nearly 13 amperes, whereas B gives only 9 amperes. In less than 60 days, however, A is delivering less than B, and thereafter it has deteriorated so much as to be quite useless, although B continues to give nearly 8 amperes at the end of 6 months.

In the better grade of cells now being manufactured, it has been found that the open-circuit voltage varies very nearly in the same way as the short-circuit amperes, so that in the tests of any *one make* and size of cell it may be sufficient to measure only the open-circuit voltage.

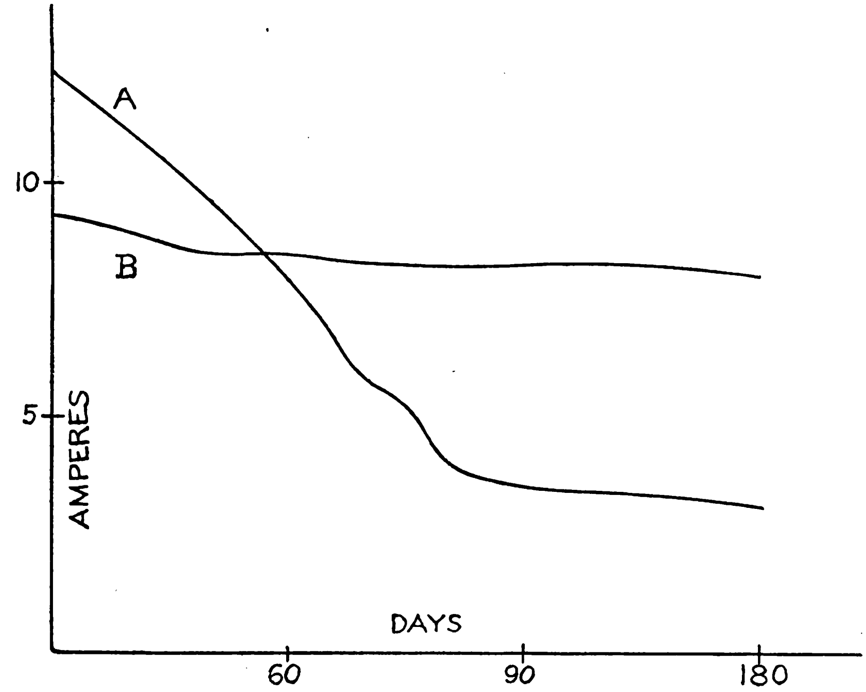


FIG. 12.—Test of dry cells.

No *one* satisfactory test of *all* types of dry cells has been devised. Thus, if the short-circuit current of a heavy-duty cell is frequently tested until it fails to deliver the necessary current, there is no test of its deterioration on open circuit during its idle intervals. If a light-duty cell is similarly tested, there is no test of its ability to deliver its small current for a long time. As a result there are special tests of cells for telephone work, ignition of gasoline engines, flash lights, continuous discharge, etc.

74. **Special tests.**—There are three special tests which should be sufficient for the selection of a suitable make and size of cell for any purpose, as follows: (1) Shelf test, to determine the cell which may remain idle for the longest time on the shelf without appreciable deteriora-

tion; (2) service test, to select the cell which will render the necessary service for the longest time; and (3) deferred service test, to combine the first two and find the cell which may remain idle on the shelf for various lengths of time and then be put into service and render that service for the longest time.

74 *a*. **Shelf test.**—This is a test for deterioration on open circuit and consists essentially of the measurement of the open-circuit voltage and the short-circuited current at regular but infrequent intervals, as once a month. There is no one standard method of defining the deterioration; in fact, there are several ways of expressing it. In some commercial work the deterioration is measured by the percentage decrease in the short-circuit current as the standard. Thus, if the first measured current was 25 amperes and one month later it was 24.5 amperes, the deterioration is 2 per cent, as follows: 25 minus 24.5 is 0.5, and 0.5 divided by 25 is 0.02, or 2 per cent. The deterioration may also be expressed as a percentage decrease in the length of service which a cell can render after being in storage for a certain number of months compared to the service which it could render when new as a standard. Thus, if a cell can render 100 days of service when new and only 90 days when six months old, the deterioration is 10 per cent, as follows: 100 minus 90 is 10, and 10 divided by 100 is 0.10, or 10 per cent.

74 *b*. **Service test.**—This is a test of the cell under service conditions or its equivalent. As this may be in furnishing an intermittent current as in telephone work, or a steady current as in the plate circuit of vacuum tubes in a radio receiving set, the test will vary with the duty for which the cell is to be used. The test is considered complete when the cell fails to give the necessary service or when its closed-circuit voltage or current falls below a certain specified value which previous experience has shown is at or near the limit of satisfactory operation. The life of the cell as shown by the service test is given in days, weeks, or months.

74 *c*. **Deferred service test.**—This is a combination of the two previous shelf and service tests. Several cells are kept in storage and subjected to the usual shelf tests of voltage and current, and every two or three months a cell is withdrawn and put on the service tests until it fails. In this way the same service test is made on cells which have been in storage for different lengths of time. In general the shorter the time that a cell has been on the shelf, the longer will be the service life; and vice versa, the longer the time that a cell has been on the shelf, the shorter will be the service life. In the case of the better grade of cells of the larger sizes, the service life after six months of shelf life is nearly as long as when the cells are new.

75. **Signal Corps tests.**—The tests of the various types of cells used by the Signal Corps are adapted as nearly as possible to service

conditions. It is beyond the scope of this pamphlet to give the details of each test, but in general they are different for each type of cell. The choice of a cell of any one type is made on the basis of these tests, and for this reason cells may be furnished by any one of several manufacturers and may be of the cloth-bag or paper-lined construction.

The tests have shown (1) a very wide range in quality for each type of cell and have emphasized the need of such tests; (2) a high temperature of storage is very destructive of the life of a cell, particularly in the smaller sizes; and (3) the design and construction of dry cells is rapidly improving.

SECTION X.

DRY CELLS USED BY THE SIGNAL CORPS.

76. **BA-1.**—The various types of Signal Corps dry cells and their specific uses and essential constants will be described in the following paragraphs. It must be remembered, however, that the values of voltage, internal resistance, life, etc., are *average* values for a large number of cells and that the constants of any one cell may differ considerably from them.

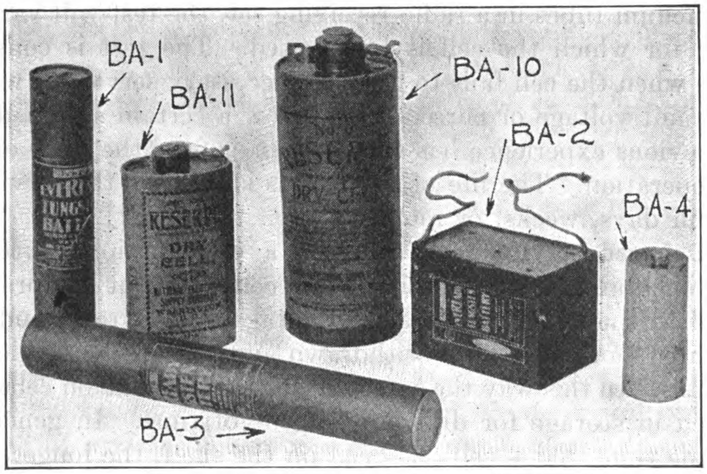


FIG. 13.—Standard Signal Corps dry batteries.

Some of the various Signal Corps batteries are shown in Figure 13.

The BA–1 battery, formerly known as Signal Corps Type A, is made up of two cells of a commercial type connected in series. They are put end to end in a cardboard tube which holds them together and also protects them mechanically. The carbon terminals of both cells are tipped with a brass cap, and the tip of the lower cell is connected by a soldered strip of metal with the bottom of the zinc can of the upper cell. The cardboard tube is open at both ends. Thus the carbon tip of the upper cell is the positive terminal of the battery and the zinc can of the lower cell is the negative terminal. Each cell is about 3 inches long and $1\frac{1}{4}$ inches in diameter. The over-all dimensions of the battery are about $6\frac{1}{8}$ inches long and $1\frac{5}{16}$ inches in diameter. Its weight is between 8 and 9 ounces, or 0.53 pound. It has an open-circuit voltage of 3.1 volts; an internal resistance of 0.3 ohm, which may increase to 0.4 ohm as the battery approaches exhaustion; a short-circuit current of nearly 10 amperes; a shelf life of 6 months; and a service life of 15 to 25 days, depending on the use to which it is put. It is to be noted that each cell has an open-circuit voltage of 1.55 volts; an internal resistance of between 0.15 and 0.2 ohms; and a short-circuit current of nearly 10 amperes.

The battery is at present used by the Signal Corps in the following equipment:

EE–1A. Buzzerphone.
EE–3. Field telephone, model 1917 (buzzer telephone).
EE–4. Portable telephone (camp telephone, model A, with condenser).
EE–4A. Portable telephone (camp telephone, model 1917, without condenser).
EE–8. Field telephone, to replace EE–3, EE–4, and EE–5 (development not completed).
EE–9. Antiaircraft artillery telephone.
EE–63. Service buzzer.
EE–64. Monocord switchboard operator's set.
EE–65. Universal test set.
EE–66. Balloon telephone winch set.
EE–67. Balloon telephone basket set.
EE–76. Simplex telegraph set.
SCR–49. Radiotelegraph pack set.

77. **BA–2.**—This battery is made up of 15 small cells connected in series and contained in a waterproof cardboard box. The box is sealed on top with a sealing wax or compound, through which the two terminal wires extend, the *positive* one being *red* and marked with a *plus* sign, and the *negative* one *black* and marked with a *minus* sign. Each cell is wrapped in paper and is separated from the other cells by cardboard, thus providing the necessary insulation between the individual cells and also between all the cells and ground. The carbon terminal of each cell is tipped with a brass cap and the cap of each cell is connected by a soldered wire to the top edge of the zinc can of the next cell, thus connecting them all in series. Each cell is

about $2\frac{1}{8}$ inches long and $\frac{5}{8}$ inch in diameter. The over-all dimensions of the battery are: $2\frac{3}{32}$ by $3\frac{7}{16}$ by $2\frac{19}{32}$ inches high. The weight is about 15 ounces or 0.9 pounds. The battery has an open-circuit voltage of 22 volts; an internal resistance of 6 ohms, increasing to nearly 10 ohms as the battery approaches exhaustion; a shelf life of 3 months; and a service life of 60 to 100 hours. A single cell has therefore an open-circuit voltage of 1.46 volts, and an internal resistance of between 0.4 and 0.06 ohms. The cells are of such a small size that they would be seriously damaged if the internal resistance and short-circuit current were measured in the usual way (see par. 24) by connecting the battery directly to an ammeter. For this reason the internal resistance is measured with an external resistance in circuit (see par. 13 *b*) and from this data the short-circuit current can be computed to be about 2.7 amperes. The battery was specially designed for use in the plate circuit of vacuum tubes in portable radio sets. Thus the cells are not of a commercial type and the demands for a very small battery made it necessary to sacrifice efficiency and life. The short life of this battery is due to (1) the small amount of chemicals that may be contained in the small size of can; (2) the fact that the process of manufacture can not be as good as in the larger size of cells; and (3) a failure of any *one* of the 15 cells may cause a failure of the whole battery. In handling this battery care must be taken not to allow the terminal wires to come in contact with each other and thus short-circuit the cells, as this would exhaust them very quickly on account of their small size. When the cells are not in use, the wires should be coiled up on top of the battery where they come out of the wax. The wires should not be cut off, as this may make them too short for connections in some of the sets. Except in certain cases, as mentioned in paragraph 80, this battery is interchangeable with BA–8.

It is at present used by the Signal Corps in the following equipment:

EE–65. Universal test set.
SCR–59 and SCR–59–A. Airplane radio receiving set.
SCR–67 and SCR–67–A. Radiotelephone set.
SCR–68 and SCR–68–A. Airplane radiotelephone set.
SCR–70. Radio receiving set, autodyne.
SCR–72, SCR–72–A, and SCR–72–B. Two-stage amplifier.
SCR–75. Airplane radio receiving set.
SCR–76 and SCR–76–A. Ground telegraph set ("T. P. S.").
SCR–77–A. Loop radiotelegraph set.
SCR–78 and SCR–78–A. Tank radiotelegraph set.
SCR–79 and SCR–79–A. Radiotelegraph set.
SCR–80. Airplane radiotelegraph set.
SCR–83. Direction-finding radio receiving set.
SCR–84. Airplane direction-finding radio receiving set.
SCR–99. Radiotelegraph set.
SCR–109–A. Radiotelephone set.

SCR–112. Loop radiotelegraph set.
SCR–115. Airplane radio receiving set.
SCR–116. Airplane radiotelephone set.
SCR–121. Two-stage audio frequency amplifier.
SCR–144. Airplane amplifier with radio and audio frequency amplification, at 1,000 meters wave length.
SCR–145. Amplifier similar to above, except for 1,000 to 3,000 meters wave length.
SCR–146. Heterodyne.
SCR–147. Two-stage audio frequency amplifier.
SCR–148. Similar to above.
SCR–149. Detector and audio frequency amplifier.
SCR–159. Radio telephone and telegraph set.

78. **BA–3.**—This battery is made up of three cells connected end to end in series and contained in a cardboard tube. The individual cells and the method of assembly are the same as in BA–1. The over-all dimensions of the battery are about $9\frac{1}{4}$ inches long and $1\frac{5}{16}$ inches in diameter. Its weight is slightly more than 13 ounces, or 0.83 pound. It has an open-circuit voltage of 4.6 volts, an internal resistance of between 0.45 and 0.6 ohms, a short-circuit current of nearly 10 amperes, a shelf life of 6 months, and a service life which depends entirely on its use.

The battery is at present used by the Signal Corps in the following equipment:

SCR–57 and SCR–57–A. Airplane interphone.
SCR–59 and SCR–59–A. Airplane radio receiving set.
SCR–60. Wavemeter.
SCR–68. Airplane radiotelephone set.
SCR–73. Airplane radiotelegraph set.
SCR–75. Airplane radio receiving set.

79. **BA–4.**—This battery consists of a single cell, being one of the cells in BA–1 or BA–3. Thus it is 3 inches long and $1\frac{1}{4}$ inches in diameter, and its weight is 4 ounces or 0.25 pound. It has an open-circuit voltage of 1.55 volts, an internal resistance of between 0.15 and 0.2 ohms, a shelf life of 6 months, and a service life which depends entirely on its use.

The battery is at present used by the Signal Corps in the following equipment:

SCR–54 and SCR–54–A. Radio receiving set.
SCR–60 and SCR–60–C. Wavemeter.
SCR–61. Wavemeter.
SCR–78 and SCR–78–A. Tank radiotelegraph set.
SCR–79 and SCR–79–A. Radiotelegraph set.
SCR–96. Wavemeter.
SCR–99. Radiotelegraph set.
SCR–111. Wavemeter.
SCR–125 and 125–A. Wavemeter.
SCR–128. Wavemeter.

80. **BA–8.**—This battery is made up of 15 cells in series and is contained in a waterproof cardboard box, sealed on top with a sealing compound, through which the two terminal wires extend, the *positive* one being *red* and marked with a *plus* sign, and the *negative* one *black* and marked with a *minus* sign. The number of cells, the voltage, and the method of assembly is the same as in BA–2, but the individual cells are larger, and hence the battery as a whole is larger and heavier. Each cell is about 2⅜ inches long and 1¼ inches in diameter. The over-all dimensions of the battery are 4 by 6½ by 3 inches high. The weight is about 4.5 pounds. The battery has an open-circuit voltage of nearly 23 volts, an internal resistance of 3⅓ ohms, a shelf life of 6 months, and a service life of 1 month. A single cell has therefore an internal resistance of about 0.2 ohm and a short-circuit current of about 7 amperes. The battery is made up of standard commercial cells and for this reason its service life of one month (720 hours) is much longer than the 100 hours of BA–2 under the same conditions. It is to be noted that BA–2 and BA–8 are interchangeable as to voltage, service, etc., except that BA–8 is too large to go into battery compartments designed only for BA–2. In this case BA–8 may be used by putting it near the set box and connecting it to the proper binding posts or clips by extra lead wires. The same precautions must be observed in handling BA–8 as BA–2; that is, the terminal wires must not come in contact with each other and short-circuit the battery; when the battery is not in use, the wires should be coiled up on top of the battery, and the wires should not be cut off.

It is used by the Signal Corps in the following equipment, plate circuits of vacuum tube radio set:

SCR–127. Radiotelegraph pack set.
SCR–130. Similar to above.

81. **BA–9.**—This battery is made up of three small cells in series, arranged side by side, and contained in a flat waterproof cardboard box sealed on top with a sealing compound. The terminals are two strips of brass, one soldered to the zinc can of one end cell, and the other to the brass cap of the carbon of the other end cell. The polarity is not marked but the *shorter* strip is *positive*, and the *longer* one is *negative*. This can be checked by noting that the shorter strip comes out of the sealing compound at a considerable distance from the edge of the battery, thus suggesting a connection to the inner or carbon (positive) terminal; whereas the longer strip comes out at the very edge of the compound, thus suggesting a connection to the outer or zinc can (negative) terminal. Each cell is about 2¼ inches long and three-fourths inch in diameter. The over-all dimensions of the battery are $2\frac{7}{16}$ inches by $2\frac{11}{16}$ inches by ⅞ inch thick. The

weight is about one-half ounce or 0.03 pound. The battery has an open-circuit voltage of 4.3 volts, an internal resistance of 4 ohms, a shelf life of 3 to 6 months, and a service life of between 8 and 30 hours. A single cell has therefore an open-circuit voltage of 1.43 volts, an internal resistance of 1.3 ohms, and a short-circuit current of 1.1 amperes. This same type of battery is in use in commercial flashlights, from which it was adopted by the Signal Corps for intermittent work in a commercial telephone set. The short life is due to the small size of the cells. In handling the battery care must be taken not to allow the terminal strips to be short-circuited by pieces of metal, etc. As ordinarily supplied, these strips are not long enough to touch each other when they are bent over on top of the cells, but if they should be long enough, the *longer* one must be cut off, to avoid the danger of a short circuit. The strips should not be bent back and forth, as they may be broken off so close to the sealing compound that it will be impossible to get a contact.

At the present time BA–9 is used only in the portable telephone Type EE–5.

82. **BA–10.**—This battery consists of a single cell, of the "reserve" or "desiccated" type, commercially known as the No. 6 size. The cell is cylindrical and is contained in a paraffined cardboard carton. The hollow carbon rod and the zinc can are provided either with spring terminals, as Fahnestock or other clips, or with binding posts. The cell is about 6 inches high and 2½ inches in diameter. Its weight when dry is about 1 pound and 12 ounces or 1.76 pounds. It has an open-circuit voltage of between 1.55 and 1.60 volts, an internal resistance of between 0.05 and 0.10 ohms, an almost indefinite shelf life in the dry condition and 6 to 8 months in the wet condition, and a service life which depends entirely on its use. The short-circuit current is about 23 amperes. This cell is of the same size, etc., as BA–17 (see par. 84), which, however, is not of the desiccated type, and the two can be used interchangeably.

It must be remembered that a BA–10 cell is "dead" when supplied and that water must be added before it can deliver current. Before adding the water, be sure that any broken pieces of cork or carbon which are loose in the hollow carbon electrode are removed. Instructions such as the following are generally printed on the carton:

> This cell will require about 3½ ounces of water for charging. When charging, fill the carbon electrode with water and add water as fast as it is absorbed during one hour; after the first hour, water should be added at intervals of thirty minutes until about 3½ ounces have been used. Allow the cell to stand for one hour after the last addition of water and then pour out all excess water which remains in the electrode.

Such a cell can, however, be used immediately if necessary, but the full voltage and current will not be attained for several hours.

When filling the cell with water, care must be taken not to have an excess of water on top of the sealing compound, as this may short-circuit the cell.

The battery is at present used by the Signal Corps interchangeably with BA–17 in the following equipment:

BD–9–A. Monocord switchboard.
BD–11–A. Similar to above.
BD–14. Camp switchboard.
EE–13. Standard wall telephone, fire-alarm telephone system.
EE–14. Buzzer instruction set.
EE–25. Composite wall telephone, plotters type.
EE–26. Composite artillery telephone, desk type.
EE–27. Similar except wall type.
EE–28. Similar except portable type.

83. **BA–11.**—This battery consists of a single cell of the "reserve" or "desiccated" type, commercially known as the No. O–4 size. The cell is not cylindrical but is of oval cross section and is contained in a paraffined cardboard carton. The hollow carbon electrode and the zinc can are provided with either spring terminals, as Fahnestock or other clips, or with binding posts. The cell is about 2⅜ by 1⅜ by 4¾ inches high. Its weight when dry is about 10 ounces or 0.61 pound. It has an open-circuit voltage of 1.55 volts; an internal resistance of between 0.15 and 0.20 ohms; and almost indefinite shelf life in the dry condition and 6 months in the wet condition; and a service life which depends entirely on its use. The short-circuit current is about 8½ amperes.

It must be remembered that a BA–11 cell, like the BA–10, is "dead" when supplied and that water must be added before it can deliver current. The same precautions must be observed as in the case of BA–10; that is, broken pieces of cork or carbon which are loose in the hollow carbon electrode should be removed. Instructions such as the following are generally printed on the carton:

> This cell will require about 1 ounce of water for charging. When charging, fill the carbon electrode with water and add water as fast as it is absorbed during one hour; after the first hour, water should be added at intervals of 30 minutes until about 1 ounce has been used. Allow the cell to stand for one hour after the last addition of water and then pour out all excess water which remains in the electrode.

Such a cell, however, can be used immediately if necessary, but the full voltage and current will not be attained for several hours.

The same precautions against short-circuiting the cell when filling it with water should be observed as in the case of the BA–10 cell.

The battery is at present used by the Signal Corps in the following equipment:

EE–6. 14 cm. projector.
EE–7. 24 cm. projector.
EE–24. Composite artillery telephone, battery commander type.

84. **BA–17.**—This battery consists of a single cell commercially known as the No. 6 size and is probably most generally used in electrical work. The cell is cylindrical and is contained in a paraffined cardboard carton. It is about 6½ inches high and 2⅝ inches in diameter, and its weight about 2 pounds. It has an open-circuit voltage of 1.54 volts; an internal resistance of 0.05 ohm, increasing to about 0.08 or more as the cell approaches exhaustion; a shelf life of 9 months; and a service life of 3 months. The short circuit current, when new, is about 30 amperes. This cell is of the same size as BA–10 (see par. 82) and the two can be used interchangeably.

The battery is at present used by the Signal Corps in the following equipment:

BD–9–A. Monocord switchboard.
BD–11–A. Similar to above.
BD–14. Camp telephone switchboard.
EE–13. Standard wall telephone, fire-alarm telephone system.
EE–14. Buzzer instruction set.
EE–25. Composite wall telephone, plotters type.
EE–26. Composite artillery telephone, desk type.
EE–27. Similar except wall type.
EE–28. Similar except portable type.
SCR–127. Radiotelegraph pack set.
SCR–130. Similar to above.

SECTION XI.

PARTS LIST AND RENEWAL PARTS.

85. **Instructions for ordering cells and parts.**—As dry cells are furnished completely assembled and are not renewable, parts lists and renewal parts for them can not be given. This data is therefore confined to wet cells as described in Sections VI, VII, and VIII.

A *parts list* includes all parts necessary for *one* complete cell. A *renewal list* includes those parts which generally require renewal as a result of the use of the cell. In some cases, however, as, for example, the breaking of a glass battery jar, an item for renewal may have to be selected from the parts list.

In ordering one or any number of complete wet cells, it is not necessary to give the parts list but simply the Signal Corps type number, as Battery Type BA–12 or Type BA–14. In ordering renewal parts, both the Signal Corps type number and the name of the part of the cell must be given. In ordering one or more dry cells, it is necessary simply to give the Signal Corps type numbers as Battery Type BA–1.

86. **Gravity cell or Type BA-12.**—The parts list for this cell is as follows:

1 battery jar.
1 copper electrode.
1 zinc electrode (crowfoot).
3 pounds copper sulphate.

The renewal list is as follows:

1 zinc electrode (crowfoot).
3 pounds copper sulphate.

87. **Edison cell No. 207 or Type BA-14.**—The parts list is as follows:

1 battery jar.
1 cover.
1 rubber gasket.
1 assembled zinc and oxide electrodes.
1 can caustic soda.
1 bottle battery oil.
1 set of terminal nuts and washers.

The renewal list is as follows:

1 assembled zinc and oxide electrodes.
1 can caustic soda.
1 bottle battery oil.

As the early type of electrodes is rapidly being used up in service, only the later and completely assembled type is included in the above lists. By reference to paragraph 57, it will be noted that the renewal list is the same as that for BA-24 in the following paragraph.

88. **Edison cell No. 202 or Type BA-24.**—The parts list is as follows:

1 battery jar.
1 cover.
1 assembled zinc and oxide electrodes.
1 can caustic soda.
1 bottle battery oil.
1 set of terminal nuts and washers.

The renewal list is as follows:

1 assembled zinc and oxide electrodes.
1 can caustic soda.
1 bottle battery oil.

The above renewal list is the same as for BA-14 in the preceding paragraph.

89. **Fuller cell or Type BA-13.**—The parts list is as follows:

1 battery jar.
1 cover.
1 porous cup.
1 carbon electrode.
1 zinc electrode.
1 can "chromac."
1 2-ounce bottle of mercury.

The renewal list is as follows:

1 zinc electrode.
1 can of "chromac."

SIGNAL CORPS PAMPHLETS.

[Corrected to June 1, 1922.]

RADIO COMMUNICATION PAMPHLETS.

[Formerly designated radio pamphlets.]

No.

1. Elementary Principles of Radio Telegraphy and Telephony (edition of 4-28-21) (WDD 1064).
2. Antenna Systems.
3. Radio Receiving Sets (SCR-54 and SCR-54-A) and Vacuum Tube Detector Equipment (Type DT-3-A).
5. Airplane Radio Telegraph Transmitting Sets (Types SCR-65 and 65-A).
9. Amplifiers and Heterodynes (WDD 1092).
11. Radio Telegraph Transmitting Sets (SCR-74; SCR-74-A).
13. Airplane Radio Telegraph Transmitting Set (Type SCR-73).
14. Radio Telegraph Transmitting Set (Type SCR-69).
17. Sets, U. W. Radio Telegraph (Types SCR-79-A and SCR-99) (WDD 1084).
20. Airplane Radio Telephone Sets (Types SCR-68; SCR-68-A; SCR-114; SCR-116; SCR-59; SCR-59-A; SCR-75; SCR-115).
22. Ground Radio Telephone Sets (Types SCR-67; SCR-67-A) (WDD 1091).
23. U. W. Airplane Radio Telegraph Set (Type SCR-80).
24. Tank Radio Telegraph Set (Type SCR-78-A).
25. Set, Radio Telegraph, Type SCR-105 (WDD 1077).
26. Sets, U. W. Radio Telegraph, Types SCR-127 and SCR-130 (WDD 1056).
27. Set, Radio Telephone and Telegraph, Type SCR-109-A and SCR-159 (WDD 1111).
28. Wavemeters and Decremeters (WDD 1094).
30. The Radio Mechanic and the Airplane.
40. The Principles Underlying Radio Communication (edition of May, 1921) (WDD 1069).

WIRE COMMUNICATION PAMPHLETS.

[Formerly designated electrical engineering pamphlets.]

1. The Buzzerphone (Type EE-1).
2. Monocord Switchboards of Units Type EE-2 and Type EE-2-A and Monocord Switchboard Operator's Set, Type EE-64 (WDD 1081).
3. Field Telephones (Types EE-3; EE-4; EE-5).
4. Laying Cable in the Forward Area (formerly designated Training Pamphlet No. 3).
6. Trench Line Construction (formerly designated Training Pamphlet No. 6-a).
7. Signal Corps Universal Test Set, Type EE-65 (WDD 1020) (2d edition).
11. Elements of the Automatic Telephone System (WDD 1096).

TRAINING PAMPHLETS.

1. Elementary Electricity (edition of 1-1-21) (WDD 1055).
2. Instructions for Using the Cipher Device, Type M-94 (WDD 1097). For official use only.
4. Visual signaling.
7. Primary Batteries (edition of 6-30-22) (WDD 1112).
8. Storage Batteries (formerly designated Radio Pamphlet No. 8).

FIELD PAMPHLETS.

1. Directions for Using the 24-CM. Signal Lamp (Type EE-7).
2. Directions for Using the 14-CM. Signal Lamp (Type EE-6).