DEPARTMENT OF COMMERCE

CIRCULAR

OF THE

BUREAU OF STANDARDS

No. 79

ELECTRICAL CHARACTERISTICS AND TESTING OF DRY CELLS

(2d Edition)
JANUARY 19, 1923

PRICE, 15 CENTS

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1923

FRONTISPIECE.—*Automatic apparatus for controlling the intermittent tests of dry cells.*

The clocks govern selective relays under the glass case on the table. If one clock should stop, apparatus will continue to operate on the other. This apparatus can carry on simultaneously a number of different tests on dry cells which are in the constant-temperature room at the left. The voltage of each group of cells may be read at the telephone jacks beneath the window.

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PREFACE.

The Bureau of Standards prepared the first edition of this circular and the specifications for dry cells during the period of the war. The specifications were submitted October 31, 1918, to a committee consisting of representatives of the manufacturers, the War Industries Board, the War Department, and the Bureau of Standards.

Experience in testing dry cells since that time has indicated certain changes in the specifications to be desirable, and much more data as to the performance of dry cells and flash-light batteries is now available. A revised edition has therefore been thought advisable.

The Bureau of Standards called a conference of leading manufacturers, various Government departments, and a few of the largest individual users of dry cells and flash-light batteries to consider the standardization of sizes and the revision of the specifications for them. This conference met at the Bureau of Standards on December 5 and 6, 1921.

The conference considered 17 different sizes of dry cells and standardized 7 of these sizes. It considered 30 different sizes and kinds of flash-light batteries and adopted 8 of these as standard sizes. It also considered assembled batteries of larger size cells for ignition and similar work of which there are approximately 30 different sizes being made at the present time and adopted 6 of these as standard sizes. Two sizes of batteries for use with radio apparatus were standardized. It is expected that the elimination of the many sizes for which there is little demand and which will no longer be considered standard should result in considerable saving in the cost of manufacture and increase the convenience of the public who buy these batteries to the extent of approximately 150,000,000 per year.

In addition to standardizing sizes, the conference standardized performance for the sizes which were accepted as standard. The bureau was requested to make a revision of its specifications for dry cells in conformity with the standardization of sizes and performances as adopted by the conference.

The bureau received hearty cooperation from the manufacturers in the work which was undertaken. It was suggested by manufacturers attending the conference that future conferences should be held at the Bureau of Standards as occasion may arise. The bureau welcomes this suggestion and is glad to assist the industry in so far as it is able.

ELECTRICAL CHARACTERISTICS AND TESTING OF DRY CELLS.[1]

ABSTRACT.

This circular summarizes the available information on dry cells. A brief description of the materials and methods of construction, and elementary theory of the operation of the cells is given. The various sizes and kinds of dry cells on the American market are described. The electrical characteristics of the cells and methods of testing them are discussed. In an appendix are given specifications for dry cells which have been prepared by the bureau with the cooperation of the manufacturers and principal users of dry cells.

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[1] First edition by G. W. Vinal and H. D. Holler. Second edition by G. W. Vinal and L. M. Ritchie.

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I. INTRODUCTION.

The commonest form of primary battery is the so-called dry cell. The dry cell is extensively used for a great variety of purposes, but comparatively little information is available in convenient form regarding its construction and operation and the methods of using it to the best advantage. Dry cells differ in electrical characteristics as well as in size and construction, but they are often used indiscriminately without reference to the purposes for which they are best adapted. The most efficient service can only be obtained when proper attention is given to the selection of the cell for the kind of service for which it is designed.

The object of this circular is to describe briefly the various kinds of cells, to indicate the service that may be expected from them, and to describe the methods of testing them. In the appendix are given specifications for dry cells which have been drawn by this bureau in consultation with the principal manufacturers and users of dry cells. These specifications are designed primarily for Government uses, but may be used by anyone.

In the preparation of this circular the literature of the subject has been reviewed and liberal use made of material contained in a number of books.[2] The bureau has also benefited by the information obtained from the leading manufacturing companies. The data on performance given in this circular is largely based on tests made at the Bureau of Standards.

TABLE 1.—The Production of Dry Cells In the United States.[1]

Year.	Number.	Value.
1899	1,946,688	$316,013
1904	4,888,361	513,026
1909	33,964,881	4,582,302
1914	71,092,438	8,719,164
1919	79,090,782	17,762,209

[1] Data obtained from Bureau of Census.

Dry cells first appeared in this country about 1890, but several years elapsed before a reliable cell of American manufacture was on the market. Since then the industry has grown rapidly, as shown by the census statistics given in Table 1, which applies to the larger sizes of dry cells. Flash-light cells are now made in

[2] Especial acknowledgment is made of our indebtedness to Primary Batteries, by W. R. Cooper.

greater numbers, but are not included in this table. In the year 1919 94,483,894 flash-light cells were made and valued at $7,514,833.

This rapid growth of the industry has been due to the use of the larger sizes for ignition and telephone service and of small sizes for flash lights. The use of the small cells for flash-light purposes has been made possible by the development of the miniature tungsten lamp.

The modern dry cell is the outgrowth of the Leclanché cell, which is still used for some purposes. Leclanché described the cell[3] that bears his name in 1868. He expressed the voltage of his cell in terms of the copper-sulphate cell, and its internal resistance in terms of meters of iron wire of a certain diameter. He refers to the depolarizing action in his cell as combustion of hydrogen. The success of the Leclanché cell led to numerous attempts to make its electrolyte unspillable. Various absorbents and fillers, such as sand, sawdust, cellulose, asbestos fiber, plaster of Paris, and spun glass, were tried by experimenters during the 20 years following. In 1888 Gassner[4] produced the first successful dry cell. His cell consisted of a zinc can serving as anode and also as the container for the cell, a carbon rod surrounded by the depolarizing mixture which was wrapped in cloth, and the electrolyte in the form of a jelly. The open-circuit voltage of this cell was about 1.3 volts, and its short-circuit current about 6 amperes. The dry cells in use to-day have been developed from this cell of Gassner.

II. THEORY AND CONSTRUCTION OF THE DRY CELL.

The dry cell has been so designated because its electrolyte is contained in an absorbent material which prevents it spilling out with the cell in any position. The cell is, however, not dry. In fact, one of the essential requirements in its make-up is that it be sufficiently wet under all ordinary conditions.

1. ELEMENTARY THEORY.

Although the chemical reactions in the dry cell are not exactly understood, a brief discussion of the principal changes taking place at the electrodes can be given here. Since the bureau has made no study of these reactions, it will be understood that this discussion represents only the generally accepted conclusions.

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[3] Leclanché, Mondes, **16**, p. 532, 1868; U. S. Patent 64113, Apr. 23, 1867.

[4] Cooper, Primary Batteries, p. 3, 1917; Ayrton and Mather, Practical Electricity, p. 192, 1912.

The relation of the principal parts of the cell to one another may be indicated as follows: Zinc metal as anode; solution of ammonium chloride; mixture of carbon and manganese dioxide as cathode.

The zinc in contact with the solution of ammonium chloride becomes *negatively* charged because of the departure of positive zinc ions Zn^{++} from its surface. As zinc dissolves in the solution, zinc ions, ammonia, and hydrogen ions are produced, according to the ionic equations:

$$Zn + 2\oplus \rightarrow Zn^{++}$$
$$NH_4^{+} \rightarrow NH_3 + H^{+}$$

The carbon-manganese dioxide electrode in contact with the solution of ammonium chloride becomes *positively* charged. This fact may be explained in, at least, two ways.

According to the first theory, hydrogen ions (H^+) are discharged at the surface of the composite electrode and render it positive:

$$2H^{+} \rightarrow H_2 + 2\oplus$$

The manganese dioxide rapidly oxidizes the hydrogen which would otherwise accumulate on the surface of the electrode and polarize the cell. The manganese dioxide (MnO_2) is thereby reduced to a lower state of oxidation, probably (Mn_2O_3):

$$2MnO_2 + H_2 = Mn_2O_3 + H_2O$$

According to the second theory, the manganese dioxide gives tetravalent ions (Mn^{++++}), which are reduced during the action of the cell to ions of a lower valency and thereby furnish positive charges to the electrode:

$$Mn^{++++} \rightarrow Mn^{+++} + \oplus$$

Aside from any theory, the fact remains that the manganese dioxide diminishes the polarization of the cell, and is at the same time reduced to a lower state of oxidation. If the *positively* charged electrode (carbon-manganese dioxide) is connected with the *negatively* charged electrode (zinc) by a wire, a current will flow through the wire from the carbon to the zinc. Within the cell the current will flow from the zinc through the electrolyte to the carbon-manganese dioxide.

2. MATERIALS OF CONSTRUCTION.

Ordinarily, the zinc serves as the container for the cell. The electrolyte consists of a water solution of ammonium chloride (sal ammoniac) and zinc chloride. It is held partly in an absorbent material that lines the zinc container and partly in the mixture of ground carbon and manganese dioxide. The latter is bulky and occupies most of the interior of the cell. Sometimes the electrolyte is made into a jelly with such colloidal material as gum tragacanth, agar-agar, gelatin, flour, or starch. The electrolyte is therefore unspillable, whether the cell is completely sealed over the top, as is most common in American practice, or is provided with a vent for the escape of gas, as is common in European practice.

Between the zinc and the depolarizing mixture there must be a lining or partition which will permit electrolytic, but not metallic, conduction. The latter would be an internal short circuit. The different kinds of linings will be described later.

When the cell is new the surface of the composite carbon-manganese dioxide electrode may be considered to be the outside surface of this mixture next to the zinc, but as the cell is discharged the manganese dioxide is reduced and the effective surface of the electrode travels toward the carbon rod which is in the center axially with the cell. This carbon rod only serves to conduct the current out of the mixture to the terminal.

(*a*) Zinc.—The zinc used in the dry cells is rolled into sheets and cut to size before it is obtained by the dry-cell manufacturer in most cases. The zinc cans are ordinarily made by soldering them with lap seams, but seamless (pressed) cans are used to a limited extent for the flash-light sizes of cells. The seamless cans, however, require special treatment before assembling the cells. The thickness of the zinc is expressed by certain gage numbers, each differing successively by 0.005 of a centimeter (0.002 of an inch); that is, No. 9 gage is 0.045 of a centimeter (0.018 of an inch) thick. Above No. 10 gage the successive thicknesses differ by twice this amount; that is, No. 12 gage is 0.028 inch in thickness. The thickness of the zinc generally used for large dry cells is from 0.035 to 0.050 cm (0.014 to 0.020 inch). For cells intended for long life the thicker zinc sheathing is used. Cells intended for heavy service are often made with thinner zinc than those for light service. In some cells thinner zinc is used for the bottoms, or sometimes the bottoms are made of tin plate. For flash-light cells No. 7 gage zinc is the thickness most commonly used. The zinc used in different sizes of flash-light cells as made by different manufacturers varies in thickness from No. 4 gage to No. 10 gage.

For electrochemical reasons zinc of a high degree of purity is desirable, but it is probably of equal importance that the metal have good mechanical properties, i. e., high tensile strength and elongation. The sheet metal must be stiff enough to withstand the strain of the processes of manufacture, as well as those of ordinary usage. The carbon-manganese dioxide mixture is tamped into paper-lined zinc cans (Sec. II–3a) by machinery under conditions which may cause deformation or even splitting of a can of soft zinc. Zinc of a high degree of purity is frequently soft. Under ordinary usage the zinc container may occasionally burst during the discharge of the cell. Undoubtedly some of such failures of the zinc are due to local corrosion of the metal at certain points. This is sometimes caused at the lap in the paper lining.

It would be desirable to have the zinc anode corrode uniformly and only in amount equivalent to the electric current furnished to the external circuit; that is, 1.219 g per ampere-hour. In reality, however, the amount of zinc consumed exceeds this figure, because some zinc dissolves without producing current in the external circuit. Local corrosion of the zinc is caused by unevenness in the distribution of the electrolyte or in the fitting of the lining of the cell. This excessive corrosion or local action at certain points may also be due to impurities in the metal, grease, or inequalities in the structure of the metal, which produce differences of potential. These local differences of potential give rise to galvanic couples, and current flows from the zinc to the impurity. As this takes place the zinc is slowly dissolved, although no useful current is delivered by the cell. The effect of metallic particles on the surface of the zinc is somewhat mitigated by several factors. One of these is the so-called overvoltage for hydrogen discharge on some metals, another is the polarization of the local circuit, and a third is the formation of insoluble products which incrust the surface. When local action is due to internal short-circuiting of the cell, the deterioration is very rapid. This may occur when the paper lining is torn or when certain impurities which were in solution in the electrolyte are precipitated in the lining of the cell. Very small amounts of copper may cause this effect.

Amalgamation of the zinc has been resorted to by some manufacturers for reducing local action, but this is more common in the European than in the American cells. Amalgamation may weaken the zinc mechanically and render it brittle.

In some cases variations in resistance of the mix may cause an unequal distribution of current over the anode surface, and thereby produce excessive corrosion of the zinc at different points.

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(*b*) CARBON-MANGANESE DIOXIDE MIXTURE.—This mixture composes the cathode of the cell, in which the carbon serves as conductor and manganese dioxide as depolarizer. The carbon rod may be considered as a collector of current from the carbon-manganese dioxide mixture. While some rods are fluted or corrugated, and thereby have a larger surface than the cylindrical form, their greatest advantage is probably that they are less apt to become loose. A carbon rod of low resistivity is necessary, as an increase in the resistance of one or two thousandths of an ohm will appreciably decrease the short-circuit current of the battery.

The electrical resistivity of the manganese dioxide is so high, as compared with that of the carbon used, that it may be considered a nonconductor. The granulated carbon is therefore added to increase the conductivity of the mixture. Since in a given volume of mixture an increase in the proportion of carbon used means a corresponding decrease in the amount of manganese dioxide possible, and therefore a shorter life of the cell, it is highly desirable that the carbon have a low resistivity. The resistivity of the carbon depends upon its source, its heat treatment, and size of granules. It has been shown that a variation up to several hundred per cent in resistivity can be made by changing only the size of the carbon grains. Graphite, which has a lower resistivity than carbon, has sometimes been added to the mixture. For this purpose both natural and artificial graphite have been used. The latter is generally used and is preferred by most manufacturers.

As previously mentioned, the manganese dioxide diminishes the polarization of the cell and is reduced, during discharge of the cell, to a lower state of oxidation. The manganese dioxide used in dry cells is usually a refined ore. The efficiency of such an ore depends upon the percentage content of MnO_2 and probably its state of hydration also.

The ores having the higher manganese content are as follows:

TABLE 2.—Manganese Ores.

Mineral.	Composition.	Manganese.
		Per cent.
Polianite	MnO_2	63.2
Pyrolusite	MnO_2-n-H_2O	60–63
Psilomelane	MnO_2 (Mn-K-Ba) O-n-H_2O	45–60
Wad	Hydrous impure mixture of manganese oxides	5–50
Manganite	Mn_2O_3-H_2O	62.4

The ore used almost exclusively for dry cells is pyrolusite. Polianite, although having a higher degree of purity, is unsuitable owing to its physical properties; that is, of not being a hydrated form.

The value of the ore as an oxidizer in dry cells varies with the content of the dioxide and, in contradistinction to its use in metallurgical industries, does not depend, except indirectly, on the content of metallic manganese. The ore must also be free from copper, nickel, or cobalt, as small traces of these metals may destroy the cell. Iron to the extent of 1 per cent is not unusual, and it has been shown by manufacturers of dry cells that even 2 to 3 per cent in some cases may be allowed. Iron in the metallic or ferrous condition is the most harmful.

In the early days an American ore was commonly used, but was later replaced by Caucasian ores and, to some extent, Japanese ores. During the war Brazil and Japan supplied large quantities of ore for dry cells until a satisfactory American supply was developed. At the present time, it is estimated that about 30,000 tons of ore are used per year for the manufacture of dry cells.

For small cells, artificially prepared manganese dioxide of a high degree of purity is sometimes used in place of the ore; but it has a bad effect on shelf life.

The physical qualities of fineness and porosity are of great importance. In general, it appears that an increase in size of the grains up to a certain limit reduces the internal resistance of the mixture of carbon and manganese dioxide, while a decrease in size of the grains increases the depolarizing power per unit weight of MnO_2. Since the depolarizing power depends upon the surface area of the manganese dioxide, a high degree of porosity is desirable.

(*c*) The Electrolyte.—The electrolyte of the dry cell consists of a solution of ammonium chloride (NH_4Cl) to which zinc chloride ($ZnCl_2$) is added to reduce the corrosion of the zinc by the ammonium salt when the cell is not in action. Information regarding the effect of the degree of purity of these materials is not available. In general, it is desirable that they be free from metals, viz, copper, lead, iron, arsenic, nickel, cobalt, and antimony, which may cause local corrosion of zinc, and free from negative radicals, viz, sulphates, which form compounds less soluble than the chlorides.

(*d*) Insulation.—The electrodes are insulated from each other at the top of the cell by a layer of sealing compound, which is usually a rosin sealing wax or a bituminous pitch. In either case a filler is generally added, such as ground silica, fibrous talc, and coloring matter. Lime is sometimes added to increase the strength. The sealing compound should make good mechanical contact with the zinc can and the carbon rod, but it is not desirable to seal the cell hermetically, as gases must escape during the operation of the cell. Other desirable qualities in the sealing compound are freedom from flowing in hot weather and excessive brittleness in cold weather.

Insulation of the zinc cans is usually provided by a cardboard tube or jacket which, in the case of the ordinary cells, is called a carton. The carton ordinarily fits the cell rather loosely so that it is possible to remove the cell from it. In the case of most cells of foreign manufacture, and some of those made in this country, the carton is of waterproof material and is an integral part of the cell. This permits the more economical use of the zinc, since leakage of the cell is prevented at those points where the zinc becomes eaten through. The zinc may be very nearly consumed without the cell becoming useless.

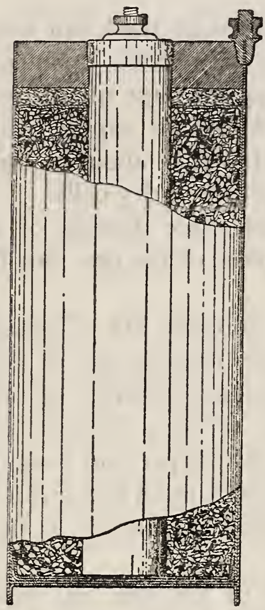

Fig. 1.—*Section of paper-lined cell.*

3. METHODS OF CONSTRUCTION.

(*a*) Paper Lined Cells.—The most familiar method of construction for the larger cells in this country is the so-called paper-lined method. Before the cell is filled with the depolarizing mixture, a side lining of pulpboard usually consisting of sulphite fiber and ground wood is placed inside the zinc can. Two or three pulpboard discs are placed in the bottom of the can. The bottom disc occasionally consists of nonabsorbent pasteboard, in order to protect the bottom of the zinc can from chemical action. The paper lining serves a double purpose. It is an absorbent for the electrolyte, and it separates the manganese-dioxide mixture from the zinc. After the manganese-dioxide mixture has been tamped into the cell around the carbon rod, the pulpboard lining is folded down over the top of the mixture. Sometimes blotting paper and strawboard are used. This method of construction, which is so common in America, is rarely found in cells of European manufacture.

The section of a typical cell of the paper-lined type is shown in Figure 1.

(*b*) Bag-Type Cells.—These are so called from the fact that the manganese-dioxide mixture is contained in a cloth bag (English call it a sack), as shown in Figure 2. The carbon rod with its surrounding mixture is wrapped in muslin and tied with string, forming a unit which can be placed in the zinc can, leaving sufficient space between the two for the electrolyte in the form of a paste. Spacers to separate the bag from the zinc can are desirable, but are not always used. These are commonly rubber bands in the small cells such as are used for flash-light batteries. Manila cord of considerable size, glass beads, or pasteboard discs are used for the same purpose in the larger sizes of cells of foreign manufacture. The solution of sal ammoniac and zinc chloride is thickened with flour or other gelatinous materials.

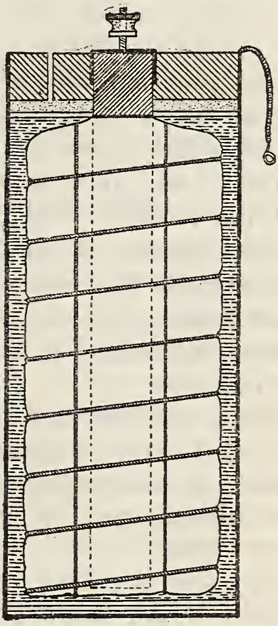

Fig. 2.—*Section of bag-type cell.*

This form of construction, which is rarely used in the larger cells made in this country, is almost universally used in making the small flash-light batteries. This may be due to several reasons. The bag-type construction tends to increase the life of the small cells, which is shorter than that of the larger sizes even when standing on open circuit. Some of these cells are so small that most of the operations can be more readily done by hand than by machinery.

The bag-type cell is commonly made in Europe in the large sizes. Two reasons which may partly account for this are (1) the relative cheapness of labor and (2) the fact that the practice of judging a cell by the magnitude of its short-circuit current, which is so commonly done in this country, is almost unknown in Europe. The bag-type cell does not usually give as large a short-circuit current as the paper-lined cell of equal size, but may have better lasting qualities. Hence to the average purchaser who thinks he is getting the most for his money from the cell that shows the largest short-circuit current, the bag-type cell is at a disadvantage. The value of this short-circuit test and also the fallacy that it may involve will be discussed under section V.

(*c*) Cells Without Paper Lining or Bag.—These cells are found on the European market, but not in this country at the present time. A paste containing the electrolyte with considerable plaster of Paris or cement is forced into the zinc can by a plunger to form a thick lining to the can. It is then cooked until the mass has become nearly solid, when the plunger is withdrawn. The manganese-dioxide mixture is tamped into the cell.

(*d*) Desiccated Cells.—These cells are manufactured dry and require the addition of water before they are ready for use. Some of them are manufactured as paper-lined cells and others are of the bag type. Each cell is provided with an opening in the seal or center of the carbon rod through which the water necessary to make the cell active may be introduced. Some of them are also provided with a vent. Only two kinds of these cells are well known in this country. One of these, called a "Reserve" cell, closely resembles an ordiniary dry cell. The other, called the "Add water," more nearly resembles some of the European types of cells. The latter is of bag-type construction with an inner zinc for the electrode. When in use it contains rather more electrolyte than the ordinary dry cell. Both of these designations are trade names and, for this reason, the bureau has chosen, as a general designation for this type of cell, the English designation "desiccated cell." There are a considerable number of different brands of desiccated cells of European manufacture.

(*e*) Partially Assembled Cells.—Since dry cells of the smaller sizes are subject to deterioration during the time that they stand on the dealers' shelves, an effort has been made by several of the manufacturing companies to furnish partially assembled cells that are freed from local action by a separation of one or both of the electrodes from the electrolytic paste. Such cells are arranged for quick and simple assembly by the purchaser.

The cells sold by A consist of a zinc can, the carbon-manganese electrode, bottle of solution, envelope of powder and cork washer for the top seal—all separate. The liquid is poured into the can and the powder added and stirred. As the liquid thickens the carbon-manganese electrode is pressed into place and the cork washer used to close the top of the cell.

The cells sold by B are more completely assembled. The electrolyte in form of a paste is contained in the bottom of the zinc can which is dropped below its usual position and held in place by a pasteboard ring attached to the carton of the cell. By removing this ring and pushing the zinc can into place the paste is forced up and around the carbon-manganese electrode.

A third variety sold by C consists of a cell in paraffined cardboard tube serving as the carton with caps top and bottom to hermetically seal the cell. When these caps are removed the zinc can, which is furnished separately, may be pushed into place within the cardboard carton, completing the cell.

All of these cells are of the unit variety and are intended for flashlight use.

III. SIZES AND KINDS OF DRY CELLS.

The dry cells manufactured in the United States fall naturally into the following general classes, which are distinguished from each other by the size and construction of the cells: Large size cells containing the absorbent paper lining, small cells of the bag-type construction used principally for flash lights, desiccated cells to which water must be added, partially assembled cells, and silver-chloride cells. These will be described in the pages that follow.

1. LARGE CELLS WITH ABSORBENT PAPER LINING.

This class is typified by the familiar dry cell about 15 cm (6 inches) high by 6.5 cm (2.5 inches) in diameter. The sizes of these cells are often designated by numbers which express the height of the zinc can in inches, but this is not universally done by the various manufacturers.

This method of designating the sizes will be used because it is convenient and expresses an important dimension of the cells, so that when a No. 6 cell is mentioned a definite impression of the size of the cell is conveyed. Sizes commonly manufactured are listed in Table 3.

TABLE 3.—Standard Sizes of Dry Cells (Cylindrical Form).

Size.	Diameter.	Height.	Weight.	Diameter.	Height.	Weight.
	Inches.	Inches.	Pounds.	cm	cm	g
4	1½	4	½	4	10	230
6	2½	6	2	6.5	15	900

Of these sizes the No. 6 is by far the more common and is made by all manufacturers, except a few who make flash-light batteries exclusively. No. 5, No. 7, and No. 8 are sizes which are no longer standard and can not generally be obtained, except when specially ordered. The dimensions given in the table are the dimensions of the zinc cans. The terminals will add about 1.5 cm (⅝ inch) to the height. The diameters are for the bare cells without the carton; however, some of them run a little under size, according to the lapping of the seam (about 3/16 inch) when the can is made. Thus the No. 6 cell is made from a sheet of zinc that is cut 15 by 20 cm (6 by 7⅞ inches), but when made into a can for the cell the diameter may be 2 mm (1/16 inch) less than the 6.5 cm (2½ inches). The No. 6 and No. 4 cells are marked A and B in Figure 3.

These cells are the so-called round form; that is, they are cylindrical in shape. This form is the easiest to manufacture and is the most efficient for this type of construction. However, some manufacturers make the so-called square form for export; that is, cells with rectangular or square cross section. When made by the paper-lined process of manufacture, the square cells are not equal in service capacity to the round cells of the corresponding size. To obviate this difficulty as well as some techinal points of their manufacture, the square cells are usually of the bag-type construction. In this case their electrical-service capacity is equal to that of the round cells of the corresponding size, particularly on light service.

It is not possible to tell from the outside of the cell whether it is of the bag-type construction. Most American manufacturers make the round form of cell. The round form of cell is preferable because the zinc is free from sharp angles and the corrosion of the zinc is more uniform. The square cells are not a regular product.

Cells of these sizes may be subdivided according to the class of service for which they are intended. They include cells for ignition and heavy service, cells for general purposes, and telephone or light service cells. These cells are also put up in the form of assembled batteries. The particular characteristics of these cells will be described below. Fundamentally, they are all of the same type of construction, but they embody features which make them peculiarly suited to the class of service for which they are intended. There is no reason why an ignition cell can not be used for telephone service, or vice versa, but to do so will not yield the maximum economical service of which the cell is capable, assuming that the cells are of equally good manufacture. Information has been furnished the bureau which shows this to be true. Comparative tests were made of two brands of cells which may be designated as "ignition" and "telephone," both made by the same manufacturer. The ignition cell gave over 20 per cent more service than the telephone cell on the ignition test (see Sec. V–3a), but the telephone cell gave nearly 20 per cent more service than the ignition cell on the telephone test (see Sec. V–3b).

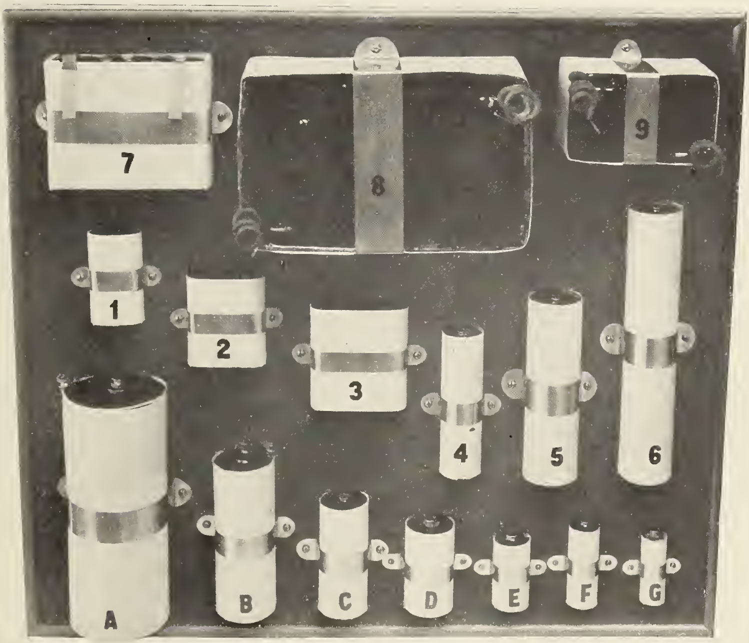

FIG. 3.—*Standard sizes of dry cells, flash light, and radio batteries.*

(*a*) Ignition and Heavy-Service Cells.—These cells are designed for use in the ignition of internal-combustion engines, lighting, and other service requiring considerable current. The open-circuit voltage is approximately 1.5 volts. The current on short circuit, when the cells are new, should be 30 amperes on the average and not less than 25 amperes as a minimum. They are intended for service that will exhaust them within a comparatively short time and are constructed to give the maximum current. The deterioration may be more rapid than that of the telephone or light-service cells when standing on open circuit. Sometimes they are made with a thinner gage zinc than the telephone cell.

(*b*) General Purpose Cells.—These cells have some of the characteristics of the ignition cells on the one hand and of the telephone cells on the other. They may be used for ignition, telephone, or for general purposes. They are convenient, having almost as low a resistance as the ignition cells and some of the lasting qualities of the telephone cell. The open-circuit voltage is the same as for the ignition cells, but the short-circuit current of these cells may be slightly lower.

(*c*) Telephone Cells.—These cells are commonly called telephone or open-circuit cells. They are intended for light intermittent service, such as telephone, bell ringing, and similar work. When used for such service they will outlast the two classes of cells mentioned above. The open-circuit voltage is the same as for the ignition cells, but the current on short circuit may be relatively low as the cells are designed for long life on light drain rather than for a heavy discharge rate. The difference between the ignition and telephone cells does not rest on the short-circuit current alone. There are differences in the materials which make each type particularly suited to the kind of service for which it is designed. A few of the smaller manufacturers, however, have made a practice of choosing cells of low short-circuit current and designating them as telephone cells, the others being labeled ignition cells, although the construction is identical. This practice is to be condemned.

2. ASSEMBLED BATTERIES.

When two or more individual cells are combined to form a unit it is called a battery. Batteries are made by several manufacturers and contain various combinations of No. 6 cells connected together by soldered connectors. These are usually

12457°—23——3

intended for some special class of service, as, for example, motor-boat ignition, and it is possible to buy these batteries inclosed in moisture proof or water proof boxes. The advantages to be derived from these batteries are numerous. They protect the cell from water or moisture; they require a minimum of time and trouble to put in service; they are free from the possibility of loose connections between the cells; and they represent the most efficient and economical grouping of cells for the purpose for which they are intended. They are sometimes designated by type numbers which indicate the brand of cell, the number of cells in series, and the size of the individual cells. Such designations, however, are not universal in use or interpretation. Standard sizes of these batteries are given in Table 4.

3. FLASH-LIGHT AND MINIATURE BATTERIES.

These cells are commonly of the bag-type construction, and are usually combined into batteries for flash lights, ear phones, and similar uses. The individual cells are of five standard sizes. These are marked C, D, E, F, and G in Figure 3. Formerly there were more than 15 sizes. This was due to the various sizes of flash lights put on the market some time ago, but certain sizes have become common, so that now they are regarded as standard. The individual cells are listed in Table 5.

FIG. 4.—*Diagrams of flash-light batteries.*

These cells are combined into batteries of various forms and sizes, Nos. 1 to 7, Figure 3, for which certain diagrammatic figures have been generally adopted. These are shown in Figure 4. The dimensions and weights of these batteries are given in Table 6. No designation of size can be given, since each manufacturer has his own system of numbering them.

The small cells are subject to more rapid deterioration than the larger sizes when standing on open circuit. Manufacturers usually date the batteries either the day of manufacture or the expiration of the guaranty period. This date is often in code.

A recent development in the American flash-light battery industry is marketing by cell units rather than by battery units. Individual cells of the sizes shown at D and E in Figure 3 are fitted with separate cartons and sold as cell units. Every present tubular flash light can use the proper number of these separate cells just as satisfactorily as an assembled tubular battery of the special size needed for that particular flash light.

TABLE 4.—Standard Sizes of Assembled Batteries.

[These batteries contain No. 6 cells. The dimensions given are the maximum.]

Assembly.	Voltage.	Length.	Width.	Height.	Weight.	Length.	Width.	Height.	Weight.
	Volts.	Inches.	Inches.	Inches.	Pounds.	cm	cm	cm	kg
2 cells, single row	3	5⅛	2¾	7½	5	13	7	19	2.3
4 cells, single row	6	10⅝	2¾	7½	10½	27	7	19	4.8
4 cells, double row	6	5⅜	5⅜	7½	10½	13.7	13.7	19	4.8
5 cells, single row	7½	13¼	2¾	7½	13	33.7	7	19	5.9
5 cells, double row	7½	8	5⅜	7½	13	20.3	13.7	19	5.9
6 cells, double row	9	8	5⅜	7½	16	20.3	13.7	19	7.3

Fifteen flash-light cells of the sizes ⅝ by 1⅞ inches and 1¼ by 2¼ inches are made into rectangular batteries for radio work. The two standard sizes are Nos. 8 and 9, in Figure 3.

TABLE 5.—Sizes of Standard Flash-Light Cells.

Designation, Figure 3.	Diameter.	Height.	Weight.	Diameter.	Height.	Weight.
	Inches.	Inches.	Ounces.	cm	cm	g
G	⅝	1⅞	¾	1.6	4.8	21
F [1]	¾	2⅛	1¼	1.9	5.4	35
E	15/16	1 13/16	1⅓	2.4	4.5	38
D	1¼	2¼	3	3.2	5.7	85
C	1¼	2⅞	3½	3.2	7.3	100

[1] Provisionally included in table.

TABLE 6.—Dimensions of Standard Flash-Light Batteries.

[Shape designations refer to diagrams in Fig. 4.]

Shape of battery.	Designation of cells.	No. of cells.	Size over all, in inches.			Net weight, in ounces.
			Height.	Width or diameter.	Depth.	
A	D	3	7	1 5/16	....	10½
	D	2	4 11/16	1 5/16	....	7
	D	1	2¼	1 5/16	....	3½
	E	2	3¾	1	....	3½
	E	1	1 13/16	1	....	1¾
B	F	3	2⅝	2 7/16	13/16	4½
	G	2	2¼	1 5/16	⅝	2
	G	3	2¼	1 15/16	⅝	2¾
C	C	3	3	4	1⅜	13¾

4. DESICCATED CELLS.

The object of these cells is to overcome the deterioration which is common to all dry cells when standing idle. Desiccated cells do not deteriorate so long as they remain dry. Their performance varies considerably with the method of construction. Those that most closely resemble the ordinary dry cell do not, in general, give as much service as the corresponding sizes of dry cell. Others of the bag-type construction and with double zinc wall and large amount of electrolyte will give considerably more. Some of these desiccated cells can be used as ordinary dry cells, but others with excess electrolyte and a venthole are for use in an upright position. They may be easily handled, however, or even inverted momentarily without spilling the liquid.

It is necessary to fill these cells with water several hours before use, and 24 hours may be necessary before the cell will give its maximum current on short circuit.

TABLE 7.—Sizes of Desiccated Cells.

Brand.	Shape.	Width or diameter.	Height.	Weight.	Width or diameter.	Height.	Weight.
		Inches.	Inches.	Pounds.	cm	cm	g
Reserve	Round	1½	4	½	4	10	227
Do	do	2½	6	2	6.5	15	908
Do	Oval	2¼ × $1\frac{3}{16}$	4	½	5.7×3	10	227
Addwater	Square	$2\frac{11}{16}$	6½	3	7	16.5	1362
Do	Round	2½	6	....	6.5	15	....

The open-circuit voltage of these cells is 1.5 volts and the short-circuit current may be 20 amperes or more in some cases, but it is usually lower.

5. PARTIALLY ASSEMBLED CELLS.

The size of the cells is 1¼ by 2¼ inches. They are sent out in such a way (sec. II–3e) that deterioration is prevented when standing on the shelf. The purchaser can put these cells together whenever he chooses to use them. When put together, however, they will deteriorate the same as any flash-light cell assembled at the factory.

6. SEMIDRY CELLS.

A number of cells have been put on the market in the past which were called semidry, but which did not differ materially from ordinary dry cells. There is, however, one brand at present on the market which is entirely different from the familiar dry cell.

These are 25 cm (10 inches) high by 12.5 cm (5 inches) in diameter and weigh 4.5 kg (10 pounds). A steel electrode replaces the ordinary zinc electrode in these large cells. The open-circuit voltage is 0.9 volt and the short-circuit current is only 4 to 6 amperes. These batteries are intended for closed-circuit work where the drain is not in excess of 50 milliamperes, but can be used for larger currents on intermittent service. They are used in telephone and telegraph work.

7. SILVER-CHLORIDE CELLS.

These are small cells having zinc and silver as the electrodes and are depolarized by a mass of silver chloride around the silver electrode. One brand is 6 cm (2⅜ inches) high and 2 cm (¾inch) in diameter, completely sealed at the top by plaster of Paris. The open-circuit voltage is 1 volt, and they can deliver a current on short circuit of one-half ampere, but they are intended for use where only small currents are required. The cells have a capacity of about 1½ ampere-hours. These cells have good lasting qualities. They can also be made in smaller sizes. On account of the silver that they contain they are expensive, but have some salvage value after being used. These cells are frequently used in medical apparatus and some radio apparatus.

8. TWIN DRY CELLS.

These cells are made of the same materials as the ordinary dry cell and have the same voltage, 1.5 volts per cell on open circuit, but their shape and construction differ from the more familiar forms. A strip of zinc of No. 9 gage, 22½ inches long by $\frac{15}{16}$ inch in width is wrapped in pulp board and is folded into a serpentine form of four lengths, about which the black mix is molded under pressure into a rectangular cake. One flat carbon rod with dowel-pin connector is placed between two such cakes, and the assembled elements are inserted under pressure into a waterproof paper box of high tensile strength. The carbon rod serves as the positive terminal for each cake of the black mix, and the two zincs are connected together through the upper seal, making a parallel arrangement from which the cell takes its name.

The cells are rectangular, 3¼ inches wide, 2 inches deep, and 6½ inches high. Advantages claimed for this form of construction are increased zinc surface, more complete utilization of the materials, and freedom from possible short circuit of the anodes of adjacent cells through the waterproof construction.

IV. ELECTRICAL CHARACTERISTICS OF DRY CELLS.

1. BEHAVIOR IN A CIRCUIT.

By the open-circuit voltage of a dry cell is meant the electromotive force of the cell when it is not producing any current. Such a measurement can be made on a potentiometer. If a resistance is connected across the terminals of a cell, a current will flow through the circuit from higher to lower potentials; that is, it flows from the carbon to the zinc. The current, however, does not begin with the carbon and end with the zinc, but flows through the cell also. It is evident, then, that within the cell the current flows from the electrode of lower potential to the electrode of higher potential, being made to do so at the expense of the chemical energy of the cell.

If a potentiometer be used to measure the potential difference at the terminals of a cell when it is discharging through an external circuit, it is found that the voltage measured is less than for the cell on open circuit. Designating the open-circuit voltage of the cell by E and the potential difference at the terminals of the cell by E', when a current I is flowing through an external resistance R it is found that

$$E' = IR \tag{1}$$

That is, Ohm's law is here applied to the portion of the circuit which is external to the cell. The difference $E - E'$, therefore, represents the voltage drop in the cell itself. Since the current is the same in the cell as in the external circuit, Ohm's law shows that

$$E - E' = Ib \tag{2}$$

where b is a quantity that represents the internal resistance of the cell.

Adding equations (1) and (2) the general expression for Ohm's law as applied to the entire circuit becomes

$$E = IR + Ib$$

or

$$I = \frac{E}{R+b} \tag{3}$$

The total resistance of the circuit is the sum of the external resistance of the circuit and the internal resistance of the cell. For the ordinary dry cell, when fresh, b is a small quantity and may usually be neglected in comparison with R, but as the cell is used up b increases and I decreases. When the cell is no longer able to perform its service, it will be found that while E has decreased somewhat, b has increased to many times its initial value.

The maximum current which a cell can deliver is by equation (3), putting $R = 0$:

$$I = \frac{E}{b} \tag{4}$$

In making measurements, R can not be made exactly zero, since the shunt and lead wires of the ammeter must necessarily have some resistance. This resistance, however, can be made very small. In standard practice it is usually 0.01 ohm. When

$R=0$, or nearly so, the value of I is called the short-circuit current of the cell.

Electrical power is the rate of expenditure of electrical energy and is measured in watts. The watt is the power when a current of 1 ampere flows through a resistance of 1 ohm. Consequently the number of volts multiplied by the number of amperes equals the number of watts; or, in general

$$IE=P$$

The power derived from the cell at any time is therefore the product of its electromotive force E by the current which flows, I. Part of the energy is expended in the cell itself and part in the outside circuit. Since the current is the same throughout the circuit the expressions for the power expended in the battery and outside of it are obtained by multiplying I by the fall in potential in each part of the circuit. Inside the cell this is

$$(E-E')I=P_1 \tag{5}$$

Outside the cell it is

$$E'I=P_2 \tag{6}$$

Referring to equations (1) and (2) above, the values for $(E-E')$ and E' in terms of current and resistance are obtained. Substituting these in equations (5) and (6) and at the same time adding these equations

$$P=P_1+P_2=I^2b+I^2R \tag{7}$$

Assuming that $R=0$, or is nearly so, I^2R also equals zero, leaving the equation for the power expended

$$P=I^2b$$

This means that when the cell is delivering its maximum current (equation 4), all the power is expended in the cell itself and is dissipated in the form of heat. Although 25 amperes or more may thus be drawn from the cell, the current does no good except to indicate the condition of the cell. On the other hand, equation (7) shows that for any value of I which may be desired, the smaller b is the less power is wasted in the cell itself. For this reason a small value of b is desirable. The equation also shows that the power expended in the cell increases as the square of the current flowing, which indicates that the importance of making b small in cells intended for ignition and heavy duty is greater than in the case of telephone and light-service cells. Certain practical limitations enter in fixing the resistance of the cells which show that excessive short-circuit currents are not a desirable feature.

Some dry cells, which in the beginning show excessively large currents on short circuit, may increase in resistance so rapidly that they will give less service than other cells of the same size, but having smaller initial currents. The tendency in this country toward cells of very large flash currents has been partly due to a mistaken idea that the more current that can be drawn from a cell the more service it will render. European cells generally are higher in internal resistance than American cells.

2. INTERNAL RESISTANCE OF DRY CELLS.

From what has been said above about the resistance of the cell itself, it might be implied that b is a definite and constant physical quantity. Such, however, is not strictly the case. The resistance of a cell is ordinarily defined by the equation

$$\frac{E-E'}{I}=b \tag{8}$$

but it can easily be shown that for various values of I different values of b are obtained apart from any consideration of polarization phenomena. By experiment it is found that the larger values of b correspond to the smaller values of I, but that for the currents ordinarily required of a dry cell the values of b are small and do not change very rapidly with changes in I. The practice of a few manufacturers to state the internal resistance of their dry cell to the thousandth part of an ohm is not to be commended, if it means nothing more than the open-circuit voltage divided by the short-circuit current, and it does not represent the resistance of the cell under working conditions.

When the cell is new, the resistance b is ordinarily small, but it increases with the age and use of the cell. This is not due to the drying out of the cell by evaporation as is often supposed, although that may be a minor cause. The reactions of the cell due to the passage of electric current result in the formation of double chlorides and basic chlorides, which probably take up water in their formation and also clog the pores of the paper lining or paste, as well as incrusting the surface of the zinc. In this way the available path for the flow of current is restricted and the resistance of the cell increased. As the cell is used, the MnO_2 is gradually reduced and the surface of the cathode moves inward, as explained in Section II–2. This makes the path between the zinc and the cathode a longer one, which also increases the resistance of the cell. The resistance of the cell increases slowly at first, but later increases very rapidly to large values. Figure 5 shows the progressive changes in resistances of dry cells by an alternating current bridge in the course of several tests. Curves are given for the 10-ohm continuous test, for a continuous discharge through 50 ohms, and for the light intermittent test.

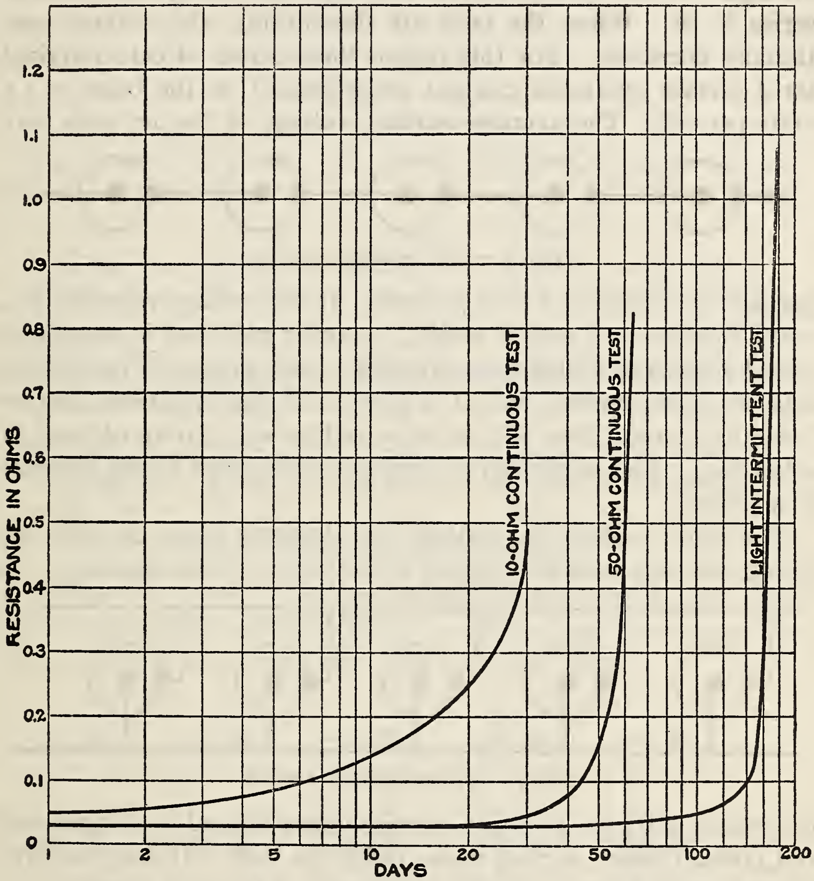

FIG. 5.—*Changes in resistance of dry cells, No. 6 size, during test.*

3. GROUPING OF CELLS.

For most purposes dry cells are used in groups or batteries, the number of cells depending on the service required. It is desirable to arrange the grouping in such a way as to secure the most economical service. Two factors are involved in arranging the cells; one is the voltage requirement and the other the current requirement. When cells are connected in series—that is, when the positive pole of one cell is connected to the negative pole of the next and so on to the end of the row, Figure 6—the voltage of the cells is additive. Two cells in series will give twice the voltage of one cell, and five cells will give five times the voltage of one, assuming that the cells, taken individually, are of the same voltage. If the voltage of one cell is E, the voltage of s cells in series is sE. When the cells are discharging, the voltage continually decreases. For this reason the number of cells required for a certain operation can not be estimated on the basis of 1.5 volts per cell. The average working voltage of the dry cells may

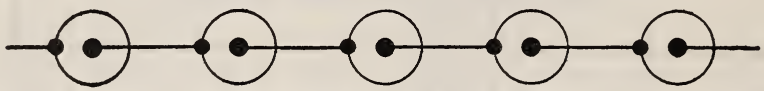

FIG. 6.—*Cells connected in series.*

perhaps be taken as 1 volt per cell. If the voltage required is 4 volts, this means 4 cells in series. Another rule that is sometimes useful when the voltage requirement is not known is to connect cells in series, adding one at a time until the apparatus can be made to operate; then add an extra cell for each group of three or a fraction. This works out to give the same result in the example just given.

The rate at which the voltage will decrease when the cells are in use will vary with the current and duration of the discharge. A

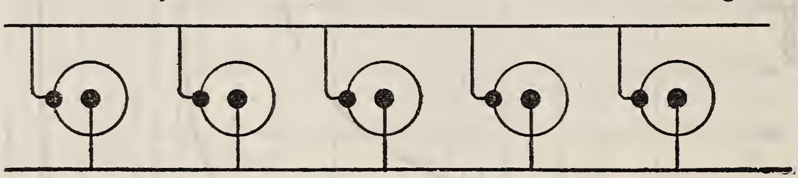

FIG. 7.—*Cells connected in parallel.*

cell which will give 40 hours' service under normal conditions will not give 20 hours' service under twice the load. It may not give more than 10 hours. On the other hand, if the load is made very light, the service actually rendered may be small because the deterioration of the cell becomes an important factor. As a guide to the proper use of the cell, the following information is given in Table 8.

The current drain on the cells can be relieved when necessary by arranging the cells in parallel, or as it is also called "multiple." Cells are arranged in parallel by connecting the like poles together. Figure 7 shows cells connected in parallel.

TABLE 8.—Current Drains for Economical Use of Dry Cells.

Duration of daily discharge.	Maximum drain on each row of cells in series.
Hours.	Amperes.
16–24	0.02
8–16	.04
4– 8	.08
2– 4	.16
1– 2	.32
1/2– 1	.75
1/4–1/2	1.50
1/6–1/4	3.00
Few moments	10–15

When more than three cells are involved in a series and parallel connection, there is a choice of arrangement. The cells may

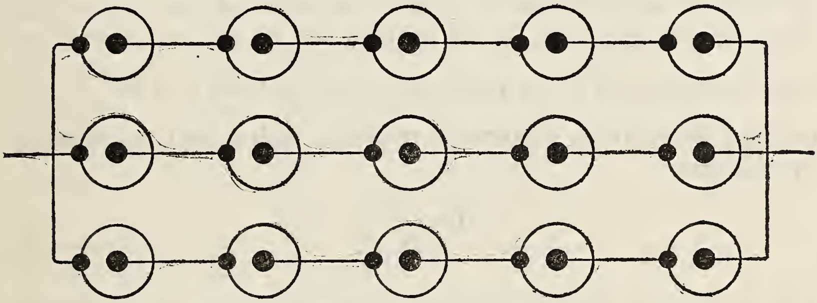

FIG. 8.—*Parallel of series-connected cells.*

be arranged in several rows connected in series and then these rows connected in parallel (Fig. 8), or they may be arranged in parallel groups which are then put in series (Fig. 9).

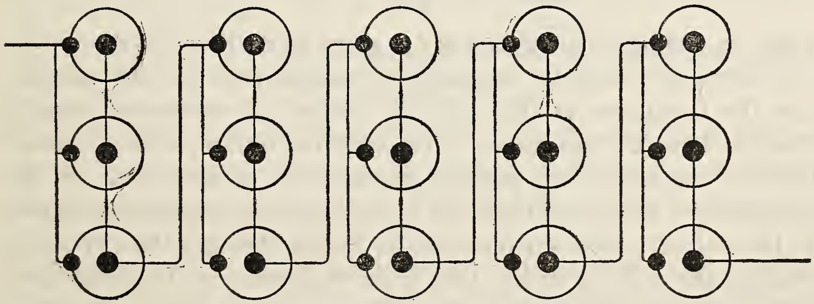

FIG. 9.—*Series of parallel-connected cells.*

Mathematically, the result is the same in either case. The voltage of the battery as shown in both figures is five times the voltage of a single cell, and the current furnished by any one cell is only one-third of the total current. The choice between the arrangements arises from the fact that one or more of the cells may fail before the others. For example, if any cell in each diagram should increase considerably in resistance, it would practically exclude one row of cells of the first diagram, Figure 8, from service, reducing the battery to practically two rows. In the second case, Figure 9, the battery would have four groups of three cells and one group of two cells, the effect of the bad cell being reduced to a minimum. In terms of resistance of the battery, the spoiling of the cell in the first diagram increases the resistance of the battery by 50 per cent, while in the second diagram it increases the resistance of the battery by only 10 per cent.

As the internal resistance of the dry cells increases the current which they will deliver to any given circuit will decrease. If there are n cells, arranged s cells in series and p rows in parallel, the electromotive force of the battery will be sE, and if each cell has a resistance of b, the resistance of the battery will be $\frac{sb}{p}$. Applying Ohm's law to a circuit containing such a battery, equation (3) becomes:

$$I=\frac{sE}{R+\frac{sb}{p}} \tag{9}$$

The maximum current that the battery can supply (when the external resistance is zero) is:

$$I=\frac{sE}{\frac{sb}{p}}=p\frac{E}{b} \tag{10}$$

which is analogous to equation (4) given in Section IV–1.

Whenever it may be necessary to use old cells for any purpose and the resistance of the cells has become of the same order of magnitude as the resistance of the external circuit, a choice arises between the series and parallel connections of the cells. If the resistance of the individual cells is less than the resistance external to the battery, more current can be forced through the circuit by putting the cells in series; but if the resistance of the individual cells is equal to the external resistance, the current is the same whether the cells are in series or parallel. If the resistance of the individual cell exceeds the resistance external to the battery, more current can be obtained by putting the cells in parallel.

4. EFFECTS OF TEMPERATURE ON DRY CELLS.

(*a*) Effect of Temperature on Voltage.—The effect of temperature on the open-circuit voltage of dry cells is small and for most purposes can be neglected entirely. The temperature coefficient is positive within the ordinary range of temperatures; that is, an increase in temperature is accompanied by a rise in voltage. Measurements carefully made on a number of dry cells of various brands, and even on different cells of the same brand, are not very concordant. Differences are also found between measurements made by a potentiometer and by an ordinary voltmeter, the temperature coefficient appearing to be greater in the latter case. In Figure 10 is given a curve that represents the average of 16 different cells, including 4 different brands measured at the Bureau of Standards. These cells were all of the No. 6 size and of the paper-lined construction. They were kept at a fixed temperature for at least 24 hours before being measured by a voltmeter having 100 ohms per volt of its scale. The voltmeter measurements are given because they are of the greatest practical use. The effect of extremely low temperatures on the voltage of dry cells is given in Scientific Papers of the Bureau of Standards No. 434.

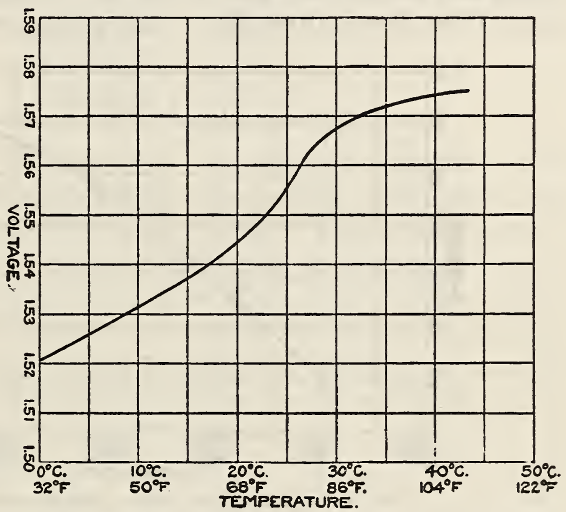

Fig. 10.—*Effect of temperature on open-circuit voltage of dry cells.*

Mean of measurements on 16 cells, No. 6 size, paper-lined construction, including four different brands. The cells were kept at fixed temperatures 24 hours before being measured.

(*b*) Effect of Temperature on Short-Circuit Current.—Between 0 and 25 °C. (32 and 77° F.) the short-circuit current increases by approximately 1 ampere for each 3° C. (5.5° F.) rise in temperature. At higher temperatures the rate of increase is somewhat less. The curve of Figure 11 shows the relation of the short-circuit current to temperature for a group of 6 cells of the paper-lined construction measured at the Bureau of Standards. Each point plotted is the mean value of the 6 cells after they had been kept at the temperature indicated for at least 24 hours. The temperatures were taken in the following order: 22, 0, 22.5, 8, 0, 21.8, 35, 41, 8, 16.8, and 9° C. This shows that the shape of the curve is well defined and that the short-circuit current reading at any temperature can be repeated with fair accuracy when the temperature of the cell is brought back to the same value.

(*c*) Effect of Temperature on Storage.—Heat produces deterioration of dry cells in two ways. First, it tends to produce leakage; this may be observed when the sticky electrolyte has oozed out around the seal of the cell. Second, it increases the rate of the chemical reactions taking place within the cell. The

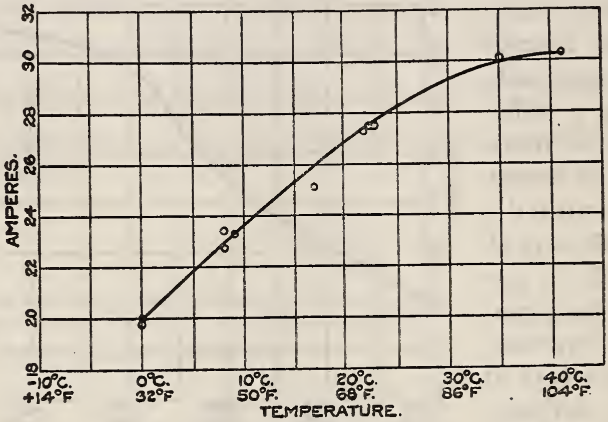

Fig. 11.—*Effect of temperature on short-circuit current.*

Mean values for a group of six cells maintained at each of the temperatures indicated for at least 24 hours prior to the measurements.

deterioration of the cells is usually measured by the decrease in the short-circuit current with time when the cells are stored on open circuit. This is not a true criterion of the decrease in service capacity of the cells, but is a convenient method of estimating the depreciation. In Table 9 is given the percentage decrease in short-circuit current at the end of 10 weeks for cells stored at various temperatures. The figures have been taken from an article by Pritz.[5] The table shows that it is necessary to keep the cells as cool as possible while they are in storage or being shipped. Temperatures of 55° C. or above are not likely to be reached under any ordinary conditions of storage.

[5] Trans. Am. Electrochem. Soc., 19, p. 39; 1911.

Recent experiments show that the measurements of Pritz for cells stored at 25° C. are approximately correct for dry cells when new, but the rate of decrease of short-circuit current becomes less as the age of the cell increases; the total decreases during a year at room temperature being about 25 per cent.

TABLE 9.—Effect of Temperature on the Short-Circuit Current of Dry Cells Stored on Open Circuit.

Temperature of storage.	Percentage decrease in short-circuit current at end of 10 weeks.
5° C. (41° F.)	4.4
25° C. (77° F.)	10.0
35° C. (95° F.)	19.0
45° C. (113° F.)	25.0
55° C. (131° F.)	52.0
65° C. (149° F.)	71.0
75° C. (167° F.)	98.0

(*d*) EFFECT OF TEMPERATURE ON SERVICE CAPACITY.—For heavy service a moderately high temperature is desirable, but for light service a low temperature is better. The data of Table 10 are taken from Pritz,[6] showing the hours of continuous service from cells of one manufacturer when discharged through various resistances until the closed-circuit voltage had fallen to 0.5 volt. The cells used for these measurements were 6.5 by 15 cm. (2½ by 6 inch) size. Exactly the same figures for the 2-ohm test were also given by Ordway [7] in a previous paper.

The following table shows that 50° C. (122° F.) is the most favorable temperature when the external resistance is 8 ohms or less. However, a word of caution is necessary in applying this table to actual use of cells. This is a continuous test, while cells are used ordinarily only part of the time. Hence, the heat that may seem to make the cell more efficient in some cases may also cause so much deterioration during the idle periods as to be disadvantageous. For example, Table 10 shows 160 hours' service at 50° C. when discharging through 4 ohms; but this is less than 7 days. Table 9 shows that at this temperature the deterioration of the cell as measured by the short-circuit current is about 4 per cent per week on the average. If the cells were to be used over a period of several weeks, the hours of actual service obtainable would be much less than those shown in Table 10. The obvious remedy is to keep the temperature lower.

[6] Trans. Am. Electrochem. Soc., 19, p. 39; 1911.
[7] Trans. Am. Electrochem. Soc., 17, p. 358; 1910.

TABLE 10.—Hours of Service of Dry Cells Discharged to 0.5 Volt at Various Rates and Temperatures.

Temperature.	Service at various resistances of external circuit in ohms—			
	2	4	8	16
	Hours.	Hours.	Hours.	Hours.
0° C. (32° F.)	40	80	270	560
25° C. (77° F.)	60	94	260	700
50° C. (122° F.)	70	160	350	650
75° C. (167° F.)	65	158	315	615

The data given in Table 10 apply to cells discharging through a fixed resistance. It is also of importance to have data for cells discharging at a fixed rate of current. Results of tests recently made at the Bureau of Standards are given in Table 11. The temperatures were kept constant by thermostatic control and the current in each case was maintained at the fixed value day and night throughout the test.

TABLE 11.—Hours of Service of Dry Cells, No. 6 Size, Discharged to 0.6 Volt at Fixed Rates of Current and at Various Temperatures.

[Average of results of tests made on three standard makes of dry cells of paper-lined construction.]

Temperature.	Service at various rates of discharge in amperes—				
	0.1	0.25	0.50	0.75	1.00
	Hours.	Hours.	Hours.	Hours.	Hours.
0° C. (32° F.)	136	40	14	7	5
25° C. (77° F.)	220	64	24	13	9
40° C. (104° F.)	300	94	31	18	11

5. CAPACITY OF DRY CELLS.

Since dry cells are mostly used on circuits of which the resistance is constant or nearly so, the capacity is usually expressed as the number of hours or days that the cell will continue to give service on such a circuit. This period is calculated to the time that the terminal voltage has fallen to some arbitrary value below which the service is not satisfactory. For example, the cut-off voltage of a group of three cells for telephone service is 2.8 volts. Such service is intermittent and extends over a number of months. The capacity of dry cells may also be expressed in terms of ampere-hours and watt-hours, but to obtain these data it is necessary to integrate carefully measured discharge curves. In any case the capacity, whether expressed as hours, ampere-hours, or watt-hours, depends on the condition of the cells, the way they are made, and the arbitrary choice of the cut-off voltage. In the pages that follow the most reliable data for the capacity of standard makes of No. 6 paper-lined cells discharging through fixed resistances and at constant current rates are given under the following headings:

(a) Discharge through constant resistances.
  Initial working voltage.
  Continuous discharges.
  Intermittent discharge.
(b) Constant current discharge.
(c) Comparison of discharge through constant resistances with discharge at constant current.
(d) Ampere-hour capacity.
  Paper-lined cells.
  Bag-type cells.
(e) Watt-hour capacity.
  Paper-lined cells.
  Bag-type cells.

Table 13 shows clearly the gain in hours of service that is to be obtained by making the current drain light. For the cut-off voltage of 1.2 volts discharging through 2 ohms, 2.2 hours were obtained, but through 8 ohms the cell gave 20 times the service, and through 64 ohms, 480 times the service.

Table 13 shows that when the voltage has fallen to one-half its initial value that the cell is by no means one-half discharged. The true measure of discharge of the cell is the ratio of the energy delivered to the total energy contained, and this must be measured in watt-hours.

Just as the voltage is not a criterion of the service capacity remaining in the cell, so also the short-circuit current is not a true measure of the cell's capacity. Excessively large short-circuit currents when the cell is new do not indicate that such cells will give more service than others yielding average currents. These excessive currents, which are sometimes produced for advertising purposes, may be the result of harmful additions to the usual ingredients of the cell. With any given brand of cell, a test that shows, for example, a decrease of 40 per cent in the short-circuit current does not mean that 60 per cent of its service capacity remains. This matter is discussed more fully under the tests for dry cells in section V–2.

(a) Discharge Through Constant Resistances.[8]—*Initial working voltage.*—It is important to know what working voltage

[8] The material in Sec. IV–5 a and b of this circular is chiefly from a paper by C. A. Gillingham, Trans. Am. Electrochem. Soc., 34, p. 297; 1918, by permission.

can be expected from the cell at the beginning of its service life under various discharge conditions. This, of course, is lower than the initial open circuit emf of the cell because of what is usually assumed to be the internal resistance of the cell. It varies with the current being drawn from the cell or with the resistance of the external circuit according to the figures in the following table:

TABLE 12.—Initial Working Voltage of No. 6 Dry Cell.

Ohms resistance of circuit.	Corresponding amperes drain.	Initial working voltage.
0.00	[a] 42.9	[a] 0.00
.01	[a] 32.0	[a] .32
.02	[a] 26.5	[a] .53
.04	[a] 18.5	[a] .74
.08	[a] 12.0	[a] .96
⅛	8.8	1.10
¼	5.1	1.28
½	2.76	1.38
1	1.45	1.45
2	.735	1.47
4	.370	1.48
8	.185	1.48
16	.092	1.48
32	.046	1.48
64	.023	1.49
128	.0117	1.50
256	.0059	1.52
512	.0030	1.52
Infinity	.0000	1.53

[a] Estimated by extrapolation.

With circuits of greater than 1 ohm the initial working voltage is but slightly lower than the open-circuit emf. The difference between open and closed circuit voltage is not readily calculated from the value for the internal resistance of the cell because the latter is not a constant quantity, since it varies with the current being drawn from the cell from about 0.04 ohm at heavy drains up to several ohms at light drains.

Continuous discharges.—In the first section of Table 13 will be found the life in hours to various cut-off voltages for cells discharged through various resistances.

A number of curves have been drawn based on the figures in Table 14, from which the characteristics of the cell can be studied more readily than from the table of figures.

If the cell discharged at the same efficiency through all resistances, a cell giving 100 hours through 10 ohms should give 10 hours through 1 ohm and 1,000 hours through 100 ohms, etc. The efficiency, however, rises more rapidly for increasing resistances up to the region of 60 to 100 ohms, above which the rise is slower than for equal efficiency. It follows, therefore, that up to this region the efficiency is increasing, and above it decreasing. Therefore, the maximum efficiency lies in the vicinity of 60 to 100 ohms, depending on the cut-off voltage.

Figure 12 shows the continuous discharge results of the first section of Table 13 plotted in terms of hours per ohm as ordinate and a logarithmic scale to the base 2 of ohms for the abscissa. By this method it is possible to put all of the results on the same plot without crowding the curves together in the region where there is the most occasion to use them. The actual hours of discharge are readily calculated from the hours per ohm by the following relation:

Hours of discharge = hours per ohm × ohms in discharge resistance.

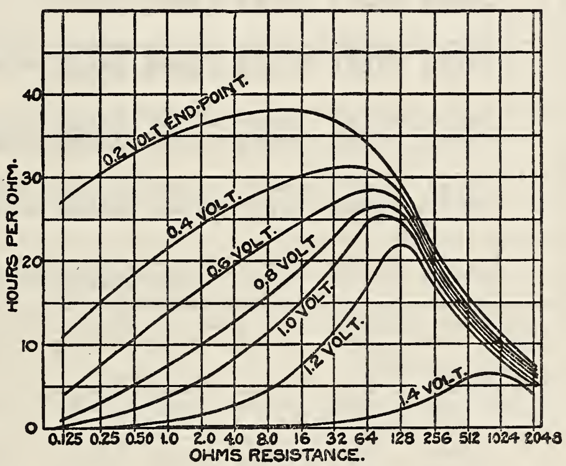

FIG. 12.—*Service efficiency curves for continuous discharges through various resistances.*

This plot shows the following characteristics of continuous dry-cell discharges:

(*a*) For any cut-off voltage the efficiency rises to a maximum as the resistance of the discharge circuit increases and then falls off rather abruptly.

(*b*) An increase in cut-off voltage causes this maximum point to move to the right.

The reason for the increasing efficiency as the resistance becomes greater (and hence the service lighter) is, no doubt, due to the increasing completeness of the depolarization. It becomes practically complete at 64 ohms.

TABLE 13.—Hours of Service for No. 6 Dry Cell.

[Note.—Figures in parentheses are interpolated.]

Cell discharged.	Cut-off voltage.	Total life for various ohms resistance of circuit— ⅛	¼	½	1	2	4	8	16	32	64	128	256	512	1,024	1,792
Continuously (1)	1.2	......	0.02	0.13	0.70	2.2	9.1	47	115	390	1,050	2,780	4,220	6,350	7,850	9,120
	1.0	0.01	.21	.95	3.7	11.1	32.5	89	233	650	1,560	3,200	4,800	6,850	9,720	10,740
	.8	.14	.76	2.3	7.4	20.7	53.0	119	304	740	1,750	3,350	5,100	7,300	10,200	11,500
	.6	.50	1.9	5.1	12.5	36.3	75.0	184	383	805	2,470	3,500	5,220	7,550	10,570	11,800
	.4	1.4	3.8	8.5	21.4	49.8	100.0	227	462	890	2,530	3,650	5,350	7,700	10,970	12,100
30 minutes every hour (2)	1.2	......	......	......	1.0	4.0	15.0	40	210	550	1,370	......	......	......	......	......
	1.0	......	......	(1.1)	5.5	13.0	37.0	120	320	810	1,570	......	......	......	......	......
	.8	(.2)	(.8)	(3.0)	9.0	26.0	61.0	190	375	920	1,630	......	......	......	......	......
	.6	(.7)	(2.0)	(5.6)	15.5	43.0	87.0	230	420	1,000	1,680	......	......	......	......	......
	.4	(1.5)	(4.0)	(9.7)	25.0	58.0	120.0	280	470	1,040	1,750	......	......	......	......	......
15 minutes every hour (3)	1.2	......	......	......	1.0	5.0	13.0	90	240	580	1,225	......	......	......	......	......
	1.0	......	.17	1.2	5.0	17.0	47.0	157	370	815	1,275	......	......	......	......	......
	.8	.31	1.0	3.0	10.5	40.0	80.0	195	445	875	1,325	......	......	......	......	......
	.6	.91	2.3	5.1	16.5	74.0	100.0	223	500	920	1,370	......	......	......	......	......
	.4	2.0	4.3	11.0	29.0	89.0	122.0	264	560	965	1,420	......	......	......	......	......
5 minutes every hour (4)	1.2	......	......	.18	2.5	10.5	45.0	115	292	508	......	......	......	......	......	......
	1.0	......	.34	2.0	7.5	28.0	75.0	166	360	542	......	......	......	......	......	......
	.8	.21	1.2	4.1	13.5	40.0	93.0	201	385	567	......	......	......	......	......	......
	.6	.75	2.3	6.4	20.0	50.0	114.0	224	403	602	......	......	......	......	......	......
	.4	1.9	4.3	11.0	33.0	62.0	128.0	236	416	625	......	......	......	......	......	......
2 minutes every hour (5)	1.2	......	......	.53	3.5	22.0	56.0	152	207	272	......	......	......	......	......	......
	1.0	.06	.53	2.3	13.0	35.0	78.0	167	216	288	......	......	......	......	......	......
	.8	.28	1.3	5.4	19.5	44.0	90.0	194	224	307	......	......	......	......	......	......
	.6	.72	3.0	10.0	28.0	59.0	103.0	209	231	333	......	......	......	......	......	......
	.4	1.8	6.0	15.0	36.0	68.0	109.0	217	240	......	......	......	......	......	......	......
½ minute every hour (6)	1.2	......	......	2.0	8.7	22.0	42.0	70	......	......	......	......	......	......	......	......
	1.0	......	1.6	6.0	15.7	29.0	46.0	76	......	......	......	......	......	......	......	......
	.8	.80	3.7	8.5	17.7	31.0	48.0	80	......	......	......	......	......	......	......	......
	.6	1.9	6.5	12.0	20.0	33.0	50.0	82	......	......	......	......	......	......	......	......
	.4	5.2	10.3	16.0	23.0	36.0	52.0	85	......	......	......	......	......	......	......	......

5 minutes every 10 minutes (7)	1.2	...	...	.14	1.5	5.0	20.0	40	220	530	1,280	2,550	...	...	...	...
	1.0	...	.42	1.3	6.0	14.5	45.0	115	340	795	1,580	2,800	...	...	...	...
	.8	.45	1.5	3.3	9.5	28.0	70.0	170	410	930	1,670	2,850	...	...	...	...
	.6	1.3	3.0	6.0	16.5	45.0	105.0	220	460	1,010	1,730	2,875	...	...	...	...
	.4	2.3	4.8	9.0	26.0	60.0	135.0	270	520	1,100	1,810	3,000	...	...	...	...
30 minutes every 6 hours (8)	1.2	...	...	...	1.3	15.0	40.0	107	309	460	...	...	...	...	...	...
	1.0	...	...	...	9.5	29.0	75.0	137	353	505	...	...	...	...	...	...
	.8	...	...	...	17.0	40.0	93.0	186	367	545	...	...	...	...	...	...
	.6	...	...	...	24.0	48.0	102.0	216	381	590	...	...	...	...	...	...
	.4	...	...	...	30.0	56.0	111.0	228	395	625	...	...	...	...	...	...
5 minutes every 6 hours (9)	1.2	...	...	.2	4.1	17.0	56.0	...	...	...	...	...	...	...	...	...
	1.0	...	.24	2.9	11.2	32.0	61.0	...	...	...	...	...	...	...	...	...
	.8	.34	1.7	6.7	16.3	37.0	63.0	...	...	...	...	...	...	...	...	...
	.6	.9	3.5	10.2	21.0	42.0	65.0	...	...	...	...	...	...	...	...	...
	.4	2.8	6.5	14.0	26.0	47.0	82.0	...	...	...	...	...	...	...	...	...

The falling off in efficiency for services lighter than that equivalent to a discharge through 64 ohms is because of the local action within the cell which is often referred to as the shelf-life deterioration.

Local action consumes the zinc can and the other constituents as well as the useful service which the cell renders, so that as the period of discharge is increased there is a relatively smaller amount of these available for service reactions.

It will be apparent also from examination of Figure 12 that the shape of discharge curve for low resistances must be quite different from that for high resistances. The relative distances between the various cut-off voltages show this.

Intermittent discharge.—The results of the various intermittent tests are shown in Table 13, from the second division down. It will be noted that the first five of these, together with the continuous division, form a series of various length discharges in hourly cycles as follows:

60 minutes per hour (continuous).
30 minutes per hour.
15 minutes per hour.
5 minutes per hour.
2 minutes per hour.
½ minute per hour.

In Figure 13 are shown the efficiency curves to the 0.8 volt end point for the various periods of hourly discharge. The maximum efficiency points move to the left toward the lower resistances as the period of discharge becomes lower, just as in Figure 12 they move to the left as the cut-off voltage is lowered. The latter is true regarding the cut-off voltage for any given period of discharge less than 60 minutes, just as it is for the continuous tests.

This leads us to a consideration of what is called "severity of service." Severity of service decreases with increased resistance and decreased period of closure. In other words, severity of service is analogous to average rate of output. Two cells would be working at the same average rate of output if, for instance, one discharged at 1 ampere continuously and the other at 10 amperes for one-tenth of an hour each hour. Each would deliver 1 ampere-hour *per hour*.

"Severity of service" may be defined as equal to the percentage of the total time during which the cell is actually discharging, divided by the resistance of the circuit. When the severity of service is low, all the discharge curves for various rates coincide if the hours of service are plotted against the severity of the service to any given cut-off voltage. In other words, the efficiency and shape of the curve is approximately the same for the same severity of service whether the discharge is continuous or intermittent. This applies to service through a resistance of 16 ohms or more.

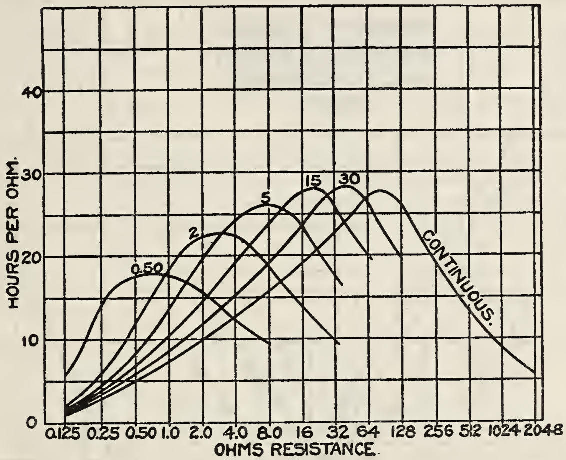

FIG. 13.—*Service efficiency curves to cut-off voltage at eight-tenths volt for various periods of discharge.*

Numbers on curves refer to minutes of discharge per hour.

Thus far all conclusions regarding the intermittent characteristics are based upon the series in which one cycle occurs every hour, the period of discharge varying between ½ and 60 minutes. In order to ascertain the effect of cycles longer and shorter than 1 hour, tests were made as follows:

5 minutes every 10 minutes
30 minutes every 6 hours
5 minutes every 6 hours

The figures for these tests are shown in the 7th, 8th, and 9th divisions of Table 13.

Tests run 5 minutes every 10 minutes are discharging the same percentage of the total time as those run 30 minutes per hour. By comparing the results for these two tests (divisions 2 and 7 of Table 13) it will be found that the two are identical (within the limit of error), except in the very low resistances where a considerable difference is found, particularly at the higher cut-off voltages. The results are, of course, lower for the longer 30 minutes discharge period than for the shorter 5-minute period. The same will appear by a comparison of the 30 minutes every 6 hours

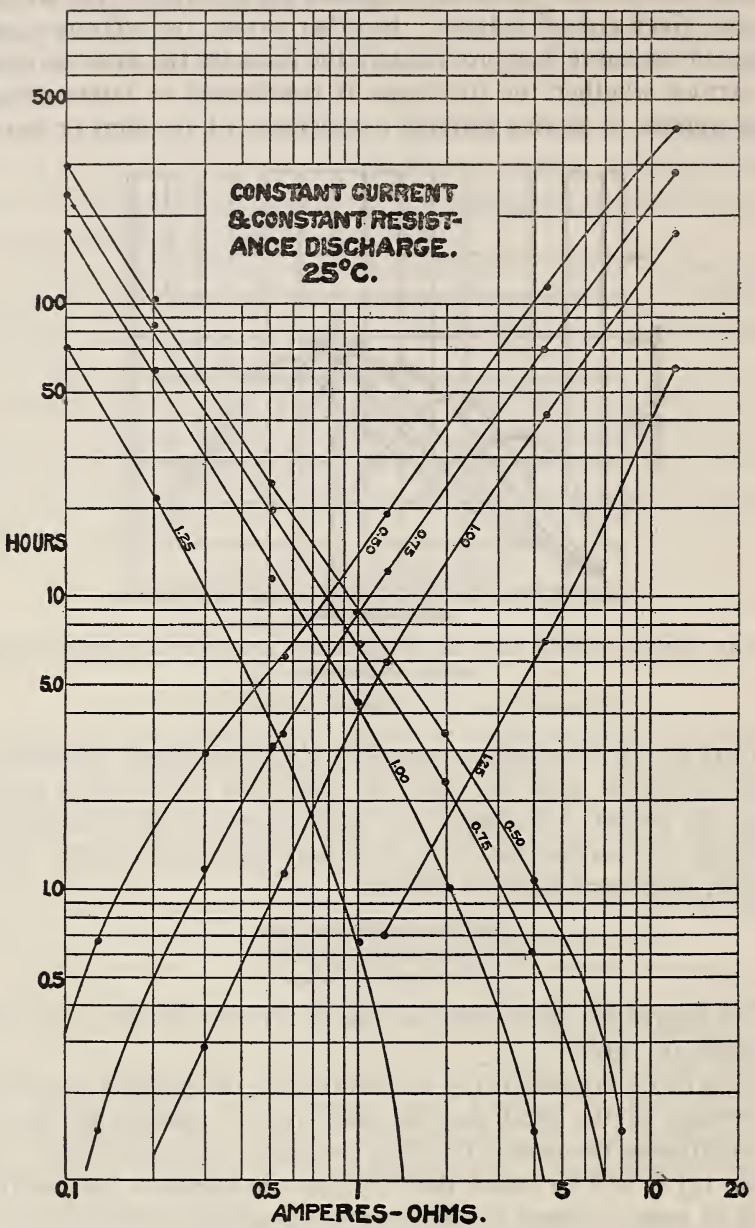

Fig. 14.—*Relation of period of continuous discharge of No. 6 paper-lined cells to the current or to the resistance.*

Curves sloping downward to the right are for discharge at constant current. Curves sloping downward to the left are for discharge through constant resistance.

with the 5-minute per hour tests (divisions 4 and 8, Table 13). Appreciable discrepancies occur only when the resistance is below 1 ohm. In most cases, therefore, it may be assumed that any discharge cycle will give the same results as the 1-hour cycle with the discharge covering the same proportion of the time. This statement, of course, must be applied with discretion especially in cases of discharge periods of considerable length and moderate resistances.

(*b*) Constant Current Discharge.—In Table 14 are shown the results of a number of tests in which the resistance of the circuit was varied as the cell ran down so that the current drain remained constant in value throughout the test.

TABLE 14.—Hours of Continuous Constant Current Discharge.

Cut-off voltage.	Total life for various amperages—						
	8	4	2	1	0.5	0.2	0.1
1.2	....	0.015	0.12	0.7	4.0	20	78
1.0	....	.24	.82	3.6	13.5	49	140
.8	0.047	.43	1.9	6.3	21.0	66	183
.6	.137	.82	3.1	9.2	27.5	80	220
.4	.240	1.29	4.3	12.0	36.0	92	237

In the constant resistance discharges, of course, the current drain decreases in direct proportion as the working voltage of the cell decreases. The cell, therefore, delivers current at a slower rate as it becomes exhausted. In the constant current test, however, the cell is forced to deliver current at the same rate when nearly exhausted as at the beginning of the test. It is, therefore, to be expected that the discharge curve will drop less rapidly at the beginning and more rapidly at the end than for a constant resistance test of about the same average drain.

(*c*) Comparison of Discharge Through Constant Resistances with Discharge at Constant Current.—Dry cells have been commonly used on circuits of which the resistance is constant, such as telephone, ignition, and bell circuits. There is now a growing tendency to use them also as a source of power for the operation of radio and other apparatus for which a constant current is necessary. The duration of the discharges of both kinds to various cut-off voltages are given in Tables 13 and 14 (Gillingham's measurements) and also in Figures 14 and 15, which are plotted from results obtained at the Bureau of Standards. Different brands of cells were used in making these experiments, and the temperature also differed by several degrees. It is not surprising therefore that there are slight differences in the results, but the general agreement indicates that the performance of paper-lined cells of standard make is reasonably uniform and consistent. The curves which are given apply to continuous discharges at constant current and through constant resistances.

In order to determine the constant current at which a cell must discharge to give comparable service to that which it can give on a constant resistance circuit, Figures 14 and 15 may be used. The former applies to the paper-lined cells and the latter to a bag-type cell of American manufacture. In either figure the curves sloping downward to the right are for the discharge at constant current for which the abscissas are amperes. The curves sloping downward to the left are for discharges through constant resistances. For these the abscissas are ohms. For example, to determine the constant current which will give the same service to 0.75 volt as for the cell discharging through 5 ohms: Starting at the 5-ohm point at bottom of diagram, follow the line vertically upward to its intersection with the curve marked 0.75 and then follow the ordinate horizontally to the left to its intersection with the other curve marked 0.75. From this intersection follow the line vertically downward to the scale of amperes at the bottom of the diagram. On Figure 14 this is found to be 0.19 ampere.

(*d*) Ampere-Hour Capacity.—The ampere-hour capacity of dry cells does not possess the theoretical interest or practical value which the ampere-hour capacity has for storage cells, but it is occasionally necessary to determine it. This may be done for continuous discharges with the aid of Figures 14 and 15.

When the cells are discharged at a constant current rate the capacity in ampere-hours to any specified cut-off voltage can be calculated immediately. It is the product of the current by the duration of the discharge. Thus in Figure 14 the ampere-hours for a cell discharging at a fixed rate of 0.5 ampere to 0.75 volt is found to be

$$0.5 \times 19 = 9.5 \text{ ampere-hours.}$$

The more usual case, however, is for the cell to be discharged through a fixed resistance, the current decreasing as the discharge progresses, because of the falling voltage of the cell. The equivalent constant current may be estimated for the discharge through any value of resistance shown in either Figure 14 or 15, as described in the preceding section, and from this the approximate

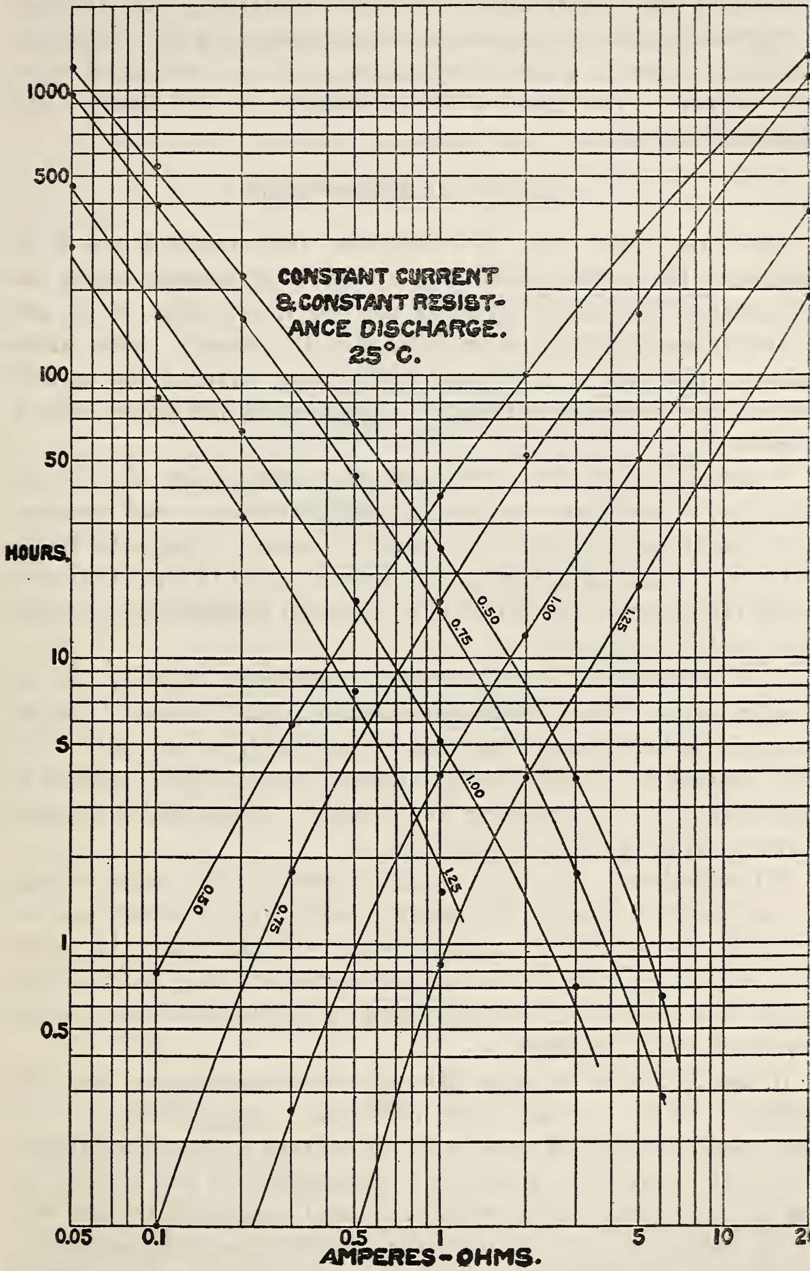

FIG. 15.—*Relation of period of continuous discharge of No. 6 bag-type cells to the current or to the resistance.*

Curves sloping downward to the right are for discharge at constant current. Curves sloping downward to the left are for discharge through constant resistance.

equivalent in ampere-hours may be computed. An example was given in which the constant current equivalent to a discharge through 5 ohms to a cut-off voltage of 0.75 volt was found to be 0.19 ampere. The time of the discharge was 85 hours. The ampere-hours were

$$0.19 \times 85 = 16 \text{ ampere-hours}$$

The most exact way of computing the ampere-hours is to determine the current flowing at a number of periods during the discharge of the cell by dividing the terminal voltage of the cell at such times by the fixed resistance of the circuit. From these values a plot can be made and the average value of the current during the discharge obtained bv integrating the curve with a planimeter.

It should be remembered that the performance of different brands of cells differs considerably, and that the age and temperature conditions also have a marked influence. The performance of typical brands of cells given in Figures 14 and 15 serve only as a rough indication of the period of service and ampere-hour capacity that may be expected.

(*e*) Watt-hour Capacity.—The watt-hour capacity is of greater interest than the ampere-hour capacity because it represents the actual energy that can be derived from the cell. It is not computed as easily as the ampere-hour capacity because of the necessity of determining the average voltage which changes throughout the period of discharge.

If the discharge is made at constant current, the average voltage is most simply obtained by plotting the voltage readings and integrating the curve by a planimeter. In this case the watt-hour capacity is the product of the average voltage by the fixed value of current and by the period of discharge to any predetermined cut-off voltage.

If the discharge is made through a fixed resistance, both the current and the voltage vary throughout the discharge. It is then necessary to plot a curve of the voltage squared for integration. The watt-hour capacity is determined as the product of the average value of the voltage squared multiplied by the time of the discharge and divided by the fixed value of the resistance.

Since the watt-hour capacity of the cells can not be computed from any of the preceding data, curves of Figures 16 and 17 are given for continuous discharges of the ordinary paper-lined cells of No. 6 size discharging through fixed resistances and at constant current to the cut-off voltages indicated on the individual curves.

V. TESTING DRY CELLS.

The difficulty in testing dry cells arises from the fact that the cells under varying conditions will yield different amounts of service. For this reason it is not possible to state the service

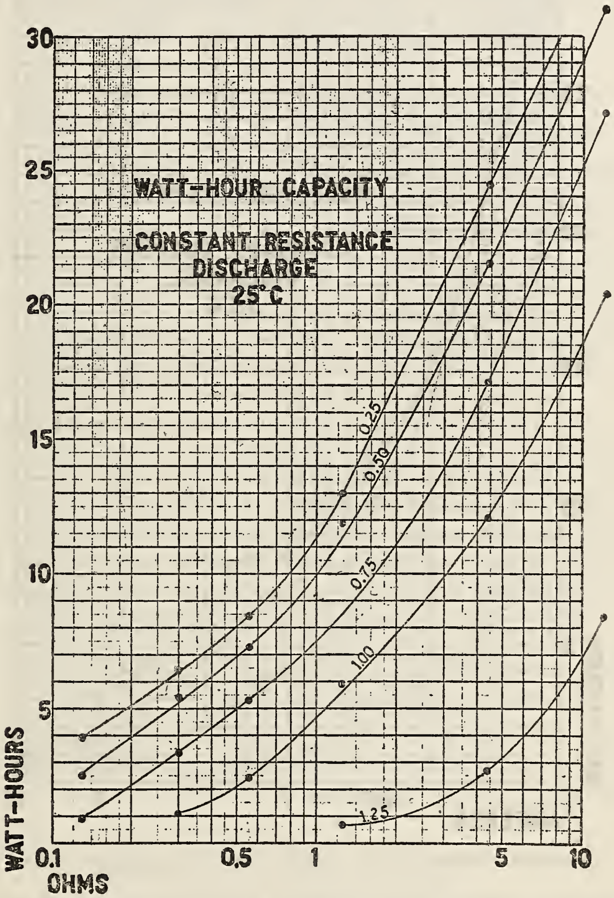

Fig. 16.—*Watt-hour capacity of No. 6 paper-lined cells, constant resistance discharge.*

capacity of any kind of dry cell in arbitrary figures, unless the test itself is practically the same as the use to which it is to be put. No way has been found as yet to make accelerated tests that shall include all the factors entering into the performance of the cells. Table 13 has shown that as the load on the cell is increased the hours of service rendered by the cell are more than proportionately decreased. Accelerated tests do not include the important matter of the open-circuit deterioration. Intermittent tests are long continued, and the results are generally not obtainable until after the cells from which the test sample was taken have lost a large part of their usefulness.

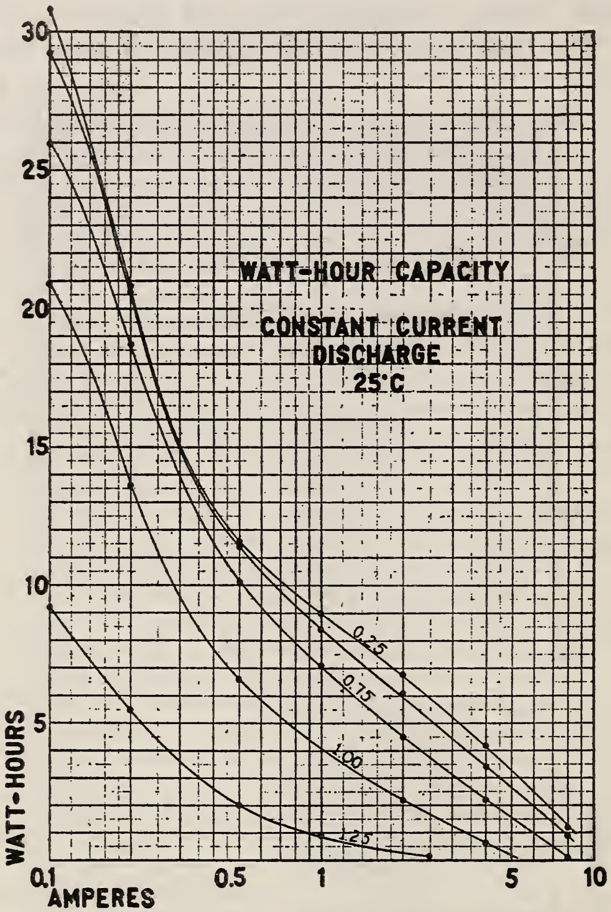

FIG. 17.—*Watt-hour capacity of No. 6 paper-lined cells, constant current discharge.*

Except for current and voltage measurements which can be made quickly and without injury to the cells, the only feasible method of testing the cells seems to be to make frequent tests on various brands of cells. These tests can give information on the relative service to be expected from the different brands and indicate the quality of materials in use and the systematic efficiency of their manufacture. The current and voltage measurements will indicate accidental imperfections in the cells, if such exist. Tests for dry cells were described in considerable detail by Ordway[9] in this country and Melsom[10] in England.

A committee of the American Electrochemical Society was appointed to investigate the subject. They made a report[11] in 1912 embodying most of the tests previously described by Ordway. The tests in general use to-day are modifications of the tests which were recommended at that time.

1. OPEN-CIRCUIT VOLTAGE TEST.

This is usually made with a voltmeter through which some current necessarily flows. It is, therefore, not strictly an open-circuit measurement, but the current which flows through the voltmeter is generally so small that the voltage of the cell is lowered by an amount which is negligible. An accurate voltmeter of at least 100 ohms resistance per volt of the scale and having at least 50 divisions per volt should be used for this purpose. The true open-circuit voltage of cells is most conveniently obtained by measuring them with a potentiometer, but this is possible only in the laboratory.

The voltage of an unused dry cell is usually from 1.50 to 1.60 volts. Higher voltages are sometimes found, but do not indicate superiority of the cell. Lower voltages than 1.45 volts may indicate manufacturing defects, deterioration due to age, or damage. Abnormally low values indicate probably low service capacity. Hence the open-circuit voltage test made with a voltmeter is the best test available for picking defective cells in a shipment.

The open-circuit voltage, measured by a potentiometer, changes by only a small amount relatively during the life of the cell. One cell under observation at the bureau for 20 years still shows 1.36 volts when measured on the potentiometer, although its resistance has increased so that a voltmeter measurement such as is described above shows only 0.215 volt.

2. SHORT-CIRCUIT CURRENT TEST.

This test, as described by the committee of the Electrochemical Society, is commonly in use at the present time. A deadbeat ammeter accurately calibrated must be used. The resistance of the lead wires and shunt of the ammeter should have a value of

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[9] Trans. Am. Electrochem. Soc., 17, p. 341; 1910.
[10] Trans. Faraday Soc., 8, p. 1; 1912.
[11] Trans. Am. Electrochem. Soc., 21, p. 275; 1912.

0.01 ohm to within 0.002 ohm. The maximum swing of the needle is taken as the short-circuit current of the cell. The lead wires are conveniently tipped with lead to make good contact and should be applied to the brass terminals of the cell. Results of tests vary with the temperature. They should be made only when the cell is at normal room temperature; that is, about 70° F.

This easily-made test is of value in judging the uniformity of a group of cells purchased at the same time or in comparing the condition of one or more cells with the normal value for the short-circuit current of the same brand, provided the normal value is known. Thus, if the brand of cell is known to average 30 amperes when new and unused and the cell under test shows about this value, it is reasonably certain that the cell is in good condition. Records show, however, that cells of low short-circuit current may give a satisfactory performance on the light intermittent service test and, therefore, the short-circuit current readings ought not to be relied upon in choosing cells for telephone or similar light duty. This test gives no indication of the service capacity of different brands of cell as is shown in Figure 18 taken from a paper by Pritz[12] in which the short-circuit current of eight different brands is compared with the service capacity of the same cells.

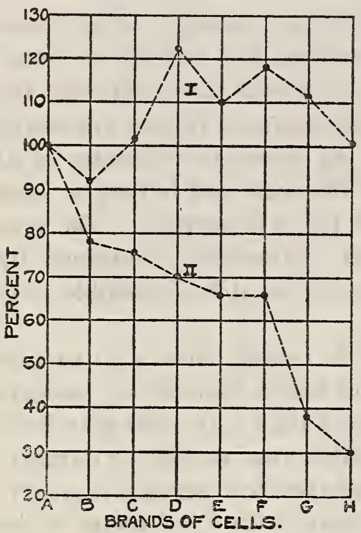

FIG. 18.—*Relative short-circuit current and service capacity of eight brands of cells. (Observations by Pritz.)*

The points connected by dotted line *I* represent the initial short-circuit currents of the cells expressed in terms of brand *A*. Points connected by dotted line *II* represent the service capacity of the same cells also expressed in terms of brand *A*.

Some cells manufactured expressly for long-continued service give only 18 to 20 amperes when new, so that it is obviously unfair to compare them with 30 ampere ignition cells. But a cell which should give 30 amperes initially, which gives only 18 amperes on short-circuit, has lost a large part of its service capacity for heavy drains.

The decrease in service capacity does not, however, follow the decrease in short-circuit current. In Figure 19 are given com-

[12] Trans. Am. Electrochem. Soc., 19, p. 33; 1911.

parative results at different periods extending over a year on cells stored on open circuit. The results as expressed by curve 1 represent the short-circuit current as a percentage of the original value. Curve 2 shows the actual service that the cells can render on the standard heavy intermittent service test at the periods shown. It will be noted that these results differ greatly from those of curve 1. Curve 3 shows the results of the light intermittent service test on these cells at the same time. The data for

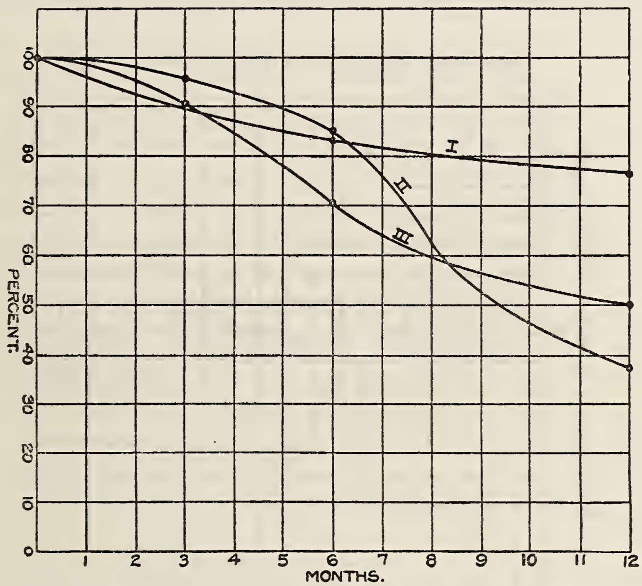

FIG. 19.—*Relation between deterioration in short-circuit current and service capacity for cells stored for various periods of time on open circuit.*

Curve *I* shows deterioration measured by the short-circuit current test; curve *II* by service rendered on the heavy intermittent test; curve *III* by service rendered on the light intermittent test.

these curves has been obtained from one of the manufacturing companies.

There are prominent brands of telephone cells on the market which show for different individual cells in good condition such a large variation in short-circuit current that the short-circuit test will not afford a correct indication of their service value. Figure 20 shows results of short-circuit current and light intermittent service tests made by the American Telephone & Telegraph Co. extending over a year's product of a prominent brand of telephone cells. The cells were all 100 days old when the short-circuit current was measured, so as to represent approximately the condition of cells as received by users. Each point shows the average short-circuit current of 3 cells in per cent of the average of all cells, and the percentage life from the same 3 cells on the light intermittent service test. It will be noted that a considerable proportion of cells with low short-circuit current have good life. A count of the points shows 21 less than the average short-circuit current and 24 more than the average. Of the 21 which are below average, 13 indicate less than the average service. The chance that a cell will be deficient

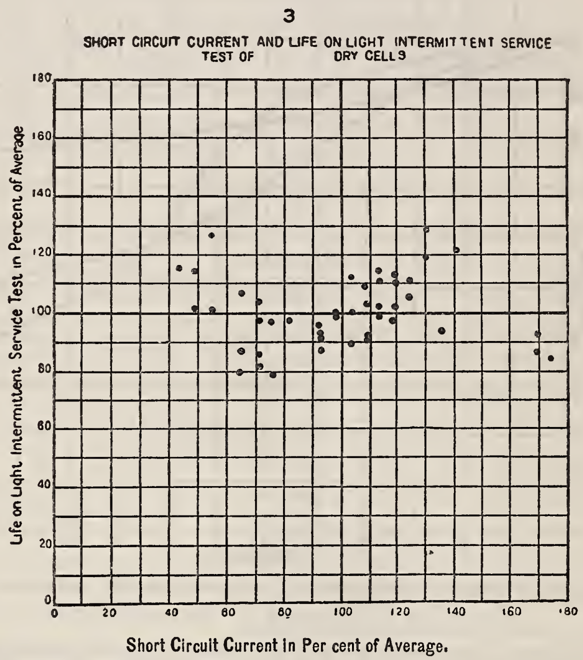

FIG. 20.—*Relation of short-circuit current to life on the light intermittent test.*

Each point is the average result of three cells connected in series. The cells were 100 days old at the time of measurement of short-circuit current and starting of test.

in capacity when it is below the average short-circuit current is 1.6 to 1. Fifteen out of the 24 points for short-circuit currents above the average, are also above the average in service capacity, from which it may be computed that the chance of such a cell being superior in capacity is also 1.6 to 1.

The two tests outlined above are the only ones at present in use that can be easily and quickly made without destroying the cells. If made with a proper understanding of what is to be expected of the particular cells under test, they afford valuable information. Otherwise they may be misleading.

3. INTERMITTENT TESTS.

These have been made to imitate the use of cells under average conditions. The three standard intermittent tests are: (1) Light intermittent tests which represents telephone and other light services; (2) heavy intermittent test, which represents ignition service; and (3) flash-light test, which represents flash-light service.

(*a*) LIGHT INTERMITTENT SERVICE TEST.—This test, as described by the committee mentioned above, consisted of discharging three cells connected in series through 20 ohms for 2-minute periods each hour, 24 hours per day and 7 days per week, until the closed-circuit voltage of the battery at the end of a period of contact falls to 2.8 volts. This was modified and supplanted by the so-called A. T. & T. telephone test, which is as follows: Three cells connected in series are discharged through 20 ohms for 10 periods of 4 minutes each in 10 consecutive hours of 6 days per week. On the seventh day every other period is omitted. The end of the test is taken at 2.8 volts for the battery on closed circuit. The results are expressed as the number of days the test lasted.

This test has been continued as the standard test for light intermittent service by the conference of December 5 and 6, 1921. The name "telephone test" was discontinued, since it implied too great a restriction in the kinds of service which this test may properly represent.

(*b*) HEAVY INTERMITTENT SERVICE TEST.—Four cells connected in series to a circuit of 10⅔ ohms are discharged for two periods of 1 hour each per day, the periods being 11 hours apart. The test is considered complete when the closed-circuit voltage has fallen below 0.85 volt per cell. The results of the test are expressed as the number of hours actual discharge to the cut-off voltage.

This test is essentially the same as the ignition test used in the past. The value 10⅔ ohms for the discharge resistance is proportionately the same for 4 cells as the 16 ohms formerly used for a group of 6 cells. The method of determining the cut-off point has been changed to a voltage reading to simplify the test.

(*c*) FLASH-LIGHT TEST.—The battery is discharged for a 5-minute period once a day through a resistance of 4 ohms for each cell in series in the battery until the working voltage falls below 0.50 volt per cell. The results are expressed as the number of minutes of actual discharge. In making this test it is necessary to use fixed resistances of the proper value rather than small lamps because the lamps differ among themselves, and the resistance of the lamps changes by a large amount as the impressed voltage changes.

4. CONTINUOUS TESTS.

These tests are simpler and quicker to make, but they do not afford such reliable information about the value of the cells as the intermittent tests, because they do not bear a close relation to actual service either in the matter of the current drain or length of service. Continuous tests have been used more in Europe than in this country.

(*a*) LARGE-SIZE CELLS.—For the No. 4 and No. 6 cells the continuous test is to discharge the cell through a fixed resistance of 10 ohms until the voltage has fallen to 0.75 volt per cell.

(*b*) FLASH-LIGHT CELLS.—Continuous tests of flash-light cells give information as to the relative manganese content, but do not take into consideration the important matter of open-circuit deterioration. It has been found by Gillingham [13] that the continuous discharge of flash-light cells through resistances of 2.75 ohms for each cell in series gives the best approximation to the actual life of the cell discharging at 0.35 ampere through a lamp. The exact value which will most nearly approximate the burning conditions will, of course, depend on the characteristics of the flash lamps, which have not been standardized. Most flash-light lamps are normally rated to take 0.25 to 0.30 amperes at their rated voltages, but there is a considerable variation in the actual ratings of lamps. The lamps of highest efficiency burn out quickly on a good battery but are sometimes used to hide the deficiencies of a poor battery. The only accurate test of a flash-light battery is to discharge it through a fixed resistance of suitable value and not to use a flash lamp, as is often done.

(*c*) RADIO BATTERIES.—These batteries are discharged continuously through 5,000 ohms until the closed-circuit voltage falls below 17 volts.

5. SHELF TEST.

This test usually consists in storage of the cells on open circuit at room temperature over a considerable period of time during which the changing condition of the cells is ascertained by open-circuit voltage and short-circuit current readings. Delayed serv-

[13] Trans. Am. Electrochem. Soc., **30**, p. 267; 1916.

ice tests are made by storing cells for a period on open circuit and then submitting them to one of the regular service tests previously described. These tests give more accurate information about the deterioration in service capacity than readings of the open-circuit voltage and short-circuit current. The delayed service tests contained in the specification at the end of this circular are made by subjecting the cells to continuous discharges as described in section 4 after storage of the cells for 3, 6, 9, and 12 months.

6. OTHER TESTS.

Beside the tests mentioned above it may be desirable to make other tests, including other physical measurements, chemical examination, noise in radio batteries, and the effect of temperature. For these no definite procedure has been established. A superficial physical examination will occasionally serve to indicate certain defects, such as loose terminals, leaking seals, and flaws in the zinc.

7. APPLICABILITY OF THE VARIOUS TESTS.

In the preceding sections standard tests for dry cells have been described. They are the tests which have been developed with the industry and were originally designed to represent certain types of service. Careful examination of the records of laboratory tests in the light of the service given by the cells in actual use shows that the test which best represents any particular type of service is that which covers approximately the same duration of time. This applies particularly to the large size cells for which light intermittent, heavy intermittent, and continuous drain tests are provided. When it is possible, the light intermittent test should be used for cells which are to be in service four months or more. The heavy intermittent test should be chosen when the period of service will last from a few weeks to 2 or 3 months. The continuous 10-ohm test lasts from 8 to 10 days and is therefore particularly applicable to service of 1 month or less. It is not always possible to allow sufficient time for the tests of long duration, and in such cases the continuous tests are of value in showing that the cells contain sufficient active materials and the general quality and uniformity of their manufacture. The 10-ohm test is of value also for determining the deterioration of cells which have been stored for various periods as described under the head of delayed service tests.

There is no direct relation between the results of the continuous 10-ohm test and the tests of longer duration. For example, in Table 16 it is shown that for a certain lot of cells submitted for test, the telephone cell gave a better result on the light intermittent test than on the 10-ohm test or the heavy intermittent test, as compared with the ignition cell, which was superior on the 10-ohm and the heavy intermittent test.

TABLE 15.—Comparison of Service of Several Types of Dry Cells.

Type of cell.	10-ohm test.	Heavy intermittent test.	Light intermittent test.
	Hours.	Hours.	Days.
Telephone	197	34	206
General	195	55	177
Ignition	203	55	196
Bag type	230	46	221

VI. APPENDIX.—SPECIFICATIONS FOR DRY CELLS.

1. DEFINITIONS.

(*a*) Dry cells to be included under these specifications must fulfill the following requirements in addition to the other paragraphs of these specifications:

(1) To be sal ammoniac cells with depolarizer.

(2) To have a nonspillable electrolyte and to be free from leakage during the useful life of the cell.

(*b*) Desiccated cells to which water must be added before the cell is put into service may be included under these specifications.

2. TYPES OF CELLS.

The following types of dry cells will be considered in these specifications:

(*a*) Telephone or light-service cells.

(*b*) General purpose cells.

(*c*) Ignition or heavy-service cells.

(*d*) Flash-light cells and batteries.

(*e*) Assembled batteries, exclusive of class (d).

(*f*) Desiccated cells and other similar cells to which water must be added.

(*g*) "B" batteries for radio service.

3. SIZES OF CELLS.

(*a*) STANDARD SIZES, IGNITION, TELEPHONE, AND SIMILAR CELLS, CYLINDRICAL FORM.—These dimensions are for the zinc container of the cell and are to be measured on the cell without the carton.

TABLE 1.

Diameter.	Height.	Diameter.	Height.
Inches.	Inches.	cm	cm
1½	4	4	10
2½	6	6.5	15

Deviations must not exceed $\frac{1}{16}$ inch in diameter and ⅛ inch in height from the dimensions as given in inches. The cells are to be of the flush-top type. Terminals must not add more than ⅝ inch (1.6 cm) to the height of the cells as given above. The maximum diameter of the cells measured over the carton shall not exceed the diameter as given above by more than ⅛ inch (3 mm).

(*b*) STANDARD SIZES, FLASH-LIGHT CELLS, CYLINDRICAL FORM.—These dimensions are for the zinc container of the cell.

TABLE 2.

Diameter.	Height.	Diameter.	Height.
Inches.	Inches.	cm	cm
⅝	1⅞	1.6	4.8
a ¾	2⅛	1.9	5.4
$\frac{15}{16}$	$1\frac{13}{16}$	2.4	4.6
1¼	2¼	3.2	5.7
1¼	2⅞	3.2	7.3

a Provisionally included in table.

Deviations from these dimensions, as given in inches, must not exceed $\frac{1}{16}$ inch in height or $\frac{1}{32}$ inch in diameter. The height, including cap on carbon rod, must not exceed the height given in Table 2 by more than ⅛ inch (3 mm).

(*c*) FLASH-LIGHT BATTERIES, STANDARD SIZES.—These batteries contain cells of standard sizes as given above. The batteries are listed in the following table. Deviations from these dimensions, as given in inches, must not exceed $\frac{1}{16}$ inch in height per cell, or $\frac{1}{32}$ inch in diameter for tubular batteries; nor $\frac{1}{16}$ inch in height or $\frac{1}{32}$ inch per cell in width, and $\frac{1}{32}$ inch in depth for flat or box batteries.

TABLE 3.

Kind.	No. of cells.	Size of cells.				Dimensions of battery.					
		Diameter.	Height.	Diameter.	Height.	Width or diameter.	Height.	Depth.	Width or diameter.	Height.	Depth.
		In.	In.	cm	cm	In.	In.	In.	cm	cm	cm
Unit cell	1	1¼	2¼	3.2	5.7	1 5/16	2 5/16	....	3.3	5.9	....
	1	15/16	1 13/16	2.4	4.6	1	1⅞	....	2.5	4.8	....
Tubular	3	1¼	2¼	3.2	5.7	1 5/16	7	....	3.3	17.8	....
	2	1¼	2¼	3.2	5.7	1 5/16	4 11/16	....	3.3	11.9	....
	2	15/16	1 13/16	2.4	4.6	1	3¾	....	2.5	9.5	....
Flat	[a] 3	¾	2⅛	1.9	5.4	2 7/16	2½	13/16	6.2	6.3	2.1
	3	⅝	1⅞	1.6	4.8	2	2¼	11/16	5.1	5.7	1.75
	2	⅝	1⅞	1.6	4.8	1 5/16	2¼	11/16	3.3	5.7	1.75
Box	3	1¼	2⅞	3.2	7.3	3⅞	3 1/16	1 5/16	9.8	7.8	3.3

[a] Provisionally included in table.

(*d*) Assembled Batteries.—The individual cells in these batteries must conform to these specifications, with the exception that the cartons may be omitted, other insulation between the cells being provided. The cells in these batteries are to be 2½ inches in diameter by 6 inches in height.

TABLE 4.—Standard Sizes of Assembled Batteries.

[These batteries contain No. 6 cells. The dimensions given are the maximum.]

Assembly.	Voltage.	Length.	Width.	Height.	Weight.	Length.	Width.	Height.	Weight.
	Volts.	Inches.	Inches.	Inches.	Pounds.	cm	cm	cm	kg
2 cells, single row	3	5⅛	2¾	7½	5	13	7	19	2.3
4 cells, single row	6	10⅝	2¾	7½	10½	27	7	19	4.8
4 cells, double row	6	5⅜	5⅜	7½	10½	13.7	13.7	19	4.8
5 cells, single row	7½	13¼	2¾	7½	13	33.7	7	19	5.9
5 cells, double row	7½	8	5⅜	7½	13	20.3	13.7	19	5.9
6 cells, double row	9	8	5⅜	7½	16	20.3	13.7	19	7.3

The height given is the maximum height over all. The body of the battery will be 6½ to 7 inches in height.

(*e*) Standard Sizes, "B" Batteries for Radio Service.—These batteries contain cells of standard sizes as shown in Table 5. The cells are to be connected in series.

TABLE 5.—"B" Batteries for Radio Service.

Assembly.	No. of cells.	Size of cells.				Dimensions of battery.					
		Diameter.	Height.	Diameter.	Height.	Length.	Height.	Width.	Length.	Height.	Width.
		Inches	Inches.	cm	cm	Inches.	Inches.	Inches.	cm	cm	cm
Rectangular box	15	⅝	1⅞	1.6	4.8	3⅜	2 9/16	2 1/16	8.6	6.5	5.2
Rectangular box	15	1¼	2¼	3.2	5.7	6⅝	3	4	16.8	7.6	10.2

Deviations from these dimensions as given in inches must not exceed the following:

Smaller battery, $\frac{1}{16}$ inch in length, width, or height.

Larger battery, $\frac{1}{8}$ inch in length, $\frac{1}{16}$ inch in width or height.

4. CARTON.

The individual cells, except those in assembled batteries, flash-light batteries, and radio batteries, shall be inclosed in a close-fitting carton of news, chip, or strawboard. Paraffined or waxed cartons may be required for special purposes. On the outside of the carton shall be printed the following information:

The name of the cell.

Its number or other designation of size.

The date of manufacture or the expiration of a guaranty period. (Optional: This may be on zinc container.)

The name of the manufacturer or such trade-mark as will identify the manufacturer.

Any necessary directions as in the case of desiccated cells.

5. ZINC CAN.

The zinc can serves as a container for the cell and as the anode. It is to be made from smooth sheet zinc, free from flaws, blisters, and cracks.

6. SEALING COMPOUND.

The sealing compound shall be an insulating material which shall not cold flow at a temperature of 45° C. (113° F.) during a static test of 24 hours' duration.

7. TERMINALS AND CELL CONNECTIONS.

(*a*) LARGE SINGLE CELLS (TABLE 1).—The terminals are to be of brass of the knurled nut and screw type (thread 8–32). Spring clips are to be furnished when specified. The terminals must not be obstructed by the cardboard carton or protruding material of the seal.

(*b*) FLASH-LIGHT SINGLE CELLS (TABLE 2).—The brass cap on the carbon rod and the zinc bottom of the cell serve as the terminals.

(*c*) FLASH-LIGHT BATTERIES (TABLE 3).—*Tubular batteries.*—The cells in these batteries are of the flush-top type assembled end to end. The brass cap on carbon rod of the top cell is one terminal, the other terminal being the zinc bottom of the lowest cell.

Flat batteries.—The cells in these batteries are to be assembled side by side with soldered connections. The terminals of the batteries are to be of spring brass, soldered to the cells.

Box batteries.—The cells in these batteries are to be assembled side by side with soldered connections. The terminals of the batteries are to be of spring brass brought out from top of the battery on the same side 2½ inches apart from center to center.

(*d*) Assembled Batteries (Table 4).—The batteries are to have soldered connections between the individual cells. The terminals are to be brought through the top of case or sealing material to binding posts. The polarity of the terminals is to be marked.

(*e*) "B" Batteries for Radio Service (Table 5).—These batteries are to have soldered connections between the individual cells. The two end cells of the series are to be at diagonally opposite corners of the battery. The terminal leads of the battery are to consist of stranded copper conductor equivalent to No. 18 B. & S. guage. The terminal wires are to be rubber-insulated, covered with single cotton braid. The positive lead is to have a red braid and the negative lead a black braid. The leads are to be 6 inches long to within one-half inch. The free ends of the leads shall be bared for a distance of one-half inch and the strands twisted and soldered together. The bared ends are to be insulated before shipment to prevent short circuits. The use of tinned copper conductors for the leads and the use of intermediate taps and the other forms of terminals are optional.

8. VOLTAGE.

The voltage of individual cells shall be not less than the values shown in Table 6 for the corresponding sizes of cells when measured with a voltmeter having a resistance of not less than 100 ohms per volt and having not less than 50 divisions per volt of its scale.

The voltage of batteries of two or more cells shall be not less than the product of the required minimum voltage per cell by the number of cells in the battery when measured with a voltmeter of equal quality having a range that provides at least 25 divisions for the nominal voltage which is to be measured.

TABLE 6.

Size of cell.		Minimum voltage.
Diameter.	Height.	
Inches.	Inches.	
2½	6	1.50
1½	4	1.50
1¼	2⅞	1.50
1¼	2¼	1.50
$\frac{15}{16}$	1$\frac{13}{16}$	1.49
¾	2⅛	1.48
⅝	1⅞	1.47

9. TESTS.

The size and kind of dry cell or the conditions of service will determine the kind of test to be applied. Cells are to be free from leaks during the period of test. The standard temperature for tests is 20° C. The tests ordinarily made are as follows:

(*a*) INTERMITTENT TESTS.—(1) *Light intermittent service.*—Three cells connected in series are discharged through 20-ohms resistance for 10 periods of 4 minutes each at hourly intervals during 6 days per week. On the remaining day every other discharge period is omitted. (There are 65 such discharge periods per week, or a total weekly service of 260 minutes.)

The following readings will be taken:

Initial open-circuit voltage of the battery.

Initial closed-circuit voltage of the battery.

The closed-circuit voltage at the end of a discharge, after 7 days, and every 7 days thereafter until the voltage falls below 3.5 volts, following which the readings are to be taken daily.

The test is considered finished when the working voltage of the battery has fallen below 2.8 volts. The service is reported as the total days on test to this cut-off voltage.

The test should be started so that the readings will be made on a day having 10 discharge periods and, if possible, the voltage reading should be taken at the end of the last discharge period for the day.

(2) *Heavy intermittent service.*—Four cells, connected in series, are discharged through 10⅔-ohms resistance for two periods of 1 hour each daily; the discharge periods are to be not less than 6 hours apart.

The following readings will be taken:

Initial open-circuit voltage of the battery.

Initial closed-circuit or working voltage.

Closed-circuit voltage every other day thereafter at the end of the second period.

The test is considered completed when the closed-circuit voltage at the end of a period of discharge falls below 0.85 volt per cell. The test is reported as the hours of actual discharge to the cut-off voltage.

(3) *Flash-light test.*—The battery is discharged for 5-minute periods, at 24-hour intervals, through a resistance of 4 ohms for each cell in series in the battery. The following readings will be taken:

Initial open-circuit voltage of battery.

Initial closed-circuit voltage of battery.

Closed-circuit voltage of battery twice each week thereafter at the end of a discharge period.

The test is considered finished when the closed-circuit voltage at the end of a period of discharge falls below 0.5 volt per cell.

The result is reported as the total minutes of discharge to the cut-off voltage.

(*b*) Continuous-Discharge Test.—Intermittent tests are to be preferred to continuous tests. "B" batteries for radio service, however, are regularly tested by continuous discharge as specified.

(1) *10-ohm continuous test.*—Cells listed in Table 1 or batteries listed in Table 4 are discharged continuously through a resistance of 10 ohms per cell until the closed-circuit voltage of the battery has fallen below 0.75 volt per cell.

The following readings will be taken:

Initial open-circuit voltage.

Initial closed-circuit voltage.

Readings daily of the closed-circuit voltage thereafter to the cut-off voltage.

The result is reported as the number of hours duration of the discharge.

(2) *2.75-ohm continuous test.*—This test is for the flash-light cells and batteries listed in Tables 2 and 3. These are discharged continuously through a resistance of 2.75 ohms per cell until the closed-circuit voltage of the battery has fallen below 0.50 volt per cell.

The following readings will be taken:

Initial open-circuit voltage.

Initial closed-circuit voltage.

Closed-circuit voltages at half hourly intervals for the larger sizes and 10-minute intervals for the smaller sizes until the voltage drops to 0.55 volt per cell, after which the readings are required twice as often.

The result of this test is reported as the number of minutes duration of the discharge.

(3) *5,000-ohm continuous test.*—This test is for "B" batteries for radio service (Table 5). These are discharged continuously through 5,000 ohms per battery of 15 cells until the closed-circuit voltage of the battery has fallen below 17 volts.

The following readings will be taken:

Initial open-circuit voltage.

Initial closed-circuit voltage.

Closed-circuit voltages twice daily for the small size; similar readings daily for the large size.

The result of this test is reported as number of hours of discharge to the cut-off voltage.

(*c*) Noise Test for "B" Batteries.—A radio head set of not less than 2,000 ohms resistance in series with 20,000 ohms is to be connected to the battery terminals. The battery shall not produce noise in the head set when the battery is jarred.

(*d*) Shelf Tests.—Shelf tests shall consist of keeping the cells on open circuit at an even temperature of approximately 20° C. (68° F.) over a period of time, depending on the size of the cell, during which measurements of voltage and short-circuit current will be made, or tests of electrical capacity, which are designated as delayed service tests in Table 8.

The procedure for making delayed service tests follows the continuous test described above.

10. PERFORMANCE.

TABLE 7.—Intermittent Tests.

Size of cell.		Test.	Minimum required performance.[1]
Diameter.	Height.		
Inches.	Inches.		
2½	6	Heavy intermittent service	40 hours.
1½	4	Light intermittent service	60 days.
2½	6	Light intermittent service	160 days.[2]
⅝	1⅞	Flash light	100 minutes.
¾	2⅛	Flash light	180 minutes.
11/16	1 11/16	Flash light	250 minutes.
1¼	2¼	Flash light	600 minutes.
1¼	2⅞	Flash light	

[1] Within one month from date of manufacture.
[2] Allowance for depreciation after one month, 3 per cent per month.