Bureau of Standards.

DEPARTMENT OF COMMERCE

CIRCULAR

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, Director

No. 79

ELECTRICAL CHARACTERISTICS AND TESTING OF DRY CELLS

ISSUED APRIL 25, 1919

PRICE, 10 CENTS

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

FRONTISPIECE.—*Standard sizes of dry cells referred to in Tables 3 and 4, and in specifications*

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ELECTRICAL CHARACTERISTICS AND TESTING OF DRY CELLS

CONTENTS

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 that are obtainable, to indicate the kinds of service for which they are adapted, and to describe the methods of testing them. In the appendix are given tentative specifications for dry cells which have been drawn by this Bureau in consultation with the principal manufacturers 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 studied and liberal use made of material contained in a number of books.[1] The Bureau has also benefited by the information and experience obtained from the leading manufacturing companies.

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 greater numbers, but are not included in this table.

TABLE 1.—The Production of Dry Cells In the United States [2]

Year	Number	Value
1889	1 946 688	$316 013
1904	4 888 361	513 026
1909	33 988 881	4 583 082
1914	71 092 438	8 719 164

[1] Especial acknowledgment is made of our indebtedness to Primary Batteries, by W. R. Cooper; and Practical Electricity, by W. E. Ayrton and T. Mather.

[2] Bureau of Census, Bull. of Elec. Mach. App. and Sup., p. 13; 1914.

It is probable that the present annual production considerably exceeds a hundred million. 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 permits use of 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 ammomium 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), zinc chloride, and other compounds characteristic of different types of cells. 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 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, and sometimes the bottom of the cell is made of tin plate. For flash-light cells Nos. 5 and 6 gage zinc is commonly used.

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 the can 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 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.

(*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 possibly its state of hydration also.

Up to the beginning of the present war in 1914 most of the high-grade ore was imported from Russia and contained on the average about 85 per cent MnO_2. Since the interruption of this source, the principal importations have come from Brazil, Cuba, India, and Japan. The domestic sources are at present small. It appears that the greater portion of present imports is from Brazil, as indicated in the following table taken from the United States Geological Survey Bulletin 666–C:

TABLE 2.—Imports, in Long Tons, of Manganese Ore

Year	Russia	India	Brazil
1913	124 337	141 587	70 200
1914	52 681	103 583	113 924
1915	....	36 450	268 786
1916	....	51 960	471 837

84318°—19——2

This table, however, represents the total imports of manganese ore, of which the amount used for dry cells is relatively a small part.

Ordinarily, specifications for manganese dioxide call for 85 per cent MnO_2 and less than 1 per cent iron. Since the Russian supply was interrupted, manufacturers have been compelled to use material containing a lower percentage of MnO_2 and much larger percentages of iron. Iron is usually considered detrimental to the cell, but there is a wide variation in opinion as to the amount which is permissible. The effect of copper in solution in amounts of only a few hundredths of 1 per cent is generally conceded to be fatal to the cell.

For small cells, artificially prepared manganese dioxide of a high degree of purity is used to a large extent and it is sometimes mixed with the natural ore for the larger cells.

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 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, but the nature of this filler is kept secret by most of the manufacturers. 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 excape 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.

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 lining of pulpboard usually consisting of sulphite fiber and ground wood is placed in the cell. This serves a double purpose. It is an absorbent for the electrolyte and it serves to separate 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 it. Pulpboard is also put in the bottom of the cell, and sometimes a disk of nonabsorbent pasteboard is added to protect the bottom of the cell from chemical action. Sometimes blotting paper and strawboard are used in lower-grade cells.

This method of construction, which is so common in America, is rarely found in cells of European manufacture. It has the advantage of cheapness in construction, since it requires less handwork, but it is generally recognized that the service capacity of these cells is not equal to that of the cells with bag-type construction (see below) when comparing cells of the same size and shape.

The section of a typical cell of the paper-lined type is shown in Fig. 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 Fig. 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, or manila cord, which is of considerable size in some of the foreign makes of cells. The solution of sal ammoniac and zinc chloride is thickened with flour or other similar materials, and may also contain other ingredients differing with manufacturers and kept secret by them.

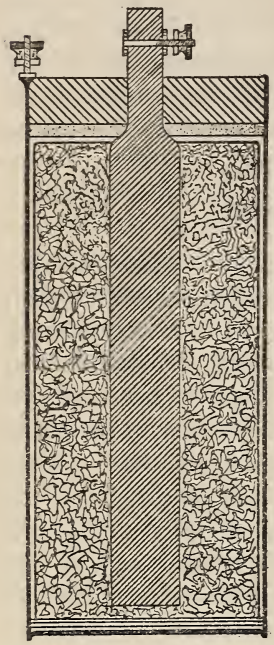

Fig. 1.—*Section of paper-lined cell*

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

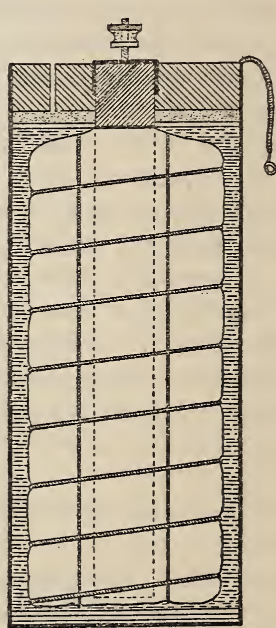

Fig. 2.—*Section of bag-type cell*

The bag-type cell is commonly made in Europe in the large sizes and has good lasting qualities. 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 as made in Europe does not give as large a short-circuit current as the paper-lined cell of equal size made in this country. 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 European bag-type cell would be 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. 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, but others are now being developed. One of these, called a "reserve" cell, closely resembles an ordinary 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.

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, 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. It includes, however, other sizes which are given in Table 3. 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.

TABLE 3.—Sizes of Dry Cells[a] (Cylindrical Form)

Size	Diameter, in inches	Height, in inches	Weight, in pounds	Diameter, in centimeters	Height, in centimeters	Weight, in grams
4	$1\frac{1}{2}$	4	$0\frac{13}{16}$	4	10	240
5	2	5	$1\frac{3}{16}$	5	12.5	540
6	$2\frac{1}{2}$	6	2	6.5	15	900
7	3	7	$3\frac{1}{2}$	7.5	18	1600
8	$3\frac{1}{2}$	8	$5\frac{1}{2}$	9	20	2500

[a] Standard sizes are the Nos. 4, 6, and 8.

Of these five sizes the No. 6 is by far the most common and is made by all manufacturers, except a few who make flash-light batteries exclusively. Next to the No. 6, the No. 8 is the most common of the remaining sizes. The third size is the No. 4, leaving the No. 5 and No. 7 as unusual sizes which 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 to the height about 1.5 cm (5/8 inch), if of the flush-top type, and 2.5 cm (1 inch) for the protruding carbon type. 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 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 7 7/8 inches), but when made into a can for the cell the diameter is frequently somewhat less than the 6.5 cm (2 1/2 inches).

These batteries are usually 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; that is, cells with rectangular or square cross section. When made by the same process of manufacture, these square cells are usually not equal in service capacity to the round cells of the corresponding size. To obviate this difficulty as well as some technical points of their manufacture, these square cells are frequently made of the bag-type construction, in which case their electrical-service capacity is equal to that of the round cells of the same 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 prefer to make the round form of cell. The round form of cell is preferable in the paper-lined construction, because the zinc is free from sharp angles and the corrosion of the zinc is more uniform. There is also less opportunity for the mix to become loose in the round cells and thereby lower the flash point. In general, the square cell will fit into the space occupied by the corresponding size of round cell. The square cells are not a regular product, but can be made in almost any desired size.

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, intermediate cells for general purposes, and telephone or light-service cells. These cells are also put up in the form of batteries which are generally spoken of as multiple and series 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 p. 35), but the telephone cell gave nearly 20 per cent more service than the ignition cell on the telephone test (see p. 36).

(*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, is about 30 amperes on the average, but rarely 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 is 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*) Intermediate 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 either for ignition or telephone service. 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 short-circuit current of these cells is slightly lower than for the ignition cells, the average being about 25 amperes, with the minimum about 20 amperes when the cells are new.

(*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. They will outlast the two classes of cells mentioned above when the use to which they are put does not exhaust them. The open-circuit voltage is the same as for the ignition cells, but the current on short circuit is considerably less, being slightly over 20 amperes on the average, with a minimum of about 16 amperes. It is not always possible for the ordinary purchaser to distinguish between the intermediate and the telephone cells, since the former are often labeled telephone and open-circuit cells, unless he is familiar with the names of the various brands. Cells of this class are usually manufactured in the smaller sizes; that is, Nos. 4, 5, and 6.

(*d*) Multiple and Series 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 cells connected together by soldered connectors. These are usually intended for some special class of service, as, for example, motor-boat ignition, and it is possible to buy these batteries inclosed in waterproof boxes, sometimes of metal, for the various standard ignition systems. The advantages to be derived from these batteries are numerous. They are waterproof; they require a minimum of time and trouble to put in service; they are free from the possibility of loose connections between the cells, impairing the service; 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, the number of rows in parallel, and the size of the individual cells. Such designations, however, are not universal in use or interpretation. Similar small batteries, not waterproofed, are also available for bell ringing, etc.

2. 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 15 or more sizes, differing sometimes by only trifling variations in the dimensions. This may have been due to the various sizes of flash lights put on the market some time ago, but certain sizes are becoming more common, so that now we may regard these as standard. The individual cells are listed in Table 4.

These cells are combined into batteries of various forms and sizes, for which certain diagrammatic figures have been generally adopted. These are shown in Fig. 3. The dimensions and weights of these batteries are given in Table 5. No designation of size can be given, since each manufacturer has his own system of numbering them. For this reason it is often confusing in comparing cells of different makes.

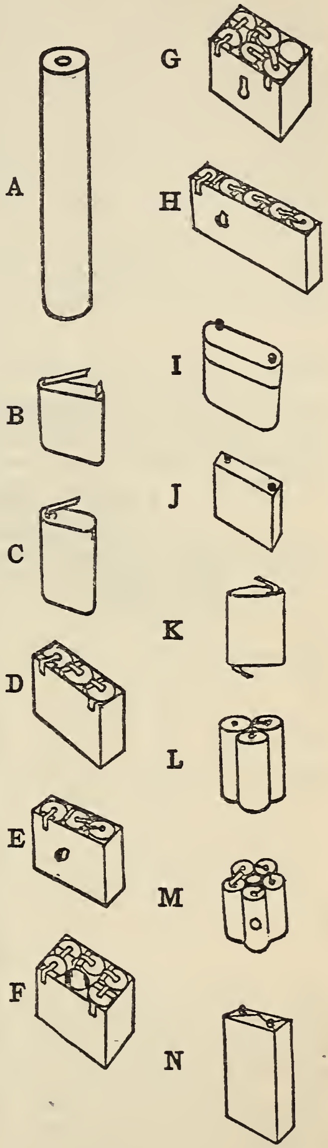

FIG. 3.—*Diagrams of flash-light batteries*

The small cells are subject to more rapid deterioration than the larger sizes when standing on open circuit. Manufacturers usually date the cells either the day of manufacture or the expiration of the guaranty period. This date is often in code. The guarantees are seldom definite, but in view of the deterioration of the cells and the use or abuse to which they may be subjected, these guarantees, when not based on the open-circuit voltage, are perhaps as definite as they can be made.

TABLE 4.—Sizes of Flash-Light Cells[a]

Type No.	Diameter, in inches	Height, in inches	Weight, in ounces	Diameter, in centimeters	Height, in centimeters	Weight, in grams
1	$\frac{9}{16}$	$1\frac{9}{16}$	$\frac{1}{2}$	1.4	4.0	14
2	$\frac{9}{16}$	$1\frac{7}{8}$	$\frac{1}{2}$	1.4	4.8	14
3[b]	$\frac{5}{8}$	$1\frac{7}{8}$	$\frac{3}{4}$	1.6	4.8	21
4	$\frac{3}{4}$	$1\frac{3}{8}$	....	1.9	3.5	....
5[b]	$\frac{3}{4}$	$2\frac{1}{8}$	$1\frac{1}{4}$	1.9	5.4	35
6	$\frac{15}{16}$	$1\frac{1}{2}$	....	2.4	3.8	....
7[b]	$\frac{15}{16}$	$1\frac{13}{16}$	$1\frac{1}{3}$	2.4	4.5	38
8	$\frac{15}{16}$	$2\frac{1}{4}$	....	2.4	5.7	....
9[b]	1	$2\frac{7}{8}$	....	2.5	7.3	....
10	1	$3\frac{1}{2}$	....	2.5	8.9	....
11[b]	$1\frac{1}{4}$	$2\frac{1}{4}$	3	3.2	5.7	85
12[b]	$1\frac{1}{4}$	$2\frac{7}{8}$	$3\frac{1}{2}$	3.2	7.3	100
13	$1\frac{1}{4}$	$3\frac{1}{2}$	....	3.2	8.9	....
14	$1\frac{1}{4}$	4	....	3.2	10.0	....
15	$1\frac{1}{2}$	$2\frac{3}{4}$	....	3.8	7.0	....

[a] This table contains only the principal sizes of flash-light cells, but other sizes differ from these only by trifling dimensions. Six of the most important are designated as standard. In choosing these standard sizes the Bureau has been in consultation with some of the leading manufacturers.

[b] Standard size.

TABLE 5.—Dimensions of Flash-Light Batteries

[Shape designations refer to diagrams in Fig. 3]

Shape of battery	Type of cells	No. of cells	Size over all, in inches			Net weight, in ounces
			Height	Width	Depth	
A	11	3	7	$1\frac{5}{16}$	....	$10\frac{1}{2}$
	12	3	$9\frac{1}{8}$	$1\frac{5}{16}$	....	$13\frac{1}{4}$
	11	5	$11\frac{3}{4}$	$1\frac{5}{16}$	....	17
	11	2	$4\frac{11}{16}$	$1\frac{5}{16}$	....	7
	7	2	$3\frac{3}{4}$	1	....	$3\frac{1}{4}$
	6	3	$4\frac{3}{4}$	1	....	$4\frac{1}{4}$
	8	2	$4\frac{3}{4}$	1	....	4
	8	3	7	1	....	$6\frac{1}{4}$
	2	2	4	$\frac{9}{16}$	....	$\frac{3}{8}$
B	1	2	$1\frac{7}{8}$	$1\frac{1}{8}$	$\frac{9}{16}$	$1\frac{1}{4}$
	5	3	$2\frac{5}{8}$	$2\frac{7}{16}$	$\frac{13}{16}$	$4\frac{1}{2}$
	3	2	$2\frac{1}{4}$	$1\frac{5}{16}$	$\frac{5}{8}$	2
	3	3	$2\frac{1}{4}$	$1\frac{15}{16}$	$\frac{5}{8}$	$2\frac{3}{4}$
C	....	2	$2\frac{1}{2}$	$1\frac{5}{8}$	$\frac{13}{16}$	3
	9	2	$3\frac{7}{16}$	2	1	$6\frac{1}{2}$
D	12	3	3	4	$1\frac{3}{8}$	$13\frac{3}{4}$
E	12	3	3	4	$1\frac{3}{8}$	$13\frac{3}{4}$
F	12	5	3	4	$2\frac{3}{4}$	$23\frac{1}{4}$
G	12	5	3	4	$2\frac{3}{4}$	$23\frac{1}{4}$
H	12	5	3	$6\frac{5}{8}$	$1\frac{1}{2}$	$22\frac{3}{4}$
I	12	3	$3\frac{3}{16}$	4	$1\frac{3}{8}$	14
J	8	3	$2\frac{1}{2}$	$3\frac{1}{8}$	$1\frac{1}{8}$	$6\frac{3}{4}$
K	....	3	3	$2\frac{3}{4}$	$2\frac{1}{2}$	14
L	....	3	3	$2\frac{1}{2}$	....	$13\frac{1}{2}$
M	....	5	3	$3\frac{5}{8}$	....	23
	....	5	3	$3\frac{5}{8}$	....	23
N	....	5	$6\frac{1}{2}$	$3\frac{1}{8}$	$1\frac{1}{2}$	$22\frac{3}{4}$

3. 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 normally 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 6.—Sizes of Desiccated Cells

Brand	Shape	Width or diameter, in inches	Height, in inches	Weight, in pounds	Width or diameter, in centimeters	Height, in centimeters	Weight, in grams
Reserve	Round	$1\frac{1}{2}$	4	$\frac{1}{2}$	4	10	185
Do	do	$2\frac{1}{2}$	6	2	6.5	15	908
Do	Oval	$2\frac{1}{4}\times 1\frac{3}{16}$	4	$\frac{1}{2}$	5.7×3	10	246
Addwater	Square	$2\frac{11}{16}$	$6\frac{1}{2}$	3	7	16.5	1362
Do	Round	$2\frac{1}{2}$	6	....	6.5	15	....
Waterlife	do	$2\frac{1}{2}$	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.

4. 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 9/10 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.

5. 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 (¾ inch) 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 wireless apparatus.

Another manufacturer has made a larger size of silver-chloride dry cell. These are incased in hard-rubber cylinders with screwed-on top so that the cell may be opened and recharged when necessary. To relieve the pressure due to the formation of gas during the action of the cell, these are provided with a small rubber nipple on the top of the cell. The cells are 5 cm (2 inches) in diameter and 10.5 cm (4⅛ inches) high, to which the terminals and nipple add about 2 cm (¾ inch). These cells are intended for use in an upright position, but may be inverted without spilling any liquid. The zinc element is heavily amalgamated. The open-circuit voltage is about 1 volt per cell, and the maximum current which they can deliver is about 2.5 amperes. When the cell has stood on open circuit for some time, both the voltage and maximum current are lower than the above figures. Both rise after some current has been drawn from the cell. This is characteristic of both kinds of silver-chloride cells.

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:

$$E' = IR \qquad (1)$$

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:

$$E - E' = Ib \qquad (2)$$

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

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

$$E = IR + Ib$$

or

$$I = \frac{E}{R+b} \qquad (3)$$

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 $R = 0$:

$$I = \frac{E}{b} \qquad (4)$$

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 energy 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

$$(E-E')I=P_1 \qquad (5)$$

Outside the cell, it is

$$E'I=P_2 \qquad (6)$$

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

$$P=P_1+P_2=I^2b+I^2R \qquad (7)$$

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 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. This is because cells giving the largest short-circuit currents often, but not necessarily, deteriorate the most rapidly, and are therefore of service only for heavy duty which will exhaust them before their usefulness is impaired by the deterioration when standing on open circuit. The following

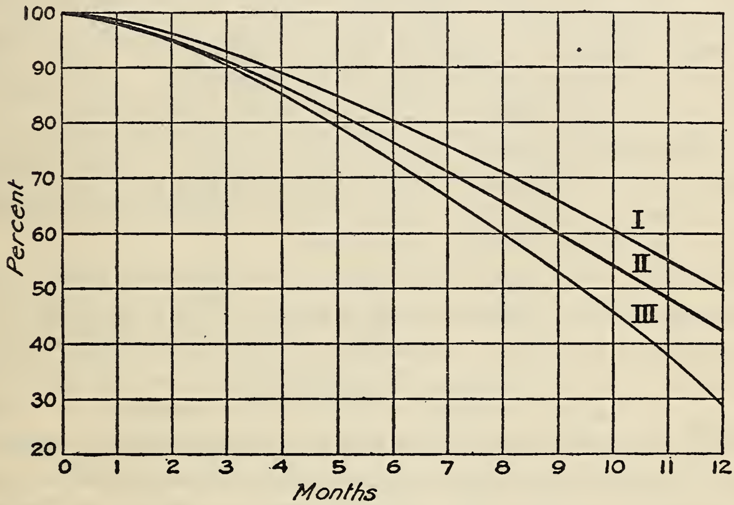

FIG. 4.—*Deterioration of dry cells on open circuit*

Curves show Hambuechen's values for short-circuit current during 12 months expressed as percentages of the initial short-circuit current. Curve *I* for 20-ampere cells; curve *II* for 25-ampere cells; curve *III* for 30-ampere cells.

curves (Fig. 4), taken from a paper by Hambuechen,[5] represent the relative deterioration of cells of differing short-circuit currents which were on the market a few years ago.

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.

[5] Trans. Am. Electrochem. Soc., 21, p. 300; 1912.

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 in not to be commended, since 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 on page 7. 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; in some cases reaching hundreds of ohms.

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, Fig. 5—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 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.

FIG. 5.—*Cells connected in series*

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 cell which will give 40 hours' service under normal conditions will not generally give 20 hours' service under twice the load. It may not give more than 10 hours. (See Table 10.) 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 obtained from one of the manufacturing companies is given in Table 7.

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. Fig. 6 shows cells connected in parallel.

When more than three cells are involved in a series and parallel connection, there is a choice of arrangement. The cells may be arranged in several rows connected in series and then these rows connected in parallel (Fig. 7), or they may be arranged in parallel groups which are then put in series (Fig. 8).

TABLE 7.—Current Drains for Economical Use of Dry Cells

Duration of daily discharge, in hours	Maximum drain on each row of cells in series, in amperes
16–24	0. 10
8–16	. 15
4– 8	. 25
2– 4	. 50
1– 2	. 75
1/2– 1	1. 00
1/4–1/2	1. 50
1/6–1/4	2. 00
Few moments	10–15

Mathematically, the result is the same in either case. The voltage of the battery as shown in both figures is five times the

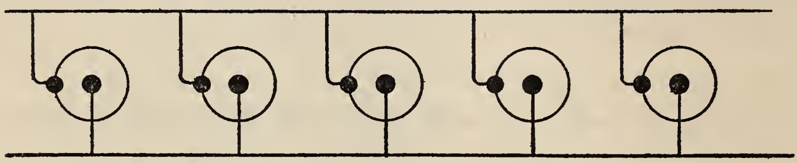

FIG. 6.—*Cells connected in parallel*

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

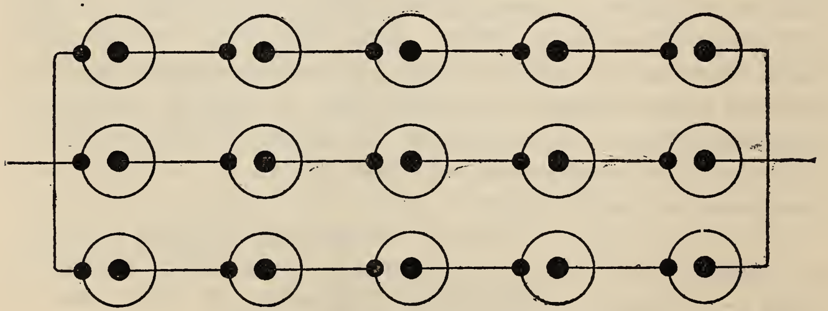

FIG. 7.—*Parallel of series-connected cells*

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, Fig. 7, from service, reducing the battery to practically two rows. In the second case, Fig. 8, 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.

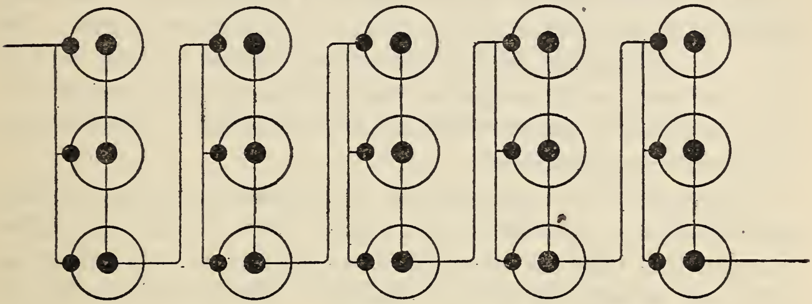

FIG. 8.—*Series of parallel-connected cells*

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 on page 21.

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

Dry cells are affected by changes in temperature. Generally speaking, temperatures above 25° C (77° F), are detrimental. The effect of temperature on the electromotive force is small, and for most purposes can be neglected, but in other respects temperature changes produce effects that are more marked. These will be discussed in greater detail.

(*a*) Effects 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 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 the most convenient method of estimating the depreciation. In Table 8 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.[6] 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.

TABLE 8.—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

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

(*b*) Effects of Temperature on Short-Circuit Current.—Between 10° C and 80° C (50° F and 176° F) the short-circuit current increases by approximately 1 ampere for each 10° C (18° F) rise. At the lower temperatures it is somewhat greater than this and at the higher temperatures somewhat less. Cells which are frozen may show only small currents, but, according to Ordway,[7] they may be thawed out and become normal. If, however, the electrolyte becomes entirely solidified, the voltage and current are reduced to zero, and it is not certain whether they can become normal again after being thawed out.

(*c*) Effect of Temperature on Service Capacity.—For heavy service a moderately high temperature is desirable, but for light service a low temperature is necessary. The data of Table 9 are taken from Pritz,[8] showing the hours of continuous service from cells of the same manufacturer when discharged through various resistances until the closed-circuit voltage had fallen to 0.5 volt. The cells used for these measurements were probably the 6.5 by 15 cm (2½ by 6 inch) size. Exactly the same figures for the 2-ohm and 32-ohm tests were also given by Ordway [9] 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, and that 0° C (32° F) is the best for the low rates of discharge on continuous service. 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 9 shows 160 hours' service at 50° C when discharging through 4 ohms; but this is less than seven days. Table 8 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 9. The obvious remedy is to keep the temperature lower.

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[7] Trans. Am. Electrochem. Soc., **17**, p. 357; 1910.
[8] Idem, **19**, p. 39; 1911.
[9] Idem, **17**, p. 358; 1910.

TABLE 9.—Hours of Service of Dry Cells Discharging at Various Rates and Temperatures

Temperature	Resistance of external circuit in ohms					
	2	4	8	16	32	40
0° C (32° F)	40	80	270	560	1800	2550
25° C (77° F)	60	94	260	700	1550	1630
50° C (122° F)	70	160	350	650	1250	1420
75° C (167° F)	65	158	315	615	1390	1510

5. CAPACITY OF DRY CELLS

Very little information that is exact is available on the capacity of dry cells. It is impossible to state their ampere-hour capacity, as is done for storage batteries, because so much depends on the condition of the cells, the way they are made, the way they are used, and the arbitrary choice of an end point.

Under specified conditions, however, some information is available for the most common size of dry cell (6.5 by 15 cm) or (2½ by 6 inches). Since dry cells are mostly used on circuits of which the resistance is constant or nearly so, the results are usually expressed as the number of hours or days that the cell will continue to give service on this circuit; that is, the number of hours until the impressed voltage has fallen to some value such that the current flowing is insufficient. It is customary therefore to express the capacity of dry cells as hours of discharge to certain arbitrary values of the voltage. Table 10 taken from Ordway's[10] paper shows the number of hours of continuous service at various discharge rates to various end points.

TABLE 10.—Hours of Service to Various Working Voltages for Various Discharge Rates

End point, in volts	Resistance of external circuit in ohms						
	2	4	8	16	24	32	40
1.2	4.3	10	39	142	260	414	549
1.0	9.3	35	94	296	548	889	1148
0.8	16.5	51	143	414	751	1078	1550
0.6	28.2	76	225	954	1240	1600	1763
0.4	55	207	648	1197	1711	2280	2040
0.2	160	450	882	1318	1914	2626	3140

[10] Trans. Am. Electrochem. Soc., 17, p. 352; 1910.

This table shows clearly the gain in hours of service that is to be obtained by making the current drain light. For the end point 1.2 volts discharging through 2 ohms, 4.3 hours were obtained, but at one-fourth this current the cell gave 8 times the service and at one-twentieth this current, 125 times the service.

When the cell is used intermittently, the actual service obtained to a given end voltage is ordinarily greater than when it is used continuously. Ordway [11] has shown that at light loads the deterioration of the cell on open circuit becomes a factor, so that the cell may be more efficient in the later stages of its discharge when the discharge is continuous.

In using Table 10 it must not be assumed that when the voltage has fallen to one-half its initial value that the cell is 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.

Ordway gives in connection with the material which we have used in Table 10 a similar table expressing the capacity of the cells in watt-hours. His figures are given in Table 11 below for No. 6 cells. It is seen that to obtain the same amount of energy at the higher rates of discharge it is necessary to carry the voltage to a lower point than is the case for smaller rates of discharge.

TABLE 11.—Energy Delivered by Dry Cell When Discharging Continuously Through Various Resistances to Various End Points

[Expressed as watt-hours]

End point, in volts	Resistance of external circuit, in ohms						
	2	4	8	16	24	32	40
1.2	3.7	4.3	8.1	15.2	18.8	21.7	23.8
1.0	6.7	13.0	16.5	26.9	33.4	39.8	42.0
0.8	9.7	16.3	21.5	32.8	40.3	44.6	50.6
0.6	12.5	19.4	26.6	48.9	49.5	52.7	53.2
0.4	15.4	27.3	39.1	52.6	54.3	58.2	54.8
0.2	19.8	32.6	41.5	53.3	55.2	59.3	57.1

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

[11] Trans. Am. Electrochem. Soc., 17, p. 354; 1910.

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 on page 34.

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 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 10 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.

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, and, with certain restrictions, will indicate the age and condition of the cells. Tests for dry cells were described in considerable detail by Ordway [12] in this country and Melsom [13] in England.

A committee of the American Electrochemical Society was appointed to investigate the subject. They made a report [14] in 1912 embodying most of the tests previously described by Ordway.

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[12] Trans. Am. Electrochem. Soc., 17, p. 341; 1910.
[13] Trans. Faraday Soc., 8, p. 1; 1912.
[14] Trans. Am. Electrochem. Soc., 21, p. 275; 1912.

The tests in general use to-day are essentially the same as were recommended at that time. Some differences, however, have been generally accepted, but these are differences of detail rather than principle. There are no tests that have been standardized and universally adopted.

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 divisions may 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 1.65 volts. Higher voltages are sometimes found, but do not indicate superiority of the cell. Lower voltages [15] than 1.45 volts may indicate deterioration due to age or short circuit or some other serious defect. The value of the open-circuit voltage test considered alone is small. It gives no indication of service capacity and it changes by only a small amount relatively during the life of the cell. One cell under observation at the Bureau for 16 years still shows 1.25 volts when measured on the potentiometer, although its resistance has increased so that a voltmeter measurement such as is described above shows only 0.30 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 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.

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[15] Report of committee on dry-cell tests. Trans. Am. Electrochem. Soc., **21**, p. 278; 1912.

The value of this easily made test lies in its indication of the condition of the cell as compared with the normal value of cells of the same manufacture and brand. 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. This test gives no indication of the service capacity of different brands of cell as is shown in Fig. 9 taken from a paper by Pritz [16] in which the short-circuit current of eight different brands is compared with the service capacity of the same cells.

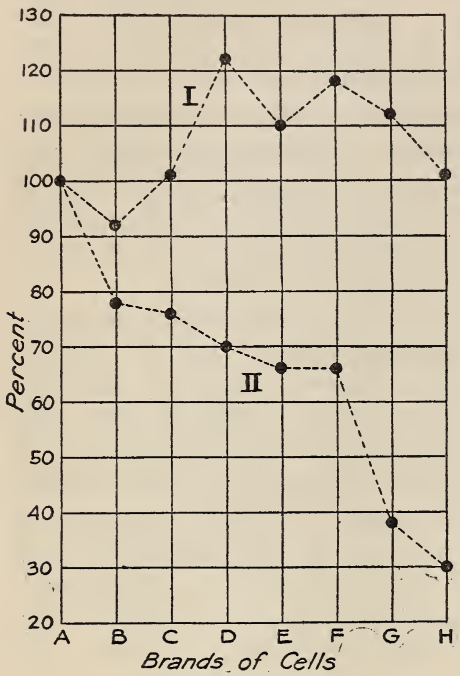

FIG. 9.—*Relative short-circuit current and service capacity of eight brands of cells. (Observations by Pritz)*

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, at least for heavy drains.

The decrease in service capacity does not, however, follow the decrease in short-circuit current. In Fig. 10 are given comparative 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 ignition 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 telephone test on these cells at

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

the same time. In this case the results follow the short-circuit deterioration more closely. The data for these curves has been obtained from one of the manufacturing companies.

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. They are of three kinds—one representing heavy service and generally called the ignition test, the second repre-

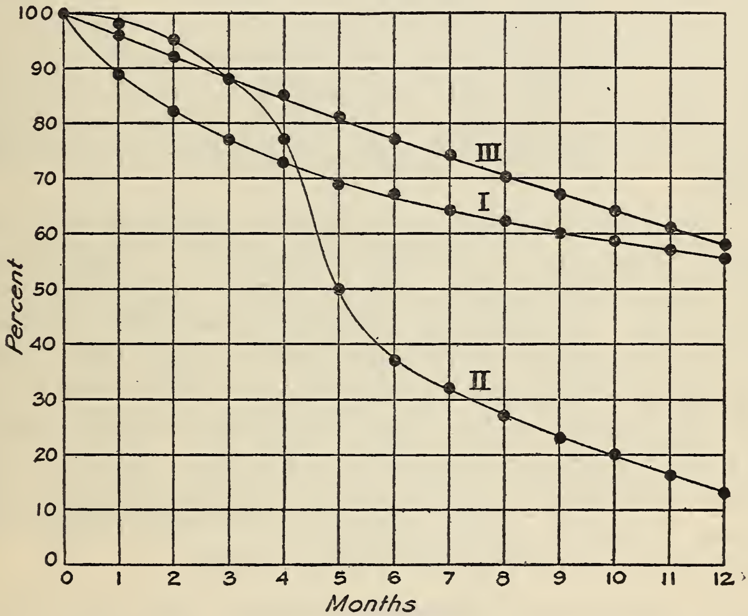

Fig. 10.—*Relation between deterioration in short-circuit current and service capacity for cells stored for various periods of time on open circuit*

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

senting light service and called the telephone test, and the third for flash-light batteries.

(*a*) Ignition Test.—Six cells connected in series to a circuit of 16 ohms are discharged for two periods of one hour each per day, the periods being 11 hours apart. The test is considered complete when the impulse current through 0.5 ohm at the end of a period of discharge falls below 4 amperes. This test has been somewhat modified in recent years by some manufacturers to permit using a smaller number of cells in the group. In such cases the resistance of the circuit and the coil for measuring the impulse current are reduced proportionately. The results of the test are expressed as the number of hours actual discharge to the end point.

(*b*) Telephone Test.—This test, as described by the committee mentioned above, consisted of discharging three cells connected in series through 20 ohms for two-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 has been modified and supplanted by the so-called A. T. and T. telephone test which is as follows: Three cells connected in series are discharged through 20 ohms for 10 periods of four minutes each in 10 consecutive hours of six 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.

(*c*) Flash-Light Test.—The battery is discharged for a five-minute period once a day through a resistance of 4 ohms for each cell in series in the battery, until the working voltage falls to 0.75 volt per cell. The results are expressed as the number of minutes of actual discharge. At the present time the end point is generally taken as 0.50 volt per cell on closed circuit instead of 0.75 volt because the modern lamps are usable to a lower voltage. 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 definite 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, possibly because so many of the European cells are of the bag-type construction with a very thick layer of paste which reduces the open-circuit deterioration.

(*a*) Large-Size Cells.—For the No. 6 and larger sizes of cell, a satisfactory continuous test is to discharge the cell through a fixed resistance of 10 ohms until the voltage has fallen to some arbitrary figure which may conveniently be taken as 0.75 volt per cell. Continuous tests at large currents give very little information of value, but at small currents afford information about the uniformity of manufacture. Sometimes the continuous tests are modified by allowing a period of rest during part of the day. This, however, does not sufficiently approach the intermittent use in actual service to be of much value.

(*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 [17] 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. Burgess [18] has recommended continuous discharge of flash-light cells for eight hours per day through 4 ohms per cell. 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. It is commonly found that flash lamps burning at their rated voltages take 0.30 to 0.35 ampere. Some lamps of low efficiency are on the market as well as some of very high efficiency. The latter will 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.

5. SHELF TEST

This test 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. No definite end point is taken, but the results are expressed as per cent drop in amperage for certain periods of time. This is an important test, and should be made at as nearly a constant temperature as possible.

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[17] Trans. Am. Electrochem. Soc., 30, p. 267; 1916.
[18] Idem, p. 257; 1916.

6. OTHER TESTS

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

APPENDIX A

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 be easily portable.

(3) To have a nonspillable electrolyte even when the cell is used in a horizontal position.

(4) No gases or other products of chemical or electrochemical reactions to be emitted in appreciable quantities (see Note 1, p. 44) during the useful life of the cell.

(*b*) Reserve cells and other similar cells to which water must be added before the cell is put into service are included under these specifications. They must fulfill the requirements stated above for dry cells, with the exception that they are for use in an upright position, unless otherwise specified for special uses.

2. TYPES OF CELLS

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

(*a*) Ignition and other heavy service cells.

(*b*) Intermediate cells for light ignition and telephone service.

(*c*) Telephone and other long-service cells.

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

(*e*) Multiple and series batteries, exclusive of class (*d*).

(*f*) Reserve or desiccated cells and other similar cells to which water must be added.

3. SIZES OF CELLS

(*a*) Standard Sizes, Ignition, Telephone, and Similar Cells, Cylindrical Form:

Diameter, in inches	Height, in inches	Diameter, in centimeters	Height, in centimeters
$1\frac{1}{2}$	4	4	10
$2\frac{1}{2}$	6	6.5	15
$3\frac{1}{2}$	8	9	20

These dimensions are for the zinc container of the cell and are to be measured on the cell without the carton. Deviations must not exceed $\frac{1}{16}$ inch from the dimensions as given in inches. These cells may be either of the protruding carbon type or of the flush-top type unless one of these is specified. Protruding carbons must not add more than 2.5 cm (1 inch) to the height of the cells as given above. Binding posts on the flush-top cells must not add more than 1.5 cm (⅝ inch) to the height of the cells as given above.

(*b*) Standard Sizes, Flash-Light and Miniature Cells, Cylindrical Form:

Diameter, in inches	Height, in inches	Diameter, in centimeters	Height, in centimeters
$\frac{5}{8}$	$1\frac{7}{8}$	1.6	4.8
$\frac{3}{4}$	$2\frac{1}{8}$	1.9	5.4
$\frac{15}{16}$	$1\frac{13}{16}$	2.4	4.5
1	$2\frac{7}{8}$	2.5	7.3
$1\frac{1}{4}$	$2\frac{1}{4}$	3.2	5.7
$1\frac{1}{4}$	$2\frac{7}{8}$	3.2	7.3

Deviations from these dimensions, as given in inches, must not exceed $\frac{1}{16}$ inch in height or $\frac{1}{32}$ inch in diameter.

(*c*) Flash-Light Batteries, Regular Sizes.—These batteries consist of cells of standard sizes as given above. They are listed in the following table. Deviations from these dimensions, as given in inches, must not exceed ⅛ inch in height or $\frac{1}{32}$ inch in diameter for tubular batteries; nor $\frac{1}{16}$ inch in height or $\frac{1}{32}$ inch in width and depth for flat batteries.

Kind	Number of cells	Size of cells				Dimensions of battery					
		Diameter, in inches	Height, in inches	Diameter, in centimeters	Height, in centimeters	Width or diameter, in inches	Height, in inches	Depth, in inches	Width or diameter, in centimeters	Height, in centimeters	Depth, in centimeters
Tubular	3	$1\frac{1}{4}$	$2\frac{7}{8}$	3.2	7.3	$1\frac{5}{16}$	$9\frac{1}{8}$	....	3.3	23.2	....
Do	3	$1\frac{1}{4}$	$2\frac{1}{4}$	3.2	5.7	$1\frac{5}{16}$	7	....	3.3	18	....
Do	5	$1\frac{1}{4}$	$2\frac{1}{4}$	3.2	5.7	$1\frac{5}{16}$	$11\frac{3}{4}$	....	3.3	30	....
Do	2	$1\frac{1}{4}$	$2\frac{1}{4}$	3.2	5.7	$1\frac{5}{16}$	$4\frac{11}{16}$	....	3.3	11.9	....
Do	2	$\frac{15}{16}$	$1\frac{13}{16}$	2.4	4.5	1	$3\frac{3}{4}$	....	2.5	9.5	....
Flat	2	1	$2\frac{7}{8}$	2.5	7.3	2	$3\frac{7}{16}$	1	5.1	8.7	2.5
Do	3	$\frac{3}{4}$	$2\frac{1}{8}$	1.9	5.4	$2\frac{7}{16}$	$2\frac{5}{8}$	$\frac{13}{16}$	6.2	6.7	2.1
Do	3	$\frac{5}{8}$	$1\frac{7}{8}$	1.6	4.8	$1\frac{15}{16}$	$2\frac{1}{4}$	$\frac{5}{8}$	4.9	5.7	1.6
Do	2	$\frac{5}{8}$	$1\frac{7}{8}$	1.6	4.8	$1\frac{5}{16}$	$2\frac{1}{4}$	$\frac{5}{8}$	3.3	5.7	1.6

(*d*) Multiple and Series Batteries.—No dimensions for these are given, but it is understood that the individual cells in these batteries conform to these specifications, with the exception that the cartons may be omitted, suitable insulation between the cells being provided.

(*e*) Reserve or Desiccated Cells.—Dimensions for these are not standardized.

4. THE CARTON

The individual cells, except those in multiple and series batteries and flash-light batteries and except those permanently inclosed in waterproof container, shall be inclosed in a neatly made and close-fitting cardboard carton. 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. (This may be put on by rubber stamp or steel die if legible. The date must not be in code.)

The name of the manufacturer or such trade-mark as will identify the manufacturer. In the latter case the legend may read "Manufactured for (name of dealer)."

A clear and concise statement of the use for which the battery is intended and any necessary directions as in the case of reserve cells.

Multiple and series batteries and flash-light and similar batteries containing two or more cells are to be inclosed in a suitable case sufficiently strong, according to the size of the battery, to permit the battery to be handled in ordinary use without the battery falling apart or the cells dropping out. Large batteries, such as those designed for motor-boat ignition, are to be in suitable cases and waterproofed. (See Note 2, p. 44.)

5. THE TERMINALS

The terminals are to be of brass, securely fastened to the zinc and carbon elements. For ordinary purposes they may be of the familiar knurled nut and screw type. When required, terminals of spring clips, screw sockets, lock nuts, or other devices are to be furnished, as may be specified, provided that the particular terminal to be furnished has been previously approved. The terminals must be easily accessible and must not be obstructed by the cardboard carton or protruding material of the seal. Terminals for flash-light and miniature batteries shall be of the following kinds:

(*a*) Tubular Batteries.—The cells in these batteries are to be of the flush-top type with brass caps on carbon rod, the other terminal being the zinc bottom of the cell. The brass cap is to be securely fastened to the carbon rod, and the bottom of the cell is to be free from an oxide film or anything which would impair the electrical contact.

(*b*) Case Batteries.—The cells in these batteries are to be connected by securely soldered connections. The terminals of the batteries are to be of spring brass, securely soldered to the cells. They shall be of such size and shape as to make satisfactory contact with the lamp circuit in the flash-light cases for which they are intended.

(*c*) Multiple and series batteries are to have permanently soldered connections between the individual cells and the terminal connections to be brought through the case or sealing material to binding posts and marked as to polarity.

6. VOLTAGE

The voltage of each large cell upon delivery by the contractor shall be not less than 1.48 volts when measured with a voltmeter having a resistance of not less than 100 ohms per volt of its scale. Flash-light cells of 1¼ by 2¼ inches and smaller sizes must be measured with a voltmeter of much higher resistance, or, if measured by a voltmeter of 100 ohms per volt, the minimum voltage may be 1.45 volts. In the case of reserve cells and other similar cells to which water is added the voltage is to be measured after compliance with the directions for filling the cells.

Multiple and series batteries and all other batteries consisting of two or more cells are to be measured as in the case of individual cells. The minimum voltage per cell of those in series is to be same as above.

7. SHORT-CIRCUIT CURRENT

The short-circuit current or amperage may be measured by a deadbeat ammeter whose resistance, including the leads, is equal to 0.01 ohm. The amperage of the cell will be relied on as an indication of the condition of the cell only in such cases as a fair average value for the size and brand of cell under test shall be known. The maximum amperage of reserve cells must not be measured less than 24 hours after filling the cells with water or in accordance with the directions on the carton of the cell.

8. ZINC CAN

The zinc can serving as a container for the cell and as the anode is to be made from smooth sheet zinc, free from flaws, blisters, and cracks. The thickness of the zinc is to be in accordance with the best commercial practice. The zinc is to be of good mechanical properties and high tensile strength. The zinc must not be subject to splitting under the ordinary conditions of use or testing. The zinc can is to be lap-seam soldered, preferably with a cupped zinc bottom soldered into place. Pressed-zinc cans without seams may be used when of good mechanical qualities.

9. THE CARBON PLATE OR ROD

The carbon rod is to be of high-conductivity carbon and is to be of such size and shape as the manufacturer may deem sufficient to make the cell conform to these specifications. The rod must make good mechanical and electrical connection with the mixture so that moderate jars will not change the short-circuit current by more than 10 per cent.

10. THE MIXTURE

The mixture shall conform to the maker's standard formula for the particular brand of cell considered. The satisfactoriness of the mixture will be judged by the results of the tests of the cell performance and, in some cases, by chemical or other examination. When it may seem necessary, manufacturers will be requested to furnish samples of materials of this or other parts of the cell.

11. THE LINING

The lining of all cells, except the bag-type cells, is to be of pulpboard or strawboard, or blotting paper, free from deleterious materials, and a good absorbent. It must be free from tears and other mechanical defects, so that none of the mixture can come in contact with the zinc can.

12. BAG-TYPE CELLS

All flash-light and miniature cells and all other cells which are so specified are to be of the bag-type construction. The depolarizing mixture is to be inclosed in suitable cloth of sufficiently small mesh so that none of the mixture may escape. The satisfactoriness of cells of this type of construction will be judged by the performance of the cells under test and by such examination of the structure or materials as may be necessary.

13. THE SEAL

The seal is to be of good mechanical and insulating properties. It must make a satisfactory joint with the zinc and the carbon rod and be smooth and neat in appearance, without protrusions to obstruct the use of the terminals. It must be sufficiently hard not to flow in hot weather and not become brittle enough to crack in cold weather under the ordinary conditions of use or transportation.

14. TESTS

The following tests are in common use and are recognized by the manufacturers. It is desired to obtain simpler and better tests, but until that can be done these tests are recommended. In each case the size and kind of dry cell will determine the kind of test as described in this circular to be applied. Unusual conditions of service may make it desirable to use some other test in special cases. The standard temperature for tests is 20° C.

(*a*) Intermittent Tests—(1) *Ignition Test.*—This ignition test gives results which are similar to the results obtained by the standard ignition test recommended by the American Electro-Chemical Society Committee (Transactions, vol. 21, p. 275). Discharge four cells connected in series through 10⅔ ohms resistance for two periods of one hour each per day six days per week. The first and last hour of the working day are used for this test.

The following readings are taken:

The initial open-circuit voltage and short-circuit current of the battery.

The initial closed-circuit or working voltage and the initial impulse which the battery is capable of forcing through a one-third ohm coil connected in series with an ammeter and in parallel with the 10⅔ ohm coil. (The combined resistance of the coil and ammeter are best adjusted to one-third of an ohm.)

Current through the one-third ohm coil at the end of the first period of closure and twice a week thereafter at the end of the second of the two daily periods.

The test is considered completed when the impulse current at the end of a period falls below 4 amperes. The test is reported as the hours of actual discharge to the 4-ampere value of the impulse current.

(2) *Telephone Test.*—The American Telephone & Telegraph Co.'s telephone test, called the "A. T. & T. test," is made as follows:

Three cells connected in series are discharged through 20 ohms resistance for 10 periods of 4 minutes each on 10 consecutive hours of 6 days per week. On the seventh day every other period is omitted, making only 5 four-minute periods on this day. There are thus 65 such periods per week or a total weekly period of service of 260 minutes.

The following readings are taken:

Initial open-circuit voltage of the battery.

Initial short-circuit current of the battery.

Inital closed-circuit voltage of the battery.

The closed-circuit voltage at the end of a discharge, after 7 days, 14 days, and every 14 days thereafter.

These readings should be taken as near as possible to the last discharge of the day.

The readings are discontinued and the test is considered finished when the working voltage of the battery, under the specified conditions, has fallen below 2.8 volts. The service is reported as the total days on test to this point.

(3) *Flash-Light Tests.*—The individual cells of a flash-light battery are to be connected in series by soldered connections before beginning the test. The battery is to be discharged for five-minute periods every 24 hours through a resistence of 4 ohms for each cell in series in the battery. Measurements of the terminal voltage of the batteries at the end of the periods of discharge will be made at suitable intervals until the potential difference of the battery has fallen to 0.5 volt per cell of those in series. The results will be reported as the total minutes of discharge to this end point. If desirable, the duration of discharge to a close-circuit terminal voltage of 0.75 volt per cell may also be reported.

(*b*) Shelf Tests.—Shelf tests shall consist of keeping the cells on open circuit at an even temperature of approximately 20° C over a considerable period of time during which measurements of voltage and short-circuit current will be made or tests of electrical capacity made after certain periods of time. The duration of the test and the character of the report will depend upon the object of the test.

(*c*) Continuous-Discharge Tests.—Continuous-discharge tests will be made when time is not available for an intermittent test or when the samples are insufficient in number, or for other reasons.

(1) *Large Cells.*—Large cells will be discharged continuously through a resistance of 10 ohms for each cell until the terminal voltage of the cell has fallen to 0.75 volt. The result will be reported as the number of hours' duration of the discharge to 0.75 volt.

(2) *Flash-Light Cells.*—The cells of each battery will be connected by soldered connections and discharged continuously through a resistance of 2.75 ohms per cell for each cell in series. The terminal voltage will be measured at intervals until the value 0.50 volt per cell is reached. The result will be expressed as the number of minutes' duration of the discharge to this voltage.

(3) *Other Tests of Continuous Discharge.*—These will be made as special tests when the particular requirements of service make it necessary to do so.

(*d*) Examination of Structure.—The examination of the cells will be made as may be necessary to ascertain the quality of the workmanship and the compliance with these specifications or with samples previously submitted.

15. PERFORMANCE

Unless otherwise specified, cells for ignition and other heavy service will be considered as ignition cells and given the ignition test. Cells for telephone and other light service will be designated as telephone cells and given the telephone test. Flash-light cells will be given the flash-light test. Continuous-discharge tests are auxiliary or substitute tests and may be used when time or facilities for the special tests are wanting. The performance required of the various sizes and types of cells when tested in accordance with the methods of paragraph 14 is as follows (for metric size see pp. 14 and 18):

Cell		Test	Minimum performance required
Diameter in inches	Height in inches		
$2\frac{1}{2}$	6	Ignition	34 hours of discharge.
$3\frac{1}{2}$	8	.....do	105 hours of discharge.
$1\frac{1}{2}$	4	Telephone	30 days of service.
$2\frac{1}{2}$	6	.....do	140 days of service.
$3\frac{1}{2}$	8	.....do	280 days of service.
$1\frac{1}{2}$	4	10 ohms, continuous	
$2\frac{1}{2}$	6	.....do	180 hours of discharge.
$3\frac{1}{2}$	8	.....do	
$\frac{5}{8}$	$1\frac{7}{8}$	Flash light	50 minutes of discharge.
$\frac{3}{4}$	$2\frac{1}{8}$	.....do	150 minutes of discharge.
$\frac{15}{16}$	$1\frac{13}{16}$	.....do	
1	$2\frac{7}{8}$	.....do	
$1\frac{1}{4}$	$2\frac{1}{4}$	.....do	600 minutes of discharge.
$1\frac{1}{4}$	$2\frac{7}{8}$	.....do	
$\frac{5}{8}$	$1\frac{7}{8}$	2.75 ohms, continuous	45 minutes of discharge.
$\frac{3}{4}$	$2\frac{1}{8}$	.....do	140 minutes of discharge.
$1\frac{5}{16}$	$1\frac{13}{16}$	.....do	85 minutes of discharge.
1	$2\frac{7}{8}$	.....do	260 minutes of discharge.
$1\frac{1}{4}$	$2\frac{1}{4}$	.....do	425 minutes of discharge.
$1\frac{1}{4}$	$2\frac{7}{8}$	.....do	600 minutes of discharge.

NOTE 1.—The cells are to be free from leaks during the useful life of the cell or while on test under normal conditions. No gases or fumes in sufficient quantities to be noticed by an observer in the open room are to be emitted.

NOTE 2.—The suitability of the cases for multiple and series batteries will be judged by the service for which they are intended. The following points will be especially noted: (*a*) Ruggedness of the battery; (*b*) waterproof qualities; (*c*) insulation between the cells; (*d*) electrical connections.

WASHINGTON, September 4, 1918.