HOW PRIMARY AND SECONDARY BATTERIES WORK

MAINTENANCE AND REPAIR

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STUDY SCHEDULE NO. 32

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. The Primary Cell .... Pages 1-10

You learn what the common dry-cell A batteries are and how they operate. You also study the air-cell type of A battery. Answer Lesson Question 1.

☐ 2. The B Battery .... Pages 10-14

The B battery supplies the high voltage and low current needed for the plate circuits of vacuum tubes. You study the different types of B batteries, how they are built, and how they are used. Answer Lesson Question 2.

☐ 3. The Lead-Acid Storage Battery .... Pages 15-21

The lead-acid battery is the most frequently used type of secondary (rechargeable) battery. You learn its construction, chemical action, and electrical characteristics. Answer Lesson Question 3.

☐ 4. Charging of Storage Batteries .... Pages 21-28

When and how to charge a storage battery is the important subject of this section. Answer Lesson Questions 4, 5, 6, and 7.

☐ 5. Storage Battery Defects and Their Repair .... Pages 28-33

This is a highly practical section in which you learn about the troubles that occur in storage batteries and how to avoid them. You learn how to take apart, repair, and re-assemble a storage battery. Answer Lesson Questions 8 and 9.

☐ 6. The Edison Storage Battery .... Pages 33-36

The Edison cell is the other type of secondary cell. Its construction, operation, and use are discussed. Answer Lesson Question 10.

☐ 7. Start Studying the Next Lesson.

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HOW PRIMARY AND SECONDARY BATTERIES WORK

MAINTENANCE AND REPAIR

The Primary Cell

BATTERIES of all types are used in radio communications. In addition to the familiar dry-cell type A and B batteries, both the lead-acid and the Edison storage cells are found in many radio applications. As a radio man, you will have to maintain these batteries—this is just as important an operating step as the care and operation of the transmitting and receiving equipment itself.

In time of emergency, batteries are used aboard ship as auxiliary power for the radio transmitters and receivers. They must, therefore, be maintained in the highest state of fitness, ready without fail, for handling an SOS or other urgent messages. The radio man is given the responsibility of maintaining the battery "log" or record, testing cells to determine their state of charge, and charging the batteries. He should also be able to disassemble, inspect, make certain repairs, and re-assemble storage batteries.

Batteries have many important uses aboard aircraft, both civil and military. In addition to frequently being the chief source of radio power, batteries are used for intercommunications, lights, instruments, and for certain auxiliary power.

"Walkie-talkie" transmitters and receivers operate on batteries. In civilian life it is a fairly common sight to see a man with a "walkie" transmitter moving through a crowd, making announcements as he goes. Somewhat similar outfits are also used by surveyors, explorers, miners, and by the Forest Service.

Radio sets for fishing boats, motorcycles, and police cars are usually run from batteries. Batteries are also used in the tiny, expendable transmitters of the "weather tracing" radiosonde balloons, and as a C-bias in some transmitters.

In some of these instances, dry-cell primary batteries supply the current; in others, secondary storage cells of the lead-acid or the Edison (nickel-iron-alkaline) types maintain a steady flow of d.c. power.

All types are important; all must be operated and maintained with proper precautions. It is the purpose of this Lesson to instruct you in the care of batteries and the methods of using them so that a maximum of trouble-free operating life can be realized.

EVOLUTION OF THE DRY CELL

Primary cells are not new. In 1798 Allesandro Volta constructed what is now called a "voltaic pile." This crude affair was made of several "sandwiches" of acid-moistened blotting paper between thin plates of copper and zinc, stacked into a pile.

Volta found that a definite voltage was developed between the top and the bottom of the pile, and that the more sandwiches he used, the higher this voltage became. Furthermore, when he attached a wire from the top of the pile to the bottom, a certain amount of direct current would flow along the wire.

Volta also discovered that in the process of generating electricity, the zinc plates were gradually eaten away. The copper plates, however, were not visibly affected.

In honor of his discoveries, the standard unit of electromotive force, the volt, was named for Volta.

► Volta's pile contained all the elements necessary to a primary cell as we know it today. Any two *different* metals immersed in an acid or salt solution will show a difference of potential between them. Any such combination of these three elements constitutes a primary cell.

Such a source of pure direct current is called a "primary" cell because it requires no outside source of energy. When one or both of the metals and the acid solution are decomposed and reunited in different chemical forms, they cannot be used in a battery again. Once discharged, a primary cell must have its elements replaced or be discarded.

In 1868, Georges LeClanché produced a more practical primary cell. He used zinc, as did Volta, but chose carbon instead of copper for the second metal. He immersed these in a solution of sal ammoniac or ammonium chloride. Such solutions are now commonly called "electrolytes."

In earlier cells, gas bubbles had accumulated so rapidly on the carbon or copper plate that the working area was reduced, and the cell current dropped to near zero after a few minutes of operation. This effect was called "polarization."

► LeClanché believed a chemical means of removing the offending gas bubbles was possible. Accordingly, he added another chemical, manganese dioxide, to the electrolyte. His idea was successful. Primary-cell performance was greatly improved. Similar chemical "depolarizers" are now used in modern cells.

The modern "dry" cell is a modification of the LeClanché cell. Of course, this cell is not dry in a strict sense of the word, for the electrolyte is absorbed in a porous material or paste. Metallic zinc is used to make the container, and, therefore, it serves not only as the negative electrode, but also as the case. To make the cell "dry," the case is sealed across the top.

DRY CELL CONSTRUCTION

Dry cells are made in two basic forms. The most familiar type is the cylindrical, general-purpose cell. Another type is made in the form of a flat "layer." Either type may be used individually for radio vacuum tube filaments, for telephone and annunciator work, for ignition purposes, or they may be combined to form various B and C batteries. Aviation, war, and the consequent demand for lightweight or portable transmitters and receivers have brought out many new forms. These cells are made in a variety of sizes and shapes, but they all are basically the same in the principle of operation.

Materials. Every dry cell, of course, must be made of two different metals and an electrolyte. A drawn or soldered zinc can ordinarily forms the case for the entire cell as well as serving as the negative terminal. A centered carbon rod core is the positive terminal. The space between this core and the zinc case is filled with an electrolyte paste mixture of ammonium chloride, manganese dioxide, and powdered carbon. A tar or asphalt sealing compound is poured around the top of the can to hold the carbon rod firmly in place, and to prevent evaporation.

Actually, more than a hundred different materials are used in manufacturing a dry cell. Some are of importance only in processing methods used to produce a commercial product inexpensively and well. For example, both flour and starch are used by most manufacturers as binding mediums. Various glues are also used for the same purpose. Graphite, calcined coke, acetylene black, zinc chloride, and other chemicals also may be found in a dry cell. These materials are incidental to construction only, though they may have a slight influence on the ruggedness and the service life of products of different manufacturers.

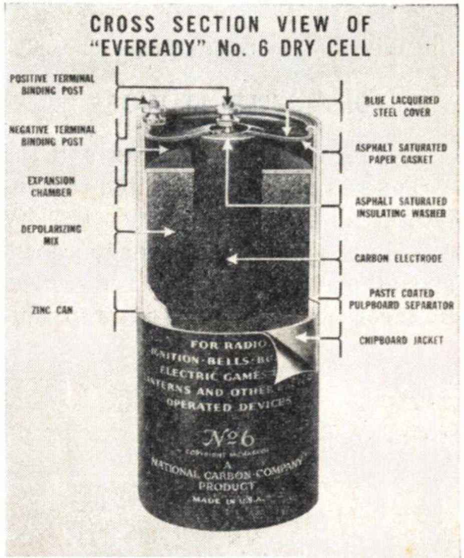
Most dry cells are well built. All nationally advertised brands of dry batteries used for radio work contain materials of good quality, and if used as specified by their makers, will satisfy the purchaser.

Parts. To understand how the relative components of a dry cell are put together, let us study the cut-away drawing in Fig. 1, which shows a common, No. 6, dry cell.

The zinc can serves as a container for the entire cell; it is one of the two dissimilar metals in contact with the electrolyte, and becomes the negative terminal. Note the terminal binding post attached at the top of the can. This can is not pure zinc, but is of a good quality commercial grade that gives satisfactory service without being too expensive for wholesale manufacture.

► It is this zinc can that is attacked and eaten away by the electrolyte, and becomes, upon complete cell discharge, a thin shell largely reduced to pulpy, whitish zinc ammonium chloride.

The carbon post, centered in the can, is the other dissimilar metal exposed to the electrolyte. It becomes the positive electrode. This carbon rod is made of compressed carbon particles, bonded together, and then baked at a very high temperature. Unlike the zinc can, the carbon is little affected by the chemical action that takes place within the cell while electricity is being generated.



Courtesy National Carbon Co.

FIG. 1. Cut-away view of a standard dry cell.

The electrolyte "mix" is the third essential element in a primary cell. The electrolyte is a solution of ammonium chloride and zinc chloride. This liquid, however, is absorbed by two powders; manganese dioxide, which serves as a depolarizer by reducing the accumula-

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tion of hydrogen gas bubbles at the surface of the carbon rod, and powdered carbon, which tends to reduce the electrical resistance of the electrolyte itself.

The precise formula of the mix varies with different manufacturers, but all mixes are prescribed to reduce polarization by absorbing excessive gas, and to keep the cell internal resistance as low as possible.

The expansion chamber is necessary to provide room for expansion of the mix due to temperature changes.

DRY CELLS AT WORK

The faces of the zinc can and the carbon rod are exposed to the electrolyte at all times. Even when the dry cell is not supplying current to a load, a small portion of the zinc is dissolved by the electrolyte and passes into solution. As it does, however, a negative charge is left behind on the zinc can, and if no current is drawn, this charge builds up to the normal cell potential which prevents any further chemical action. *If it were not for impurities or leakages, a cell without a load would last indefinitely.*

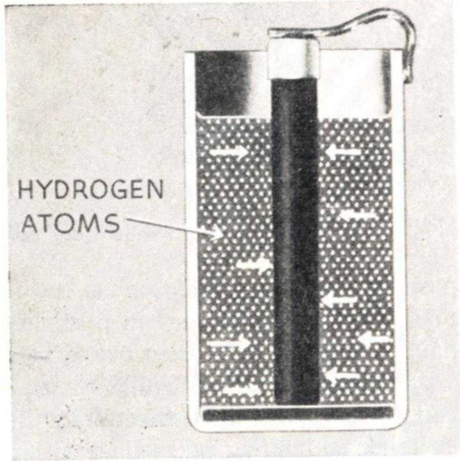

FIG. 2. Formation of hydrogen gas by chemical action.

Chemical Action Under Load. When a load is attached, and the cell delivers current, *electrons* flow from the zinc can, through the load and back to the electrolyte by means of the carbon rod. Flow of current tends to dissipate the charge on the zinc can so that it is again attacked by the electrolyte, and the charge is constantly replenished. *Current in the load is maintained by the zinc dissolving in the electrolyte.*

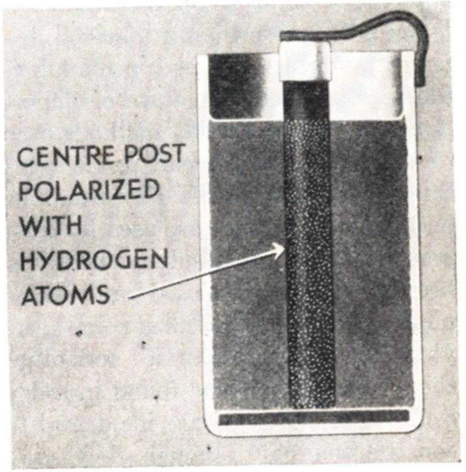

FIG. 3. How hydrogen screens the positive electrode when no depolarizer is used.

Several chemical reactions take place during this process, however. Hydrogen gas is released as the zinc dissolves; part of the electrolyte is affected by the electrons arriving at the carbon rod thus forming ammonia gas, and this ammonia immediately reacts with the water of the electrolyte to form ammonium hydroxide.

As the hydrogen is in "ion" form* and has a positive charge, it is attracted by the negative electrons arriving at the carbon rod electrode. Consequently, hydrogen atoms tend to migrate and flow toward the carbon rod as shown in Fig. 2.

If no provision is made to dispose of these excess hydrogen particles, they will accumulate rapidly at the carbon rod surface, as shown in Fig. 3, and effectively break the contact of the rod with the electrolyte. This is called "polarization," and presents a very serious problem, for it can make the internal resistance of a cell so high that the cell is useless.

Depolarization. With the manganese dioxide added to the electrolyte mix, the concentration of hydrogen is greatly reduced. This is brought about chemically by the excess oxygen of the manganese dioxide combining with the hydrogen to form water. The relative reduction of gas with such a "depolarizer" is shown in Fig. 4. Without such a gas-removing agent, no practical cell would be possible.

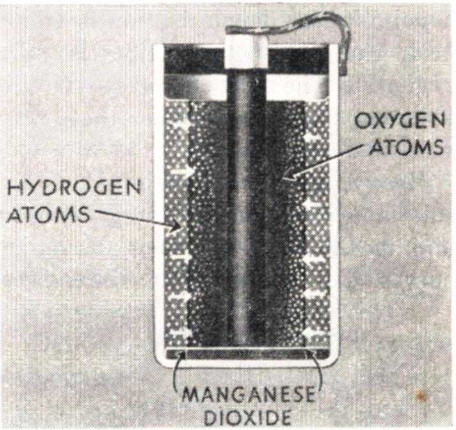

FIG. 4. How depolarizer oxygen unites with the hydrogen to form water.

Although depolarization lengthens useful cell life, such life is not indefinite. As the zinc is consumed, waste products accumulate which slow up the current-producing action. Also, as the available oxygen from the manganese dioxide becomes depleted, the depolarizing action becomes less effective; all of which eventually brings the working life of any cell to a normal end. See Fig. 5.

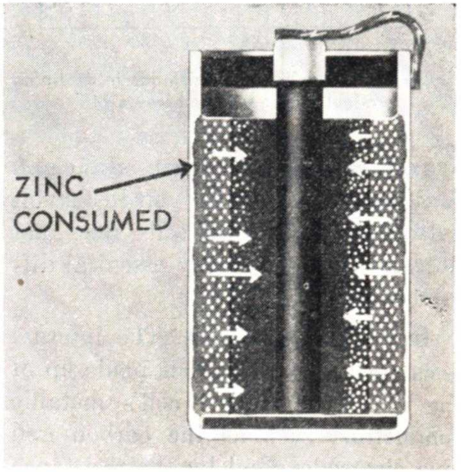

FIG. 5. Zinc consumed, depolarizer depleted at end of life.

DRY CELL CHARACTERISTICS

In order to understand the use of dry cells, we must first study their characteristics.

Voltage. The voltage of any type of primary cell depends entirely on the nature of the electrodes and the electrolyte used.

All dry cells are constructed to produce the maximum voltage obtainable from a given primary type. The average initial open-circuit voltage from a new, zinc-carbon dry cell is 1.5 volts. Sometimes this voltage may be as high as 1.6 volts or as low as 1.4 volts. In normal use, however, 1.5 volts is the average value, and it is this figure that is used in computing the available volt-

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*When one or more electrons have been removed from an atom, the remainder is called a positive "ion."

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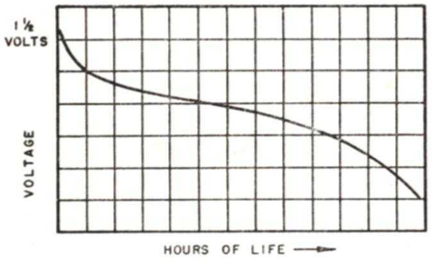

FIG. 6. Effect of internal resistance in dropping terminal voltage as cell wears out.

age of a cell as a circuit source of e.m.f. A difference of from 0.1 volt to 0.2 volt between two *unused* cells does not necessarily indicate any essential difference in quality.

Internal Resistance. The internal resistance of a dry cell is made up of the resistance of the cell's metallic conductors, such as the carbon and zinc electrodes, and by the resistance of the electrolyte itself. It is a combination of these resistances that gives the resulting internal cell resistance.

Cell resistance varies somewhat under different load conditions. When the cell is not in use, its internal resistance is very low—a few hundredths of an ohm. As a cell deteriorates, its resistance tends to increase.

The amount of current delivered to a circuit depends on the internal cell resistance as well as on the load resistance. In general, as the cell is depleted, its internal resistance becomes higher, and less voltage is available at the cell terminals. The characteristic manner in which voltage decreases with operating hours is shown in Fig. 6.

Service Life. The service life of a cell cannot be stated correctly as a single definite value, because the amount of electrical energy that can be withdrawn varies under different conditions. A cell functions at different degrees of efficiency, depending upon the amount of the load imposed upon it.

If the current drain is too heavy, the depolarizer cannot completely take care of the hydrogen that develops; also, other reaction products generated in the cell cannot diffuse fast enough to allow the current to continue to flow at its original rate. For these reasons, the working voltage drops off, and the cell does not function properly.

With a low discharge rate, the depolarizer is able to function efficiently, and diffusion takes place as it is necessary. If the withdrawal of energy is too slow, however, we run into another source of depletion. Self-deterioration, caused by impurities, detracts from the cell's available energy, and so reduces the total service life.

Between different conditions of service—the heavy and the light, the steady and the intermittent—there is a point where depolarization is at its best, and self-deterioration is still negligible. The most effective service is obtained from a cell under these service conditions.

Heavy, light, and medium loads result in a difference in energy output and in the shape of their discharge curves. The characteristic differences are shown in Fig. 7, which is based on actual discharge curves for general-purpose, 6-inch dry cells under different severities of discharge.

DISCHARGE CURVES

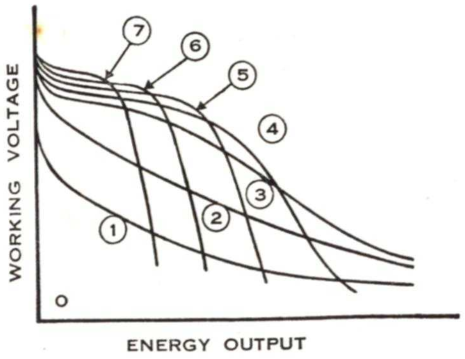

FIG. 7. Effect of average current drain on total energy output.

Curve 1 shows the heaviest withdrawal of energy. The effect of incomplete depolarization is evidenced by the rapid decline in voltage from start to finish. The elapsed time of this test may have been only a few hours, which will be recognized as severe usage.

Curves 2, 3, and 4 represent progressively less and less severe service. Depolarization becomes better as illustrated in curves 2 and 3, and in curve 4 a highly efficient performance has been attained. The cell efficiency represented by curve 4 is the best shown in the diagram. Here the voltage is well maintained during most of the cell's life, and begins to decline rapidly only when it is near the stage of final exhaustion. The elapsed time shown in curve 4 probably represents six months or a year.

Curves 5 to 7 show the effect of self-depreciation in reduction of output energy. The lightest service curve 7 covers a period of perhaps two or three years. It is easy to understand how self-losses would affect the service output over such an extended period.

The longer a cell can remain idle without self-depreciation, the longer is the period of time over which this cell can maintain maximum efficiency when operating under a load. The better a cell's ability to depolarize, the higher will be the permissible current drain for maximum efficiency.

► One of the very important factors affecting the service life of dry cells is the minimum, or "cut-off," voltage at which they are allowed to operate. In general, the lower the cut-off voltage used, the more completely the cell's energy is extracted. But this is not always so.

In Fig. 8A is a service curve for a cell that is subject to moderate conditions such as in radios. Here, the advantage of using a low cut-off is very marked. As is always the case with a discharge curve of this shape, the lower the cut-off, the greater is the advantage in service life. Also, the more severe the service, the greater this advantage becomes. For these reasons the cut-off may be set as low as 0.8 volt in such use.

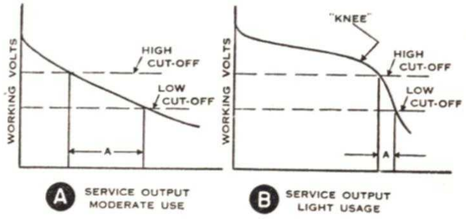

FIG. 8. Use of high and low cut-off voltages in different kinds of service.

If the service is light, however, as in telephone or other applications having low average drain, the advantage of the low cut-off is not so pronounced. See Fig. 8B. Here the "knee" of the curve occurs above 1.0 volt, and there is little gain in using a low cut-off value. Accordingly, for light service, a relatively high cut-off of 1.0 volt per cell is usually established.

HOW TO USE DRY CELLS

There is a suitable dry cell for every normal radio circuit requiring this type of power source. To be used properly, a single cell, or a combination of cells, must be capable of supplying the required current when connected to a specified load for a definite length of time.

Ampere-Hour Ratings. Cells are usually given an ampere-hour rating

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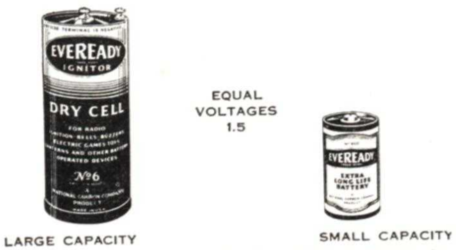
by the manufacturer. To say that a given cell has a 5-ampere-hour rating does not mean, necessarily, that it will deliver 5 amperes for 1 hour, unless such high current drain does not exceed the specified maximum current rating recommended by the maker. It does mean, however, that the cell will probably deliver nearly 0.5 ampere for 10 hours, or still more closely, 0.25 ampere for 20 hours.



Courtesy National Carbon Co.

FIG. 9. Cells of equal voltage but very different ampere-hour capacity.

► The ampere-hour capacity of a cell is determined principally by the area of zinc and carbon exposed to the electrolyte. For this reason, the standard general purpose dry cell shown in Fig. 9 can deliver a much *greater current* during an *equal length of time,* than can the small, flashlight cell in the same figure; or the larger cell can supply an *identical current* for a *longer time.*

To use dry cells correctly, the maximum current drain and the ampere-hour capacity given by the manufacturer should be considered. Cells should never be used where the recommended maximum current is exceeded, for the stated ampere-hour capacity cannot then be realized.

How to Connect Dry Cells for Increased Voltage or Current. For large currents where one cell is not sufficient, several cells can be connected in parallel as shown in Figs. 10A, 10B, and 10C. In each case, the total load current is divided equally between the separate cells, and each cell's share should be less than its maximum current rating.

If voltage greater than 1.5 volts is necessary, several cells may be connected in series as shown in Figs. 11A and 11B. The total voltage is equal to the sum of all the cell voltages, or 1.5 times the number of cells in series. The *same* load current, however, flows through all cells, and should not exceed the value recommended for a single cell.

If increased voltage and additional current capacity are both needed, a number of cells can be connected in various parallel-series combinations. Two such arrangements are shown in Figs. 12A and 12B.

Testing Dry Cells. Reading the terminal voltage of a cell by means of a voltmeter when no current is being delivered, gives no usable information in regard to the condition of the cell. Dry cells that are absolutely worthless will often show full voltage without load.

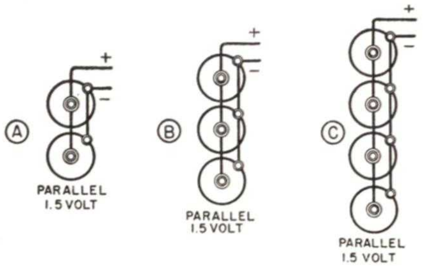


FIG. 10. Cells in parallel have greater current capacity, but voltage is not increased.

► Standard 6-inch cells are tested by subjecting them to "dead-short" conditions. This is done by *momentarily* connecting an ammeter directly across the cell terminals. If the cell is in good condition, a current in excess of 30 amperes will be indicated. A current of 20 amperes means that about half-life remains; if only 5 to 10 amperes is noted, the cell should be discarded.

A word of caution: *Do not leave the ammeter connected any longer than necessary to read the amperage.* The excessive current may damage the cell.

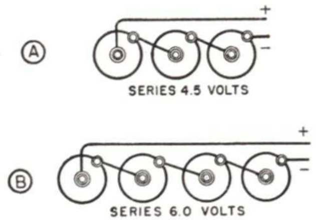


FIG. 11. Voltage is raised by cells in series, but current capacity is the same as for a single cell.

It is essential for the cell to be tested at a temperature of about 70°F, because a low temperature reduces chemical activity within the cell, and causes abnormally low readings to be obtained. Warming to room temperature restores proper current readings.

Intermittent Use. It is not always easy to determine, particularly for intermittent service, what the ampere-hour capacity of the cells should be.

A good measure of severity of service is the length of time required to exhaust a cell. Severe service includes heavy current drains, and continuous or long discharge periods. These conditions must be avoided if efficient use of a cell's energy, and good voltage maintenance during discharge are to be obtained.

A relatively heavy drain is permissible if the discharge periods are very short, or if the rest periods constitute a very large proportion of the time. Continuous use is not inefficient if the drain is very light.

If service conditions permit the cell to last three months or longer, efficient service can be expected. If the service extends over a year or longer, some energy will be wasted through self-deterioration.

THE AIR-CELL BATTERY

The Eveready "air-cell" battery is not, strictly speaking, a dry battery, but it is manufactured and shipped dry, and many of its applications are those for which dry batteries were formerly used.

Unlike the dry battery, the air-cell battery does not need an oxygen-bearing chemical depolarizer such as manganese dioxide. Instead, it gets oxygen directly from the air through a special carbon "lung."

A cut-away view of an air cell is given in Fig. 13. Two zinc plates, acting as the negative electrode, are placed one on each side of a large, porous carbon rod that serves as both the positive electrode and the lung. The electrolyte in which the zinc and carbon are immersed is a water solution of caustic soda.

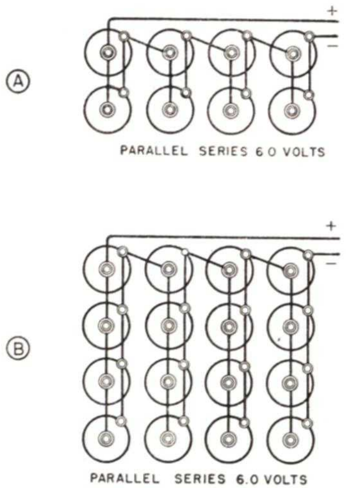


FIG. 12. Parallel-series combinations raise both voltage and current capacity.

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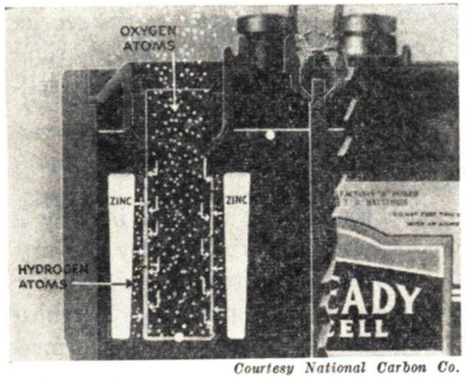

Courtesy National Carbon Co.

FIG. 13. How oxygen from the air is drawn in by the carbon lung to depolarize an air-cell.

The drawing shows how the hydrogen atoms, normally collecting on the carbon rod, are dispersed by being combined with oxygen, flowing in from the atmosphere, to form water.

As the supply of atmospheric oxygen is unlimited, the air cell is continually depolarized, and its voltage is relatively constant. An initial voltage of 1.25 volts per cell gradually drops to about 1.0 volt per cell near the end of service life. Fig. 14 shows a characteristic voltage discharge curve for an air cell. Observe that it is much flatter than the characteristic curve of the dry cell, indicating that the air-cell voltage is maintained near the maximum until almost the end of service.

When manufactured, the air cell is kept dry. For electrolyte material, a large caustic soda block is included. The cell is activated by the addition of pure water. Because it is shipped and stored dry, there is practically no depreciation before activation begins.

Air-cell batteries are used for telephone switchboards, train dispatching, railway signalling, radio, and similar services where the current drain does not exceed 0.65 ampere. They are made in single-cell units and in batteries having two cells in series. Capacities of 300 and 600 ampere-hours are available.

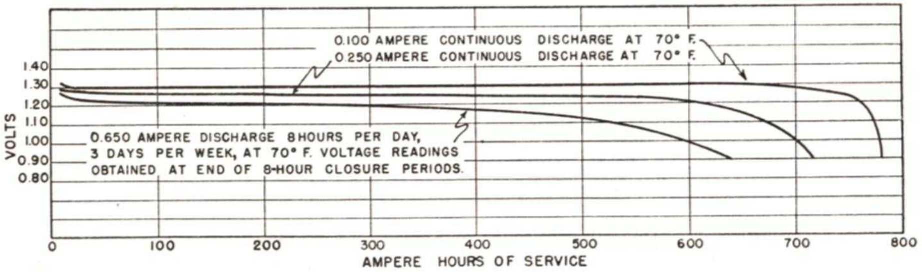

FIG. 14. Air-cell terminal voltage variation over service life.

The B Battery

The conventional 22½- or 45-volt "B" battery, commonly used for plate power in radio receivers and transmitters, is generally made by connecting 15 or 30 zinc-carbon dry cells in series, and packaging the complete assembly in a single cardboard or metal case.

These individual dry cells, of course, are much smaller than the standard general purpose cell, but they contain the same metals and use a similar electrolyte mix.

B BATTERY CONSTRUCTION

A typical cylindrical B-battery cell is shown in Fig. 15. Note that the construction is very similar to the standard general purpose cell and that it is almost identical to the ordinary flashlight cell.

Cylindrical Cell B Battery. One type of 45-volt B battery is made like the one shown in Fig. 16A. Observe in the cut-away drawing how the individual cells are connected in series and encased in the battery "block."

A vertical view of a 30-cell, 45-volt B battery is given in Fig. 16B. The method of making cell connections is shown.

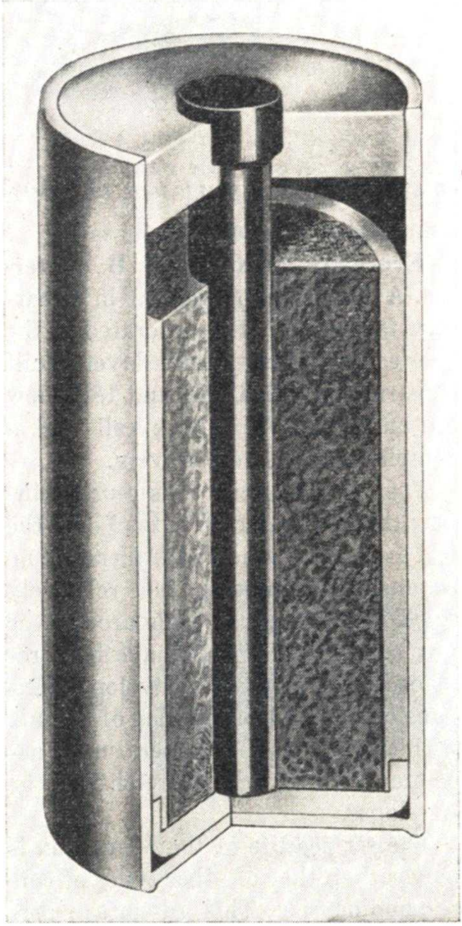

FIG. 15. Individual cell used for B battery element.

Courtesy Burgess Battery Co.

FIG. 16A. Cut-away view of an early 22½-volt B battery.

Space was not important in the early home receivers with which these batteries were used. The cells occupy less than half the space taken by the entire battery as a whole. This sort of battery is still being manufactured, but since it makes such inefficient use of the total battery volume space, it is being superseded by a form of "layer-built" battery.

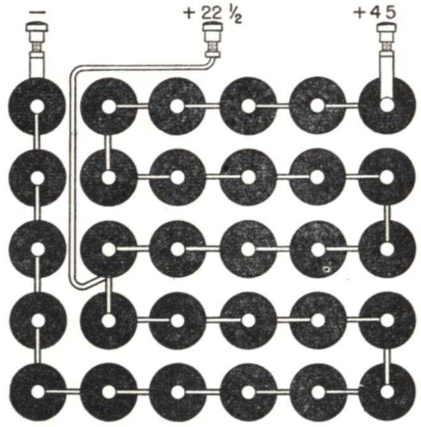

FIG. 16B. Method of connecting 30 cells to make a 45-volt B-battery block.

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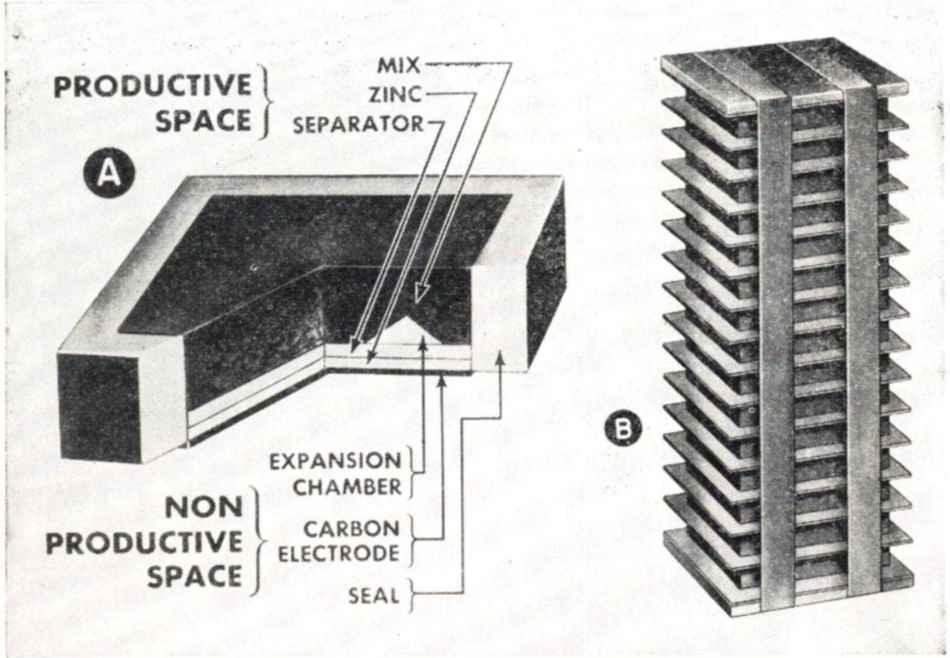


FIG. 17. Showing how layer-built cells are constructed and then stacked in tiers to form a B battery.

Layer-Built B Battery. In the layer-built battery, flat, wafer-like cells are used. These are laid one on top of the other in the same manner as in the early "voltaic pins."

A cross-sectional view of an individual layer cell is pictured in Fig. 17A. The manner in which a number of such cells are stacked to make a complete B-battery block is shown in Fig. 17B. The decrease in lost or wasted space is quite apparent.

Layer-built construction has several advantages in addition to reduction in size. For instance, the zinc is completely covered by the carbon backing it up so that all the zinc surface can be exposed to the electrolyte without danger of electrolyte leakage or loss.

Another advantage is the elimination of all soldered connections between the cells. Notice that the cells are in direct contact, and hence, there is less possibility of defective or noisy intercell connections developing.

Eveready "Mini-Max" B Batteries. A further improvement in B battery fabrication is incorporated in the Eveready "Mini-Max" layer-built construction. Figs. 18A and 18B show an individual Mini-Max cell and a completed stack, respectively.

The carbon electrode is much thinner; the mix materials extend over the full area of the zinc plate; there are no expansion chambers; the relatively thick insulating disk seals around the former layer-built cells have been replaced by thin, elastic envelopes. Expansion of gases, or swelling of the mix with the increase of temperature is accommodated by the "stretch" of the envelopes.

The service life of the Mini-Max is longer than that of other types of corresponding size. This advantage permits the design of the miniature radio receivers, such as the "personal" radio sets, and other electronic devices of lighter weight and smaller dimensions, thereby greatly increasing their convenience.

Mini-Max Characteristics. The Mini-Max battery was designed for portable radio equipment where current drains are moderate, where usage approximates two to four hours daily, and cut-off voltages are not very high. Under these conditions it has very good service life.

A Mini-Max battery will last approximately twice as long as batteries of ordinary round cell design and comparable size; but it cannot be expected to maintain its great service advantage if it is in continuous use with high drains and high cut-offs.

If used under adverse conditions, the Mini-Max still has an advantage in being highly resistant to break-down and internal short circuits, at high temperatures sometimes met in practice.

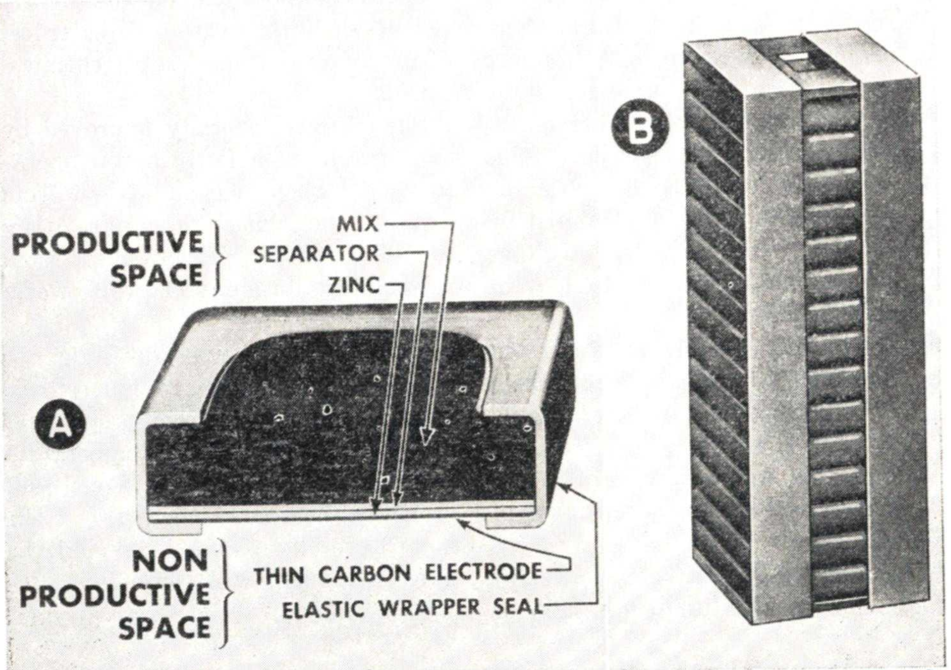
Another good characteristic is the dependability and good shelf-life behavior, especially in warm climates where Mini-Max batteries have shown satisfactory performance.

USE OF B BATTERIES

Just as with dry cells, a B battery should never be subjected to current drain greater than the maximum recommended by the manufacturer.

If a battery of a given size is not adequate for a given application, a larger one should be used; or several B batteries may be connected in parallel, or in parallel-series combinations.

Heavy current drain is permissible if long rest periods are allowed between times. Batteries, of course, last longer with light current drain, but this drain should not be so light that self-deterioration becomes an important



Courtesy National Carbon Co.

FIG 18. Showing Mini-Max improvement in layer-building by elimination of insulating disc seals.

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factor. The same general rules given for the intermittent use of dry cells also apply to B batteries.

Cut-Off Voltages. The amount of service life a B battery has is determined, to a great extent, by the cut-off voltage it is permitted to reach. Compared to the standard dry cell, B battery current drain is relatively low, so it is common practice to use an equivalent high cut-off voltage value. Generally a value of 20 per cent below 1.5, that is, 1.2 volts per cell is used. This allows about 18 volts for a 22½-volt B-battery block or 36 volts for a 45-volt battery. In some applications, however, the voltage may be allowed to drop as low as 15 or even 12 volts for each 22½-volt battery.

Testing B Batteries. A B battery should be tested by measuring the voltage of the battery when it is connected to the usual load. If the voltage under load is below the desired cut-off point, the battery should be discarded.

► For batteries on the shelf, and where proper load is not convenient, a dummy load resistor can be shunted across the battery terminals, and the voltage measured while full load current is flowing. The proper value for the dummy resistor can be calculated by dividing the *nominal* battery voltage by the maximum recommended current drain in amperes.

► A B battery should never be tested by shorting its terminals to produce a spark. Likewise an ammeter should never be used to test B batteries. To attempt this would result in serious damage to the battery or destruction of the meter.

Storing of B Batteries and Dry Cells. The service life of a battery or dry cell begins when it is connected into a working circuit. If left idle on the shelf, however, it will gradually deteriorate, and after a long period it will become useless.

This self-depletion is the unavoidable result of very slow chemical reactions and moisture changes which take place within the cells themselves. These changes are caused principally by leakage or evaporation, and by "local action" between impurities and the electrodes or electrolyte.

Cells of good quality and reasonable size, such as a No. 6 dry cell, should remain usable for two years or longer if they are not subjected to abusive storage conditions. Smaller cells have a proportionately shorter shelf life. In the case of very small cylindrical cells, the useful period of shelf life may be only a few months. This means that B batteries do not ordinarily keep as well as large dry cells.

Continued high temperature greatly reduces shelf life because of greater loss of moisture and accelerated chemical action.

Shelf life is generally improved by storing cells at a fairly low temperature, but when cells are taken from storage and put into service they should, if possible, first be held at room temperature for a day or two to warm them.

Extreme low temperatures do not cause permanent damage, but cells or batteries do not perform properly if they are too cold. If the temperature falls as low as —10° F., a cell will probably become inoperative. Cells that have been frozen should be warmed and they will regain their original efficiency.

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The Lead-Acid Storage Battery

A "storage battery" consists of a group of two or more secondary cells. A secondary cell differs from a primary cell in that a secondary cell can be recharged and used over and over again, but a primary cell must be discarded after it is exhausted.

When a *primary* cell is exhausted, the zinc electrode has been eaten away by the electrolyte and converted into useless chemical compounds. The chemical reactions are not reversible. Once the zinc metal has been consumed, a primary cell must be thrown away.

When a *storage* cell is discharged, however, the chemical reactions which occurred to generate electrical energy may be made to reverse themselves and restore the cell to its original condition. This reversal of chemical action is called "charging," and is brought about by attaching the cell to a source of direct current so that the current is made to flow back through the cell in the opposite direction to that in which it flowed during discharge. After charging, the cell again behaves as a new cell.

This cycle of charge and discharge can be carried on for a great number of times. Since a secondary cell actually stores and returns part of the energy put into it, the term "storage" cell is an appropriate name for it.

Several kinds of storage batteries have been developed, but only two types are of commercial importance. They are the lead-acid battery, which is the familiar type used in automobiles, and the Edison alkaline battery.

These two types of storage batteries have very little in common. They differ in method of construction, in materials used, and in the electrolyte employed. Their performance is not identical, and ordinarily the two types of batteries are not used under the same conditions.

We shall see in this Lesson how these two types are constructed, the best method for using and charging them, and the care of storage batteries in general.

LEAD-ACID CELL CONSTRUCTION

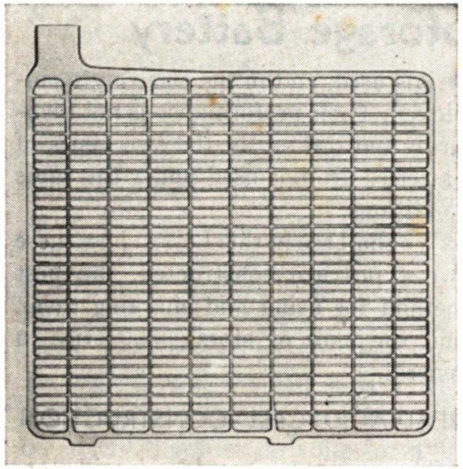
The simplest type of lead-acid storage cell consists of a negative electrode plate of pure lead, and a positive electrode plate of lead peroxide both immersed in an electrolyte of sulfuric acid diluted with water.

The internal resistance and ampere-hour capacity of a storage cell depend upon the area of the electrode plates. To keep the resistance as low as possible, and to provide adequate current capacity, commercial cells are usually constructed with a number of positive and negative plates in parallel. These plates are inter-leaved with adequate insulation, to provide very short current paths through the electrolyte.

Although it is possible to form the electrode plates by electrical means, this method is not commercially practical. Positive plates are made by pressing brown lead peroxide into a lead and antimony skeleton called a grid. This rectangular grid structure is shown in Fig. 19.

Negative plates are formed in a similar way as shown in Fig. 20, but the material pressed into the grid is pure, gray, spongy lead.

For the insulation between the plates, grooved cedar wood separators, such as shown in Fig. 21, are used. In



Courtesy Willard Storage Battery Co.

FIG. 19. A positive plate which was formed by forcing lead peroxide into a metal grid.

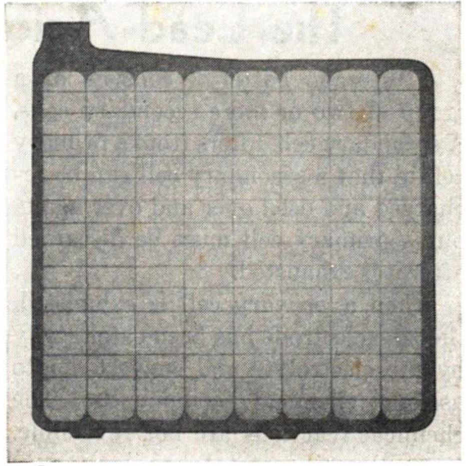


FIG. 20. A negative plate of spongy lead pressed into the grid.

the better-grade batteries, separators of glass wool or rubber may be substituted, and instead of being grooved, they may be slotted, perforated, or porous.

For connection in parallel, positive and negative plates are "leaded" to two post straps.* See Figs. 22A and 22B. These separate assemblies are then sandwiched together with the separators in place to form a completed cell unit as shown in Fig. 22C.

Each storage cell when fully charged will have an e.m.f. of slightly over 2 volts. For the standard 6-volt battery, therefore, it is necessary to connect three cells in series.

Three complete cells are inserted into a hard rubber case or a glass container similar to the one shown in Fig. 23. Each compartment is acid-tight, and there is no internal electrical path between the cells. Ridges along the bottom of the case help to support the cell plates.

Each cell is given a cover, like the one shown in Fig. 24, through which the electrode post straps protrude, and each cover is provided with a removable vent plug through which gasses can escape, and water or acid can be added to the cells.

Finally, the cells are connected in series by lead-burning cell connectors,

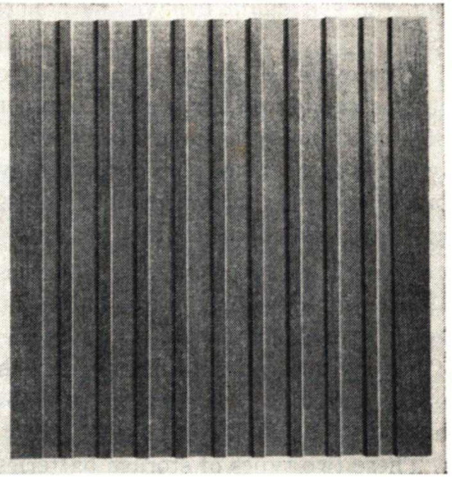


FIG. 21. A wood separator for insulation between plates.

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*The term "leaded" means that a source of heat, such as a blowtorch, is used to melt the lead at the two points to be joined, and the mixing of the molten lead at these points produces the mechanical and electrical connections needed. This is also known as "lead-burning" or "lead-welding."

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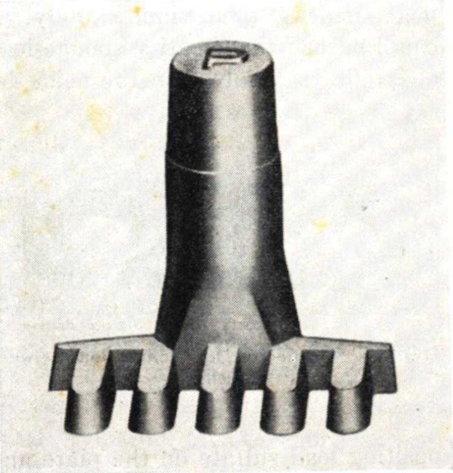
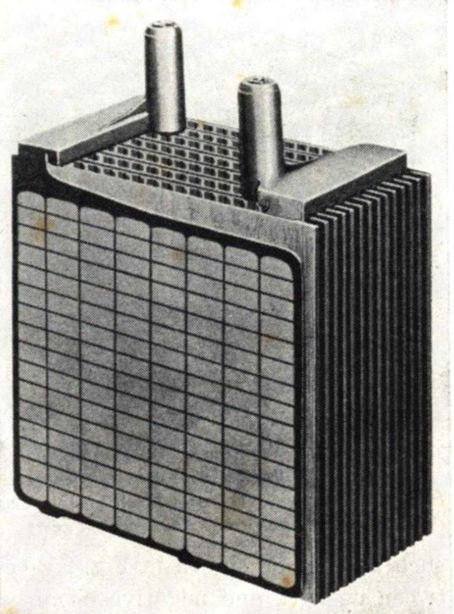


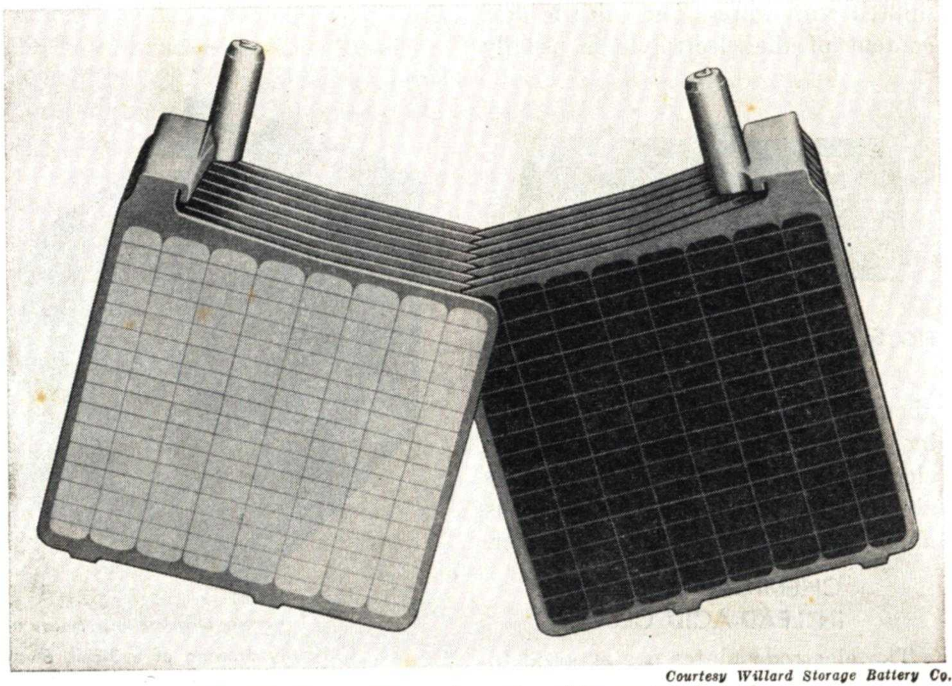
Courtesy Willard Storage Battery Co.

FIG. 22A. A post strap, to which the battery plates are attached. The "fingers" are leaded to the plates. This post is identified as the positive one by the letter P on its top. The negative post will have an N on it when this system of letter identification is used. Other batteries may use + and — as the post identifier. In any event, the battery posts will be marked, as polarity is very important in most storage battery uses. Fig. 22B shows the posts connected to the plates.



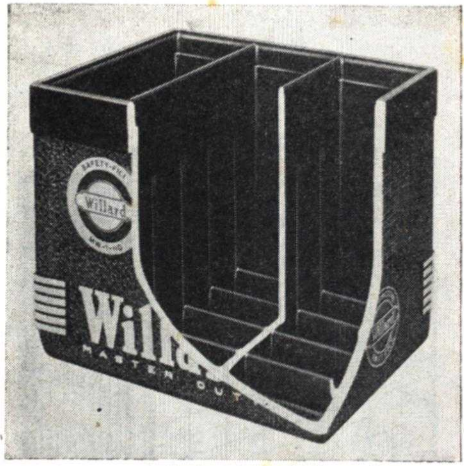
Courtesy Willard Storage Battery Co.

FIG. 22C. The complete cell assembly after insertion of separators.



Courtesy Willard Storage Battery Co.

FIG. 22B. How positive and negative plates are interleaved.



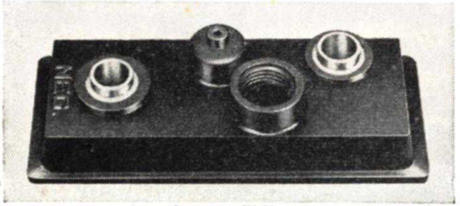
Courtesy Willard Storage Battery Co.

FIG. 23. Cut-away view of a 3-cell battery case showing cell partitions and element rests.

such as the one shown in Fig. 25, between positive and negative posts.

A completed 6-volt battery is shown in Fig. 26. The cut-away view shows the positions of the elements.

To provide an electrolyte, each cell is filled with a solution of sulfuric acid diluted with water. The sulfuric acid content of the electrolyte is usually about 38% by weight or about 27% by volume. The specific gravity of the electrolyte in a fully charged cell is about 1.30, which means that it is about 30% heavier than pure water.

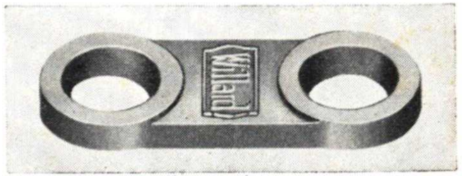


Courtesy Willard Storage Battery Co.

FIG. 24. An individual cell cover with threaded vent.

CHEMICAL ACTION IN LEAD-ACID CELLS

The electrode plates are exposed to the electrolyte at all times, and the acid attacks them immediately. A small part of the negative sponge-lead electrode is dissolved in the acid, depositing lead sulfate on the plate and liberating some hydrogen gas. In this process, the negative plate is given a negative charge. If the cell does not deliver external current, the charge potential builds up until the action is stopped. Here again, *if there were no leakages or loss, a cell without a load would remain fully charged indefinitely*. Practically, however, there is always some leakage.



Courtesy Willard Storage Battery Co.

FIG. 25. Connector for connection between cells.

Courtesy Electric Storage Battery Co.

FIG. 26. Cut-away drawing of a 3-cell, 6-volt battery with all the elements in place. Electrolyte is not shown.

However, when the cell delivers current to a load, *electrons* flow from the negative plate, out through the load, and back to the electrolyte through the positive plate.

As the electrons leave the negative plate, the potential of the plate is slightly reduced. This allows more acid action to take place, and the current is kept flowing.

Electrons arriving at the positive plate promote still further chemical reactions. The lead peroxide is attacked and broken up to form more lead sulfate and oxygen. The oxygen combines with the liberated hydrogen and forms water, and the sulfate is deposited on the positive plate. **These actions, as they occur with cell discharge, are outlined in Fig. 27A.**

► Summing up, on discharge, the spongy lead negative plate becomes lead sulfate by combining with a part of the electrolyte; the positive plate changes from lead peroxide to lead sulfate, and at the same time, oxygen is given off from the peroxide positive plate and unites with the liberated hydrogen to form water.

We see then, that on discharge, both plates change to lead sulfate and that the electrolyte, by being robbed of most of its sulfate ions and being diluted with added water, gradually drops in acid concentration to become almost pure water.

► When the cell is charged by being connected to a source of direct current flowing in the opposite direction, the chemical actions are reversed. This process is illustrated in Fig. 27B.

Electrons, forced into the electrolyte from the negative plate, carry the sulfate ions with them, and the plate is changed from lead sulfate back to its original spongy lead. At the same time a great amount of hydrogen gas is set free to bubble up and escape into the air through the vent caps.

At the positive plate, the lead sulfate is broken down into lead and sulfate ions while in the electrolyte some of the water is decomposed into hydrogen and oxygen. The sulfate ions combine with this hydrogen to form sulfuric acid thus restoring the acid concentrations. At the same time, the lead of the positive plate absorbs the oxygen and becomes, once more, brownish lead peroxide.

The electrolyte is then brought back to its proper acid concentration by charging, and the positive and negative plates are changed back from lead

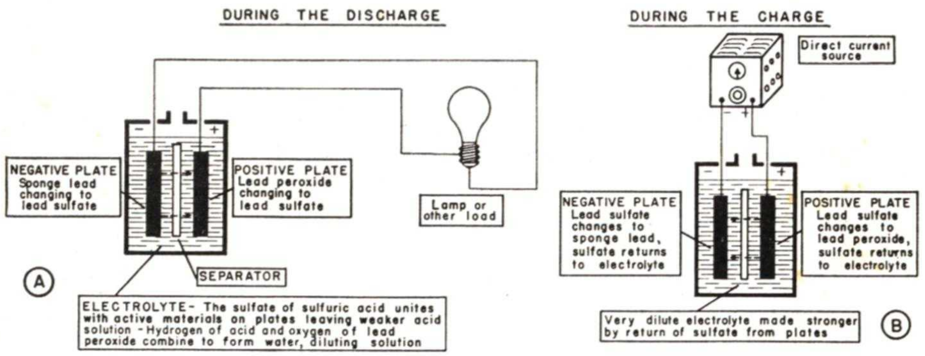


FIG. 27. (A) Chemical actions of the lead cell when supplying current. (B) Reversal of chemical reactions when the lead cell is charged.

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sulfate to their original states of lead peroxide and pure lead, respectively. The cell is now ready to deliver electrical energy once more.

LEAD-CELL BATTERY ELECTRICAL CHARACTERISTICS

Lead-acid storage batteries have extremely low internal resistance. This is partly because 13, 15, or as many as 19 plates are used in each cell of the commercial product, and partly because of the very low resistance of sulfuric acid as an electrolyte.

If a standard 6-volt automobile battery is short-circuited, it may deliver, momentarily, as much as 500 amperes. Such usage, of course, if continued, would ruin the battery because of overheating and other effects, but it shows that the battery resistance can be as low as 0.012 ohm.

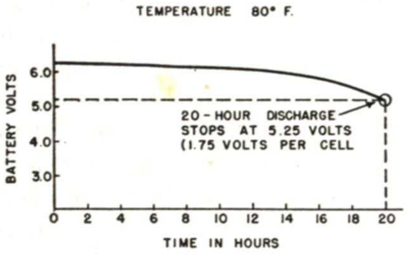

FIG. 28. Slight voltage variation of a lead-cell battery during discharge.

Very low resistance enables a storage cell to maintain its terminal voltage very nearly constant over a full discharge cycle. This is illustrated in Fig. 28 which shows the voltage variation for a 6-volt battery that has been discharged completely in 20 hours of service. Note how flat the curve is, showing an initial voltage of 6.3 volts, and a drop to only 5.25 volts at full discharge. It is interesting to compare this curve with the characteristics of other dry batteries discussed earlier.

Ampere-Hour Ratings. Storage batteries are rated in terms of their ampere-hour capacity. For example, a battery may be said to have a capacity of 200 ampere-hours. This means that it may be discharged at the rate of 1 ampere for 200 hours, 2 amperes for 100 hours, 5 amperes for 40 hours, or even 10 amperes for 20 hours. However, a 200-ampere-hour battery will not deliver 200 amperes for 1 hour, because when very large currents are drawn, the capacity is reduced by sulfation of the plates, increased cell resistance, and failure of the electrolyte to diffuse properly.

► The effective capacity of a battery varies with the rate of discharge; the lower the rate, the greater is its capacity. The following table gives the approximate relative ampere-hour capacities obtainable from a typical battery at different rates:

Time for Complete Discharge	Maximum Ampere-Hour Capacity Realized
1 hour	55%
2 hours	65%
3 hours	75%
6 hours	90%
10 hours	100%

Batteries must be rated in ampere-hour capacity at some definite rate of discharge. Some Navy batteries, for instance, are rated over a 10-hour discharge period; others are rated over a discharge period lasting as long as 200 hours.

The Society of Automotive Engineers' ampere-hour capacity rating for passenger car batteries is found by discharging the batteries over a period of 20 hours. For motorcoach batteries, a 4-hour discharge is used. In each case, final terminal voltage is allowed to drop to 1.75 volts per cell.

To illustrate this definition of capacity, let us suppose that a manufacturer claims that his 6-volt battery has a 100 ampere-hour capacity at a 20-hour rate. To test his product, the fully charged battery would be discharged at 1/20 of the published 20-hour capacity. In this case, it would be 1/20 of 100, or 5 amperes that would have to be drawn from the battery until the terminal voltage fell to 5.25 volts. The number of hours required for the discharge, multiplied by the rate of 5 amperes, would be the true ampere-hour capacity of the battery and its actual 20-hour rating.

Charging of Storage Batteries

After a storage battery is discharged, it must be recharged by having direct current passed through it in a backward direction before it can be used again.

The source for charging current may be an a.c. to d.c. motor-generator, or it may be a copper-oxide (dry disc) rectifier or a gaseous tube (Tungar) rectifier, used in conjunction with a suitable transformer for obtaining power directly from the a.c. mains.

► In any event, charging current through the battery must be direct current or pulsating direct current. Alternating current cannot be used without rectification, for although the battery would tend to be charged on one half-cycle, the polarity would be reversed on the alternate half-cycle, and the battery would be discharged again.

At first, it would seem to take no longer to charge a battery than it would to discharge it. This is not true. For instance, the voltage of the battery constantly rises as the charge continues, and less and less current flows through the cells. This effect is shown in Fig. 29. Note the gradual voltage rise as charge builds up, and the consequent drop in charging current flow.

Change in Electrolyte Density. As we pointed out earlier, the concentration of sulfuric acid in the electrolyte changes with the amount of discharge of a battery. At full charge, the electrolyte has a specific gravity, near 1.30, which means that it is 30% heavier than water; at full discharge, the electrolyte density drops to a specific gravity of about 1.10, only 10% heavier than water.

This change in specific gravity is exactly proportional to the degree of battery charge. See Fig. 30. The curve showing the relationship between charge and electrolyte weight is a straight line.

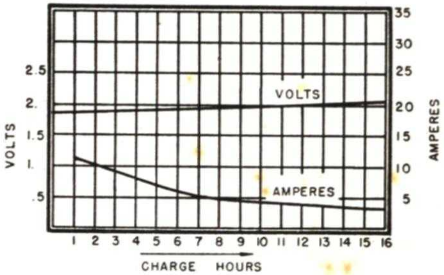

FIG. 29. Variation of terminal voltage and the current drawn by a battery cell being charged.

► Now if we have some means of measuring the electrolyte concentration, we can determine the condition of battery charge or discharge. And *if*

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acid has not been lost through spilling or leakage, *this is the most accurate and most convenient means of testing lead-acid storage batteries.*

Electrolyte specific gravity is usually measured with an instrument called the *hydrometer,* shown in Fig. 31A. It is a syringe with a rubber bulb and a glass tube barrel containing a "float."

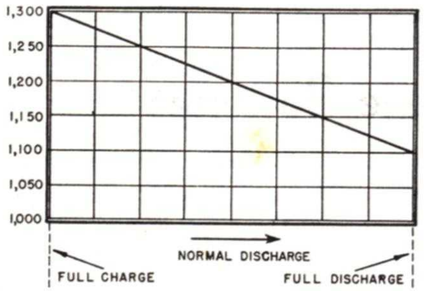

FIG. 30. Variation of electrolyte specific gravity with state of charge.

This float is a sealed glass cylinder weighted with lead shot. The upper part of the float carries a graduated scale. **The weight of the float is adjusted so that when pure water is** drawn into the glass barrel, the float will not rise; but when some solution that is heavier than water is drawn in, the float will rise, and the heaviness of the solution, with respect to pure water, can be read by noting the rise of the solution level on the float scale.

Fig 31B shows how the float is buoyed by the solution so that the specific gravity is measured at the liquid level on the scale.

► For convenience, most hydrometer scales are not marked with decimal figures as 1.1, 1.17, or 1.28. Instead, these are multiplied by 1000 and are written as 1,100, 1,170, 1,280, or simply 1100, 1170, or 1280. The significant figures, however, are always the same.

Methods of Charging. Many types of battery chargers are now on the market. It is impossible to do more than outline general methods for using them. In any case, be sure to follow the instructions furnished by the charger manufacturer.

Several different types of charges may be given to a battery. They are:

1. Initial Charge. A long, low-rate charge, commonly called a "forming" charge, which is given to place new plates in service.
2. Normal Charge. A routine charge at moderate current rate to restore the battery to a fully charged condition.
3. Equalizing Charge. An extended charge at relatively low or "finishing" rate, given periodically to insure that all the sulfate is driven from the plates, and that all cells are restored to a uniform maximum specific gravity.
4. Trickle Charge. A *continuous* charge at *very low rate* to keep a battery in a fully charged state.
5. Emergency Charge. A quick, high-rate charge given in an emergency to put the maximum amount of energy into a battery in the shortest length of time.

Putting the Battery on the Charging Line. Whenever possible, batteries should be charged at their normal charging rate. The proper charging rate of any battery depends on its ampere-hour capacity. The following table indicates the normal charging rates for the commonly used sizes of storage batteries:

Normal charge

Ampere-hour Capacity	Charging Rate
2 to 5	¼ to ½ ampere
20 to 50	2 to 2½ amperes
120 to 180	5 to 8 amperes
200 to 250	10 amperes or more

To force charging current backward through a battery, the charging voltage must exceed that of the battery. Ordinarily, the charging voltage is about 30% higher than the battery voltage. Proper charging voltage for a 3-cell, 6-volt battery, therefore, is about 8 volts.

Because each cell of the battery offers a back pressure of approximately 2 volts, the effective charging potential is 8 minus 6, or 2 volts. Even with this low effective voltage, because the battery resistance is small, the current must usually be limited by the insertion of a series resistor. In this example, a resistor of ½ ohm would result in a charging current of 4 amperes, (this is determined by dividing the ½ ohm into the 2 volts).

For another example, let us suppose that we have a 12-volt battery that has been discharged until the terminal voltage is 9.6 volts, and that the internal resistance of the battery is 0.3 ohm. Let us assume further that we have a 14-volt source, and that the initial charging rate is to be limited to 10 amperes. Since the voltage difference between the battery and the charging source is 4.4 volts (14-9.6), the resistance of the limiting resistor and of the battery should be 0.44 ohm (4.4 volts/10 amperes), in order to limit the current to 10 amperes. Since the battery resistance is 0.3 ohm, the value of the limiting resistor should be 0.14 ohm.

► Before charging, each cell should be filled with pure distilled water. The proper electrolyte level is about one-half inch above the plates. Do not put in too much water, it is generally sufficient merely to cover the plates; otherwise the bubbling which occurs when the battery is being charged may make the electrolyte overflow.

While being charged, or as we say while "on charge," a lead-acid battery will give off gasses (mostly hydrogen), and some means for escape must be

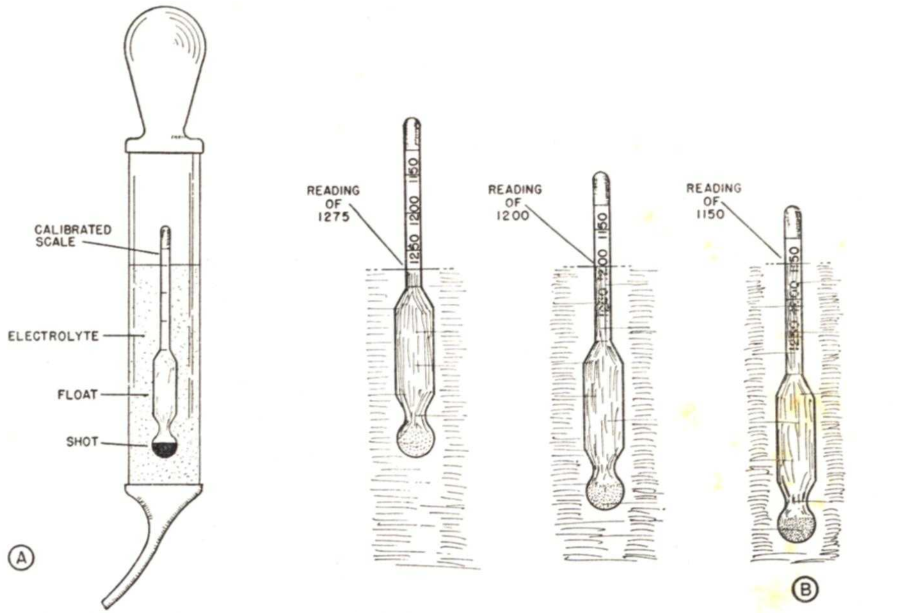

FIG. 31. In A is shown the construction of a hydrometer used for testing the condition of a storage battery. B, examples of hydrometer readings.

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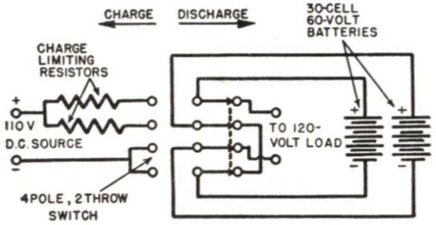
provided. The vent in the cell cap is adequate for gasses that are released during normal use, but does not provide for excessive gassing when the battery is on charge. For this reason *the cell caps of a battery on charge should be removed.*

Sparks and flames should be kept away from charging batteries, for the expelled gasses are explosive.

► When the cells expel gas freely, the charging rate can be reduced to one-half the normal rate and the charge continued. At this reduced charge rate, the amount of gassing will be reduced. When the cells are again gassing freely, the charge can be discontinued, and the battery tested for full charge with a hydrometer.

If inadequate charge is indicated, the battery should be put back on the charging line and charging continued at the "finishing" rate, or one-half the initial charging current.



This shows how the two 30-cell (60 volt) sections of a 60-cell bank of lead-acid storage batteries are connected in parallel to permit charging from a 110-volt d.c. source, and are connected in series when discharging into a load. Notice that a 4-pole, double-throw switch is used to change from charge to discharge. This type of circuit is used on shipboard where the supply voltage is 110 volts d.c., and the batteries are used for emergency power.

► Charging should be stopped when the cells are all gassing freely, and the specific gravity shows no further rise when tested at three one-hour intervals.

If no hydrometer is available, it can be assumed that a good battery is fully charged when it continues to gas freely for two hours. The state of charge can be determined by measuring the voltage under a normal load. There should be little change between the no-load and normal load voltages.

Most batteries can be recharged at a normal rate in from 12 to 16 hours. An excess of charging wastes current, decreases the water content of the electrolyte, and can be harmful to the plates.

Do not stop short of the fully charged state, however, even though it may take 24 hours to complete the charge. Keep charging as long as the specific gravity continues to rise. A battery badly sulfated from idleness or from long periods of undercharge will require a longer charging time than normal.

Hydrometer Readings. In using the hydrometer, draw in and then expel the electrolyte several times to remove gas bubbles. Then, keeping the barrel vertical so that the float will not drag on the wall of the hydrometer, allow the barrel to fill sufficiently to raise the float. With the liquid level at eye level, read the specific gravity on the float scale.

► A fully charged battery in good condition will register between 1280 and 1300 on the scale. A reading less than this indicates that the battery is not fully charged. A battery completely discharged will have a specific gravity of about 1100.

If a charging battery has been heated by a high-charging rate, or the electrolyte temperature is appreciably higher or lower than 80° F, which is the normal temperature, the hydrometer readings will not be accurate unless corrected for temperature. A high temperature tends to expand the electrolyte and make it less dense. A low temperature tends to increase the specific gravity.

In general, each 10-degree change in electrolyte temperature will cause the electrolyte density to change by 4 "points of gravity." Suppose that we have a cell whose specific gravity is 1270, and the electrolyte temperature is 100° F. Since this is 20° above normal, the temperature correction would be 2 times 4, that is, 8 points of gravity. When the electrolyte temperature is *above* the normal value, then the correction must be *added* to the measured specific gravity. Thus the temperature-corrected specific gravity in this case is 1278.

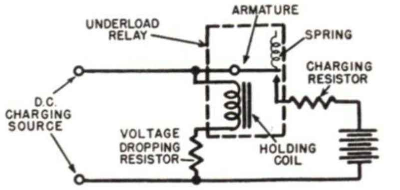
If the electrolyte temperature is *below* normal, the temperature-correction factor must be *subtracted* from the hydrometer reading. As another example, suppose that the specific gravity of a cell is 1300 at 30° F. Since this is 50° below normal, the correction factor is 5 times 4, that is, 20 points of gravity, which must be subtracted from 1300. The corrected specific gravity is, therefore, 1280.

► Some hydrometers have built-in thermometers which make calculations unnecessary. A temperature-correction scale is generally mounted on such a hydrometer. The scale is marked in points to be added or subtracted from the float reading.

Incidentally, lead-acid batteries that are subjected to low temperatures should be kept fully charged to prevent the electrolyte from freezing.

Trickle Chargers. Charging a battery continuously at a very low rate, usually less than 1 ampere, is called trickle charging. Special, low-capacity chargers are made for this purpose.

Trickle charging is not intended to restore a completely dead battery to normal. Instead, it replaces only that energy that a battery dissipates hourly or daily. If a battery is not discharged suddenly or rapidly, trickle charging will keep it in a constant state of full charge.



One type of underload circuit breaker used in battery charging circuits. The spring tension is adjusted so that when the d.c. charging source voltage is too low to charge the battery, the current through the holding coil is unable to pull the armature down, and the source is not connected to the battery. However, when the source voltage is high enough to charge the battery, the current through the holding coil is enough to overcome the spring tension, and the source is connected to the battery.

Proper current for trickle charging depends entirely on the battery condition, the average battery current drain, and the design of the charger. It is very important that the manufacturer's instructions, which are supplied with trickle chargers, be carefully observed. Overcharging a battery for an indefinite time, even though at a very low rate, can be very harmful to the plates and grids. Trickle chargers are quite effective in keeping auxiliary "stand-by" batteries freshly charged for emergency use.

Constant Potential Chargers. Some chargers are designed to start battery charging at a high rate, then as the battery voltage builds up, it automatically tapers off the current flow.

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A battery in good condition is not harmed by this type of charging. A completely dead or badly sulfated battery, however, may not come up to full charge in a normal way. The temperature of the electrolyte must be watched carefully, for it can rise to serious values in a short length of time.

If the specific gravity of the electrolyte is not normal, because of spilling or leaking through cracked cases, constant potential charging should not be attempted.

High-Rate Chargers. Emergency charging can be accomplished by using a high-rate charger. These have become popular because of their ability to charge a battery very rapidly. They are usually constant potential devices of very high capacity so that initial charge rates of 80 to 100 amperes are common.

Where means to control the temperature and the violence of gassing are provided, it is practical to charge normal batteries in this way. Some high-rate chargers are equipped with a time-limiting or temperature-limiting device to protect the battery, and to prevent its exceeding a temperature of 110° F.

A *good* battery may be charged *occasionally* at *any* high rate that does not cause the electrolyte temperature of the cells to become higher than the critical temperature of 110° F., and does not cause excessive bubbling and loss of electrolyte. *Completely discharged or heavily sulfated batteries should never be given a high-rate charge.*

High-rate chargers cannot fully charge batteries within an hour, but they *can* charge the battery sufficiently so that it can continue to give service commensurate with its condition and state of charge for temporary use.

► Caution: High-rate chargers can cause irreparable damage on any battery if the safeguards suggested by the manufacturer are ignored. Operating instructions for such chargers should be very strictly followed.

Polarity of Charging Source. It is important that the charging source be connected, with the proper polarity, to the battery being charged. The positive lead of the source should connect to the positive lead of the battery, and the negative lead of the source should connect to the negative lead of the battery.

If the leads were reversed, the battery would be connected in series with the charging source, and *the battery would discharge.* The current flow through the battery is generally larger than the normal charging current so that the battery is likely to be damaged.

This increased current flowing through the battery produces a larger voltage drop across the internal resistance of the battery. Thus, if the battery voltage *decreases* when connected to the charging source, the leads are reversed.

► To determine the polarity of a battery or a source, a voltmeter with a known polarity should be used.

Adjustment of Electrolyte Specific Gravity. The specific gravity of the electrolyte depends on the state of charge, on whether electrolyte has ever been lost through spilling or leaking, and on the level of the electrolyte. The electrolyte level should be maintained above the plates by adding pure distilled water only. (If the electrolyte level is low, water evaporation is the usual cause, and since this changes the ratio of water to acid, the hydrometer reading would be above normal for the actual state of charge.)

Always check the electrolyte level before charging, and add water if necessary. Normal charging should now raise the hydrometer reading to between 1270 and 1300.

If the charging raises the hydrometer reading far above 1300, someone may have added acid to the cell in the past. In this case, remove some of the electrolyte with the hydrometer and replace it with pure water.

On the other hand, if even extended charging does not raise the specific gravity to 1270 or higher, then either the cell is defective, or electrolyte has been lost in the past and replaced with water. If the cell is *good,* you can remove some of the electrolyte and replace it with acid. This is the ONLY case in which acid should be added to a storage cell.

In either case, continue the charge in order to give the electrolyte a chance to mix, then read the gravity an hour later to note the effect of the additions. Continue this adjusting procedure until the gravity is brought to the desired value.

Inspection of Batteries. At the conclusion of each charge, wash the battery and dry it. (Use ammonia or baking soda solutions to neutralize spilled electrolyte, but don't allow it to get in the cells.) If the sealing compound is rough and uneven, a gentle "flaming" with a small torch will improve the appearance and will close any cracks. Be sure to remove accumulated gas in each cell first by blowing with a battery filler syringe. Hydrogen gas mixed with air in a confined space is highly explosive. For this reason, a room where batteries are being charged should be adequately ventilated.

Close examination during flaming may reveal deep cracks or loss of seal adhesion on the case or the covers. If acid seeps from these cracks, the battery should be resealed with new compound. Never use old compound.

To prevent corrosion, the terminals of a lead-acid storage cell should be washed with a mild alkaline solution, and covered with a non-corrosive grease such as Vaseline.

A pressure pump, made from a filler syringe by running the hard rubber tip through a large one-hole rubber stopper, can be used for creating pressure inside a cell to detect seal leaks. Hold the stopper tightly over the vent opening, and squeeze the bulb to create a moderate pressure. Do not exert pressure long enough to displace the sealing compound. The exterior of the container should be inspected for any evidence of cracks or seepage of acid through the walls.

► It is normal to add some water occasionally to a storage battery that is periodically charged and discharged. However, watch for battery cells that require an excessive amount of water or need water more often than usual. The need for excessive water may indicate any of three conditions: The charging system is out of adjustment and the battery is being subjected to overcharging; the cell that needs the excessive amount of water is leaking electrolyte; or the cell is defective and is generating excessive heat internally because of a short circuit.

Battery Self-Discharge. The grid framework of the plates is cast from an alloy of lead and 6% to 12% antimony. During the charging of a battery, a small amount of antimony dis-

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solves from the positive plate grids and deposits on the sponge lead of the negative plates where it sets up a local electrochemical action with the sponge lead. This action discharges the negative plates slowly. The presence of small quantities of other impurities may affect, to a lesser extent, either the positive plates or the negative plates, or both.

"Local action" will cause batteries to discharge much faster when they are warm than when they are cold. They will also discharge faster when fully charged than when only partially charged. At normal temperatures of about 70° to 80° F., loss of capacity by self-discharge may amount to about 1 point of specific gravity per day.

To minimize self-discharge, it is better to store batteries in a cool place, away from hot air ducts or radiators in winter, and to shield them from direct sunlight in summer.

Storage Battery Defects and Their Repair

By far the most common battery troubles are internal short circuits in the cells, and the destruction or alteration of the active materials of either the positive or the negative plates.

Shorted Cells. Short circuits within a cell may be caused by bent or buckled plates, or by charred, split, or perforated separators. Short circuits between two adjacent cells may be caused by cracks or leaks in the insulating case partitions.

Cells with short circuits cannot be charged, even after prolonged attempts to bring them up to normal. Occasionally they will charge, but they promptly discharge themselves.

Defective Cell Plates. Cells in which the plates have been destroyed or changed in chemical structure by abusive treatment will not charge. These cells quite often exhibit a high resistance, and it is sometimes difficult to pass normal charging current through the battery.

► Defective cells of all kinds usually make themselves evident by abnormal heating or violent gassing while on charge. This causes an increased loss of water, and, of course, any excessive need for water is indicative of a defective cell.

► **Common Abuses.** Almost all *premature* battery troubles can be traced to three common causes of failure:

1. Overcharging.
2. Undercharging.
3. Failure to add water.

Overcharging. To overcharge a battery, or to charge it at a too-rapid rate, is harmful in several ways:

(a) Violent gassing washes active material from the plates. This not only reduces the activity of the plates, but also frees material that can puncture a separator and cause a short circuit.

(b) Excessive loss of water, carried away by abnormal gassing or overheating, leaves the electrolyte acid more concentrated. Over long periods at high temperatures, the separators become charred and burned, and the negative plate material is rendered sandy and granular by this concentrated acid.

(c) High internal heat greatly accelerates the corrosion of the positive plate grids, and if a battery has become sulfated from long periods of undercharge or idleness, sudden charging will cause severe buckling and warping of plates which may perforate or split the wood separators and cause an internal short circuit.

Undercharging. A battery operated with insufficient charge over a long period of time may develop in the plates a type of sulfate that is dense, hard, and crystalline, and which cannot be electrochemically converted to normal active material again. This is known as "sulfation."

Such abnormal formations impose severe strains on the positive plates and may warp them so badly that the separators become pinched or torn, thus developing a short circuit. This buckling is aggravated, too, if an attempt is made to put the battery into service by overcharging.

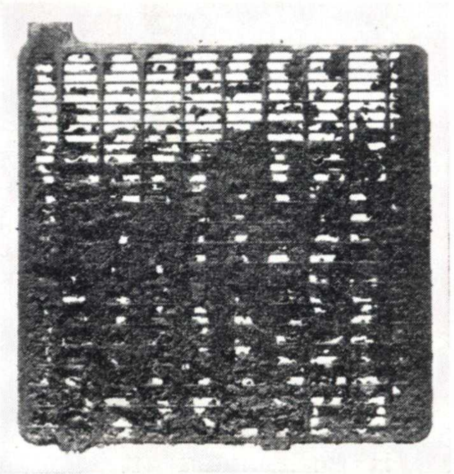
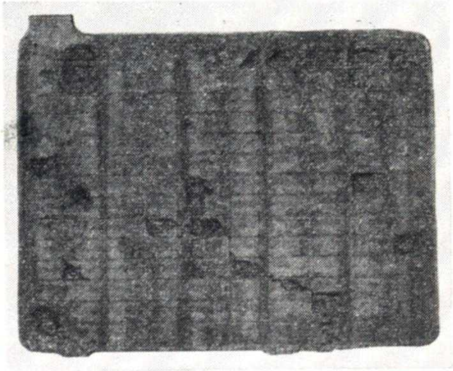


FIG. 32. Deterioration of a plate in long, normal service.

Lack of Water. If the electrolyte level is allowed to fall below the plates, part of the active material is exposed to the air. This reduces the capacity of the battery because all the plate area cannot work, and white lead-sulfate formations may accumulate on the exposed surfaces, and if allowed to remain, will ruin the plate material.

In addition to this, the acid concentration of the electrolyte is markedly increased. Under such conditions, the wood separators may become charred, and the negative plates become blistered, or turned into soft, mushy material.



Courtesy Willard Storage Battery Co.

FIG. 33. Collapse of positive plate grid, and alteration of active material caused by severe overcharging.

Appearance of Damaged Plates. Plates that have been damaged by abusive treatment are usually quite obvious when a cell is opened for examination.

In Fig. 32 is shown the appearance of a cell plate after long, normal service. Note that although some of the active material has fallen away, the grid structure is whole and intact, and not warped in any way. Material that has escaped probably did so very gradually, and dropped to the sediment space below the plates where it caused no harm.

For contrast, look at Fig. 33. This is a picture of a positive plate destroyed by severe overcharging. Observe that

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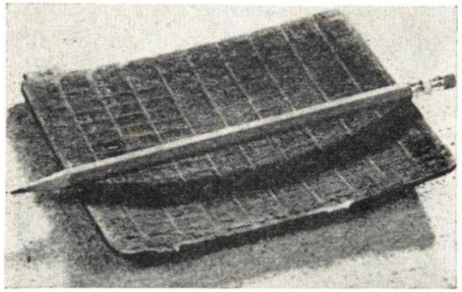
the grid framework has been so eroded that it has collapsed; note also, that the active plate material has been reduced to scaly, lumpy masses.

Serious buckling, or warping, of a plate is shown in Fig. 34. This was probably caused by overcharging after the plate had been sulfated during a long period of idleness or undercharge. It is obvious how this deformation could bind or crack a separator, and thus short-circuit a cell.



Courtesy Willard Storage Battery Co.

FIG. 34. Plate buckling caused by overcharging a sulfated cell. How much the plate is buckled can be determined by comparing it with the straight pencil lying across it.

Fig. 35 shows a positive plate very badly sulfated from lack of water. Notice the line of white lead-sulfate that marks the average electrolyte level. The material that was exposed to the air has turned white; the portion that remained in the electrolyte has retained its normal brownish hue.

Worn separators, with ribs almost destroyed and the back web perforated, are characteristic of separators subjected to excessive pressure from buckled plates. See Fig. 36. Note the cracks along the bottom through which short circuits can occur

Contaminated Electrolyte. The presence of any foreign matter in a storage cell often results in increased "local action" or self-discharge. Although it is impossible to prevent some foreign substances from getting into the materials of a cell, even in the process of manufacture, these should be kept at a minimum.

Only distilled water is approved for battery use, and this should be kept in a covered glass, earthenware, hard rubber, or lead container.

Colorless liquids like gasoline, kerosene, turpentine, alcohol, or carbon tetrachloride are sometimes mistaken for water and added to a battery. If this should happen, and the liquid added is lighter than the electrolyte and does not mix with it, the undesired liquid can be removed by flooding each cell carefully with water to flow off the impurities. After removal, the specific gravity of the electrolyte should be adjusted as it is likely that some of the acid will be lost in this process.

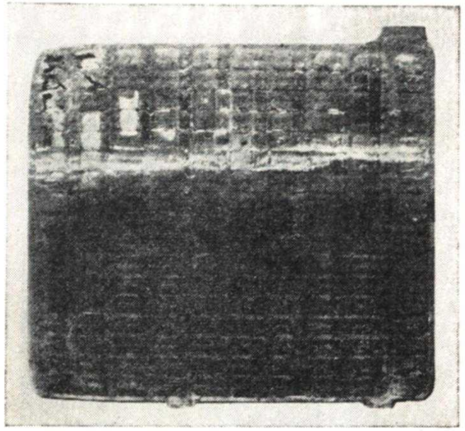


FIG. 35. Plate deterioration when electrolyte is not kept at proper level.

Soluble liquids such as sea water, vinegar, and alcohol, or harmful commercial acids such as nitric, muriatic or acetic, must be emptied from the cell, together with the electrolyte, at once. Fill the cells with fresh water and empty them several times. Then fill the cells with 1350 gravity sulfuric acid electrolyte only, fully recharge the battery, and finally adjust the gravity, if necessary, to 1280 at 80° F.

REPAIRING OF LEAD-CELL BATTERIES

Except for minor repairs or replacement of broken parts, no extensive repairs of an old battery are justified.

A battery that has failed after a reasonable service life is usually not worth repairing, since plates and separators wear out about the same time, and the material cost and labor involved are excessive.

Present-day storage batteries of reputable make are designed and constructed so that with reasonable care they will usually not require any repairs during their normal life.

For the benefit of those who are interested in battery service, however, the following accepted practices are described briefly.

Need for Experience. Most of the necessary service tools are of simple but effective design, and may be procured readily from service station supply houses.

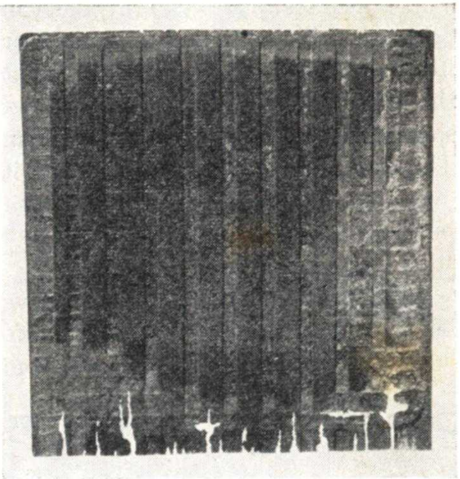
However, considerable skill and experience are required in lead-welding of battery parts. It is recommended that the beginner practice on junk batteries or spare parts in order to acquire the necessary technique in the use of the lead-welding torch.

Precautions. *Never attempt to open a battery cell for examination unless a prolonged attempt has been made to charge it, and it is definitely known that the cell is defective.*

Even the parts of a good cell, after some service, are likely to be in a fragile condition. Accidental damage can easily occur, and is sometimes very difficult or too expensive to repair.

Opening a Battery for Repair. To open a battery for minor repair, such as replacement of container or case, cut the sealing compound loose from the container walls and partitions with a hot putty knife. Do not remove the seal from the cell covers until after these elements are removed.

Lift all three elements by putting an equal pull on each at the same time. Keep any element shims with the elements to insure a snug fit if it is transferred to a new container.



Courtesy Willard Storage Battery Co.

FIG. 36. A chafed and perforated separator from a shorted cell.

If individual cells need to be removed, use a thin hack-saw blade to saw through the centers of the cell connectors that are attached to the posts of each cell. See Fig. 37. To prevent lead from clogging the teeth of the saw blade, run the cutting edge of the saw through a little sealing compound to fill the teeth. This will lubricate the saw. This sawing method will not disturb the post-to-connector welds.

To re-assemble, file or saw the metal away from each side of the saw cut to

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a 45° bevel. A V-shaped trough is thus provided, with the width of the saw cut at the bottom. By placing the blade **of a putty knife underneath the cut,** and small blocks of metal alongside the connector for dams, the V-notch can be welded closed with the addition of new 4% antimony stick lead. The dam assembly is shown in Fig. 38. The weld can be smoothed with a file and lead scraper.

An alternate method of removing cell connectors is shown in Fig. 39. The button-shaped welds at the cell posts are drilled out, and the connector lifted off intact. The resulting rings at the ends will have to be cleaned and shaped before they can be used again. The connector is replaced by fitting it over the remains of the cell posts and building up new "buttons" with fresh stick lead.

After the necessary connectors have been removed, with a hot putty knife cut the sealing compound loose from the container walls and the cell partitions near the defective cell. Pull out the element, and set it back across the container top at an angle to allow it to drain for a few minutes. Clean the sealing compound from the covers and the container with a hot putty knife, and throw the used compound away.

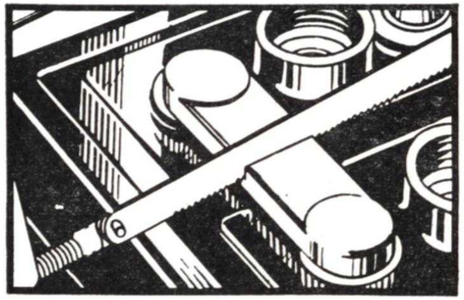

FIG. 37. Method of sawing a connector for individual cell removal.

Removing Separators. Lay the cell on its edge and spread the plates slightly to relieve pressure on the separators. Take care not to spread the plates too far, as they may break easily.

Beginning with the outside separators, carefully push each separator by its top edge which is near the cell cover; do not pull from the bottom edge or the separators may break.

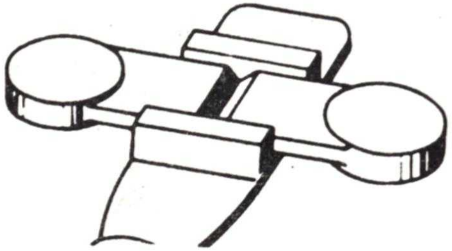

FIG. 38. Repairing the saw-cut by means of a "dam."

Inspection of Parts. Examine the cell plates carefully. If they are badly warped, have lost excessive material, or show other signs of deterioration, they are probably worthless, and the cell should be junked.

If the plates appear to be in good condition, cell failure may have been caused by a split, perforated, or broken separator. Examine each separator carefully. Discard those that are worn, burned, or questionable in any way.

Reassembling. Using only good or new separators, begin to insert them in the middle of the cell, and gradually work to the outside plates. Be sure each one fits snugly, and is in its proper position.

After all separators are in place, press the assembly firmly together, then re-install the cell in its container. Make certain that all shims are in the correct position and that the cell fits firmly.

"Flame in" new sealing compound with the torch, and reweld the connectors as described previously.

Check the electrolyte level, adding water if needed, and put the battery on the line to charge at a normal rate.

If good, the battery should charge in the normal length of time. Finally, check the specific gravity of the cells and adjust it if necessary.

The Edison Storage Battery

Any voltaic cell, primary or secondary, must contain two different metals and an electrolyte. The Edison storage cell is no exception.

An elementary Edison cell consists of a positive electrode of nickel hydrate, a negative electrode of black oxide of iron, and a water solution of potassium and lithium hydroxide.

Note that these elements do not resemble the lead-acid cell components in any way; the electrolyte, instead of being acid, is a caustic alkali.

HOW EDISON BATTERIES ARE CONSTRUCTED

In the commercially produced Edison battery, positive plates are made by attaching a number of perforated nickel-steel tubes to a nickel-steel grid. The tubes are filled with alternate layers of nickel hydrate, which is the active material, and metal nickel flakes, which are included to improve the conductivity. The tubes are reinforced by seamless steel rings, and then permanently mounted in the grid under a pressure of forty tons.

The negative plates are of similar construction, except that finely divided oxide of iron is used as the active material, and is contained in rectangular pockets instead of tubes.

A cut-away view of a standard Edison cell is given in Fig. 40. The relative positions of the positive and negative grids are shown in the picture.

The perforations in the positive tubes and in the negative pockets of the Edison cell provide ready access for the electrolyte, but are small enough to preclude any possibility of loss of active material, as is so common in the lead-acid type of storage battery.

Because the alkaline electrolyte does not attack steel, this material is used throughout the cell. Positive and negative grids are connected in parallel by means of steel spacing washers, connecting rods, and nuts. The terminal posts, too, are steel, and are threaded for convenience in making connections. The case also is welded steel with the bottom and the cover permanently welded into place.

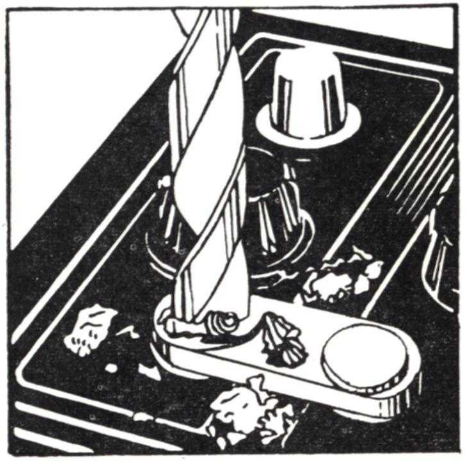

FIG. 39. Alternate method of removal by drilling connector.

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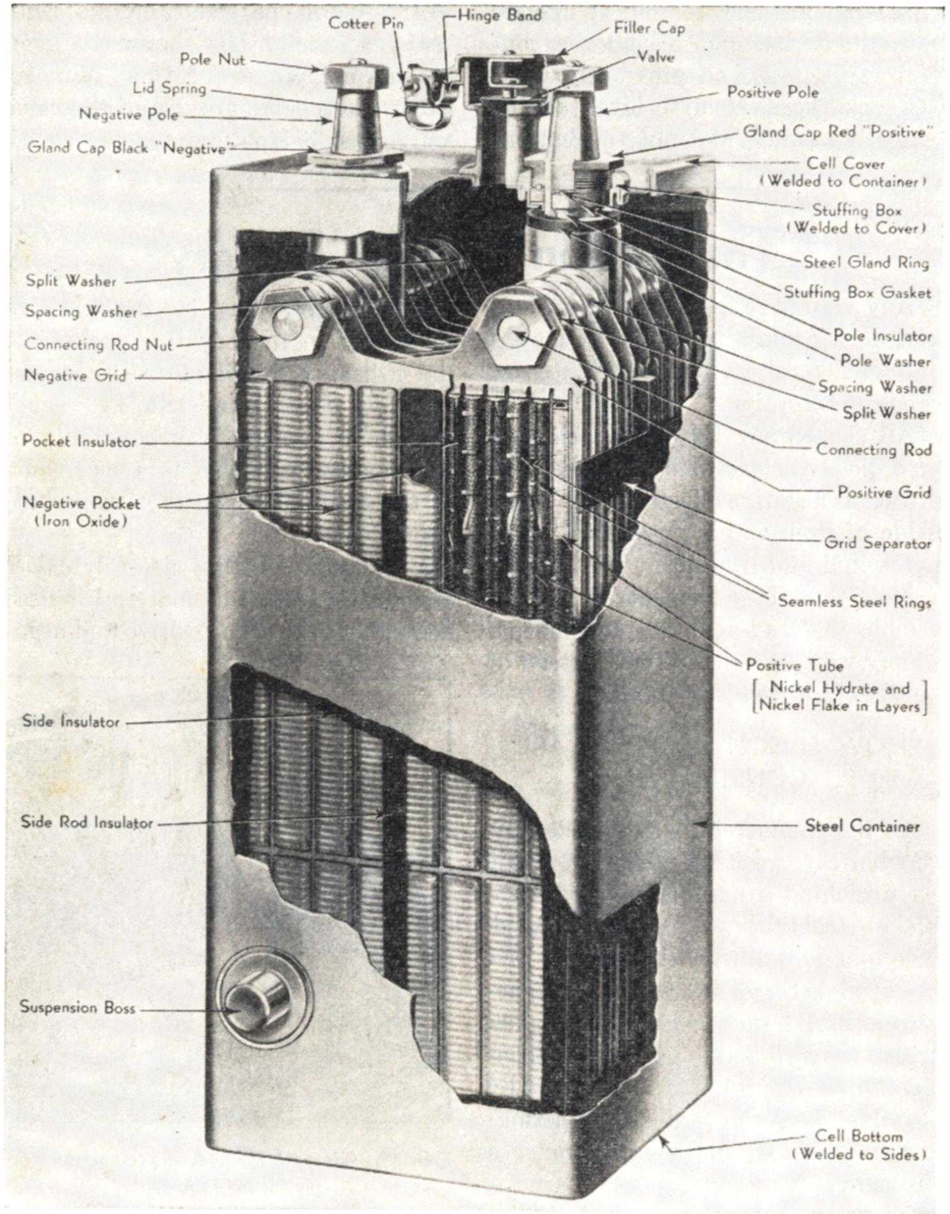

FIG. 40. A cut-away drawing of a standard Edison nickel-iron-alkaline storage cell.

GENERAL PROPERTIES OF THE EDISON BATTERY

When fully charged, an Edison cell has a terminal voltage under load of about 1.4 volts. This decreases gradually during use to about 1.0 volt at full discharge. The *shape* of the voltage discharge curve of the Edison battery is very similar to the shape of the curve for the lead-cell battery, as voltage is maintained very well almost to complete exhaustion.

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Electrolyte. In normal use, the electrolyte of an Edison cell requires an occasional addition of water to replace what is lost by gassing and evaporation. As with other batteries, the electrolyte of the Edison battery should be kept above the level of the plates.

Because of dilution and gradual depletion during use, it may be necessary to renew the electrolyte once or twice during battery life. This is done whenever the specific gravity, as measured with a hydrometer, falls to between 1160 and 1170.

Testing for Charge. During a normal charge-discharge cycle, the Edison cell electrolyte does not change its composition appreciably, and hence, the specific gravity *does not vary*. Therefore, the state of charge of an Edison battery *cannot* be determined by use of the hydrometer.

In an Edison battery, the terminal voltage is very nearly proportional to the battery charge. An easy, reliable method of testing charge is to measure the terminal voltage with a voltmeter, and compare the reading with full charge and discharge values. This is done best when the battery is under load.

A special "charge test fork," such as shown in Fig. 41, is recommended by the Edison cell manufacturer for testing batteries. This is a two-prong fork with a voltmeter attached. Shunted across the prongs is a low-resistance metal grid. When the fork is touched to the battery terminals, normal load current is sent through the resistance, and terminal voltage can be read on the voltmeter.

Charging Rate. As with lead-cell batteries, each Edison battery has a normal recommended charging rate depending upon the capacity of the battery. Proper rate of charge is always stated on each cell case by the manufacturer. If the battery is not charged at this rate, the ampere-hour capacity of the battery may be temporarily reduced.

High-rate charging can be used without harm, however, if the electrolyte temperature is not allowed to exceed 115° F. Even excessive overcharging will not damage an Edison battery, although it does result in the loss of more water, and wastes charging current. Trickle charging may also be used if desired.

Courtesy Thomas A. Edison, Inc.

FIG. 41. Method of using the charge test fork in checking Edison batteries for charge.

Ampere-Hour Capacity. Edison cells are made in a number of ampere-hour capacities. These ratings, of course, depend upon the size and number of the electrode plates used in the construction. All necessary information for proper use is stamped on the side of each cell.

In marked difference from the lead

cell, the available ampere-hour capacity of an Edison cell does not decrease appreciably as a result of high discharge rates. Minimum useful voltage is the only limiting factor in the percentage of rated capacity that can be realized during discharge.

Storage of Edison Batteries. All that you need to do before storing an Edison battery for an indefinite period is to discharge it to zero, or to a very low voltage, add water if necessary to cover the plates, and place a short circuit across the terminals.

To put the battery back in service, remove the short circuit, add water to replace what has been lost by evaporation, and recharge the battery.

It is interesting to note that such treatment would quickly destroy a lead-acid battery, which requires an equalizing charge periodically to prevent sulfation and deterioration.

Length of Service Life. Edison batteries are extremely rugged. They have a very long service life during which they may be subjected to thousands of charge-discharge cycles.

It is not uncommon for a battery that is completely charged and discharged each day to last from 7 to 10 years.

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Lesson Questions

Be sure to number your Answer Sheet 32RC-1.

Place your Student Number on *every* Answer Sheet.

Most students want to know their grade as soon as possible, so they mail their set of answers immediately. Others, knowing they will finish the next Lesson within a few days, send in two sets of answers at a time. Either practice is acceptable to us. However, don't hold your answers too long; you may lose them. Don't hold answers to send in more than two sets at a time or you may run out of Lessons before new ones can reach you.

1. What effect does polarization have on a primary cell?
2. How should a 45-volt B battery be tested?
3. How does a secondary cell differ from a primary cell?
4. Suppose that a 12-cell (24-volt) aircraft battery has been discharged until the output has dropped to 21 volts and the internal resistance has increased to .36 ohm. What value of series resistance is required to limit the initial rate of charge to 10 amperes if a 27.5-volt d.c. aircraft generator is used to charge this battery?
5. How does the hydrometer show the condition of a lead-acid storage battery?
6. What special precautions should be taken when lead-acid storage cells are subjected to low temperature?
7. If a hydrometer reading is 1220 but the electrolyte temperature is 110° F., what is the true specific gravity?
8. What are the three causes of premature lead-acid battery failure?
9. Give three reasons why it is unwise to overcharge a lead-acid battery.
10. Can the state of charge of an Edison cell be determined by using a hydrometer?

PERSONAL NEATNESS PAYS

Clothes may not make the man, but all too often they do determine the degree of his success in business. The radio man who keeps himself clean and neat gets the respect of his customers, and that one thing pays big dividends.

Good appearance is achieved by wearing appropriate conservative clothes for whatever kind of work you are doing, and keeping these clothes clean and well pressed at all times. Thus, inexpensive brown work shirts and trousers are fine for shop use and even for service calls, *provided they are clean and pressed.* But keep your shoes shined, keep your hair combed and cut, wash your hands immediately after handling a dusty or greasy chassis, and watch all those other little personal-neatness items which are being stressed so much in advertisements today.

To sum up, the cost of maintaining a neat personal appearance is negligible in comparison to the higher price a neat, well-dressed, businesslike radio man can demand and get for his services. Neatness inspires confidence, and confidence in turn makes customers accept your prices without question. Make a habit of neatness—it pays!

J. E. SMITH

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