American Railway Signaling Principles and Practices

CHAPTER V

BATTERIES

Published by the Signal Section, A. A. R.
30 Vesey Street, New York 7, N. Y.

REVISED JUNE 1948

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PUBLISHED BY
ASSOCIATION OF AMERICAN RAILROADS, SIGNAL SECTION
30 VESEY STREET, NEW YORK 7, N. Y.

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CHAPTER V

BATTERIES

Batteries are to the signal system what engines are to trains. They supply the power or energy to operate the direct current apparatus.

While there are many different types and makes of batteries, they are divided into two general classes, primary and secondary, which will be treated separately. Each class is divided into various types. The three principal types of primary batteries used are copper-oxide caustic soda, carbon caustic soda, and dry. The first two types use a solution of caustic soda as an electrolyte. The secondary batteries are lead acid and nickel-iron-alkaline. The service which the battery is called on to perform usually determines which class and type is to be used. Ordinarily, primary cells are used for direct operation of signals where the ampere-hour consumption is relatively small, or where line power is not commercially practicable. Where the ampere-hour load is large and where commercial power is available the primary cells are widely used for stand-by. The secondary (or storage) cell is generally used where charging facilities are available.

Methods of connecting.

There are four general arrangements for connecting and operating batteries: namely, series, multiple, multiple-series and series-multiple.

Series. The series connection is generally used with storage cells and where a single set of primary cells is used for other than track circuit energy. This method of connection is used where more than the voltage of one cell is required for the circuit. Series connection is illustrated in Fig. 1 and consists of the positive terminal of one cell being connected to the negative terminal of the next.

Fig. 1.

Multiple. The multiple connection is used largely on track circuits where energy is furnished by primary cells and where the voltage of one cell is sufficient but where the capacity of more than one cell is desired. A broken jar or connection will not prevent the battery from functioning as the remaining cells are still connected to the circuit. Multiple connection is illustrated in Fig. 2 and consists of connecting the positive terminals to one side of the circuit and the negative terminals to the other side.

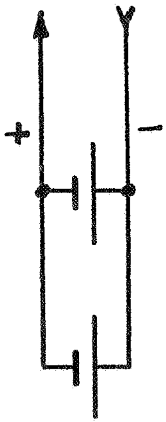


Fig. 2.

Multiple-series. The multiple-series connection is used where more than one group of series cells is necessary, either to provide additional capacity or uninterrupted service while renewing one of the series sets. A broken connection or defective cell in a series-connected battery puts the entire set out of service, but this is not true of a multiple-series connection. Multiple-series connection is illustrated in Fig. 3 and consists of connecting in multiple two or more sets of cells connected in series.

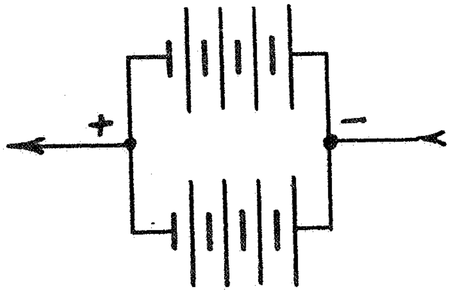


Fig. 3.

Series-multiple. The series-multiple connection is occasionally used where it is desired to remove one cell without putting the entire series connection out of service. Series-multiple connection is illustrated in Fig. 4 and consists of connecting in series two or more groups of cells connected in multiple.

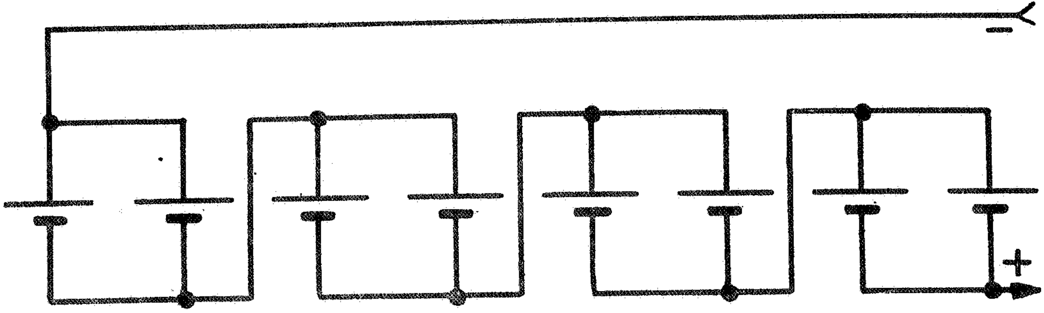


Fig. 4.

In Figs. 1, 2, 3 and 4, the short heavy line is used to designate the cathode or negative electrode of the cell to which is connected the positive terminal, while the long light line is used to designate the anode or positive electrode of the cell to which is connected the negative terminal. The use of the short heavy and the longer light lines outside the signal field is usually the opposite to signal practice.

PRIMARY BATTERIES (GENERAL)

Definition.

The Signal Section, A.A.R., defines Primary Cell as: A device for the direct transformation of chemical energy into electrical energy.

History.

At the close of the eighteenth century there was no recognized connection between chemical and electrical energy, the knowledge of electricity being confined at that time to static phenomena, such, for example, as the attraction of amber or a glass rod, which has been rubbed violently, for small pieces of paper or pith balls.

In about the year 1785, Galvani, who was an Italian physician, observed that recently skinned frogs, in the neighborhood of an electrical machine, moved whenever an electrical discharge took place, and later, that frogs' legs hung by a copper wire to an iron balcony were convulsed whenever they touched the iron. After studying the matter, he finally concluded that the legs were convulsed by electricity which he attempted to explain as the static with which he was familiar. His conception was that whenever the specimen touched the iron support there was a separation of positive and negative electricities on the nerves and muscles which caused the parts to move.

The error of Galvani's reasoning was finally demonstrated by Allessandro Volta, who had continued to experiment along the same lines as had Galvani. He, in turn, discovered that if any two of the common metals were joined at one end, the other ends of which were caused to touch the same muscles, convulsion also occurred. He concluded that it was not due to separation of electricities in the specimen, but to a junction of the two metals. This theory, called "Volta's Contact Theory" is now known to be insufficient to explain his results, but, nevertheless, the fundamental principle of two dissimilar metals in contact with each other was recognized as a source of electricity under certain conditions.

Believing that a current of electricity was set up at the junction of two unlike metals, Volta proceeded to construct a device which should have as large an area of contact between metals as seemed practicable. Discs of copper and zinc were arranged alternately in a pile with pieces of moist cloth between each pair and in this manner were extended to a considerable height. All of Volta's expectations must have been realized, for this apparatus gave a current at a very high pressure and his theory, therefore, was considered of great importance. This was in 1799 and it is generally agreed that his device, the first "Voltaic Pile" should properly be regarded as the first primary battery.

The theory that the junction of two unlike metals was the source of an electric current suffered a serious blow when it was found that a pile of copper and zinc plates alternated as before, but with dry paper separating each pair instead of moist cloth, would give no appreciable current at all. It, therefore, became necessary to recognize another essential for a primary cell: namely, moisture; although the notion prevailed for a long time that the real seat of the current was the junction of the two metals, but that the passage of current was conditioned upon the metals being in contact with water.

Only a very short step remained for Volta to find that his plates gave out much more current when immersed in a solution of common salt than in water, following upon which discovery he made what he himself called his "Crown of Cups." This consisted simply of a series of cups containing common salt solution, in each of which was immersed a copper and zinc plate, the copper in each being connected to the zinc of the next. This arrangement, which will certainly be recognized by any modern user of primary cells as a battery connected in series, not only yielded a current of high pressure but also of much greater quantity than had the "Voltaic Pile" and for this reason marked a very decided advancement in the art.

As is common in such cases, these first primary cells took their name from their originators and are, to this day, known as Voltaic cells and possibly just as frequently as Galvanic cells, after Galvani, who first gave Volta his clue and who afterward contributed much toward the success of primary cells.

The difference between voltage and quantity was recognized at an early date and various modifications were introduced by Wollaston, Hare and others toward the reduction of internal resistance.

Kemp, followed by Sturgeon in 1830, drew attention to the important decrease in local action brought about by the amalgamation of zinc plates.

The gravity cell, patented by Varley in 1854, was modeled after the Daniell cell and it came into a considerable amount of prominence somewhat later. This cell is now practically obsolete but it is mentioned several times in this Chapter and, for that reason, it justifies a brief description. The gravity cell was a so-called "two fluid" cell. In the bottom of the jar there was a metallic copper sheet having crystals of copper sulphate packed about it and a water solution of copper sulphate was poured over this group to half fill the jar. In the top of the jar, usually hung from the edge thereof, was a zinc electrode often called a "crow-foot." A water solution of zinc sulphate was poured carefully on top of the underlying copper sulphate solution to cover the zinc. This form of cell was suited to discharge continuous current but its internal resistance was very high. It had the further disadvantage that frequent cleaning of the zincs was required during the life of the cell. This type of cell was used by the Philadelphia & Erie Railroad in its installation of the Robinson automatic signals at Kinzua, Pa., in 1870.

Though several cells were brought out in the interim, the Leclanche cell which appeared in the year 1868 marked the beginning of that class of cells known as "open circuit cells" and in their present form as "dry cells" which will be taken up later in this Chapter.

It was in the year 1867 when the late Dr. William Robinson entered actively upon the development of an automatic signal system for preventing accidents of various kinds on railroads. He had at his disposal two main types of cells (power distribution having not yet been developed): namely, those patterned after the Leclanche cell or open circuit class and those patterned after the Daniell cell or closed circuit class.

As would naturally be the case, the early designs of signals were very largely influenced by characteristics of those early primary cells and as the cells functioned best at low current rates all those designs which preceded the electric semaphore were of types requiring exceedingly small rates of current either continuously or intermittently.

The Lalande cell, which was destined to play a very important part in railway signaling, was brought out in the year 1883 and marked the beginning of that class of cells known today as the "copper-oxide caustic soda type." Its most noteworthy assets as compared to its predecessors were an ability to deliver relatively high rates of current continuously and maintain a uniform voltage, even under relatively low temperature conditions, as well as an ability to exhaust its entire capacity without any labor being involved in the interim.

Since the Lalande cell was first brought out many variations of this original cell have been devised, and from these the several types of copper-oxide caustic soda primary cells that serve as the most important source of power for operation of present-day railway signal systems have been evolved. The commonest form of this cell has come to be known as the Type "A," or "Standard Voltage" cell, as covered in A.A.R. Signal Section specifications. A variation in this cell is the A.A.R. Type "B," or "High Voltage," which through a special treatment of the copper-oxide depolarizer results in a cell voltage about 25 per cent greater than that of the Type "A" at discharge rates for which the cell is designed.

The most recent development in the way of a primary cell which utilizes caustic soda as electrolyte is the "air depolarized" type. Possibility of utilizing atmospheric oxygen for primary battery depolarization had for a long time been recognized. Even the early wet type Leclanche cells were known to be partially air depolarized. In fact, some experimenters estimated that only half the total depolarization in the wet type Leclanche cell was due to the manganese dioxide provided for that purpose. Back as far as 1860 this led to attempts to produce operating cells utilizing air only as the depolarizer, but only in the first part of the twentieth century did it appear that the electrochemical conversion of oxygen had been utilized for depolarization in a cell which could be considered a commercial success.

Essentially, the air depolarized cell comprises a caustic soda electrolyte, an anode of zinc, and a cathode of carbon, the carbon being specially processed to render it capable of utilizing atmospheric oxygen for depolarization.

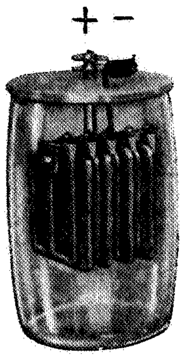
Type "A" Copper-Oxide Caustic Soda Primary Cells

History.

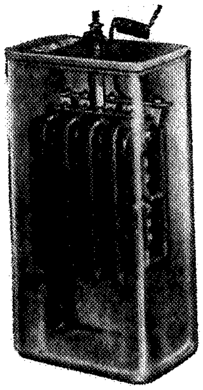
The Type "A" copper-oxide caustic soda cell, because of its reliability and ease of maintenance, was well established during the latter part of the nineteenth century but it did not come into common use for railway signaling until the advent of the electric semaphore signal. As is the case today, the early types of semaphore signals required a very low rate of current normally to hold them in the proceed position, but a rate far beyond the range of a single series set of gravity cells to clear them. Because of the comparatively low internal resistance of the copper-oxide caustic soda cell it was possible for it to operate the semaphore signal with one series-connected set of battery, even under low temperature conditions, whereas with gravity battery, because of its high internal resistance, it would have been necessary to use several series sets in multiple for each signal.

Between the advent of the electric semaphore signal and the year 1915 copper-oxide cells had generally displaced gravity and all other types of primary cells on practically all signal units with the exception of track circuits. However, about 1910, their adaptability for track circuits was finally demonstrated, after which their use gradually became general. The first copper-oxide cells tried were of the same low internal resistance type as those in common use on signal motors, but the low internal resistance characteristics which made the copper-oxide cell ideal for semaphore operation militated against it on the earliest track circuit tests, making its life uneconomical because of the severe waste of current during the train shunt condition. A study of the cause of this condition led to the universal adoption of the present track circuit limiting resistance unit which is dealt with further in Chapter VII—Non-Coded Direct Current Track Circuits.

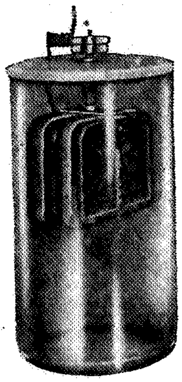
In the years which have followed there has been a gradual evolution of signal apparatus including the development and use of light signals and many other innovations. A corresponding development of the copper-oxide type of caustic soda cell has taken place and different types and sizes have been introduced to meet the changing needs and times. Also, the so-called "AC-Primary" system has been perfected whereby a great deal of relatively heavy powered signal apparatus may be operated entirely, or in part, by commercial alternating current power under normal conditions but still have a local stand-by reserve of copper-oxide primary battery capable of operation independently during failures of the commercial power.



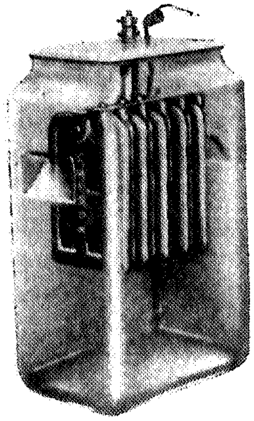
Type HA-504
AAR Class 4



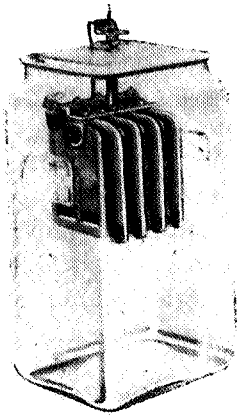
Type HA-252
AAR Class 1



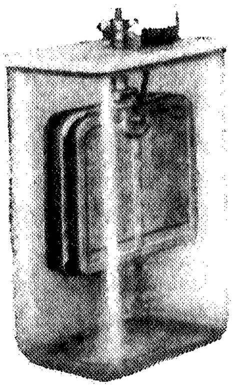
Type M-501
AAR Class 3



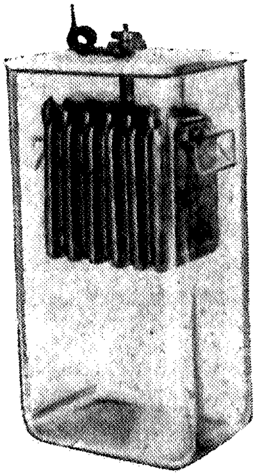
Type HA-1002
AAR Class 6



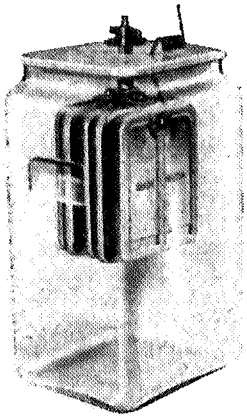
Type HA-902



Type S-502
AAR Class 2



Type HA-1302

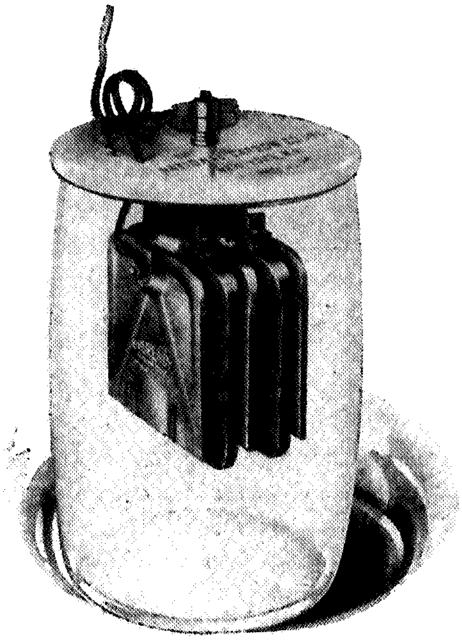


Type M-1002
AAR Class 5

Edison Type "A" Primary Cells

In the more modern AC-Primary installations, alternating current is used normally for direct lighting of all signal lamps while rectifiers are used for operation of all direct current apparatus such as line relays, signal mechanisms, etc., which otherwise would take direct current from the wayside battery. Both the alternating current for the lights as well as the rectified direct current for the rest of the equipment is fed through the front points of a power transfer relay leaving the stand-by primary battery normally on open circuit. When the alternating current fails completely or approaches a low value which might otherwise cause the lights and other equipment to fail, the power transfer relay opens by gravity and through its back points temporarily connects the stand-by battery to all functions. When the alternating current again reaches a satisfactory value the power transfer relay picks up and automatically restores the system to normal. The open circuit stand-by battery is kept active by discharging it at approximately 15 amperes for 5 minutes every 2 weeks or 10 minutes once a month.

"Eveready" Type 3-555
AAR Type A, Class 2



"Eveready" Type 5-500
AAR Type A, Class 3

Where AC-Primary is used for track circuit operation, either a conventional or automatic rectifier is generally floated across the primary track batteries. In such cases the rectifiers are so adjusted that the primary cells usually last for several years. In some cases power transfer relays are used to transfer the track circuit load from a constant potential rectifier to a reserve primary battery on failure of the alternating current supply.

Description.

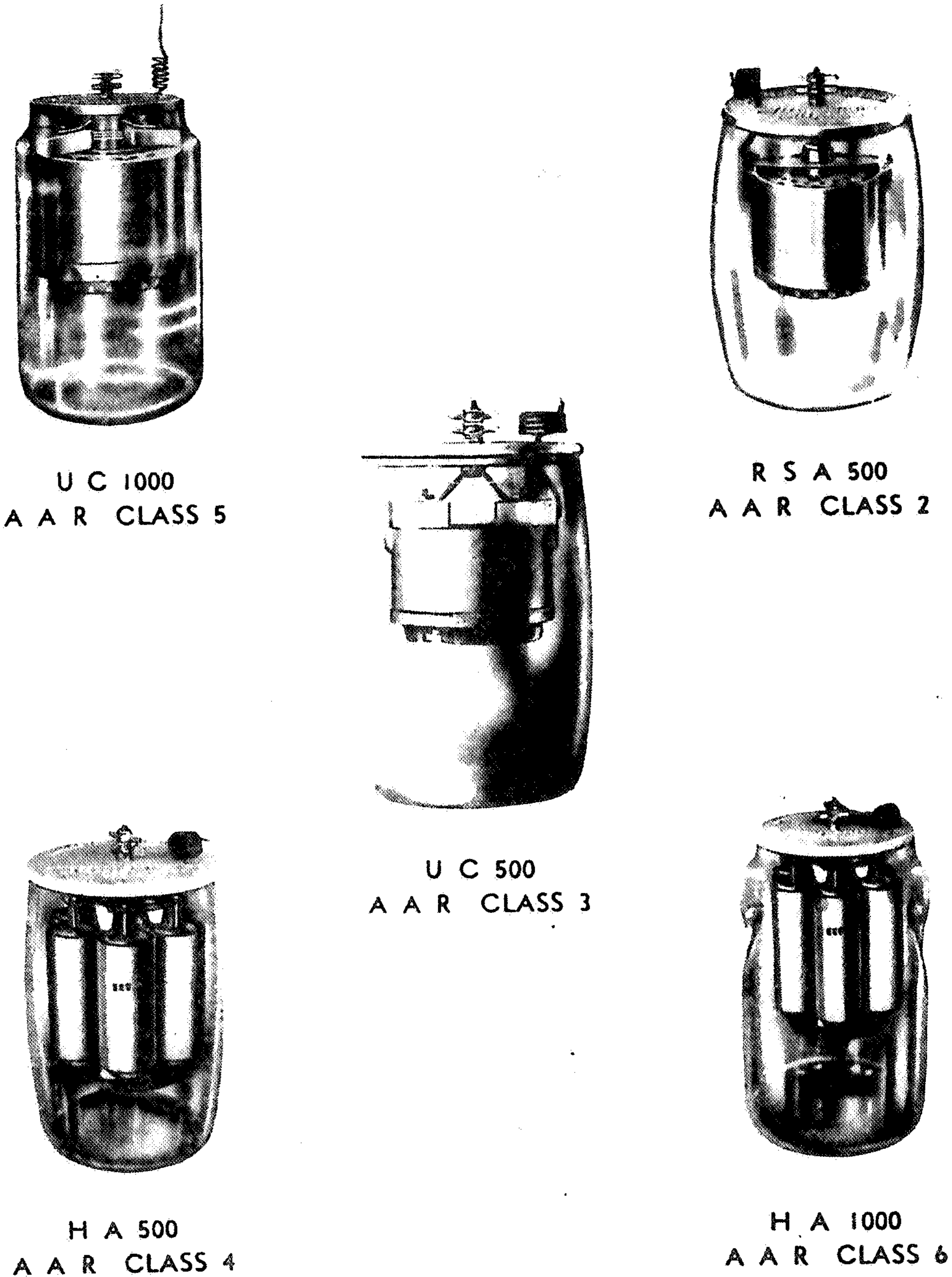
The copper-oxide zinc couple immersed in a caustic soda solution of the proper density in a container constitutes the cell.

The ampere-hour capacity of the cell is fixed by the proper amount or proportion of the materials mentioned above.

The elements of a cell are the cathode and anode. The cathode is the negative element and is the electrode by which current leaves the cell when it is on discharge and has connected to it the positive terminal. The depolarizing element or cathode of a Type "A" primary cell is composed of copper oxide.

The anode is the positive element and is the electrode by which current returns to the cell when it is on discharge and has connected to it the negative terminal. The zinc element in a Type "A" primary cell is the anode.

Since the ampere-hour capacity has a fundamental bearing upon the number of days service cells will render between renewal periods, it was possible to reduce the effort necessary for the maintenance of the cells by increasing the ampere-hour capacity of the cells themselves, thus decreasing the number of renewals of the cells over any extended period of time. This general procedure has been carried to the point where Type "A" copper-oxide cells today are manufactured in sizes which, though convenient to handle, have capacities ranging upward to 1,000 ampere hours.



U C 1000
A A R CLASS 5

R S A 500
A A R CLASS 2

U C 500
A A R CLASS 3

H A 500
A A R CLASS 4

H A 1000
A A R CLASS 6

Waterbury Primary Cells

The general increase in ampere-hour capacity has not been accomplished entirely by a mere proportionate increase in the size of the original jars and active materials, but also to a large extent by refinements as follows:

The use of higher quality materials to improve efficiency.

The better proportioning of the relative amounts of active materials to take full advantage of the capacity of the jar.

The limiting of the size of the inactive members such as insulators, structural parts, etc., which, though necessary, take up otherwise valuable space in the electrolyte.

The increase in porosity of the copper oxide to allow maximum contact with the electrolyte.

The making of the copper-oxide electrode in a form to assure perfect physical and electrical contact between the minute particles as well as between the entire electrode and the supporting frame.

The moulding of the zinc electrode in such manner that at the normal exhaustion point of the battery it will contain a minimum amount of excess zinc, but still have as nearly as practicable its original surface. This to prevent a waste of otherwise useful space and still allow a sufficient surface of zinc exposed to the solution when most needed.

Improved amalgamation of the zinc electrode to increase efficiency.

The proper spacing and design of the electrodes in relation one to another and the cell as a whole to permit better electrochemical action.

Refinements in processing and proportioning the soda for battery solution to insure maximum safe capacity.

Another important improvement which has had a tendency to increase the ease with which copper-oxide cells may be maintained, and to a certain extent increase their effective ampere-hour capacity, is the use of heat-resisting glass jars.

The fact that it is possible to see the elements through the glass jars had led to the use of zinc electrodes designed by various manufacturers to indicate by their physical appearance the gradual exhaustion of the cells. By noting the changing appearance of the zincs it is possible to use the full rated capacity of the cell for useful purposes and yet have sufficient warning of approaching exhaustion to renew the active materials before the voltage of the cell fails.

Theory of chemical action.

As mentioned previously, the major active elements are in the two electrodes: the zinc in the anode and the copper oxide in the cathode. In a very real sense, the solution of caustic soda and water has a secondary function which is that of providing a medium in which the primary reactions at the electrodes can take place.

In the action of the cell the zinc anode goes into solution and copper oxide is reduced to copper at the cathode. The over-all reaction may be expressed as:

$$2\,Zn + NaOH + 2\,CuO + H_2O = \\ Zn\,(OH)_2 + NaHZnO_2 + 2\,Cu$$

The copper oxide reduces to copper and the zinc oxidizes to zinc oxide. The electrical output derives from the fact that the electrochemical energy of the materials at the finish is less than at the start. The difference is the energy which is given off as electrical output.

Users know that the reduction of CuO to Cu is easily seen to be true. The conversion of Zn to ZnO is not seen—the zinc just dissolves without being visibly converted to anything. This is because of the secondary function of the caustic solution which happens to have the desirable property of dissolving the ZnO as fast as it forms, thus keeping the metallic zinc from becoming overlaid with an isolating and insulating layer of ZnO. A moment's reflection will show that it is the ZnO and not the metallic zinc which dissolves. Indeed, if metallic zinc dissolved, the cell would be useless. It is only when the circuit is closed and the formation of ZnO begins that anything dissolves. What appears to be a dissolving of the zinc is actually a conversion to zinc oxide and then the secondary dissolving of the zinc oxide.

Considering the caustic solution as playing the secondary role of being a medium for the main reactions does not by any means imply that the caustic solution is relatively unimportant. Quite the contrary. If the caustic solution is to dissolve the ZnO for the full capacity of the battery, it must be adequate in quantity and quality to do that. All the materials, the copper oxide, the zinc, and the caustic solution must be accurately proportioned and balanced to each other to attain maximum usefulness.

The degree to which the cells actually use precisely so many ounces of each ingredient per 100 ampere hours is astonishing. Efficiencies very close to 100 per cent are attained. Because of this a proper examination of any cell in an unknown state of discharge will disclose the extent of prior discharge with great accuracy. With respect to the zinc electrodes, this fact is used to enable users to see an advance indication of approaching exhaustion by the appearance of the zincs themselves. With respect to the other members, progressive states of discharge are less easily seen with the eye but they are easily shown by chemical analysis of the solution, or Baumé readings, or measurements of the extent of reduction of the copper oxide.

The proper proportion or amount of caustic soda for the electrolyte is furnished by the manufacturer and if used as directed there should be no difficulty caused by the electrolyte. If, however, the amount of soda is varied thus changing the density of the solution, the solution will then clearly indicate the irregularity thus caused, by various forms of crystallization, which in turn indicate the exact nature of the difficulty.

Polarization.

When any electric battery passes an electric current, certain chemical reactions take place at each electrode. The end products of these reactions tend to create forces counter to the original forces of the battery. All of these counter forces taken together are called the "counter *e.m.f.* of polarization," and the effect is called "polarization." In most primary cells the greatest degree of polarization is encountered at the cathode, or externally positive electrode, where the chemical reaction is, predominantly, the reduction of some oxide by hydrogen. The term "polarization" is applied to the effect of hydrogen at the cathode.

Local action.

In all electric batteries there are the normal and intended chemical reactions which take place as current flows. Due, in part, to the fact that commercial chemicals out of which batteries must be manufactured are not of absolute purity, there are also minor chemical reactions in addition to those which are intended. These foreign reactions, taken together, are called "local action." In primary batteries it is a very common usage to limit the term "local action" to the foreign effects at the zinc anode. These effects are reduced to a negligible point by incorporating a small quantity of mercury in the zinc. This is called "amalgamation." The exact mechanism by which amalgamation has its effect is better understood than it used to be but, unfortunately, the explanation involves the rather highly technical question of over-voltage. The old-fashioned explanation that the mercury mingles with the zinc and the impurities to form a common mixture in which the separate identities of impurities are lost is still a useful way to put the matter for most practical purposes.

Crystallization.

There are three forms of crystallization that occur under certain conditions in the use of these cells, as follows:

1. Granular, glassy crystals (usually called sugar crystals).
2. Fine, white powder precipitate (usually called milky solution).
3. Long, needle-like crystals.

The granular, glassy crystals form upon the inner surface of the jars and upon the surface of the zinc and copper-oxide electrodes, usually starting near the bottom of the jar. The formation of these crystals indicates approaching exhaustion or saturation of the solution. These crystals form when a solution of normal density is discharged beyond its capacity.

The fine, white powder precipitate forms in combination with the granular, glassy crystals or may form separately between and around the zinc and copper-oxide electrodes, and in the bottom of the jar. When this precipitation occurs before the exhaustion of the zinc and copper-oxide electrodes, it indicates a solution of less (weaker) than standard density, due to the use of insufficient caustic soda for the volume of water. This condition is intensified by higher temperatures.

The long, needle-like crystals usually form first on the zinc and between the zinc and copper oxide, starting at the bottom of the electrodes, and then rapidly filling the space between and around the electrodes and in the bottom of the jar. The formation of these crystals usually indicates a solution of greater (stronger) than standard density, and it is most likely to occur when cells in an advanced state of exhaustion are subjected to low temperatures, especially if an excess of soda or too little water had been used in mixing the solution. These crystals will dissolve or go back into solution when the temperature is sufficiently higher than that at which the crystallization occurred.

Application.

The two standard capacities of cells now in most general use for signal purposes are the 500 and 1,000 ampere hour. Each capacity cell is available in two or more types capable of continuously or intermittently handling different rates of current.

The following tables are useful for reference purposes in judging the types and size of cell suited to different service demands. It should be noted carefully that the maximum safe discharge currents are higher for intermittent than for continuous discharges. It should also be clearly understood that the actual solution temperatures are generally much higher than prevailing air temperatures during cold weather when the battery is properly housed below ground. Generally speaking, the current rates shown under the 25 degrees F. column are applicable to primary batteries housed in properly insulated boxes below ground while the 40 degrees F. column applies to batteries housed in deep wells. For batteries housed in heated buildings a solution temperature of 60 degrees F. is considered a satisfactory minimum. As the tables indicate, all cell types are serviceable at maximum rates to a minimum solution temperature of 25 degrees F. and some types are suitable for solution temperature of zero degrees F.

The following tables illustrate the current-carrying capacity of the now existent Type "A" copper-oxide cells at various solution temperatures:

TABLE I

Maximum Amperes Continuous Discharge Per Cell at Various Constant Solution Temperatures to Full Rated Capacity

Type "A" cell	Ampere-hour capacity to 0.50 volt per cell	Continuous amperes at following temperatures: 0°F.	10°F.	20°F.	25°F.	30°F.	40°F.	50°F.	60°F.	70°F. to 90°F.
AAR Class 1	250	1.6	2.4	3.3	3.8	4.4	5.6	7.0	7.8	9.00
AAR Class 2	500				0.6	0.7	0.8	1.1	1.3	1.75
AAR Class 3	500				0.8	0.9	1.2	1.5	1.9	2.25
AAR Class 4	500				2.0	2.4	3.4	4.5	5.5	6.50
HA-902	500	2.0	3.0	4.2	5.0	5.6	7.0	8.5	10.0	12.00
AAR Class 5	1000				1.0	1.2	1.8	2.2	2.8	3.50
AAR Class 6	1000				2.5	3.2	5.2	7.0	7.8	9.00
HA-1302	1000	1.5	3.5	5.5	6.5	7.6	9.8	12.0	16.0	20.00

In terms of railway signal service, Table I is applicable in the field only where strictly continuous current rates are in effect. Examples of such service are found in the continuous lighting of certain switch or semaphore lamps and color or position light signals, requiring the maximum current rates shown in the table.

When the maximum rates shown for any class cell are lowered, the cut-off voltage of 0.5 volt per cell rises toward the open circuit voltage of the cells which is approximately 0.90 volt. For this reason in switch and semaphore lighting service, using low-wattage lamps taking 250 milliamperes or less, the cut-off voltage of even Class 2 cells is generally found to be nearer 0.60 volt than 0.50 volt.

Strictly speaking, Table I should be taken literally only where service conditions exactly simulate the conditions of the table. Wherever current rates less than those shown are in effect, higher cut-off voltages will be obtained.

TABLE II

Maximum Amperes Intermittent Discharge Per Cell at Various Constant Solution Temperatures to Full Rated Capacity

Type "A" cell	Ampere-hour capacity to 0.50 volt per cell	Intermittent amperes at following temperatures: 0°F.	10°F.	20°F.	25°F.	30°F.	40°F.	50°F.	60°F.	70°F. to 90°F.
AAR Class 1	250	2.1	3.2	4.3	5.0	5.7	7.3	9.00	9.7	10.4
AAR Class 2	500				1.0	1.1	1.4	1.75	2.0	2.2
AAR Class 3	500				1.3	1.4	1.7	2.00	2.2	2.6
AAR Class 4	500				3.6	4.0	5.0	6.00	6.7	7.5
HA-902	500	2.6	3.9	4.9	6.4	7.0	8.1	10.50	12.2	13.5
AAR Class 5	1000				2.5	2.7	3.1	3.70	4.0	4.5
AAR Class 6	1000				4.5	5.4	7.0	8.70	9.5	10.4
HA-1302	1000	2.0	4.4	5.8	8.0	9.2	12.0	14.50	19.2	22.0

Table II shows the maximum recommended discharge rates for Type "A" cells in many classes of service where current requirements vary from a few milliamperes normally to the maximum intermittent rates shown. These discharge rates can be maintained for several hours at a time to a cut-off voltage of 0.50 volt per cell and for protracted periods thereafter at slightly less than 0.50 volt, depending upon the state of exhaustion of the cells.

In terms of railway signal service, Table II is applicable in the field to many classes of service such as the approach lighting of color and position light signals and highway crossing signals whether used with the straight primary battery system or the AC-Primary battery system.

The maximum current rates shown are based upon years of experience with Type "A" cells in these classes of service in the field.

From the foregoing it is apparent that neither Table I nor Table II applies to services such as the clearing of semaphore signals requiring from two to three amperes for only a few seconds at a time while the signals are clearing. For such services, Class 2, 3 and 5 cells are used extensively in all parts of the country with entire satisfaction.

The service for which intended usually determines the particular capacity or type cell to be used; generally, circuits requiring relatively few ampere hours per day use the 500 ampere-hour cell, while those requiring more ampere-hour capacity over an equal period of time use the 1,000 ampere-hour cells.

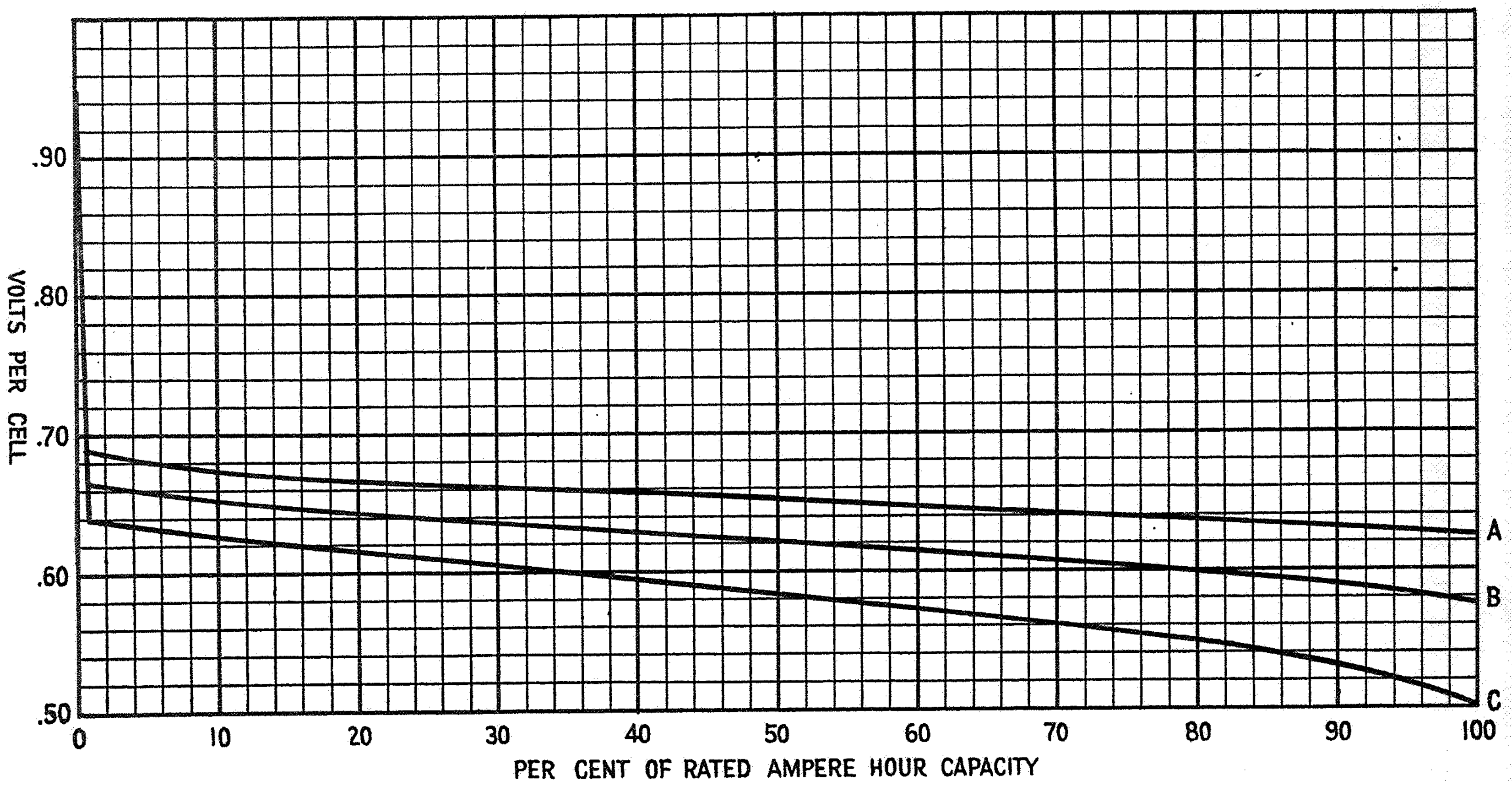


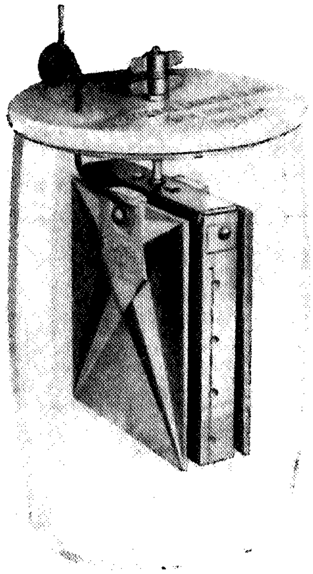
Fig. 5.

Illustrative Voltage Characteristics of Type "A" Copper-Oxide Caustic Soda Cells at 10 Per Cent (Curve A), 50 Per Cent (Curve B), and 100 Per Cent (Curve C) of the Maximum Continuous Discharge Rates Shown in Table I, Solution Temperature 70 Degrees F.

Type "B" Copper-Oxide Caustic Soda Primary Cells

The development of the Type "B" copper-oxide caustic soda primary cell has followed closely that of the Type "A" with respect to improvement in design, production and efficiency. The general arrangement of zinc anode and copper-oxide cathode in an electrolyte of caustic soda is essentially the same in both types. The theories of chemical action, polarization, local action and crystallization, as described for the Type "A" cell in the preceding pages, also apply to the Type "B" cell.

The chief feature which distinguishes the Type "B" from Type "A" is its higher voltage. A special treatment of the copper-oxide depolarizer results in an average cell voltage approximately 25 per cent higher than that of Type "A" cells at the discharge rates for which the cell is recommended.



"Columbia" High Voltage—Type 572
AAR Type B

Application.

The Type "B" cell is available only in the 500 ampere-hour capacity type.

Because of its higher voltage characteristics, the Type "B" cell is adaptable for operation of certain track circuits with cells connected in multiple which otherwise require a multiple-series connection of Type "A" cells. The higher voltage of the Type "B" cell also permits the use of a fewer number of these cells in series-connected batteries where discharge rates are within the current-carrying capacity of the cell.

Table III will be found useful for reference purposes in judging the suitability of the Type "B" cell for various service applications. When using this table it should be kept in mind that, generally speaking, the current rates shown under the 25 degrees F. column are applicable to primary batteries housed in properly insulated boxes below ground, while the 40 degrees F. column applies to batteries housed in deep wells. For batteries housed in heated buildings a solution temperature of 60 degrees F. is considered a satisfactory minimum.

TABLE III

Maximum Amperes Continuous Discharge Per Cell at Various Constant Solution Temperatures to Full Rated Capacity

Ampere-hour capacity to 0.80 volt per cell	Continuous amperes at following temperatures: 25°F.	30°F.	40°F.	50°F.	60°F.	70°F. to 90°F.
500	0.165	0.195	0.280	0.350	0.400	0.470

Instructions

Type "A" and Type "B" copper-oxide caustic soda primary cells should be maintained and tested in accordance with Signal Section, A.A.R. Instructions as follows:

Housing.

1. Cells must be protected against rain, snow, extreme heat or cold, and should be kept clean.

2. Where freezing temperatures prevail for prolonged periods, outside housings should be equipped with frost covers and buried to such depth that the frost cover will be at or below the ground level.

3. Drainage must be provided to prevent flooding.

4. Cells must set level on floors, shelves or racks. Where required, provision must be made to keep cells from shifting.

Material.

5. One complete cell (except water) must consist of the following:
   1 Jar
   1 Cover
   1 Hexagonal nut
   2 Wing nuts
   2 Washers
   1 Complete renewal
6. One complete renewal must consist of the following:
   1 Element
   1 Can caustic soda
   1 Bottle battery oil (when not self-contained)
7. Renewals must not be unpacked except as required.
8. Elements must not be lifted or carried by their connecting wires.
9. Packages containing cells or renewals must be kept dry.
10. Caustic soda which has been damaged by exposure to air or dampness must not be used.

Precautions to be used in handling caustic soda.

11. Care must be exercised in handling the dry soda or mixed solution because caustic soda is a caustic poison which will burn or injure the skin, eyes or clothing. It must never be taken internally. Where the skin is likely to be burned from exposure to caustic soda, it is good practice to protect to some extent the exposed skin by applying a coating of vegetable or animal oil, such as olive, linseed, cottonseed, castor or lard. If these oils are not available, mineral oil is of some value, although not as effective as the oils mentioned. If caustic soda does come in contact with the skin, it should immediately be

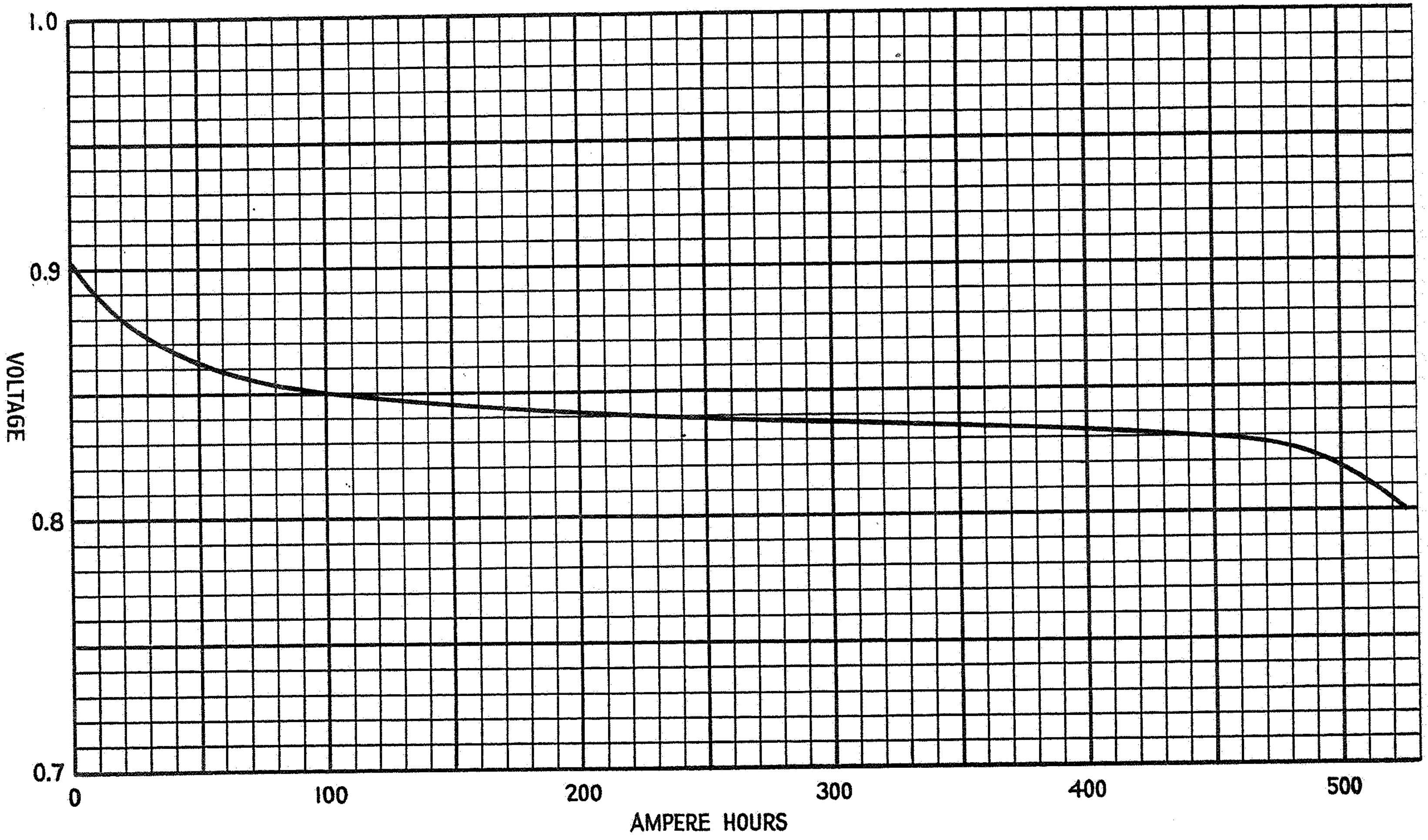


Fig. 6.
Illustrative Voltage Characteristics of Type "B" Copper-Oxide Primary Cell at Continuous Discharge of 200 Milliamperes at 70 Degrees F. Solution Temperature.

washed off with plenty of water and neutralized with a weak acid such as vinegar. If a skin burn has resulted from contact with the caustic soda, after washing with water, apply one of the vegetable or animal oils specified herein. Mineral or lubricating oil may also be used but it is not as effective. Should caustic soda get into the eye, immediately wash with plenty of water, flush freely with a pure vegetable oil, such as olive oil, and see a physician as soon as possible. Where caustic soda has been taken internally, immediately drink vinegar and water in equal parts or lemon juice and water in equal parts, and get to a physician as soon as possible. If clothing becomes wet with caustic soda solution, it should immediately be removed. If the wet portion of the clothing came in contact with the skin, the skin should be treated as recommended herein. Such clothing should be thoroughly washed before it is worn again. The above treatment of caustic burns is recommended as good first-aid practice until medical assistance can be obtained.

Setting up and renewing cells.

12. Material must be checked to see that jars, covers, nuts, washers, elements, caustic soda and oil (when not self-contained) are of proper size and quantity.

13. Separators and other packing material must be removed from elements.

14. Elements must be examined to see that they hang approximately in a vertical position, that the electrodes are parallel to each other and uniformly spaced, and that connections are firmly made. Broken or cracked electrodes must not be used.

15. Jars and covers must be thoroughly cleaned. Cracked or defective jars or covers must not be used.

16. Material unfit for use must be called to attention of proper authority for disposition.

17. Clean water must be used for mixing solution. Water known to contain an excess of metallic salt, acid, alkali, sewage or other impurities must not be used.

18. Jars should be filled with clean water to within approximately 2¾ inches from the top or as specified in manufacturer's instructions.

19. Caustic soda must be added gradually and stirred with a circular and pendulum-like movement until thoroughly dissolved, using a clean, untreated strip of wood which should be long enough to reach the bottom of the jar.

20. The exact amount of soda and only that furnished by the manufacturer for the type of renewal must be used.

21. Connecting wire and suspension bolt must be passed through holes in cover and element securely tightened to cover by means of hexagonal nut. Two washers and two wing nuts must be placed above the hexagonal nut. Before applying element to cover, bend connecting wire so that it will pass freely through hole in cover to prevent damage to insulation. Avoid bending wire at point where it is connected to electrode.

22. If the cells being set up or renewed are for normally open circuit service or for service where the discharge rate is very low, any special instructions issued by the manufacturer for such service must be followed.

23. Element must be inserted in solution, where practicable, after jars have been placed in permanent position. Where necessary, water must be added to bring top of solution, when cool, ¾ inch from top of jar with electrodes in position and stirred thoroughly by agitating entire bulk of solution by a brisk

pendulum movement of narrow stick reaching to bottom of jar. Solution must never touch underside of cover but must be well above top of electrodes.

24. Except when oil is self-contained, exact amount and kind furnished by manufacturer of renewal must be added to top of solution after element is permanently in place. Element should not be raised through the oil.

25. When oil is self-contained in electrodes or soda, element must be inserted before solution has cooled.

26. Connections must be clean and tight.

27. The performance should be recorded on Form 7007, Fig. 7, as instructed.

Renewal of cells.

28. Except when necessary to make replacements of individual cells, all cells of a battery should be renewed at the same time.

29. When renewing or installing cells, care must be exercised to avoid interruptions to traffic.

30. Discarded solution, cans and bottles must be disposed of where they will not damage property, inflict injury to persons, animals, etc., nor pollute any stream or source of water supply. Cans should be flattened out when emptied.

Inspection.

31. Battery must be inspected, tested and renewed as often as necessary. Voltage readings of the battery should be taken during maximum discharge.

32. Broken or cracked jars and covers must be replaced promptly.

33. Any unusual appearance or performance of cells must be promptly reported to proper authority. If cells must be replaced, the old cells, where practicable, should be held intact for instructions as to disposition.

Disposition of exhausted elements.

34. Exhausted elements must be drained and then spaced on racks, floors, or shelves away from inflammable material until thoroughly dry, after which they must be placed in paper bags, if available, then packed and forwarded to the storehouse or other designated place. Each container to contain only one type and make and plainly marked to show name of shipper, quantity, type and manufacture.

35. Exhausted elements must be kept dry as chemical action when wet may cause fire. Containers should be labeled "Keep Dry."

Adjustment of rectifiers used with Type "A" primary cells.

36. Rectifiers must be adjusted when each cell reads 0.85 volt. New cells reading over 0.85 volt should be brought down to this voltage by temporarily discharging them through a resistance while making the adjustment. Cells which read less than this voltage should be brought up to 0.85 volt by charging the cells for a short period before permanently adjusting rectifiers.

37. When adjusting rectifiers, make sure that the primary cells do not receive more charge than discharge, calculated in ampere hours, over a definite period of time such as 24 hours. The output of the rectifier should always be slightly less than the entire current requirement of the circuit.

38. If the rectifier is set too high and the cells are being charged, this condition will be indicated by an increase in the thickness of the extreme lower portion of the zinc electrode, or by the formation of a "mossy" deposit on the surface of the electrodes. These warnings will appear depending upon the

ARA
SIG. SEC.
7007
SEPT 1926
M-1927

PRIMARY BATTERY RECORD

HOUSING, TYPE AND CAPACITY.................................. LOCATION...................... BATTERY NUMBER.................

APPARATUS (OPERATED FROM THIS BATTERY)

NUMBER OF CELLS	HOW CONNECTED	MAKE	TYPE	CAPACITY	DATE SET UP	DAYS LIFE	NORMAL LOAD AMPS.	NUMBER OF CELLS	HOW CONNECTED	MAKE	TYPE	CAPACITY	DATE SET UP	DAYS LIFE	NORMAL LOAD AMPS.

Fig. 7.

state of exhaustion of the cells as well as upon the rate and duration of the charge long before any permanent damage can be done to the battery.

General.

39. Instructions issued by manufacturers must be followed unless they conflict with general or detailed instructions in which case proper authority must be consulted.

Air Depolarized Caustic Soda Primary Cells

The air depolarized cell differs essentially from the copper-oxide caustic soda type in that the cathode is a porous carbon block instead of copper oxide. This porous carbon is specially processed to render it capable of utilizing atmospheric oxygen for depolarization.

One type of air depolarized cell is available in a composition case construction with the carbon electrode exposed at the top and with self-contained dry caustic soda. Activation is accomplished by addition of water. The entire cell, including the case, is discarded when removed from service. Capacities commonly available in this type of cell are 300 and 600 ampere hours, both as single and two-cell series-connected batteries.

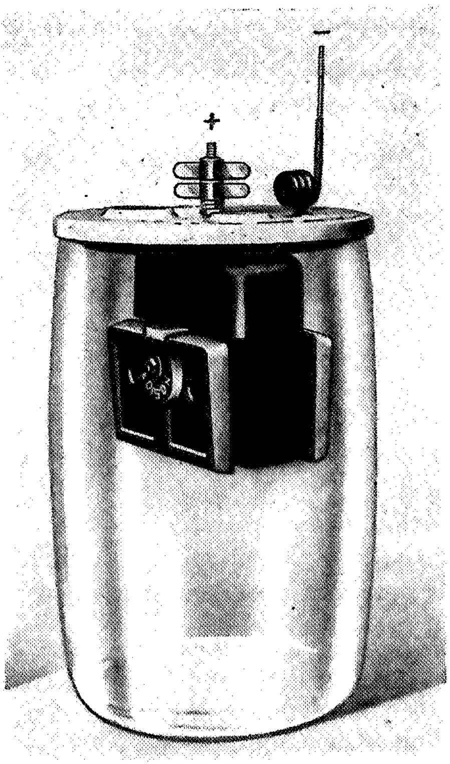
For railway signal service, a special design of air depolarized cell, adapted to use in standard A.A.R. glass jars, is available as a 500 ampere-hour capacity unit. The construction is similar in its general features to Type "A" and Type "B" copper-oxide caustic soda primary cells, comprising an assembly of zinc plates but with a porous carbon electrode replacing the usual copper-oxide electrode. This electrode assembly is suspended from a porcelain cover and immersed in an electrolyte of caustic soda contained in the glass jar. The porcelain covers differ from the usual covers for Type "A" and Type "B" cells in having openings provided for access of air to the top of the carbon electrode. The entire electrode assembly is discarded when removed from service.

Application.

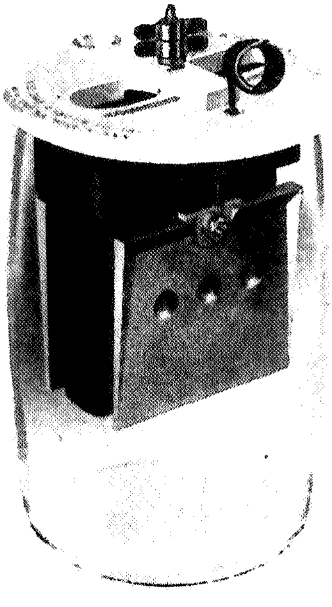
The operating voltage of the signal type air depolarized cell ranges from approximately 1 volt under heaviest recommended continuous load to 1.3 volts for light current loads. Allowable current rates depend upon the solution temperature, as in the case of all primary batteries.

Air depolarized signal cells perform better when protected against very low temperatures. They should be afforded the same protection with respect to adequate battery housing as is given copper-oxide caustic soda cells. The air depolarized type requires ventilation of the battery housing or compartment in order to provide a continuous supply of fresh air.

Since service applications, as well as detailed instructions for setting up and renewing the air depolarized type, may vary somewhat for different makes of cells such information should be obtained direct from the manufacturer.



Air Depolarized Primary Cell



"Eveready" Type AC-500 "Air Cell" Signal Battery

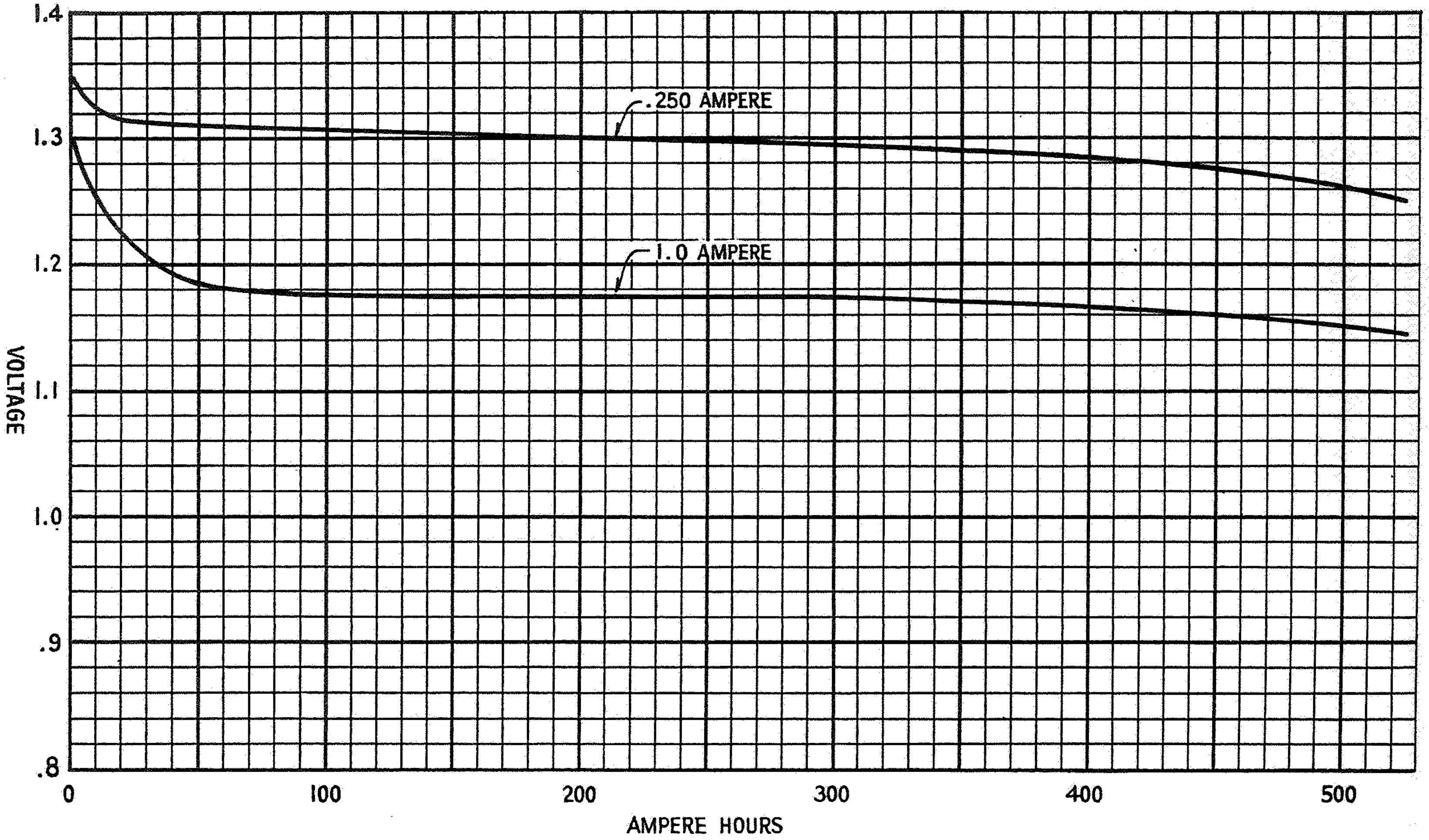


Fig. 8.

Illustrative Voltage Characteristics of Railway Signal Type of Air Depolarized Caustic Soda Primary Cell at Continuous Discharge Rates as Shown and at 70 Degrees F. Solution Temperature.

Dry Cells

Definition.

The Signal Section, A.A.R., defines Dry Cell as: A primary cell using zinc as the positive electrode, carbon as the negative electrode and ammonium chloride for the electrolyte.

Historical.

The present-day 6-inch dry cell, widely used by the railroads, is the outgrowth of nearly 60 years of experience, study, and intensive research by the dry battery industry. In size and form it is essentially the same as the first practical dry cells produced by the industry back in 1890. From it have sprung the other types of battery—for flashlights, radios, hearing aids, etc., of many sizes and types.

The dry cell, like all other batteries, had its origin in Volta's experiments as early as 1798, which established the electrochemical basis for the generation of electricity.

The earliest practical primary battery was made by Leclanche about 1868. He made wet cells assembled in glass jars, and using zinc, sal ammoniac, and carbon, the latter surrounded by a manganese dioxide depolarizer. These same elements are used in the dry cells of today, but the "dry" cell utilizes porous materials for absorbing the electrolyte and is enclosed in a sealed container, thus becoming portable and non-spillable.

Since the early years of dry battery production great advances have been made in quality and dependability. The present-day dry cell has a capacity many times greater than its early predecessors and is a highly efficient electrochemical device.

Throughout the life of the dry battery industry, many new uses have arisen and subsequently disappeared due to the development of power devices. In spite of this, the commercial demand for dry batteries of many varied types is greater today than ever before. Many millions of cells are made every year. During the war the demand for cells for military use actually rose into the billions.

The 6-inch dry cell.

All dry cells are assemblies of zinc as the negative electrode, an electrolyte of sal ammoniac, and a positive electrode of carbon having a depolarizer of manganese dioxide.

A typical construction for the 6-inch type is illustrated in Fig. 9.

Theory of chemical action.

The physical make-up and chemical formulae differ according to the manufacturer, which explains the wide differences in quality. Also, the manufacturer may, by variations in formula, design cells of widely different characteristics to meet the various conditions of use encountered in the industrial field.

The reactions within a dry cell by which electricity is generated are quite complicated if considered in detail, and furthermore differ somewhat, depending upon the manner in which the cell is used. It is believed, however, that what takes place may be clearly and simply illustrated by presenting only the basic chemical reactions which occur. While "ionic" equations are more modern in concept, they are being neglected because it is believed they add little to the picture from a practical standpoint.

At the negative electrode the following takes place:

$$Zn + 2\ NH_4Cl = Zn\ (NH_3)_2\ Cl_2 + 2H.$$

The zinc dissolves in the sal ammoniac, liberating hydrogen and forming diammoniated zinc chloride. The latter then dissolves in the electrolyte until it becomes saturated, after which it begins to crystallize out forming the crystals or white deposit seen in exhausted dry cells.

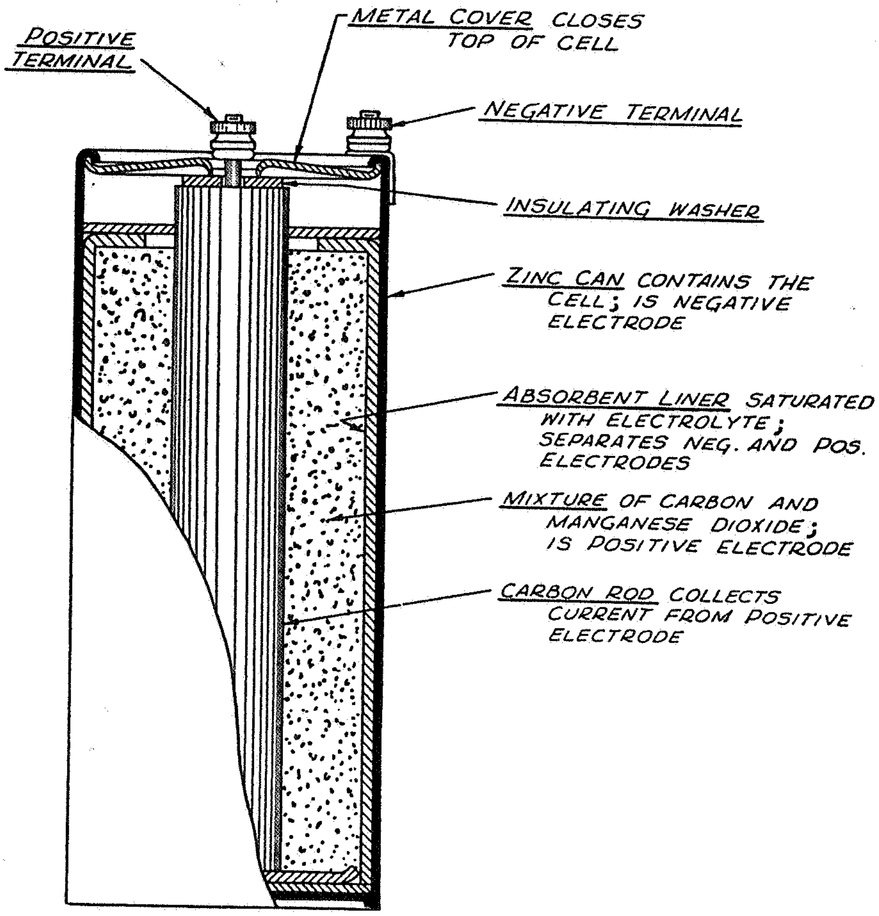


Fig. 9.
Cut-a-way of No. 6 Dry Cell.

At the positive electrode the following takes place:

$$2H + 2MnO_2 = Mn_2O_3 + H_2O.$$

The liberated hydrogen combines with oxygen from the manganese dioxide, thus keeping the cell free of polarization. The manganese dioxide is gradually reduced to a lower oxide until in the exhausted cell it has largely lost all activity.

Application.

The service conditions under which dry cells are used on the railroads vary widely in severity, ranging from ignition battery for the gasoline engine which drives the maintainer's "speeder," where the service is heavy, exhausting the battery in a few weeks, to the telephone battery where the service is light and the battery life may be as much as 3 years. Cells of three different types or grades are available and that grade should be chosen which best takes care of the application:

Railroad and industrial cells (heavy service). Cells of this classification are designed for use as ignition battery of internal combustion engines, and for similar high current uses. They are also highly efficient for telephone and bell-ringing service. The short circuit current of these cells when new is commonly intermediate between the high amperage of the general purpose cell and the relatively low amperage of the telephone cell.

General purpose cells. This type offers good performance in ignition, telephone, and general purpose applications. For ignition and heavy service they are better than the telephone cells but do not equal the high performance of the railroad and industrial cell. For telephone service they are surpassed by both the telephone and railroad cells.

Telephone cells (light service). These are also referred to at times as "open circuit" cells. They are intended for light intermittent service such as telephone, bell ringing, and similar work. They are not considered suitable for ignition service.

Testing dry cells.

Open circuit voltage. For testing dry cells on open circuit voltage, a meter having a scale of not less than 50 divisions per volt and a resistance of not less than 100 ohms per volt should be used. It should, of course, be accurately calibrated. The voltage of fresh cells should run 1.50 to 1.60. Cells several months old may read as low as 1.45 volts. A cell among a group of similar cells of the same age, which reads 0.05 volt or more below the average of the rest of the group, is probably defective. Voltage reading is no criterion of output capacity except that it may indicate an old or a defective cell.

Short circuit amperage. For reading so-called "amperage" of a dry cell, the user should employ an ammeter with a damped or "dead beat" movement, so that there is a minimum of overswing of the needle. Also, the total resistance of the ammeter with its two leads should be adjusted to 0.01 ohm plus or minus 0.002 ohm. Leads should have terminals capable of making good contact with the terminals of the cell. The inexpensive pocket meters sometimes employed are highly inaccurate and should not be used. Amperage varies widely in cells of different brands and different grades. It is not a measure of cell output or service capacity. It is useful in judging uniformity of a group of similar cells of the same age and in judging shelf deterioration of unused cells provided the amperage of the fresh cells is known. It is not considered suitable as a service termination cut off.

Storage of cells.

To obtain the most out of dry cells they should be used as fresh as possible. Cells should be stored no longer than absolutely necessary and stocks should be carefully rotated to use the oldest cells first.

Storage should be in a cool dry place. Cells are best kept in their original packages.

Deterioration with time is slow under normal conditions but is greatly accelerated by high temperatures.

Installation and maintenance.

When installing cells they should be located in a dry place and one which is not subject to extreme heat. Jackets, of course, must be left on the cells as they provide insulation between cells.

In connecting cells, wires used should be of the insulated type, with ends skinned and scraped bright to make good connection with cell terminals. Knurled nuts should be firmly tightened against the wires, using pliers. Excessive twisting, however, may break the terminals off the cell.

Tools or wires should not be allowed to short circuit cells by touching both terminals at one time, or wires leading from them.

Temperature effects.

Dry cells operate best at room temperature, approximately 70 degrees F.

The effect of temperature on open circuit voltage is small and for most purposes can be neglected. On amperage, however, the effect is quite pronounced, amperage reading higher at high temperatures and much lower at low temperatures. When amperage readings are taken, therefore, the cells should first be held long enough at normal 70 degree temperature to permit the interior of the cell to attain this normal temperature.

Continued high temperatures, 100 degrees or over, are very likely to lead to leakage and ultimate breakdown of the cell. Shelf deterioration is greatly hastened due to loss of moisture and accelerated chemical action. Voltage and depolarization are increased but any beneficial effect is apt to be offset by more rapid shelf deterioration except on very heavy service.

Low temperatures cause no permanent damage to the cell, and warming again to 70 degrees will restore the cell to normal. While cold, the cell will have lowered amperage. Its chemical action is retarded so that shelf deterioration is less. In service, low temperatures will depress operating voltage and so tend to reduce output, especially if the service is of a severe type. This must be taken into consideration in determining the number of cells in series required to properly operate equipment.

If temperatures fall very low, the cells will freeze and become inoperative. The freezing point is a variable one and depends somewhat on the conditions of use.

STORAGE BATTERIES (GENERAL)

Definitions.

The Signal Section, A.A.R., defines Storage Cell as: A secondary cell used primarily for storing electrical energy at one time for use at another, and Secondary Cell as: Any combination of two metals or metalloids immersed in an electrolyte which in itself will not produce electricity without first having the metallic portion of the element decomposed by the passage of electric current.

The process of putting energy into a battery is termed "charging;" of taking energy out "discharging." Direct current must be supplied at battery terminals for charging purposes.

Strength of electrolyte is measured in terms of specific gravity.

Historical.

The storage battery of today is the outgrowth of many early experiments in electrochemistry as mentioned under primary batteries. Shortly after Volta's discovery of the galvanic battery, Gautherot discovered in certain experiments that after the passage of an electric current through a cell which he used for studying the decomposition of water, a feeble current was returned when he connected the external wires of a cell after having disconnected the source of current.

In 1803, Ritter went a step further by constructing small piles from plates of several metals between which he placed moistened layers of cloth. These piles were charged with an electric current from which a discharge current was obtained after disconnecting the charging source. He thought the piles stored electricity in much the same way as a condenser. Volta indicated that this explanation was incorrect, attributing the effect to the decomposition of water.

A number of other experiments were made by various men, but it remained for Plante to develop a valuable form of cell as the result of his study of electrolytic polarization which he began in 1859.

As a result a battery was devised for the storage of electrical energy which consisted of two sheets of lead separated by strips of rubber rolled into the form of a spiral, all of which was immersed in a dilute solution of about 10 per cent sulphuric acid. Following periods of charge he would discharge the cell or allow it to remain on open circuit for a while, during which time local action transformed the covering of peroxide on the positive plate into lead sulphate. He also found he could materially increase the capacity of the cell by a process which is now called "formation."

One of the noticeable advantages which this cell possessed at this time was its ability to deliver much larger currents than could be obtained from the Voltaic piles.

There were serious disadvantages with this cell, however, chief of which was the time required for formation, also primary batteries were the only means available for charging these storage cells which made the process costly.

Since 1881 the development of storage batteries has been very rapid on account of decreased time required for formation of the plates and the development of machines for generating electric current for charging purposes.

While there are numerous types of storage batteries in use today, this article will deal only with those in general use in the signal field.

General.

The types of batteries usually used in railway signal service are known as the lead acid and nickel-iron-alkaline, each of which will be treated separately.

Lead Acid Type

Description.

Under this class the Signal Section, A.A.R., has prepared specifications, etc., for composite type stationary, lead type portable and pure lead type stationary. However, in a general description they can all be grouped under the heading of "lead acid type."

The essential parts to make up a complete cell are one group each of positive and negative plates, separators, glass or hard rubber jar, cell cover and electrolyte.

Plates.

The plates are connected into positive and negative groups and so arranged that the positive plates always have a negative plate exposed to them.

The positive plates are of different types, depending on the particular cell in question. Certain ones are of the pasted type, others consist of a hard alloy grid securely supporting cylindrical forms of pure lead, while others are of the Plante type made from one integral piece of pure rolled or case lead, and still another type wherein the grid and active material is contained within circular, finely slotted, hard rubber tubing.

The negative plates also vary, depending on the cell in question; some are of the pasted type, others for larger sized cells are either pure lead or made with the active material enclosed in a hard alloy frame with finely perforated sides, while others are of the Plante type similar to the positive plates.

In the pasted type of plates, the grids serve as supports for the active material as well as conductors for the electric current on account of their low resistance.

Pastes are made from the various oxides of lead, and also from finely divided lead and lead sulphate, but the oxides are more generally used.

The pastes most commonly used are made from litharge, PbO, or red lead, Pb_3O_4, or a combination of these two oxides made into a stiff paste with sulphuric acid, which may range from 1.100 to 1.250 in specific gravity.

The paste has about the consistency of mortar and is applied to the grids where it is subsequently converted electrochemically into the active materials of the finished plates.

The pasting of the plates is considered the most secret part of all the manufacturing process. The formula for mixing the paste must be adapted to the physical and chemical properties of the lead oxides which are used.

Plante plates differ essentially from pasted plates, in the fact that the active materials of the former are derived from the body of the plate itself instead of being formed from oxides or other pastes, which are applied to the plate mechanically. The active materials of the Plante plate are obtained by oxidizing the surface of the lead plate or reducing this material to sponge lead.

Separators.

The Signal Section, A.A.R., defines Storage Battery Separator as: A partition of insulating material introduced between the plates of a storage battery to prevent short circuiting.

Adjacent plates are separated in various ways to prevent their being short circuited; in one type of cell by a board and dowel separator, in another type by a combination of grooved wood and glass fibre mat, and still another by a porous rubber separator. Where wood and glass fibre mat are used, the flat side of the wood separators is placed against the negative plate and the glass fibre mat against the positive plate.

Jars.

The Signal Section, A.A.R., defines Battery Jar as: A container for the solution and elements of an electric cell.

The jars are made of glass or hard rubber depending on the type and use of cell. They are rectangular in shape and their dimensions are dependent upon the particular size or capacity and type of element.

Cell covers.

The covers are generally of the same composition and arranged to accommodate the particular jar for which intended.

Electrolyte.

The Signal Section, A.A.R., defines Electrolyte as: The fluid surrounding the elements of an electrolytic cell.

The electrolyte used is of the best quality of dilute sulphuric acid, the specific gravity of which is approximately 1.210 to 1.220. When necessary to add water to dilute the acid, only distilled or other approved water should be used. By "other approved water" is meant that which has been found safe, for use in storage batteries, by chemical analysis.

Capacity.

The capacity of the various cells used is expressed in ampere hours at a given rate of discharge and cell or electrolyte temperature. The sizes most generally used for signal purposes are 6, 12, 40, 50, 60, 75, 80, 100, 120, 160, 200, 320 and 400 ampere hours at the 8-hour capacity rating at 77 degrees F. The particular size depends upon the service for which the cell is required.

*Theory of chemical action.**

Space will not permit an elaborate explanation of the action taking place during charge and discharge. This can be gone into further by the student, if desired, from standard text-books on storage batteries.

In a fully charged cell the active material of the negative plates is metallic sponge lead and is represented by the chemical symbol Pb. The active material of the positive plate is lead peroxide and is represented by the chemical symbol PbO_2. The active material of both plates is in a porous condition. Figure 10 illustrates a charged cell.

The electrolyte is a mixture of sulphuric acid (H_2SO_4) and water (H_2O), mixed in proper proportion to obtain the specific gravity desired. For batteries used in signaling the sulphuric acid and water are usually mixed in a proportion to give a specific gravity of from 1.210 to 1.220. As an example, concentrated sulphuric acid has a specific gravity of 1.835 and water has a specific gravity of 1.000. If it is desired to mix this acid and water to obtain a specific gravity of 1.210 the proportion would be four parts of water by volume to one part of sulphuric acid.

When a lead acid storage cell is being charged or discharged, chemical action takes place within the cell in accordance with the following equation:

$$\frac{\text{Charge}}{Pb + PbO_2 + 2H_2SO_4} = \frac{\text{Discharge}}{2PbSO_4 + 2H_2O}$$

in which:

Pb = metallic sponge lead (active part of negative plate charged).

PbO_2 = lead peroxide (active part of positive plate charged).

$2H_2SO_4$ = sulphuric acid (active part of the electrolyte at full charge).

$2PbSO_4$ = lead sulphate (negative and positive plate at end of complete discharge).

$2H_2O$ = water (electrolyte at complete discharge).

In order to explain the foregoing equation a simple cell having one negative and one positive plate will be followed through a cycle of discharge and charge and the results noted. The left side of the equation $Pb + PbO_2 + 2H_2SO_4$, as it

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* For more complete information see "Storage Batteries" (third edition), by George Wood Vinal.

is written, represents the chemical state of a fully charged cell, as shown in Fig. 10; that is, the active material of the negative plate, as stated before, is now sponge lead (Pb) and the positive plate lead peroxide (PbO_2). In this fully charged condition, there is no acid combined with the active material, all the acid (H_2SO_4) is in the electrolyte within the pores of the plates and surrounding the plates.

As the cell discharges, the acid separates from the electrolyte which is in the pores of the plates, by forming a chemical combination with the active material changing it to lead sulphate. As the discharge continues, additional acid is drawn or diffused from the electrolyte in the pores of the plates and further lead sulphate is formed, and it can be readily understood that as this process continues, the proportion of acid in the electrolyte is decreasing and the specific gravity will gradually decrease. This action will continue until all the acid has separated from the electrolyte and combined with the negative and positive plates to form lead sulphate. The cell is now said to be completely discharged, and can be represented by the right-hand side of the chemical equation: namely, $2PbSO_4 + 2H_2O$. These two symbols show the state or condition of the completely discharged cell.

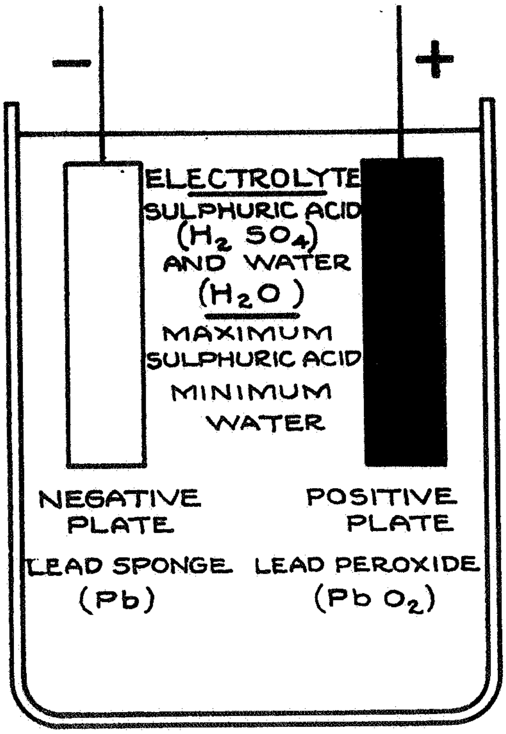


Fig. 10.

Charged Cell.

There are now two plates that are chemically alike. The acid penetrating the pores of the positive and negative plates has combined with the active material of these plates to form lead sulphate ($2PbSO_4$) and only water ($2H_2O$) is left as electrolyte. This state of condition, however, is only theoretical because in actual practice not all the acid in the electrolyte enters into combination with the plates to form lead sulphate, and there is always some acid left in the electrolyte and the plates are not completely converted into lead sulphate as the acid does not penetrate to the center of the plates. The central portion or core of the active material of the negative plates remains metallic lead, and the positive plates lead peroxide. A completely discharged cell is shown in Fig. 11.

The completely discharged cell will be placed on charge to see what action takes place.

As the current from the charging source flows into the positive plate, through the electrolyte and out through the negative plate the SO_4 part of the acid that is combined with the plates in the form of lead sulphate ($2PbSO_4$) will be gradually driven out of the plates into the electrolyte as the charge progresses. Thus, it is seen that as the charge continues and acid is being returned from the plates back into the electrolyte the proportion of acid in the electrolyte increases, the specific gravity of the electrolyte will continue to increase until all the acid is driven out of the plates, back into the electrolyte, and when this state is reached, the cell is at its maximum gravity, and is said to be fully charged.

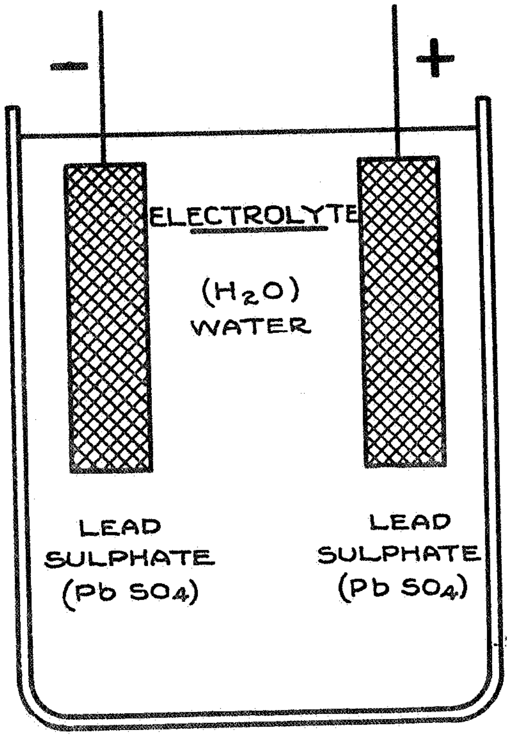


Fig. 11.
Discharged Cell.
(Complete)

Referring again to the chemical equation, it will now be written in the reverse order to show what took place when the cell was charged; that is, when electrical energy was supplied or added to the discharged plates ($2PbSO_4$) and the electrolyte ($2H_2O$); $2PbSO_4 + 2H_2O = Pb + PbO_2 + 2H_2SO_4$. This equation shows that by charging a discharged cell $2PbSO_4 + 2H_2O$, it is restored to a fully charged condition, as is represented on the right side of the equation $Pb + PbO_2 + H_2SO_4$.

The fact that the chemical equation is reversible, that is, can be written forward or backward, indicates that the lead acid cell is "restorable" or in other words, after discharge it can be recharged and used over again.

The chemical equation and explanation as given above represents the reaction which takes place in an ideal or perfect cell when the discharge is carried to completion; that is, when the discharge is carried to where all the active material of the plates is in combination with all the acid of the electrolyte as lead sulphate, and as a result chemical action ceases, and the cell will not give any further energy or current even though it be short circuited on itself.

In the fully charged cell the electrolyte is shown in the equation of reaction as sulphuric acid ($2H_2SO_4$). However, the electrolyte in this case is really a mixture of sulphuric acid (H_2SO_4) and water (H_2O) and the reason that only $2H_2SO_4$ is shown in the equation is because only the acid of the electrolyte and not the water is active in producing chemical energy. During discharge the acid of the electrolyte ($2H_2SO_4$) is ionized or broken up into $2H_2$ and $2SO_4$, the $2H_2$ part going to form water in the electrolyte and the $2SO_4$ part going to form lead sulphate in combination with the lead (Pb) of the plates. The full and complete reaction can be explained by reference to the following equation wherein the electrolyte is a mixture of $4H_2SO_4$ and $2H_2O$:

$$\frac{\text{Negative plate}}{Pb} + \frac{\text{Positive plate}}{PbO_2} + \frac{\text{Electrolyte}}{4H_2SO_4 + 2H_2O} = \frac{\text{Neg. and pos. plates}}{2PbSO_4} + \frac{\text{Electrolyte}}{2H_2SO_4 + 4H_2O}$$

On discharge, some of the sulphuric acid ($2H_2SO_4$) of the electrolyte is broken up into SO_4, SO_4 and $2H_2$. The two SO_4 parts from the acid combine with the negative and positive plates to form $2PbSO_4$, the positives losing O_2 in this reaction. This leaves O_2 from the positive plates to combine with the $2H_2$ left from the acid so as to form additional water $2H_2O$.

At the beginning of discharge, the electrolyte was $4H_2SO_4 + 2H_2O$ and at the end of discharge it is $2H_2SO_4 + 4H_2O$. Thus, it is seen that acid has been taken from and water has been added to the electrolyte during discharge.

On charge the reverse is true and acid is added while water is taken or subtracted from the electrolyte as shown in the equation.

In the reaction just given, the purpose was to show the changes that take place in the electrolyte and, therefore, showing the active material of the discharged plates as $2PbSO_4$ is not strictly correct as the plates are not fully converted to lead sulphate.

In the practical operation of storage batteries the discharge cannot and is not carried so far that the reaction is complete. A cell could not be discharged to where all the active material is converted into lead sulphate if desired, and discharge is usually stopped while there is still some energy left in the battery. Consequently there is always some acid left in the electrolyte at the end of a normal discharge and the central portion or core of the plates is not converted into lead sulphate as the acid does not penetrate sufficiently deep into the pores of the plates to do so. A discharged cell in practical operation is shown in Fig. 12.

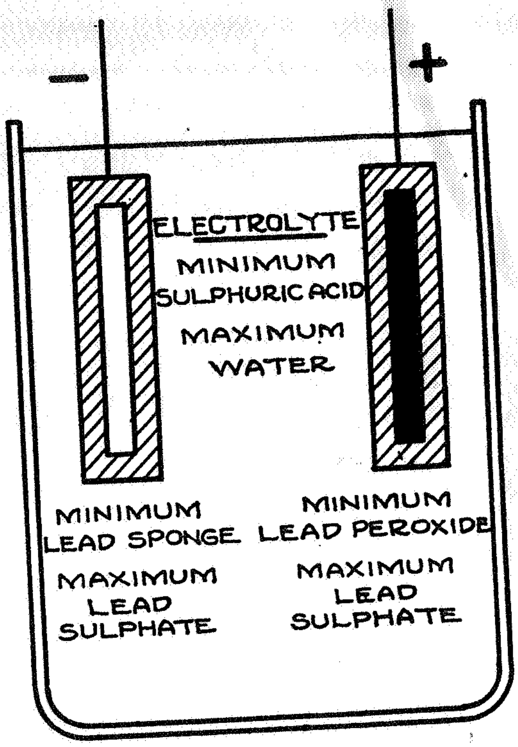


Fig. 12.
Discharged Cell.
(Practical)

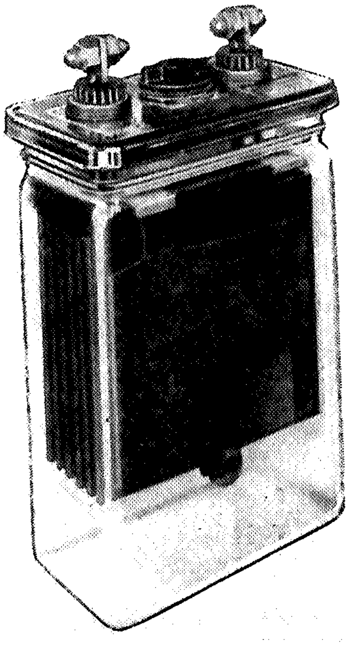
The following equation should make clear the reaction which takes place during a cycle of charge and discharge in the normal or actual operation of a cell:

Charged

$$\frac{\text{Negative plate}}{\text{Maximum Pb}} + \frac{\text{Positive plate}}{\text{Maximum PbO}_2} + \frac{\text{Electrolyte}}{\text{Maximum H}_2\text{SO}_4 + \text{Minimum H}_2\text{O}} =$$

Discharged

$$\frac{\text{Negative plate}}{\text{Minimum Pb} + \text{PbSO}_4} + \frac{\text{Positive plate}}{\text{Minimum PbO}_2 + \text{PbSO}_4} + \frac{\text{Electrolyte}}{\text{Minimum H}_2\text{SO}_4 + \text{Maximum H}_2\text{O}}$$



Typical Sealed Glass Jar Signal Cell.

Maintenance—Lead Acid Type

Lead acid type storage batteries should be installed and maintained in accordance with the following instructions:

Precautions

1. Do not bring an exposed flame, match, candle, cigar, etc., near the battery as this may cause an explosion. Extreme care must be exercised to avoid a spark or flash when changing connections or working on or near a battery.

2. Care must be taken when mixing sulphuric acid and water, to pour acid slowly into water, thoroughly stirring with glass or hard rubber paddle. Never pour water into acid as an explosion may result.

3. To avoid injury caused by electrolyte coming in contact with clothing, a bottle of strong ammonia should be kept in battery room at all times, and in the event of accidental splash of acid on clothing an immediate application of a small quantity of ammonia may neutralize the acid and prevent burning hole in material. A strong alkaline solution of baking soda and water will be found useful for washing the hands after working in electrolyte. In the event of splash of electrolyte in eye, it should be washed out at once with clean water, preferably warm water, and then put one or two drops of olive oil in the eye, and a physician should be consulted as soon as possible. If olive oil is not immediately available, any kind of engine oil is better than none.

Information

1. Lead storage batteries used in railway signal service are of two general types: stationary and portable.

2. Lead storage batteries may be recognized by their lead plates and lead-covered terminals.

3. The positive pole is designated by the dark color of its plates, and/or by a plus (+) mark or red paint, on or adjacent to terminal.

4. The negative pole is designated by the light color of its plates, and/or by a minus (−) mark or black paint, on or adjacent to terminal.

5. During discharge some of the acid is absorbed by the plates; during the charge acid is driven out. When all of the acid is driven out of the plates the battery is fully charged.

6. The specific gravity of electrolyte changes during charge and discharge of cells and indicates condition of charge.

7. The specific gravity and voltage of cells increase during charge.

8. All storage batteries require direct current for charging. If the power supply is alternating current, then this must be changed to direct current by means of a suitable motor-generator set or rectifier.

9. When charging a storage battery, there are three characteristics to consider:

   (a) Amperes, which is the rate of current to be put into the battery.

   (b) Ampere hours, which is the quantity of current put in and is the average ampere rate times the number of hours on charge.

   (c) Voltage, which is the potential required to force the desired ampere rate into the battery.

10. The amount of charge which must be put into a battery to fully charge it is dependent on how much has been taken out and the efficiency of the battery.

Instruments

1. Where practicable, hydrometers and thermometers in accordance with Figs. 13 and 14 should be used. They must be thoroughly cleaned before using.

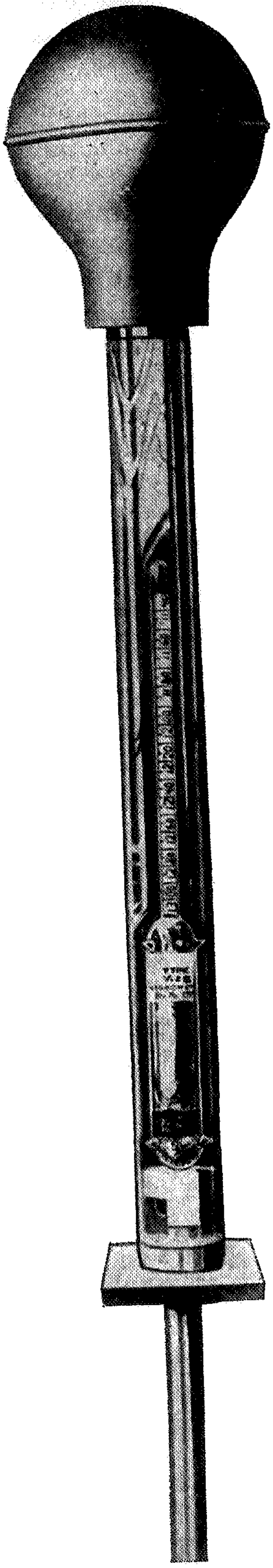


Fig. 13.
Hydrometer Syringe for Lead Battery.

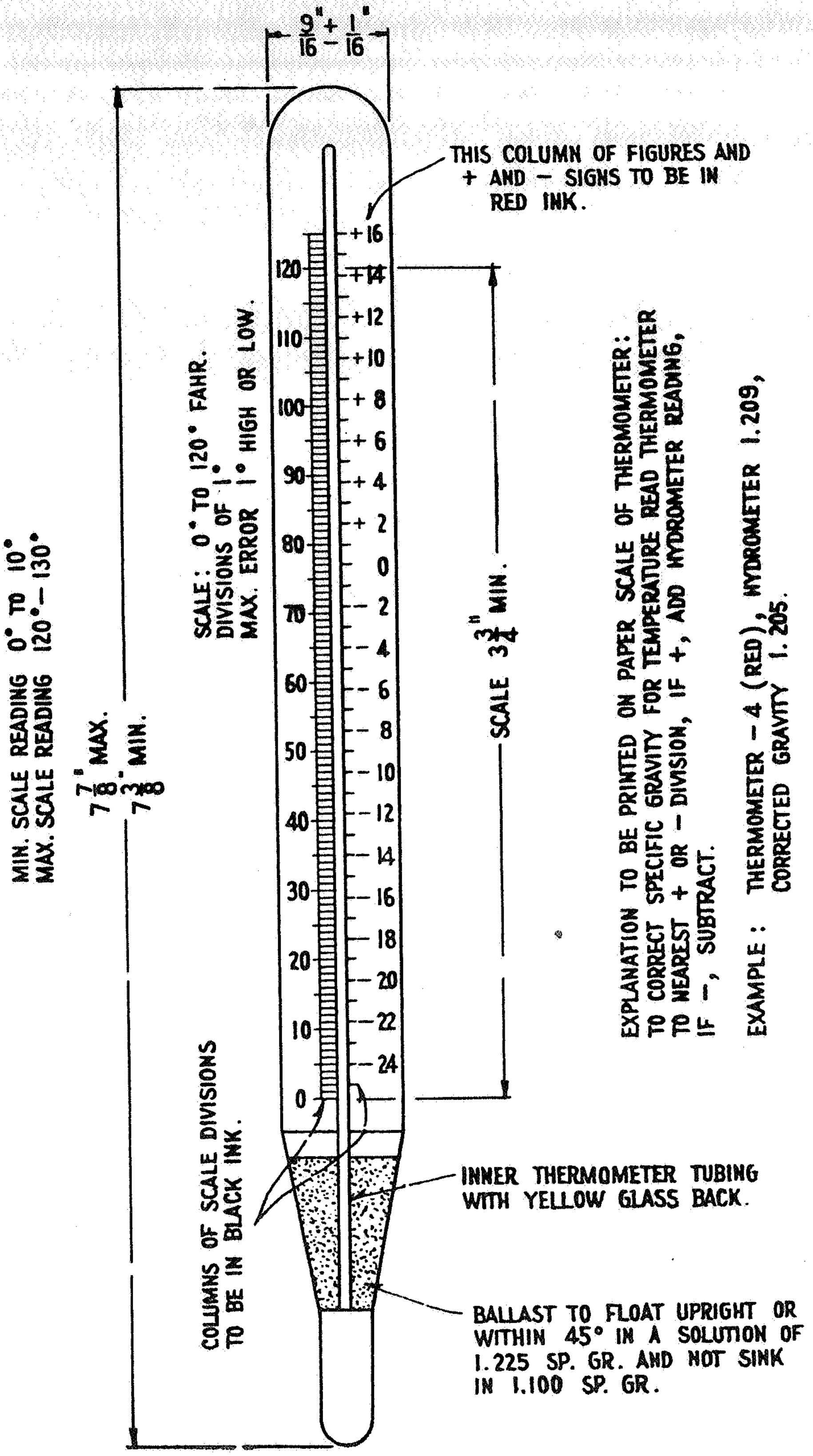


Fig. 14.
Thermometer for Lead Battery.

2. Hydrometers, thermometers or utensils used for nickel-iron-alkaline batteries must not be used for lead batteries.

3. Meters must be in accordance with A.A.R. Signal Section Specification 85, and must be checked frequently and calibrated when necessary.

Installation

1. New cells should be examined for leaky or cracked containers or other damage. Defective or damaged cells should not be used.

2. Lead storage cells used in railway signaling are shipped by the manufacturer, assembled, charged and filled with electrolyte to the proper level on sealed glass jars and also to a level just below the bottom of the filling tube in sealed rubber jars. Manufacturers usually furnish instructions which define proper level. Upon receipt of cells, they should be carefully inspected. If electrolyte has been lost in transit, and level is higher than ½ inch below top of plates, add water or preferably electrolyte of 1.210 specific gravity to bring the electrolyte level up to the proper filling limit in all cells. If the level is lower than ½ inch below top of plates, claim should be made against the carrier for a new cell, as the "spilled" cell is more than likely to have been permanently damaged.

3. Care should be taken in unpacking and handling. Keep the cell right side up. Do not lift or carry it by grasping the cell posts or covers. In removing sealed glass jar cells from packing case, lift the smaller sizes by grasping the cable tied around the cell. After removing the smaller cells from packing case, place hands under jar and carry to desired location. For the larger size cells, the procedure is described on tag attached to each cell, and consists of fastening a webbed belt to the wire wrapped around the cell and pulling the belt under cell by pulling on free end of wire. Then, lift cell by means of belt.

4. Remove temporary short rubber strings, if used, from the holes in top of vent plugs and discard them. Their use is for shipment only.

5. Arrange cells for series connections by having positive terminal of one cell adjacent to negative terminal of adjoining cell. Positive is marked plus (+), negative minus (−). Positive of charging source should connect to positive of battery, and negative of charging source to negative of battery.

6. Covers of cells should be separated from each other and from contact with sides of battery shelter and cells cleated in place.

7. Before bolting the inter-cell connectors to the terminal posts of the cells, scrape the posts bright and clean. Then apply a thin film of No-OX-Id grease (or vaseline), which should also be put on the studs of the bolt connectors. Wipe the inter-cell connector clean, do not use sandpaper, and apply a film of No-OX-Id grease for about 1 inch around the bolt holes.

8. Tighten bolt connections. Wipe off surplus grease. Check connections to see that polarity is correct. Retighten bolt connections.

9. After all connections are completed, take a voltmeter and check each cell to make sure that polarity is correct.

10. Sealed type batteries need not be isolated to prevent damage to other equipment.

11. The battery housing must be kept as dry as possible and if battery housing ventilation is provided, the ventilating means must be such as to prevent entrance of snow, water, dirt, etc.

12. Where racks or shelves are used for supporting cells they must be of sufficient strength to prevent sagging.

13. The storage battery record card should be started at the time the battery is placed in service by recording all required data.

14. All types of batteries lose some of their charge during shipment, and while standing idle. Therefore, before any installation can be considered complete, it should be made certain that the battery is fully charged by giving it a "freshening charge," as covered under that sub-heading immediately following.

Charging methods

Freshening charge.

1. A "freshening charge" means continuing a charge as long as the specific gravity of the lowest cell shows any increase and then for 3 hours after the last increase is shown, if the normal charge rate is used. If the charge rate used is much lower than the normal charge rate, then the 3-hour period should be lengthened in proportion.

2. Where such close supervision as in the paragraph above is not advisable, or where low capacity charging equipment is available, adjust the rectifier output to its safe maximum, which should be at least one-tenth the 8-hour discharge rate of battery. *Example:* On a cell having an 8-hour capacity of 60 ampere hours, 60 ÷ 8 = 7½ amperes which is the 8-hour discharge rate; one-tenth of 7½ amperes is 0.75 ampere or 750 milliamperes. Charge until gravity and voltage rise no higher when these are read once a week.

Caution: Watch solution lines when charging at temporary high rates. Never let them drop below recommended minimum. See "Watering cells," page 44.

3. At the end of the freshening charge, take and record specific gravity, temperature and electrolyte level of all cells for future comparison with later readings.

Floating charge.

1. Having installed and given the cells a "freshening charge" as covered under that sub-heading and with rectifier still adjusted for maximum output as outlined therein, float the battery by reducing the rectifier output in small steps until the voltage directly at the terminals of each cell is 2.15 volts average value under summer temperature conditions. The voltage may vary below and above the average value of 2.15 volts per cell according to traffic conditions, power interruptions, or atmospheric temperature, but should not be continuously above 2.20 or below 2.10 volts per cell, but as stated should average 2.15 volts.

2. Adjust as necessary once a week until the correct voltage is obtained, and make written records of each change in rectifier output, and voltage of each cell, and specific gravity of one cell. The rectifier should not be disconnected when taking voltage readings of the battery.

3. During cold weather the voltage during continuance of low temperatures may be allowed to increase to the following values:

Temperature of electrolyte, degrees F.	60	50	40	30	20	10	Zero
Voltage per cell.	2.19	2.22	2.26	2.30	2.33	2.37	2.40

4. Once a month or oftener, if schedule permits, or as instructed, read and record on the record card the voltage of each cell and specific gravity of one cell. If the gravity tends to decrease, increase the rectifier output. Cell voltages

must be taken while the charging current is being maintained and not after it is reduced or interrupted. During these readings, the charging current should be kept constant.

5. The monthly readings of specific gravity should be reviewed and promptly compared with those taken the previous month. In this manner, prompt action may be taken upon indication of trouble.

6. If the power has been off and the battery has carried the load, upon restoration of the alternating current power supply, adjust the rectifier to the maximum output in order to recharge the battery promptly, and prepare for the next alternating current power failure. Leave rectifier at maximum output or setting until gravity and voltage rises no higher when these are read once a week. During this emergency charge solution lines must not be allowed to drop below minimum recommended values shown under sub-heading "Watering cells," page 44. After fully charging the battery, reduce the output to the proper floating rate, previously found.

7. If upon regular inspection voltage of battery is found to be lower than normal, take a gravity reading of at least one cell and compare with reading on record card when battery was in a fully charged condition. If gravity is found to be more than 15 points low, proceed as in paragraph 6 above.

Note.—The specific gravity varies with temperature as outlined in the following paragraph.

8. The full charge specific gravity is between 1.200 and 1.220 when it is at the proper level, and electrolyte temperature of 77 degrees F. The specific gravity is affected by temperature; therefore, when taking a hydrometer reading, it should be corrected if the temperature of the electrolyte is very much above or below 77 degrees F. For each 3 degrees F. above 77 degrees F., add one point (0.001) to the hydrometer reading, and for each 3 degrees F. below 77 degrees F., subtract one point (0.001) from the hydrometer reading. The correction for hydrometer readings at various electrolyte temperatures are:

Degrees F.

122—add 15 points
107—add 10 points
92—add 5 points
77—no correction
62—subtract 5 points
47—subtract 10 points
17—subtract 20 points

9. Allow a day or more for water to mix with the electrolyte before taking readings. Readings below 1.195 are a cause for investigation.

10. Annually in the Fall in order to determine that cells are fully charged, make regular voltage records, then raise the rectifier output to a maximum obtainable. If voltage rises almost immediately, cells gas freely and uniformly and all cells in battery are of almost uniform voltage they may be considered fully charged and in a healthy condition. If not, proceed as in paragraph 6 above.

11. If a battery is removed from service for any reason whatsoever, it should be put on charge in accordance with procedure in paragraph 3, under sub-heading "Batteries out of service," page 45.

Cycle charge.

1. In the manually cycled charge method, the battery may be charged at any rate that will not produce gassing or bubbling of the electrolyte or a cell temperature in excess of 110 degrees F. As soon as gassing starts, or before, if the temperature reaches this limit, the rate should be reduced and the remainder of charge completed at not higher than the normal charge rate for the particular battery. Do not charge at a rate higher than normal charge rate while the cells are gassing. If charging at constant current is more convenient, the entire charge may be given at the normal charge rate or at a lower rate (the normal charge rate for a glass jar battery is the 8-hour discharge rate or the 8-hour capacity in ampere hours divided by 8). For example, the normal charge for a 120-ampere hour cell at the 8-hour rate and temperature of 77 degrees F. is 120 divided by 8 or 15 amperes. The normal charge rate of a rubber jar battery is given on the name plate of the particular battery, or in the manufacturer's instruction book.

2. The best method of charging the battery will depend on the number of cells in the battery, the time available for charging and the voltage and capacity of the charging equipment. Wherever possible the charging equipment should be permanently arranged so that the rate of charge is automatically (and not manually) tapered to the normal rate of charge or to less by the time the charge is completed.

3. Charge battery at least frequently enough to keep the specific gravity of the electrolyte from falling below the discharge limit in specific gravity or below the limiting voltage corresponding to the discharge rate for the particular type and size cell.

4. If the battery becomes completely discharged, it should be charged promptly and not allowed to stand completely discharged.

5. If the battery requires less than one charge a week, make every charge an equalizing charge.

6. If the battery requires more than one charge a week, charge until the cells are gassing and until the specific gravity of the pilot cell is within 5 to 10 points of the maximum obtained on the last equalizing charge, then stop the charge. Every sixth or seventh charge should be continued into an equalizing charge.

Equalizing charge.

1. An equalizing charge is a charge at a rate not higher than the normal 8-hour rate and continued until all cells gas freely and it is certain that any low cells have been fully charged. Low cells are usually found in the warmest section of the battery: for example, in the top tier of two or three-tier racks or in sections near the heating equipment, and are usually indicated by a lowering in gravity between equalizing charges as compared with adjacent cells. When the charge rate is held constant at the normal rate of charge, the equalizing charge may be considered complete when five consecutive readings of specific gravity and voltage taken at 15-minute intervals show no further rise or increase. If the charge rate is lower than normal, a longer period of maximum voltage and gravity must be obtained. For example, if the charge rate is one half of normal, a 2-hour period of maximum gravity must be obtained.

Two-rate charge.

This method involves the use of a relay to control the output of a rectifier so that normally with relay energized a low charge rate is delivered sufficient to supply the internal losses of the battery and any steady connected load. When relay is de-energized due to battery being called upon to deliver additional current, the high charge rate is automatically applied and this rate continues until such time as the battery voltage has reached its fully charged value when the relay will again energize and restore the low charge rate. The high charge rate generally should be from 10 to 20 per cent of the 8-hour discharge rating of the battery.

The voltage value indicating full charge varies with temperature and the rate at which it is being charged. The two-rate charge relay therefore must be provided with adjustment to allow for the number of cells used and the high rate value of the charging current. Furthermore, the relay must be designed to automatically compensate for varying temperature conditions to which it and the battery are subjected. The manufacturer's instructions furnished with the relay should be followed in making adjustments for temperature and charge rate to insure that the battery is maintained in a fully charged condition at all times.

The advantage of the two-rate charge method over the conventional trickle charge method is that it eliminates the likelihood of either undercharging or overcharging, especially at locations subject to intermittent and varying current drains on the battery. The two-rate charge eliminates the human element involved in manual adjustments of the charging rate at such locations, thereby not only minimizing battery maintenance but also insuring much longer battery life and less probability of a battery failure during an alternating current outage, due to the battery being only partially charged.

Watering cells

1. The electrolyte must be maintained at a level ¾ inch above top of plates, or at electrolyte level mark. Exposure of top of plates to air causes rapid sulphation and will seriously injure plates and wood separators.

2. Add approved water at intervals. Never add water so as to bring the electrolyte higher than the proper level, and add before the level drops below the top of separators. If water is added during freezing weather, stir solution with syringe to mix the water with the electrolyte to prevent the water from freezing.

3. In floating service, if the floating charge adjustment is about right, it should be necessary to add water only twice a year—in the early Fall and in the Spring. This will avoid the danger of freezing.

4. The local water supply is usually suitable, but should not be used unless it has been analyzed and approved.

5. Hard rubber, glass, lead-lined or porcelain vessels only must be used in handling electrolyte or water for lead storage battery use. They should be thoroughly cleaned before using and kept clean while in use.

Renewing or adding electrolyte

1. Electrolyte should be handled carefully as it is injurious to person, clothing, and other foreign matter. (See "Precautions," page 37.)

2. Electrolyte recommended by manufacturer must be used.

3. Special solutions (patent electrolytes), powders, jellies or impurities must not be used.

4. Electrolyte lost due to spillage must be replaced with the proper amount of electrolyte of the same specific gravity as that of other cells of the battery.

5. Never add electrolyte or acid unless some should be spilled and then only on instruction from the Signal Supervisor.

6. Metals must not be used to stir electrolyte.

7. Care must be taken when mixing sulphuric acid and water, to pour acid slowly into water, thoroughly stirring with glass or hard rubber paddle. Never pour water into acid as an explosion may result.

8. Fresh mixed electrolyte must not be placed in cells until it has cooled.

9. If there is any doubt as to the condition of electrolyte a half-pint sample taken at end of discharge (replacing with an equal amount of electrolyte of same specific gravity) should be taken out, placed in a perfectly clean bottle and held for disposition. If all the electrolyte is to be removed, cell should be thoroughly flushed with water approved for storage battery use, before old electrolyte is replaced with new electrolyte.

10. Thermometers, hydrometers or other utensils that have been used for other purposes must not be used for testing and handling sulphuric acid electrolyte, as electrolyte may become contaminated. Hydrometers should be free from attached gas bubbles and cleaned frequently.

Note.—Also see instructions under sub-heading "Batteries out of service," immediately following.

Batteries out of service

1. In the event of jar being cracked or broken, and there is no jar or electrolyte available and the plates and separators have not dried out, immerse element in approved water in a container of wood, glass or earthenware. If a jar and electrolyte are not available within one week, the element should be dismantled, the separators and negative group kept in water, but the positive group allowed to dry out.

2. When a new jar and electrolyte are procured, reassemble element in jar and fill with electrolyte of specific gravity about 10 points (0.010) higher than balance of cells in battery. Give the cell a thorough charge and readjust the specific gravity to normal if necessary before placing back into service.

3. If the use of a battery is to be temporarily discontinued, place it on trickle charge if this can be done, continuously charging it at a rate to maintain the voltage at approximately 2.15 volts per cell. If not, give battery a charge until all cells gas and add water to the proper level to all cells during the charge, so that the gassing will insure thorough mixing and prevent its freezing in cold weather. After the charge is complete, remove all fuses or disconnect battery to prevent its use during the idle period. Make sure all vent plugs are in place. Repeat this procedure at least every 6 months.

4. To put battery into service again, add water if needed, and give battery a thorough or equalizing charge.

General

1. Battery must be arranged to permit access for inspection and cleaning.

2. Proper ventilation must be maintained and housing kept neat, clean and dry.

3. Temperature of battery housing should be maintained as near as practicable to 70 degrees F. and should not be allowed to exceed 115 degrees F. Battery must be shielded from direct sun-rays.

4. Defective jars or containers must not be left in service.

5. Cells showing defects must be taken out of service and held for instructions.

6. Keep the battery, its connections and surrounding parts clean, level and dry, but do not wipe the grease from the seal nuts. Keep the vent plugs in place and tight. If the electrolyte is spilled or surrounding parts are damp with acid, apply a solution of baking soda in the proportion of one pound of soda to one gallon of water and then rinse with clear water and dry. Do not allow the soda solution to get into the cells.

7. Terminal nuts should be gone over and tightened at intervals after the first tightening until they are firmly set, then retightened yearly.

8. If terminals or connectors show any tendency to corrode, scrape the corroded surface clean, wash it with soda water solution, then wipe dry and coat it thinly with No-OX-Id grease, or vaseline. No corrosion will be experienced unless electrolyte is spilled.

9. Water of electrolyte is depleted through gassing that occurs during charge. Water in accordance with instructions under sub-heading "Watering cells", page 44.

10. Excessive gassing causes abnormal deterioration of plates.

11. Care must be exercised to avoid external short circuiting or dropping foreign matter in the cells. Should any foreign matter be found in the cells, it must be removed at once.

12. Batteries must not be repeatedly over or undercharged.

13. The voltage of the charging source must be sufficiently greater than the battery voltage to cause the proper charging current to flow in the circuit.

14. Charging wires to battery terminals must be connected with the positive wire of the charging circuit connected to the positive terminal. Polarity of charging circuit must be determined by meter test.

15. Two or more sets of batteries may be charged together, either in series or multiple, provided the charging rate of each is properly regulated and is within the limits of the charging unit.

16. The prescribed method of charging must not be changed, except by proper authority.

17. If battery has been completely discharged, it should be charged immediately and not allowed to stand completely discharged. Part of a charge is better than none.

18. On batteries charged by the non-floating method the regular charge should be prolonged to constitute an equalization charge every 30 days or after each sixth regular charge.

19. When one or more cells, relative to balance of cells in battery, shows falling off in specific gravity or voltage, deficiency in gassing on equalization charge, or color of plates markedly darker or lighter, the conditions may be caused by short circuit between plates, reversal of charging current, impurities in electrolyte (such as iron, rust, mineral waste, etc., which may cause plates to be darker or lighter in color). Conditions should be immediately corrected.

20. When a cell fails to gas freely or specific gravity fails to rise to proper point on regular charge, after short circuit or other trouble has been remedied, the cell may be brought up to proper condition, where practicable, by disconnecting it from battery during discharge and again connecting into the circuit just before beginning the next regular charge or separately charge cell from another rectifier with the cell in circuit.

Nickel-Iron-Alkaline Type

Description.

This type of battery is more familiarly known as the Edison storage battery and is covered in A.A.R. Signal Section Specification 49. It is radically different from the lead-acid type in that lead does not enter into its make-up, neither is sulphuric acid used as the electrolyte. It was a later development than the lead acid type, having been invented and developed by Thomas A. Edison and placed on the market in its present form about 1908.

The make-up of a complete cell consists essentially of the positive and negative plates, grid separators, container and electrolyte.

Plates.

The positive plates consist of perforated nickel-plated steel tubes made from cold-rolled steel strips in which are placed nickel hydrate and flake nickel in alternate layers, the latter being required to give the active material sufficient electrical conductivity. The finished tubes are 1/4 inch in diameter and 4 1/2 inches in length. After the tubes have been filled they are closed and trimmed. Several tubes are then mounted on nickel-plated steel grids and locked into place to form the positive plate.

The negative plates consist of perforated steel pockets which are also made from nickel-plated cold-rolled steel strips. The strips are folded into a rectangular pocket and loaded with an iron oxide and then closed. These pockets are clamped into place under hydraulic pressure in a nickel-plated steel negative grid to form the negative plate.

Separators.

The positive and negative plates are spaced by hard rubber grid separators which are grooved to fit the edges of the plates. Hard rubber pin or hairpin insulators are placed between the plates to keep them from touching in case of shock.

Thin sheets of hard rubber and side rod insulators are also used to insulate the assembled element from the container on the two sides not already insulated by the grid separators.

Containers.

Cell containers are made of nickel-plated steel or monel metal. Those made of monel metal are so marked on the cell tops. The sides are formed in a mechanical press, the side seam welded and the bottom welded into position. Steel supporting bosses are electrically spot welded on the sides of the container. The nickel-plated steel or monel metal cover has the two pole stuffing box rings and the valve box assembly welded into the three cover openings. After the elements have been placed in the container the cover is welded in place. The valve lid group is hinged to the top of the valve box assembly and employs a hard rubber valve to allow the gas generated during charging to escape but prevents impurities or air from entering the cell.

Electrolyte.

Cells are filled with alkaline electrolyte which is a solution of caustic potash and lithia in pure water. The normal specific gravity is approximately 1.200. The low limit beyond which it is inadvisable to continue an electrolyte in service is 1.160. It is not necessary to take specific gravity readings during charge and discharge as the electrolyte does not change appreciably except by evaporation of water due to gassing. The state of the charge is determined by voltage readings during the charge or discharge periods. The electrolyte is a natural preservative of steel.

Assembly.

The correct number of positive and negative plates for the particular size of cell are mounted on the horizontal connecting rods which pass through the ears of the grid at the top of the plate. The plates of the same polarity are separated from each other by means of nickel-plated steel spacing washers and are locked in place by a lock washer and nut which is screwed over each end of the rod. The groups of positive and negative plates are intermeshed to form the element, there being one more negative than positive plate. After the separators and insulators have been applied to the assembled element, it is placed in the container after which the cover is welded on and the stuffing box washer assembly completed. The cells are then filled with electrolyte and formed ready for use, after which they are assembled in wooden trays and connected by solid wire inter-cell connectors and flexible wire inter-tray jumpers into complete batteries.

The recommended capacities of the cells used in signal work are usually from 12 to 640 ampere hours at the 8-hour discharge rate and usually of either the "AH" or "BH" types. The letter H indicates high type cells. These cells have exactly the same electrical characteristics as the standard, or low, type cells which do not carry the letter H but are built higher so as to hold more electrolyte. They are used in installations where frequent watering is not convenient. Where space is available high type cells are usually preferred. The various capacity cells are designated by a letter and figure such as B4H, A4H, A8H, etc. in which the letter before the number represents the type of plate and the figure the number of positive plates in the cell. The "BH" type plates have one row of 15 standard positive tubes while the "AH" type of plate has two rows of 15 vertical tubes one above the other. At the 8-hour discharge rate B4H cells are rated at 80 ampere hours to 1.10 volt per cell average at solution temperatures from 75 to 85 degrees F. Likewise the A4H cell is rated at 160 ampere hours, the A8H cell at 320 ampere hours, etc.; and so it may be said that the capacity of each type cell depends upon the size and number of plates.

Theory of chemical action.[*]

In the nickel-iron-alkaline cell the effects of the reactions are oxidation and reduction. During discharge the positive active material (a nickel oxide) is reduced to a lower oxide and the negative (metallic iron) is oxidized to form an iron oxide. Reoxidation to the higher oxide of nickel and reduction of the iron oxide to metal are the reactions of charge. In brief, the effect of the reactions can be described as a transfer of oxygen from positive to negative plates during discharge and from negative to positive plates during charge.

The simplified reactions can best be represented as shown in Fig. 15.

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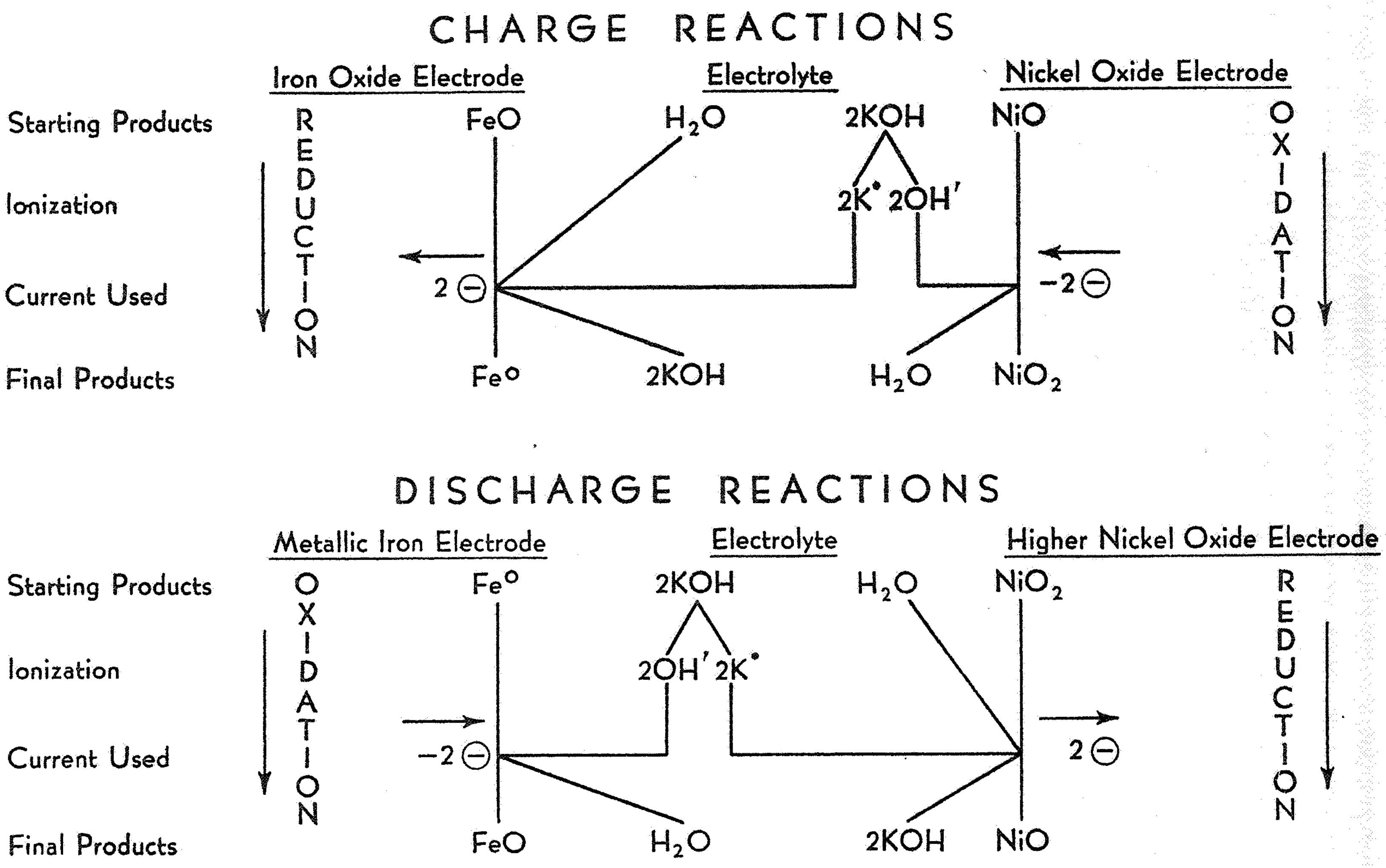
[*] For more complete information see "Storage Batteries" (third edition), by George Wood Vinal.


CHARGE REACTIONS
Iron Oxide Electrode
Electrolyte
Nickel Oxide Electrode
Starting Products
Ionization
Current Used
Final Products
REDUCTION
OXIDATION
FeO
H_2O
$2KOH$
NiO
$2K^{\bullet}$ $2OH'$
2 ⊖
−2 ⊖
Fe°
$2KOH$
H_2O
NiO_2
DISCHARGE REACTIONS
Metallic Iron Electrode
Electrolyte
Higher Nickel Oxide Electrode
Starting Products
Ionization
Current Used
Final Products
OXIDATION
REDUCTION
Fe°
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NiO_2
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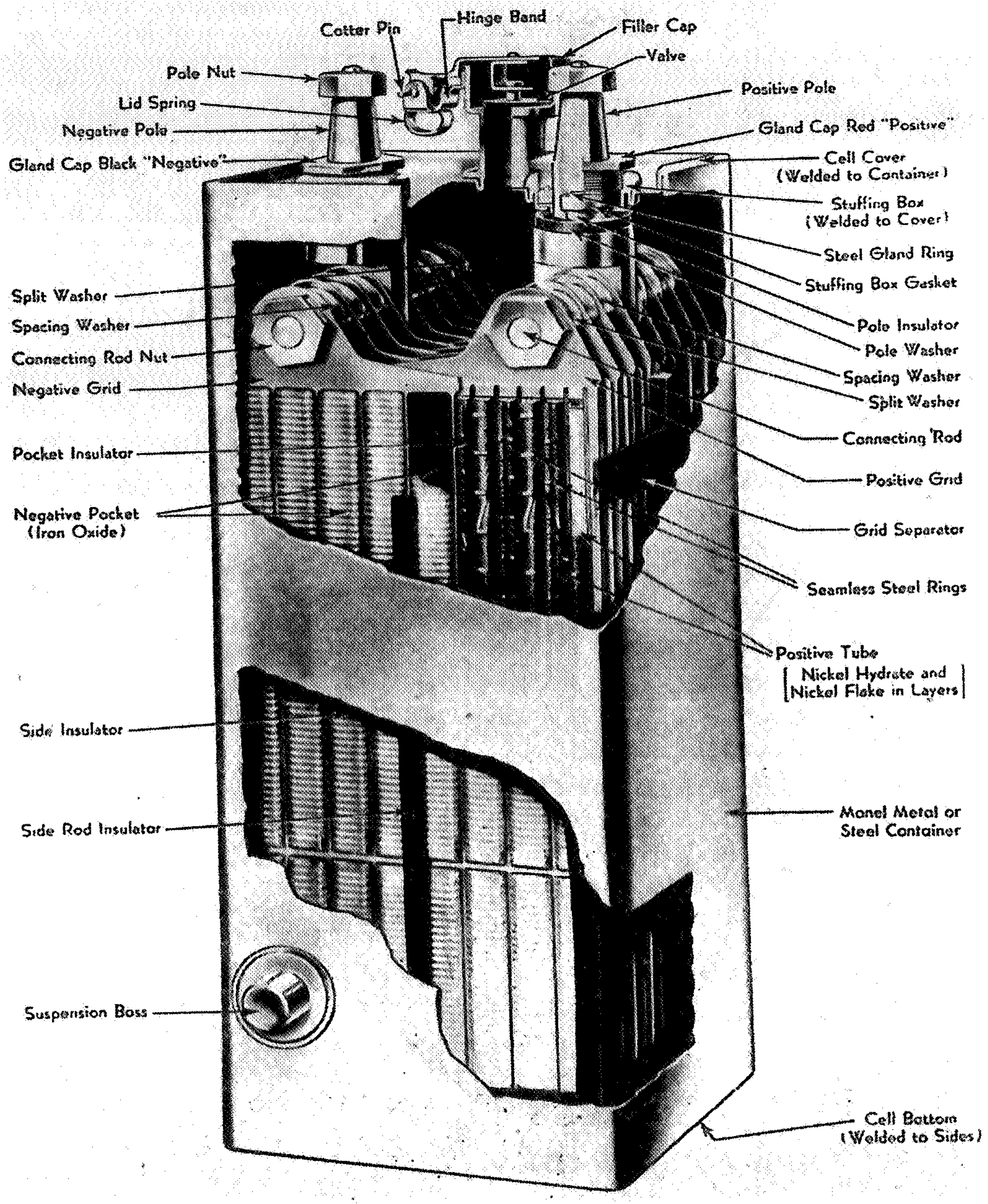
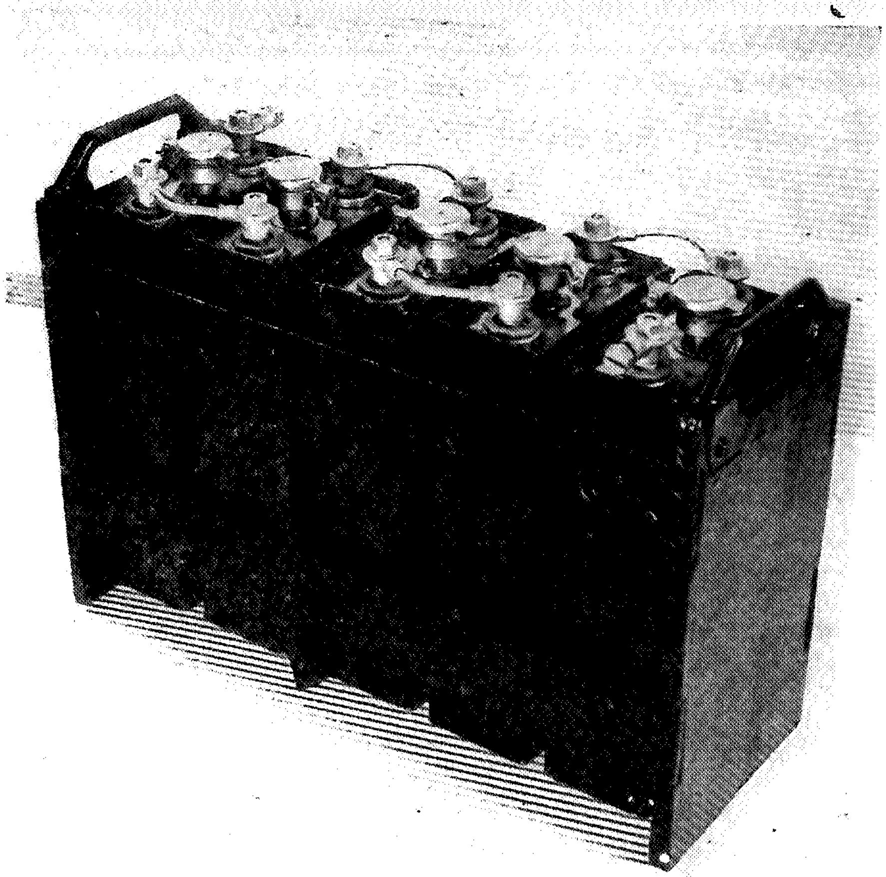
−2 ⊖
2 ⊖
FeO
H_2O
$2KOH$
NiO

Fig. 15.



Nickel-Iron-Alkaline Storage Battery with Container Cut Away to Show Construction Detail.



Nickel-Iron-Alkaline Storage Cells.
Five-Cell Tray Type B4H.

Maintenance—Nickel-Iron-Alkaline Type

Nickel-iron-alkaline storage batteries should be installed and maintained in accordance with the following instructions:

Precautions

1. Do not bring an exposed flame, match, candle, cigar, etc., near the battery as this may cause an explosion. Extreme care must be exercised to avoid a spark or flash when changing connections or working on or near a battery.

2. To avoid injury caused by electrolyte coming in contact with person or clothing, it should be immediately neutralized with a weak acid such as a 5 per cent acetic acid solution or commercial vinegar, or in the absence of these acids plenty of water must be used and then a vegetable oil, such as olive, linseed or cottonseed oil, or an animal oil, such as lard or fish oil. Mineral oil is not of much use as it will saponify and, therefore, will not combine with the potash electrolyte as will the vegetable or animal oils, but may be used in the absence of these to ease any burns, after plenty of water and the weak acids mentioned have been used. Should potash or soda electrolyte get in the eyes or mouth, use pure olive or cottonseed oil.

Information

1. Nickel-iron-alkaline storage cells used in railway signal service are assembled in standard bottomless wooden trays for stationary use or wooden carrying cases for portable use.

2. Nickel-iron-alkaline cells may be recognized by their steel or monel metal containers.

3. The positive pole is designated by a red bushing around the pole and a plus (+) mark stamped on top of container.

4. The negative pole is designated by a black bushing around the pole.

5. The specific gravity of the electrolyte remains practically constant during charge and discharge, but in time will decrease due to gassing. It, therefore, furnishes no indication of the state of charge.

6. The voltage of cells increases during charge and indicates condition of charge.

7. All storage batteries require direct current for charging. If the power supply is alternating current, then this must be changed to direct current by means of a suitable motor-generator set or rectifier.

8. When charging a storage battery, there are three characteristics to consider:

   (a) Amperes, which is the rate of current to be put into the battery.

   (b) Ampere hours, which is the quantity of current put in and is the average ampere rate times the number of hours on charge.

   (c) Voltage, which is the potential required to force the desired ampere rate into the battery.

9. The amount of charge which must be put into a battery to fully charge it is dependent on how much has been taken out and the efficiency of the battery.

Instruments

1. Where practicable, hydrometers and thermometers in accordance with Figs. 16 and 17 should be used. They must be thoroughly cleaned before using.

2. Hydrometers, thermometers or utensils used for lead batteries must not be used for nickel-iron-alkaline batteries.

3. Meters must be in accordance with A.A.R. Signal Section Specification 85, and must be checked frequently and calibrated when necessary.

Installation

1. New cells should be examined for leaky containers or other damage. Defective or damaged cells should not be used.

2. When uncrating, look for the pole nut wrench and disconnecting jack which are regularly supplied with new batteries; also for any other tools which may have been specially ordered.

3. After unpacking the cells, carefully remove all packing material or other foreign substance from cells and trays with particular reference to between and underneath the cells.

4. Check the solution level in every cell. See correct height for each type cell under sub-heading "Watering cells," page 59.

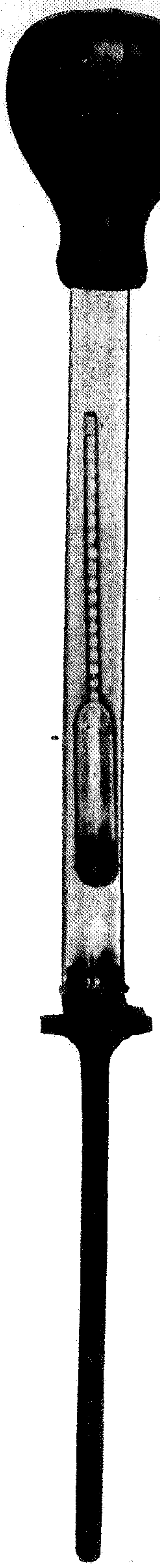


Fig. 16.
Hydrometer for Nickel-Iron Storage Battery.

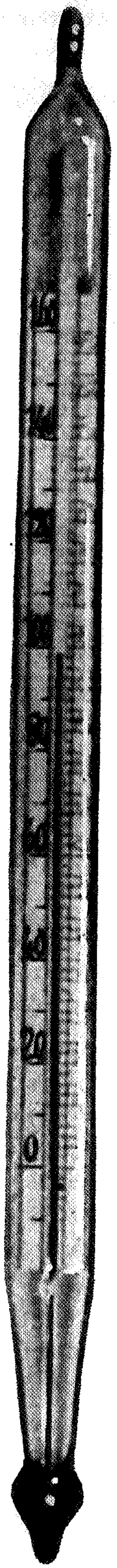


Fig. 17.
Thermometer for Nickel-Iron Storage Battery.

5. If solution level is low it may be because of natural evaporation, in which case add pure distilled water. If solution is low because of spillage during shipment this will be indicated by yellow stains on the inside of the packing case, in which case add "refill electrolyte" (1.215 specific gravity at 60 degrees F.) to raise solution lines to proper level. Do not use "standard renewal electrolyte" (1.250 specific gravity at 60 degrees F.) for this purpose as its specific gravity is too high.

6. If refill electrolyte is not available, add water to bring the solution to proper level until electrolyte is obtained. Thereafter flush with refill electrolyte instead of water until a specific gravity of 1.200 to 1.230 at 60 degrees F. is reached. (For other temperatures refer to Table VII.)

7. If not more than ⅜ inch of electrolyte has been spilled the loss may be replaced with distilled water.

8. Contact surfaces of connectors or jumper lugs and cell poles must be clean to insure good electrical connection. The connector and jumper lugs must be tightened by screwing down the pole nuts after connections are completed. All cell tops must be covered with a light film of battery oil.

9. Batteries are usually shipped in a charged condition and lose capacity if allowed to stand idle. Before batteries are placed in service they must be charged as follows:

10. If less than 30 days have elapsed since cells were shipped from the factory, or since they were fully charged, the cells should preferably be charged at the normal 7-hour* charging rate (see Table VI), until the voltage remains constant for three readings at 15-minute intervals.

11. If more than 30 days have elapsed since the cells were shipped from the factory, or since they were fully charged, the following procedure should be followed:

(a) Discharge cells to 0.5 volt per cell at normal 5-hour discharge rate. (See Table IV.)

(b) Short circuit cells for at least 2 hours in groups of not more than 5 series cells.

(c) Raise solution height to recommended level.

(d) Charge cells preferably at the normal 7-hour* charging rate for 15 hours.

12. Nickel-iron-alkaline batteries need not be isolated to prevent damage to other equipment.

13. The battery housing must be kept as dry as possible and if battery housing ventilation is provided, the ventilating means must be such as to prevent entrance of snow, water, dirt, etc. To provide sufficient air circulation, at least ¼ inch space must be maintained between adjacent battery trays and between trays and adjacent objects.

14. Where racks or shelves are used for supporting cells they must be of sufficient strength to prevent sagging.

15. The storage battery record card should be started at the time the battery is placed in service by recording all required data.

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* If facilities for charging at the 7-hour rate are not available cells may be charged at lower rates as explained under the sub-heading "Cycle charge," page 57.

Charging methods

The following table gives the ratings for various types and sizes of nickel-iron-alkaline cells ordinarily used in railway signal service:

TABLE IV

Type cell	5-Hour Rating* Ampere-hour capacity	5-Hour Rating* Ampere discharge rate	8-Hour Rating** Ampere-hour capacity	8-Hour Rating** Ampere discharge rate
N2	11.25	2.25	12	1.50
B1, B1H	18.75	3.75	20	2.50
B2, B2H	37.50	7.50	40	5.00
B4, B4H	75.00	15.00	80	10.00
B6, B6H	112.50	22.50	120	15.00
A4, A4H	150.00	30.00	160	20.00
A5, A5H	187.50	37.50	200	25.00
A6, A6H	225.00	45.00	240	30.00
A7, A7H	262.50	52.50	280	35.00
A8, A8H	300.00	60.00	320	40.00
A10, A10H	375.00	75.00	400	50.00
A12, A12H	450.00	90.00	480	60.00
A14, A14H	525.00	105.00	560	70.00
A16, A16H	600.00	120.00	640	80.00

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* To 1.00 volt per cell, following a 7-hour charge at 5-hour discharge rate.

** To 1.10 volt per cell, following a 7-hour charge at 5-hour discharge rate.

Trickle charge.

1. In trickle charge service, batteries are continuously charged at a very low current rate only sufficient to compensate for internal losses.

2. Where trickle charging is used, the charging source is continuously connected to the battery which is normally disconnected from the external load usually by means of a power transfer relay.

3. To keep fully charged nickel-iron-alkaline batteries from losing capacity in trickle charge service, they should be initially charged continuously at current rates not less than those shown in Table V.

TABLE V

Type cell	Minimum trickle charge rate, in amperes	Type cell	Minimum trickle charge rate, in amperes
N2	0.024	A6, A6H	0.480
B1, B1H	0.040	A7, A7H	0.560
B2, B2H	0.080	A8, A8H	0.640
B4, B4H	0.160	A10, A10H	0.800
B6, B6H	0.240	A12, A12H	0.960
A4, A4H	0.320	A14, A14H	1.120
A5, A5H	0.400	A16, A16H	1.280

4. From Table V it will be noted that the general rule is to give nickel-iron-alkaline batteries in trickle charge service no less than 2 milliamperes for each

ampere hour of rated capacity based upon their 8-hour capacity ratings shown in Table IV.

5. After initially adjusting the normal charging rate in accordance with Table V, charging should be regulated by voltage as described under following sub-heading, "Charging by voltage in trickle and floating service."

6. When the power supply fails in trickle charge service, the load is usually automatically transferred to the battery by means of a power transfer relay. When power is restored, the battery is automatically relieved of the external load.

7. Following power failures in trickle charge service, charging rates should be temporarily increased until the batteries are again fully charged, after which the charging rate should be reduced again to the normal trickle rate.

Caution. Watch solution lines when charging at temporary high rates. Never let them drop below recommended minimum. (See "Watering cells," page 59.)

Floating charge.

1. In floating charge service, batteries are continuously charged at a current rate sufficient to operate the external load plus enough additional current to compensate for internal losses in the battery.

2. Where floating charge is used, the battery is continuously connected to the charging source and to either a part or the entire external load in multiple.

3. In floating service, charging rates should initially be set higher than necessary and gradually reduced from week to week until consecutive voltage readings of individual cells at normal solution temperatures of from 60 to 70 degrees F. consistently remain between 1.5 and 1.6 volts per cell. From then on, charging should be regulated entirely by voltage as described under following sub-heading, "Charging by voltage in trickle and floating service."

4. Following power failures in floating service, charging rates should be temporarily increased to the maximum capacity of the charging equipment until the batteries are again fully charged, after which charging rates should be gradually reduced again to the normal floating rate as outlined in the preceding paragraph. During this emergency charge solution lines must not be allowed to drop below minimum recommended values shown under sub-heading "Watering cells," page 59.

5. In floating service, it will take longer to fully charge a battery at location than in trickle charge service because part of the charger output in floating service goes to the load or may be required to replace current intermittently discharged to the load. Only that part of the charger output remaining after subtracting the current required to put back into the battery the current intermittently being taken out of the battery and the current which may go direct from the charger to the external load, should be considered as effective charge.

Charging by voltage in trickle and floating service.

1. Before attempting to adjust charging rates to their permanent values in trickle or floating service, it should be known for a certainty that batteries are fully charged. If there is any doubt as to a battery being fully charged, it is recommended that it be given a complete charge either at a central charging station or at its permanent location.

2. After making certain that the batteries at location are fully charged, continuous charging rates should be adjusted from time to time so that individual cell voltages will consistently remain between 1.5 and 1.52 volts per cell in trickle service or between 1.5 and 1.6 in floating service depending upon the charging rate. These voltages per cell of 1.5 to 1.6 refer to adjustments made at normal solution temperatures between 60 and 70 degrees F. Having once made proper adjustments at normal temperatures, charging rates should not be changed as voltages rise or fall due to temperature alone. At normal temperature the voltage may be at the proper value, while if the temperature rises to 120 degrees or above, the cell voltage may drop to 1.4 volts per cell, while at unusually low temperatures the cell voltage may rise to 1.7. The point is to adjust the cell voltage properly at normal temperature and do not change the adjustment when the temperature thereafter is temporarily above or below normal.

3. The charging voltages shown in the following are typical of fully charged cells when being charged at the minimum trickle charge rates shown in Table V:

Solution temperature, degrees F..........	80	70	60	50	40	30	20	10	0
Voltage per cell......	1.48	1.50	1.52	1.55	1.58	1.60	1.61	1.62	1.63

Cycle charge.

1. Cycle charging is where the battery is put on discharge for any given period until a certain capacity has been removed and is then given a charge. In other words, the service requires that the battery be alternately charged and discharged. This cycle charging may be done either by the constant current method or the modified constant potential method.

2. Constant current charging which is generally used in cycle charge service is where the battery is charged at a given fixed rate of current throughout the charge. The recommended rates for charging nickel-iron-alkaline cells are as follows:

TABLE VI

Cell type	Normal charge rate in amperes for 7 cont. hours	Cell type	Normal charge rate in amperes for 7 cont. hours
N2	2.25	A6, A6H	45.00
B1, B1H	3.75	A7, A7H	52.50
B2, B2H	7.50	A8, A8H	60.00
B4, B4H	15.00	A10, A10H	75.00
B6, B6H	22.50	A12, A12H	90.00
A4, A4H	30.00	A14, A14H	105.00
A5, A5H	37.50	A16, A16H	120.00

3. Where less than one third of the normal 7-hour charging rate is used, only that part of the charging current in excess of that required to offset internal losses as shown in Table V should be counted as effective charging current.

4. The foregoing are the "normal" charge rates, and best results will be obtained if this rate is used, although constant current charging can be done at higher or lower than normal rate provided the battery is given an equivalent ampere-hour charge.

5. As a battery is being charged its voltage rises, therefore the charging voltage must be increased if constant current is to be maintained. As a nickel-iron-alkaline battery approaches full charge the voltage required will be approximately 1.85 volts per cell to maintain the charge at normal rate, therefore the charging line must be capable of delivering 1.85 volts at the battery terminals times the number of cells in series. *Example:* a 30-cell battery would require 30 × 1.85 or 55.5 volts. However, the voltage required at the beginning of charge might only be 1.50 volts per cell, so some regulation is required and this is usually obtained by having an adjustable series resistance in the charging line. Adjustments are made periodically during the charge to maintain the rate desired.

6. The length of time which the battery should be charged will depend upon how far it has been discharged prior to charging. Charge until the voltage ceases to rise over a period of 30 minutes with constant current flowing.

7. Cells may be charged at a higher rate than normal, during brief periods of idleness, provided the temperature of electrolyte does not exceed 115 degrees F. Frothing at the filler opening is an indication that the higher rate has been carried too far (if the electrolyte is of the proper height) and the high rate must be discontinued at once.

Modified constant potential charge.

1. Modified constant potential charging is where the battery is charged from a line having a fairly constant voltage. A fixed resistance is used in series with the battery. When a discharged battery is put on the line the current rate is high, then as the charge progresses and battery voltage builds up, the current rate tapers off.

2. It is recommended that nickel-iron-alkaline cells be charged so that the rate will approximately average the normal 7-hour rate. (See Table VI.) To do this requires a voltage at battery terminals of at least 1.85 volts per cell. The series resistance should be determined according to the following formula:

$$\frac{\text{Line volts available} - 1.7 \times \text{number of cells}}{\text{Normal charge rate in amperes}} = \begin{array}{l}\text{Total series resistance required}\\ \text{between line and battery.}\end{array}$$

Example: 20 cells A8 charged from a line delivering 50 volts; $50 - (1.7 \times 20) \div 60 = 0.27$ ohm required. There will be some resistance in leads and switches, therefore allow for this when selecting the resistance unit; the resistance of the unit plus that of the line and switches leading from bus to battery should equal the total resistance required as calculated by the formula. By using a resistance calculated according to the formula, a fully discharged battery will become fully charged in from 6 to 7 hours and the current rate will average approximately normal. The initial and finishing rates will be dependent on the voltage used, according to the following:

Volts per cell....................	1.85	1.90	1.95	2.00	2.05	2.10
Initial amperes, per cent (% of normal rate)...........	167	155	147	140	134	128
Final amperes, per cent (% of normal rate)...........	67	70	74	78	81	84

3. Although best results will be obtained if modified constant potential

charging is done as outlined so that the rates average normal, charging can also be done to averages higher or lower than normal.

4. Ampere-hour meters should be used with modified constant potential charging installations. Where a circuit breaker is used with the ampere-hour meter, this method of charging is fully automatic after the battery has been put on charge. The ampere-hour meter should be set to put in at least 25 per cent excess charge over discharge, the actual value depending upon service conditions.

Two-rate charge.

This method involves the use of a relay to control the output of a rectifier so that normally with relay energized a low charge rate is delivered sufficient to supply the internal losses of the battery and any steady connected load. When relay is de-energized due to battery being called upon to deliver additional current, the high charge rate is automatically applied and this rate continues until such time as the battery voltage has reached its fully charged value when the relay will again energize and restore the low charge rate.

The high charge rate generally should be from 10 to 20 per cent of the 8-hour discharge rating of the battery.

The voltage value indicating full charge varies with temperature and the rate at which it is being charged. The two-rate charge relay therefore must be provided with adjustment to allow for the number of cells used and the high rate value of the charging current. Furthermore, the relay must be designed to automatically compensate for varying temperature conditions to which it and the battery are subjected. The manufacturer's instructions furnished with the relay should be followed in making adjustments for temperature and charge rate to insure that the battery is maintained in a fully charged condition at all times.

Watering cells

1. The electrolyte in a storage battery is necessary to obtain the proper electrochemical action between the plates; this action, plus natural evaporation, gradually uses up the water in the electrolyte. The loss must be compensated for by periodically replenishing with pure distilled water. If the level of the electrolyte is permitted to get too low the plates become exposed and the solution becomes too concentrated. These conditions are injurious to any battery. On the other hand, adding too much water means a weaker solution with possible overflowing during charge.

2. Following are the correct solution levels and the minimum recommended solution levels for nickel-iron-alkaline cells. Best results will be obtained by maintaining solution levels as nearly as possible at the correct levels indicated. Solution levels should never be allowed to fall below the minimum levels shown:

Type of cell	Correct solution height above top of plates, inches	Minimum solution height above top of plates
N	½	Must cover plate tops
B	½	Must cover plate tops
B-High	2¼	1 inch
A	½	Must cover plate tops
A-High	3	1½ inches

3. After adding distilled water in cold weather, thoroughly mix the water with the electrolyte by agitating with hydrometer syringe. This precaution will prevent the water from remaining on top of the electrolyte where it may freeze before mixing.

4. Water used in batteries must be either distilled or from a source which has been tested and approved for storage battery use. Water must be kept only in approved containers.

5. Containers for distilled water for use with nickel-iron-alkaline cells should be of glass, enamel ware, earthen-ware, agate ware, nickel-plated metal, porcelain or rubber and should be thoroughly cleaned before using and kept clean while in use.

6. The frequency of watering periods is governed by the type of service and the type of cell used; naturally, high type cells require less attention than standard (low) type as they hold more electrolyte.

7. When testing cells for electrolyte level, use a heavy walled glass tube about 8 inches long of not less than 3/16 inch inside diameter to which has been tightly fitted a short length of rubber tubing. Insert the tube until the tops of the plates are touched, then close the upper end with your finger and withdraw the tube. The height of the liquid in the tube shows the solution level in the cell. For trickle or floating charge installations this test may be made at any time; in cycle charge installations test before or one-half hour after charging as gassing during charge creates a false level.

8. The use of an electric filling outfit equipped with bell insures the proper watering and saves labor and trouble.

9. Electric filler must be tested before using by making metallic connection between metal collar and tip of nozzle. If bell does not ring, trouble should be remedied before filler is used.

10. When electric filler is used, tank must be perfectly clean, then filled with distilled water. When gravity feed is used, tank should be a sufficient height above top of cells to allow proper flow of water. Insert the nozzle into the cell. With electrolyte at proper height, bell will ring. When bell rings, stop the flow and remove nozzle from cell. Care should be taken not to break rubber insulation on the nozzle as it is liable to cause short circuit. Never use filler for renewing electrolyte.

11. Filler caps must be kept closed except when it is necessary to open them to fill cells, etc.

Cleaning

1. Nickel-iron-alkaline cells require no interior cleaning and because of this the cell tops are welded to the jar resulting in strong and durable construction.

2. The sides, especially between cells, should periodically be freed from dirt, etc., so as to avoid any collection of moisture; this applies also to the bottoms. Where such cleaning has been neglected for a long period, the cleaning job will be easier if a steam jet is used. Persistent neglect of this cleaning item may result in a collection of moisture between cells causing electrolytic action with possible corrosion of the cell container.

3. The tops should be cleaned and given a light film of battery oil applied with an oily rag. This will prevent corrosion and present a neat appearance.

4. The filler opening, inside, including the valve, should be oiled with battery oil; this insures proper operation of the valve and retards incrustation of the salts. Avoid spilling the oil into the cell.

5. The gland caps on the pole pieces should be tightened occasionally especially if leakage is indicated by incrustation around the poles. A special wrench is provided for this purpose. The gland caps are made of hard rubber and care should be used when tightening to avoid damaging.

6. The connectors should be kept firmly seated on the poles to insure good electrical contact. At high charge or discharge rates, loose connectors will get hot. Before connecting, remove any vaseline, grease or dirt from the tapered part of the poles, using fine emery or crocus cloth. A special wrench and jack are provided for removing and replacing connectors.

Painting*

1. When nickel-iron-alkaline cells are manufactured, the sides, bottoms and trays are given a heavy coating of special paint which serves as an insulator as well as a corrosion resistant.

2. In event that repainting of cells or trays is required, the following procedure is recommended:

(a) Remove the individual cells from the tray and place them in solvent naphtha for approximately 1 hour to soften the old paint.

(b) While waiting for the paint to soften inspect the trays for defects making repairs where necessary. After making these repairs, the trays should be painted with special paint furnished by the manufacturer and set aside to dry.

(c) By this time the paint on the cells should be soft enough to remove readily with a stiff bristled brush—never use a steel brush or metal scraper as so doing may injure the nickel-plated surface. The surface of the container should be wiped clean and dry with gasoline or naphtha.

(d) The cells may now be conveniently examined for any defects or necessary replacement of parts. Lid group assembly should be in proper alignment so as to assure free operation of the valve. The gland caps should be screwed down tight, particularly where there is evidence of leakage around the stuffing box assembly.

3. After completing the above, the cells may be brush-painted with, or dipped in, the manufacturer's special paint—both sides and bottom. A thin coating of battery oil should then be applied with a cloth to the cell tops.

4. While the paint is drying, clean the cell poles with fine emery or crocus cloth. After the cells are dry and assembled in the trays, inter-cell connectors may be replaced and nuts set down snugly with the special wrench provided for this purpose.

Specific gravity; condition of electrolyte

1. The specific gravity of the electrolyte does not change materially from charge to discharge. Therefore, readings are not taken to determine the state of charge but occasional readings should be made to determine the condition of the electrolyte.

2. When it is planned to take readings of cycle charged batteries the following method should be followed:

(a) Bring solution level to the proper heights.

(b) Charge battery.

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* Monel metal containers do not require painting but steel containers sometimes do.

(c) Take readings not less than 30 minutes after charging so that the solution is properly mixed and gassing has diminished. In trickle or floating charge service it is only necessary to take gravity readings once each year, preferably in the Fall. Such readings should not be taken until several days after watering.

3. The temperature of the electrolyte will affect the gravity; therefore, determine its temperature at the time of taking readings. Table VII shows the recommended limits of specific gravity for various temperatures.

TABLE VII

Temperature of electrolyte, degrees F.	Maximum recommended gravity	Minimum recommended gravity
110	1.217	1.147
100	1.220	1.150
90	1.222	1.152
80	1.225	1.155
70	1.227	1.157
60	Normal 1.230 Gravity	1.160
50	1.232	1.162
40	1.235	1.165
30	1.237	1.167
20	1.240	1.170
10	1.242	1.172
0	1.245	1.175

4. During the course of the life of the battery the solution may become weakened to a point where the specific gravity reaches the minimum listed in Table VII. When this occurs, the solution should be renewed. Operating a cell which has low gravity electrolyte not only results in poor performance but damages electrodes if continued over a long period.

5. Sometimes impurities get into the electrolyte even though the gravity may not be low; this may affect the performance of the battery. If there is reason to suspect that there are impurities in the solution, the manufacturer will be glad to make an analysis of the electrolyte. Special containers for shipping solution samples will be furnished upon request.

Electrolyte renewal

1. Electrolyte should be handled carefully as it is injurious to person, clothing and other foreign matter. (See "Precautions," page 51.)

2. Electrolyte recommended by manufacturer must be used.

3. Special solutions (patent electrolytes), powders, jellies or impurities must not be used.

4. Solution renewal may be carried on without removing cells from the trays, but since cleaning and painting are usually done at the same time, it is suggested that cells be removed from trays for solution renewal. The following procedure is recommended:

(a) Discharge cells to 0.5 volt per cell at normal 5-hour rate. (See Table IV.)

(b) Short circuit cells for at least 2 hours in groups of not more than 5 series cells.

(c) Remove cells from trays.

(d) Pour out and discard exhausted electrolyte.

(e) The cells should then immediately be filled with standard renewal electrolyte (1.250 specific gravity at 60 degrees F.) to the normal level, and charged at the normal 7-hour rate for 15 hours. (See Table VI.) The cells are then ready for service.

5. If cells do not come up to capacity after electrolyte renewal they should be discharged to zero volts per cell at the normal 5-hour discharge rate then short circuited for 2 hours in groups of not more than 5 cells. After this treatment they should be charged at normal 7-hour charging rate for 15 hours.

6. Thermometers, hydrometers or other utensils that have been used for other purposes must not be used for testing and handling potash electrolyte, as electrolyte may become contaminated. Hydrometers should be free from attached gas bubbles and cleaned frequently.

Treatment for lower than normal voltage on discharge

1. Where batteries give capacity at a voltage which is reasonably steady and sustained, but lower than normal for the existing discharge conditions, while at the same time the gravity of the electrolyte is correct, they should be given the following treatment:

(a) Discharge cells to 0.5 volt per cell at normal 5-hour discharge rate. (See Table IV.)

(b) Short circuit cells for at least 2 hours in groups of not more than 5 series cells.

(c) Raise solution height to recommended level.

(d) Charge 15 hours at normal 7-hour charging rate. (See Table VI.)

(e) Discharge at normal 5-hour discharge rate to approximately 1.0 volt per cell average.

(f) Charge 7 hours at normal 7-hour charging rate.

(g) Discharge at normal 5-hour discharge rate until all cells are below 1.0 volt per cell.

(h) If satisfactory improvement is not obtained, repeat above procedures (a) to (g), inclusive.

Batteries out of service

1. Either new or used nickel-iron-alkaline cells may be stored for an indefinite length of time after the following recommended procedure. This procedure should be followed if cells are to be out of service more than 2 months:

(a) Discharge cells to 0.5 volt per cell at normal 5-hour discharge rate. (See Table IV.)

(b) Short circuit cells for at least 2 hours in groups of not more than 5 series cells.

(c) Raise solution height to recommended level.

(d) Store in a cool, dry place.

2. When nickel-iron-alkaline cells, which have been in storage, are to be put in service, the following procedure is recommended:

(a) If required, clean the cells and connectors. (See sub-heading "Cleaning," page 60.)

(b) Bring solution height to proper level. (See sub-heading "Watering cells," page 59.)

(c) If the cells have been stored in a completely discharged condition as directed above, charge them for 15 hours at the normal 7-hour charging rate. (See Table VI.)

(d) If the cells have been standing in a partly or fully charged condition, discharge to 0.5 volt at the normal 5-hour discharge rate; then short circuit for not less than 2 hours in groups of not more than 5 cells.

(e) Charge for 15 hours at normal 7-hour charging rate.

3. The foregoing procedure should ordinarily restore the battery to regular working condition. If not, repeat treatment outlined under foregoing subheading "Treatment for lower than normal voltage on discharge."

General

1. Battery must be arranged to permit access for inspection and cleaning.

2. Proper ventilation must be maintained and housing kept neat, clean and dry.

3. Temperature of battery housing should be maintained as near as practicable to 70 degrees F. and should not be allowed to exceed 115 degrees F. Battery must be shielded from direct sun-rays.

4. Defective containers must not be left in service.

5. Cells showing defects must be taken out of service and held for instructions.

6. Keep the battery, its connections and surrounding parts clean, level and dry.

7. Terminal nuts should be kept tight at all times.

8. Water of electrolyte is depleted through gassing that occurs during charge. Water in accordance with instructions under sub-heading "Watering cells," page 59.

9. Care must be exercised to avoid external short circuiting or dropping foreign matter in the cells. Should any foreign matter be found in the cells it must be removed at once.

10. The voltage of the charging source must be sufficiently greater than the battery voltage to cause the proper charging current to flow in the circuit.

11. Charging wires to battery terminals must be connected with the positive wire of the charging circuit connected to the positive terminal. Polarity of charging circuit must be determined by meter test.

12. Two or more sets of batteries may be charged together, either in series or multiple, provided the charging rate of each is properly regulated and is within the limits of the charging unit.

13. Cells may be discharged to zero voltage without harmful effect, but in regular operation must not be discharged below 1 volt.

14. Nickel-iron-alkaline cells may be overcharged occasionally at high rates or continuously at very low rates without injury. Avoid overcharging at high rates as a regular practice as it causes excessive loss of water from the electrolyte, overheating, over-gassing, and loss of electrolyte salts with the result that more watering and more frequent electrolyte renewal is required in addition to impairing the performance of the battery.

15. By undercharging is meant operating a battery which is seldom brought up to full charge. Naturally, this is poor practice as a battery of a given capacity is applied to a job to do certain work and if the battery is not properly charged it cannot deliver its rated capacity. Failures may be caused by undercharging but are seldom caused by overcharging.

16. The prescribed method of charging must not be changed, except by proper authority.