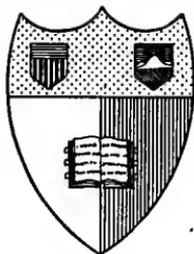


# STORAGE BATTERY MANUAL

LUCIUS C. DUNN



**New York**  
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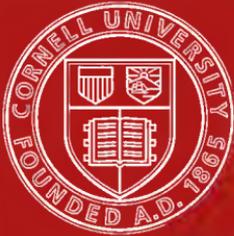
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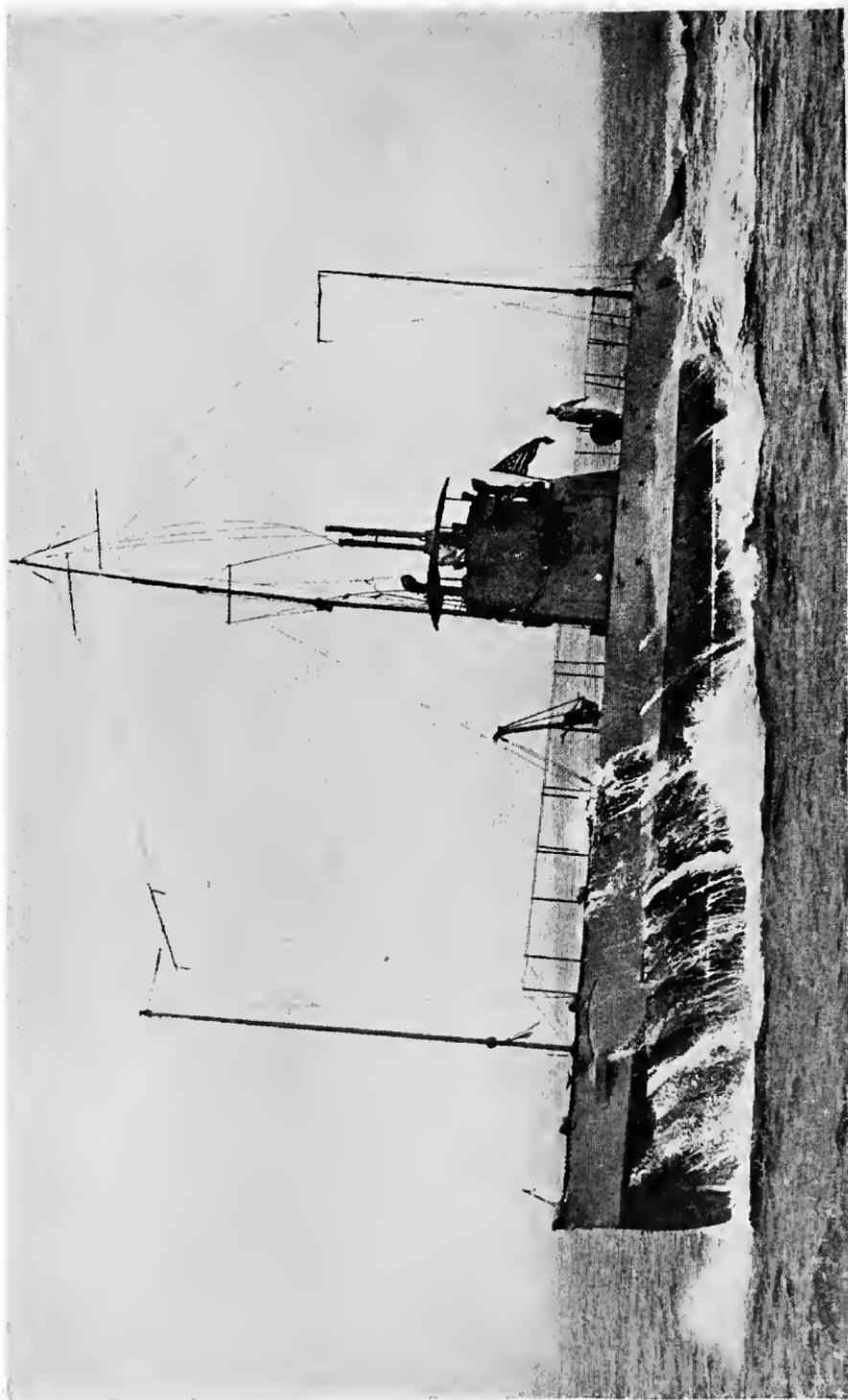
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STORAGE BATTERY  
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# STORAGE BATTERY MANUAL

INCLUDING PRINCIPLES OF  
STORAGE BATTERY CONSTRUCTION AND DESIGN  
WITH THE APPLICATION OF  
STORAGE BATTERIES TO THE NAVAL SERVICE

BY  
LUCIUS C. DUNN  
Lieutenant Commander, U. S. Navy



1920

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ANNAPOLIS, MARYLAND

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## PREFACE.

Owing to the very rapidly increasing application of storage battery engineering to our naval service, and believing that there exists a growing need for a modern text-book on this subject, effort has therefore been put forth in the production of this volume with the hope that it will prove of assistance in the instruction of our personnel in this very important and interesting branch of electrical engineering. Special effort has also been put forth in an attempt to present the subject matter of the text in as simple and as practical a manner as possible and with the use of only those involved formulæ and mathematical expressions as have been deemed absolutely essential in developing and supporting the text. Great pains have also been taken in composing and selecting the various drawings and photographs used for clearly illustrating the text.

My very sincere thanks are due and are extended to many of the battery engineers of the following companies for the numerous valuable and helpful hints received from them in relation to this subject and which have been crystallized into the production of the text of this volume, and also for the use of many of the illustrations used in connection with the text: The Electric Storage Battery Co., The Gould Storage Battery Co., The General Lead Batteries Co., The Philadelphia Storage Battery Co., The U. S. Light and Heat Corporation, The Willard Storage Battery Co., The Goodrich Rubber Co., The Brown Instrument Co., The Werner and Pfleiderer Co., and The Cutter Electrical and Mfg. Co.

LUCIUS C. DUNN,  
Lieutenant Commander,  
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U. S. Naval Forces  
Operating in European Waters.  
June, 1920



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## CHAPTER I.

### HISTORICAL.

#### Discovery of the Voltaic Couple.

In 1790 Alessandro Volta, an Italian physicist, discovered that if electrodes of two chemically dissimilar conducting substances are immersed in an electrolyte which is capable of attacking one or both of the electrodes, an electromotive force is produced which accordingly sets up a flow of current when the external circuit between the two electrodes is closed. Such a combination of electrodes and electrolyte has since been called a "Voltaic Couple," after its discoverer.

In continuing his search in this direction, Volta also found that as long as the external circuit between the electrodes of the couple remained open, practically no chemical reaction between the electrolyte and the electrodes resulted; but, as has been stated, as soon as the external circuit was closed, chemical reaction was instantly brought about between the electrolyte and the electrodes, with the resultant flow of electrical current through the external circuit. This chemical reaction resolved itself into either dissolving the affinitive electrode in the electrolyte, or its combining with the electrolyte to form another substance.

This discovery having been made, it next became the logical step for man to so select and combine the electrodes and electrolyte composing this couple as to commercially utilize the resultant current and energy thus generated.

#### PRIMARY BATTERY.

The first commercial utilization of the voltaic couple as an electrical energy producing medium was in the form of the well-known primary cell or "primary battery," as it is commonly known. There have been various designs of this type cell developed and of which the Le Clanche cell and the various dry or "sparker" batteries are familiar examples. In this type of battery, the wasting away or exhaustion of the electrodes or the electrolyte necessitates a removal of the resultant substances thus formed, or even a renewal of the wasted or exhausted portion of the couple before the cell is capable of producing any further useful electrical energy. In other words, the voltaic couple in this type of cell is not reversible.

**SECONDARY OR STORAGE BATTERY.****Planté's Discovery and Experiment Explained.**

Many years had elapsed since Volta gave his discovery to the world, and since which time many of the most prominent physicists of their respective times had diligently applied themselves to the task of evolving the theory and principles co-incident with the action of the voltaic couple, when in 1860 Gaston Planté, a French physicist, while engaged in certain related electrolytic research work in his laboratory, had set up a small cell in connection with his work; the electrodes of this cell consisted of plain rolled sheets of pure lead, while the electrolyte consisted of dilute sulphuric acid. Also, in series with the external circuit of this cell was connected a galvanometer.

During the course of his experiments and after he had been passing direct current through this small cell for some little time, Planté, while changing his connections, accidentally brought the terminals of the external circuit of this cell into contact with each other, whereupon he was surprised to observe the needle of the galvanometer swing to the opposite side of the scale, thus indicating that current was flowing through the external circuit in an opposite direction to that in which it had originally been flowing when passing current through the cell. Although it was noted that this secondary current lasted for a few seconds only, in following up his experiments Planté discovered that each time he repeated the operation, the duration of the secondary current increased, until after several such trials the secondary current became of quite appreciable magnitude. Furthermore, in continuing his research along this line, Planté discovered that if the direction of charging current through the cell were reversed each time, the resulting secondary current was increased in magnitude much more rapidly.

Upon further investigation Planté noted that whereas the surfaces of the lead plates were originally bright before placing them in the sulphuric acid, they immediately became coated with a white filmy substance when placed in the acid. This feature of the experiment is accounted for by the fact that sulphuric acid has a great affinity for metals, and the white filmy substance on the surfaces of the lead plates was the lead-sulphate formed as a result of the action of the sulphuric acid on the lead.

Planté also noted that when current had been passing through the cell for some little time the white coating on the surface of the positive plate became dark brown in color, and that on the negative plate a light gray. Subsequent chemical analysis proved the dark brown substance on the surface of the positive plate to be lead-peroxide, or a sort of lead rust, and the light gray substance of the negative plate, sponge lead, or metallic lead in a spongy state.

Also, upon discharging the cell, Planté noted that these substances gradually changed in color until they again became white. Further examination revealed the fact that at the end of the discharge the surfaces of both plates had again been converted into lead-sulphate. Also, each time this experiment was repeated, the coatings on the surfaces of the plates became thicker, which accounts for the increase in capacity of the cell noted during the course of his experiments. This type of plate has since been called a "Planté plate," after its discoverer.

Thus it is seen that Planté, in passing a direct current through this small cell containing the pure lead electrodes and dilute sulphuric acid, had unconsciously converted it into a formidable voltaic couple, the active components of which were lead-peroxide ( $\text{PbO}_2$ ), sponge lead ( $\text{Pb}$ ), and dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ). Moreover, he had produced a voltaic couple, all elements of which were capable of restoration to their original state, after exhaustion, by passing current through the cell in the opposite direction, and it is as a result of this discovery and the principles involved that the modern storage battery has been developed.

#### **Difference Between Primary and Secondary Cell.**

As has been described in the preceding paragraphs, the fundamental principle of the secondary or storage battery cell is based on the reversibility feature of its voltaic couple. Furthermore, this feature of reversibility constitutes the radical difference between the primary and the secondary cell; in other words, the voltaic couple of the primary cell is not capable of reversibility, whereas that of the secondary cell is capable of such reversibility.

It is, therefore, essential to a proper understanding of this subject that this distinction be thoroughly understood in the beginning and, since this distinction has thus been explained in the preceding paragraphs, the succeeding text of this book will deal entirely with the reversible voltaic couple and its application to the storage battery or accumulator, as used in the naval service.

#### **Faure or Pasted Plates.**

Although Planté had discovered a reversible voltaic couple, months of charge, discharge and reversal were necessary with his process in order to form layers of lead-peroxide and sponge lead of sufficient thickness to produce a battery having any material capacity. Therefore it remained for the next important step in the development of the storage battery to be taken in the direction of a reduction in the time element necessary to complete this "forming process."

This highly important and advanced step in the development of the storage battery was achieved in 1880 when a Frenchman, Camille Faure, in France, and an American, Charles F. Brush, in America, practically simultaneously discovered a process by which a thick coating of lead-oxide, when mixed with sulphuric acid and worked up into a paste of putty-like consistency, could be applied to a skeleton framework or "grid," thus forming a plate, and that by placing these plates in dilute sulphuric acid and passing a single low rate charge through them, the lead-oxide on the respective positive and negative plates was converted into highly porous lead-peroxide and sponge lead. These plates have since been called "Faure" or "pasted plates."

Since their discovery, these paste plates have undergone successive stages of development in the way of improved methods of combining and mixing the paste, as well as improvement in the design and construction of the grids, separators and other component parts.

#### **Improvement in Process of Forming Planté Plates.**

Although the development of the pasted type plate had insured the ultimate success of the storage battery as an efficient energy producing agent, the development of this art was not confined entirely to the paste type plates, as physicists, electrochemists and inventors were constantly engaged in trying to develop an improved method for the "forming process" of Planté plates. Happily, this field of endeavor was not without favorable results, as is indicated by the fact that the modern "forming" methods employed in the manufacture of Planté plates are capable of producing these plates about as quickly and as cheaply as those employed in producing Faure or "paste plates."

Among these modern "forming" methods may be included the various fashioned grooving of the surfaces of these plates to increase their surface area in contact with the acid, and also the employment of various rapid electrochemical forming agents, such as hydrochloric acid, nitric acid, perchloric acid and other lead corroding acids acting in conjunction with the sulphuric acid of the electrolyte.

Moreover, the development of both of the above types of plates has proceeded hand in hand, each having contributed its share to the successes achieved in this very important branch of electrical engineering. Each type of plate has its own particular field of efficient service, and in some instances these services require that both types be installed in the same cell. In this regard, it may be said that, generally speaking, paste plates are used where maximum capacity per unit of weight is required and where life is not a governing factor, whereas, Planté plates are used for services in which weight is not a material factor and the desirability for long life is paramount.

## CHAPTER II.

### CHEMICAL THEORY AND DESCRIPTION OF THE LEAD-ACID STORAGE BATTERY CELL.

#### Development of the Storage Battery Cell.

As explained in the preceding chapter, the storage battery cell, in its modern conception, consists of an application of the reversible voltaic couple in a highly developed stage of perfection. Moreover, in bringing the storage battery cell to this highly developed stage of perfection, such that it efficiently performs the many duties required of it in the modern electrical engineering world, it has been necessary for the storage battery engineer to carefully consider three very important fundamental factors entering into the design and construction of this cell and to so arrange and combine these factors as to produce a well-balanced, practical and workable unit. These factors are as follows :

1. Mechanical.
2. Electrical.
3. Chemical.

#### Mechanical Factor.

The mechanical factor enters primarily into fulfilling the various structural requirements of the battery, such as design and construction of the grids and plates and methods of retaining in position the active material of the plates; methods of connecting the plates to their corresponding straps and terminal posts, as well as securing the element in the jar; various methods of plate separation and insulation; design of the jar and cover and the various cover fittings, such as filling vents, terminal post bushings, gaskets, terminal post nuts, etc.; design and construction of inter-cell connectors and methods of connecting the cell terminals to their corresponding service lines. In brief, obtaining necessary structural ruggedness and durability in the general design of the storage battery is the prime function of the mechanical factor.

#### Electrical Factor.

In the art of storage battery construction and design the electrical factor is equally as important as the mechanical factor. Upon the electrical factor largely depends the true and practical efficiency of the battery, since, as is true with other electrical apparatus, in order that the battery may satisfactorily perform its designed function, it is necessary that certain electrical characteristics be obtained.

Therefore, in point of design, the electrical factor consists in so proportioning the grids, plates, straps, terminal posts, connectors, etc., that they will possess ample current carrying capacity, without undue voltage drop and heating, when the battery is subjected to the regular operating conditions of charge and discharge for which it was intended. In addition to the above general conditions to be fulfilled by the electrical factor, the following specific points of design may also be included under this heading:

(a) The design of the grid and plate and the distribution of the active material should be such as to produce uniform working of the plate over its entire surface.

(b) The active material should be applied to the plate or grid in such manner that it will maintain proper contact with itself and the grid and thus produce maximum electrical conductivity.

(c) In the larger type cells of high ampere-hour capacity, such as the submarine type, which require copper inserts in the straps, terminal posts and connectors, it is necessary that good electrical contact be obtained between the copper and the lead-alloy casting or plating around same in order that heating and the consequent loss of energy and efficiency may be prevented. The copper inserts should also possess a high degree of electrical conductivity. Improper contact between the copper and the lead-alloy casting has been a source of much trouble in the past in the storage battery engineering world, and this feature has been the subject of much study by battery engineers, and a great deal of development work has gone on, until now the modern methods employed produce a very satisfactory union between the copper and the lead-alloy castings. This subject will be taken up in detail in a later chapter.

(d) Design of separators and methods of plate insulation should be such that internal resistance of the cell will be reduced to a minimum. This feature consists in selecting suitable woods for separators and specially treating these woods to lower their resistance to the passage of electrical current. Various methods of treating these woods have been devised. The design of the rubber separators, such as percentage of porosity, thickness, composition, etc., may also be properly placed under this heading.

(e) Such details of the designs of the cells, jars, covers, connectors, trays, etc., as have to do with proper insulation and prevention of grounds.

(f) Various methods and designs of attachments used in connecting the several cells to each other and to their service lines.

### **Chemical Factor.**

Unlike practically all other types of electrical apparatus, the designs and methods of operation of which depend principally upon mechanical and

electrical factors, the storage battery cell depends upon a third essential factor—the chemical factor. Moreover, it should be understood that in designing and operating the storage battery cell, the chemical factor is deserving of equal consideration with those other two factors, that is, the mechanical and the electrical factors. Also, although the application of the chemical factor involves many complex and intricate problems, both practical and theoretical, when certain of the chemical fundamentals connected with the action of the storage battery cell are studied and understood, many of the apparent complex features of this subject will have been removed. It is therefore well in beginning the study of this subject to consider the prime constituents of the lead-acid storage battery cell and the fundamental equation of the reactions which take place in this cell during the cycle of charge and discharge.

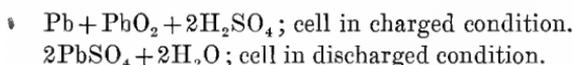
The active constituents of the lead-acid storage battery cell are as follows:

(a) Positive plate; lead-peroxide ( $\text{PbO}_2$ ), which is of a velvety “chocolate” brown color.

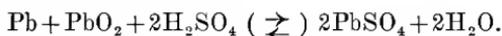
(b) Negative plate; finely divided sponge lead ( $\text{Pb}$ ), which is of a “battleship” gray color.

(c) Electrolyte; dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ), consisting of chemically pure sulphuric acid diluted with pure distilled water.

The generally accepted fundamental equation for the normal chemical action which takes place in this cell may be thus indicated as follows:



Therefore, in combining the above, the fundamental equation of the complete reaction is written as follows:



In other words, the conventional sign ( $\rightleftharpoons$ ) indicates that this reaction is completely reversible; that is, reading this equation from left to right ( $\rightarrow$ ) denotes the action which takes place during discharge of the cell, and reading from right to left ( $\leftarrow$ ), that which takes place during charge.

It is therefore apparent from the above equation that during discharge the acid radical,  $\text{SO}_4$ , of the electrolyte combines with the active materials of the positive and negative plates and converts both of these plates into lead-sulphate ( $\text{PbSO}_4$ ). Moreover, during charge the lead-sulphate is reduced by the charging current and the acid radical returned to the electrolyte, the active materials of both plates being accordingly restored to their original states; that is, to sponge lead and lead-peroxide.

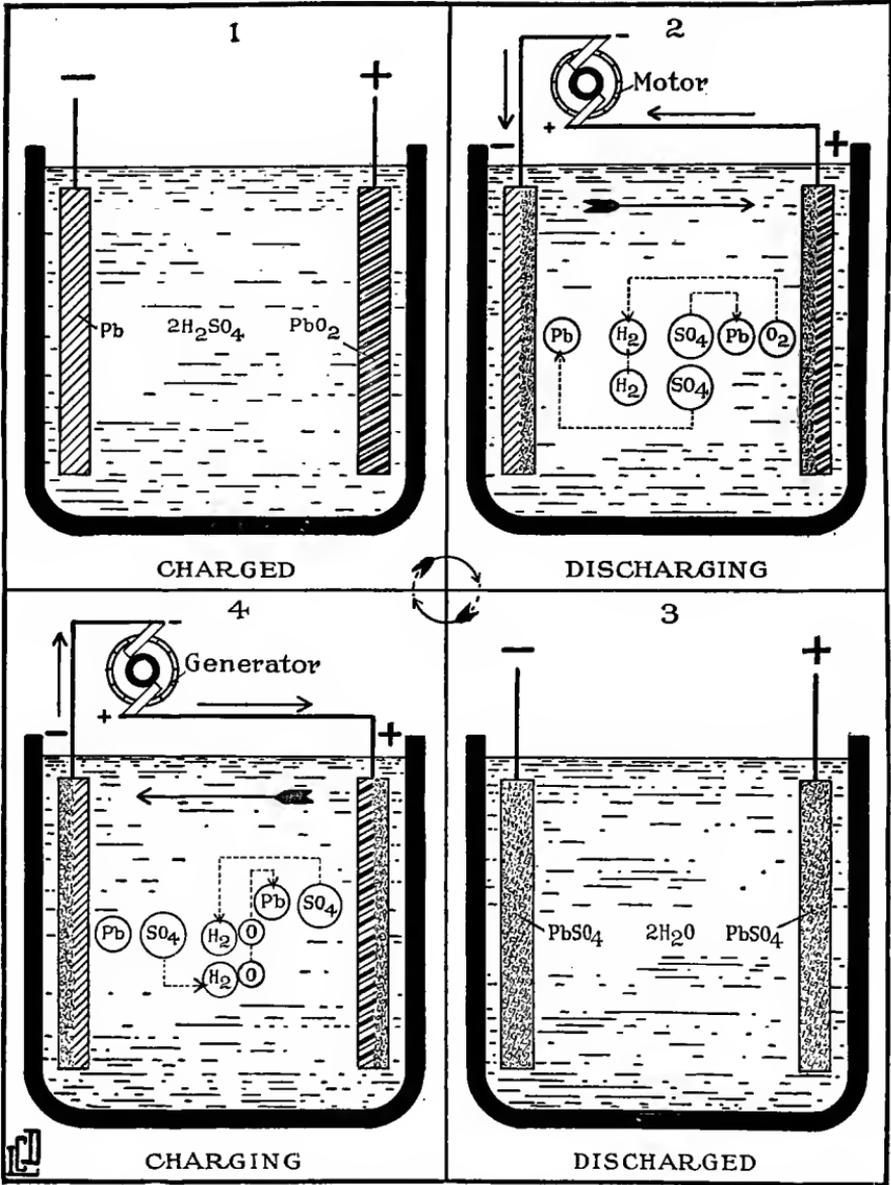


FIG. 1.—The Four Stages of the Operating Cycle in the Storage Battery Cell.

### Graphical Illustration of the Cycle of Charge and Discharge.

There is shown in Fig. 1 a diagrammatic illustration of the four stages constituting a complete cycle of charge and discharge, which stages are as follows:

- I. Cell in *charged* condition.
- II. Cell *discharging*.
- III. Cell in *discharged* condition.
- IV. Cell *charging*.

The four stages enumerated above are given in the natural order in which they occur during the accomplishment of the cycle, and the illustration in Fig. 1 should be studied in conjunction with the text of the fundamental equation of the lead-acid storage battery cell and as outlined in the preceding paragraphs. The direction of flow of current through the cell is shown by the arrows in the drawings.

**The Characteristic Curves of Charge.**—We have seen by the equations in the preceding paragraphs that when the cell is placed on discharge the acid radical ( $\text{SO}_4$ ) of the electrolyte combines with the active materials of the plates and accordingly converts them into lead-sulphate. We have also seen that when the cell is placed on charge the electrolytic action resulting from the charging current manifests itself in reducing the lead-sulphate contained in the plates, and of returning the acid radical ( $\text{SO}_4$ ) to the electrolyte.

Fig. 2 contains a set of curves illustrating the typical characteristics of the storage battery cell during charge, and an analysis of these curves will assist in obtaining a clear idea of the actions which take place in this cell during charge.

Let us first consider the voltage curve. It will be noted that at the beginning of the charge the cell voltage is around 2.15 to 2.17 volts, and as the charge progresses and as the sulphate is being reduced there is a gradual and regular increase in the voltage until approximately 2.35 volts is reached, at which time the voltage increases rapidly for the remainder of the charge, the voltage at the end of the charge averaging around 2.65 to 2.70 volts, which value represents the voltage of the fully charged cell. Moreover, if the charge be continued beyond this point, as will later be explained, practically all of the charging current is wasted since it is utilized in electrolysis or decomposing the water of the electrolyte.

Now, at the beginning of the charge, since the plates are composed for the most part of lead-sulphate there is an abundant supply of this sulphate available for reduction by the charging current; furthermore, during the early stages of the charge this supply of sulphate is easily accessible to the charging current since the surfaces of the plates are practically entirely composed of pure lead-sulphate. For this reason, therefore, the rise in the cell voltage during this period is relatively slight.

However, as the charge progresses all of the lead-sulphate at the surfaces of the plates is reduced, and the remaining sulphate being located in the interior of the plates, it is accordingly less accessible to the charging current and in consequence its reduction is effected with increasingly greater difficulty, this feature being manifested by a gradual rise in the cell voltage, as is shown by the curve.

This condition continues until a point is reached at which the charging current is in excess of that capable of being absorbed by the cell in the reduction of sulphate, and the surplus current is therefore spent in electrolysis or

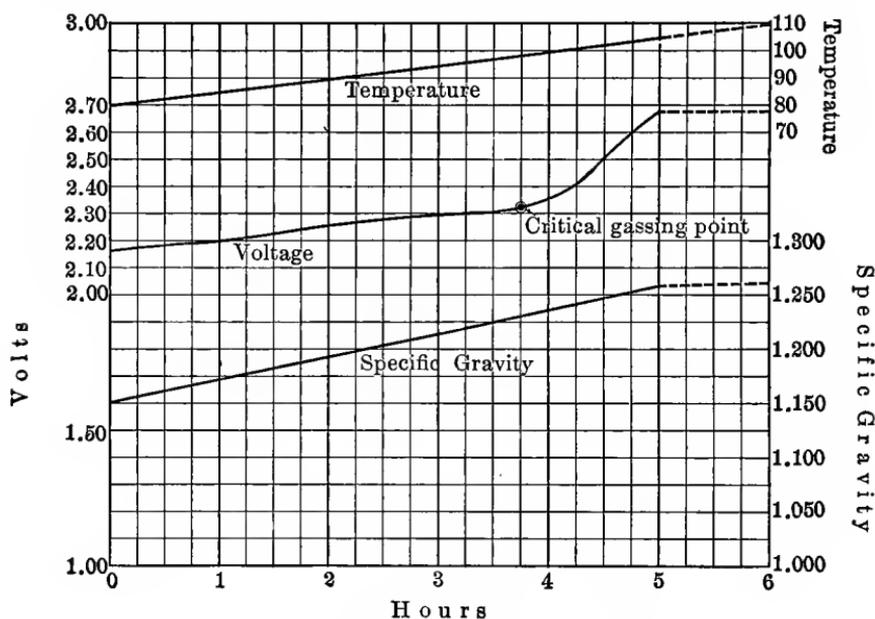


FIG. 2.—Characteristic Curves of Charge.

decomposing the water of the electrolyte into its gaseous constituents, hydrogen and oxygen. This condition obtains when the cell attains a voltage of approximately 2.35 volts, and this point is known as the *critical gassing point* of the cell and is plainly indicated on the curve in Fig. 2.

From this point on, due to the fact that the amount of lead-sulphate remaining in the plates is getting smaller all the time as well as less accessible to the charging current, there is a rapid increase in the cell voltage, until 2.65 to 2.70 volts is reached and at which time there is practically no lead-sulphate remaining in the plates, hence the specific gravity of the electrolyte ceases to rise and the cell may be said to be in a fully charged condition. If the charge

be continued beyond this point the temperature of the cell rises rapidly and the cell in reality resolves itself into a hydrogen and oxygen generator, since practically all of the charging current at this stage goes to electrolysis.

A study of the specific gravity and the temperature curves in conjunction with the foregoing analysis of the voltage curve should therefore enable the student to form a clear idea of the principal reactions which take place in the cell during charge.

**The Characteristic Curves of Discharge.**—Having fully charged the cell as described above, we will next place it on discharge and note the characteristics during this operation.

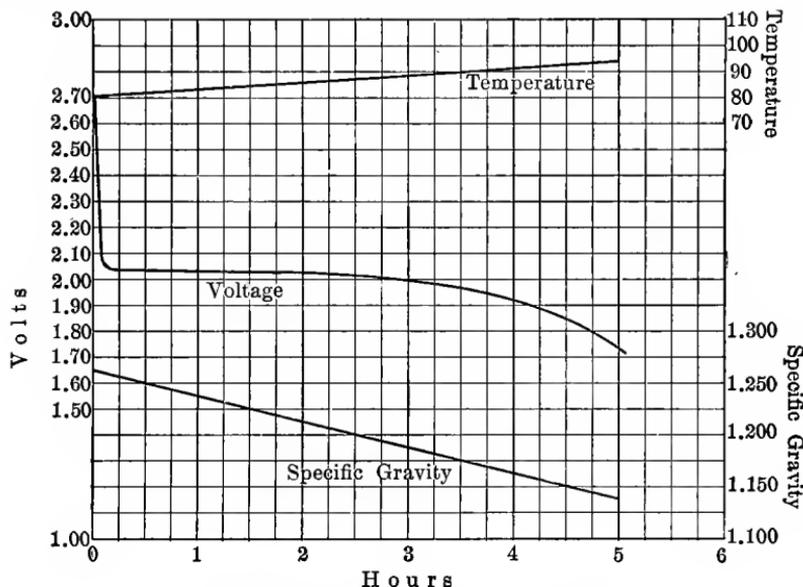


FIG. 3.—Characteristic Curves of Discharge.

There is shown in Fig. 3 a set of curves representing the typical characteristics of the cell during a discharge and an analysis of these curves will assist in bringing out the salient features incident to the reactions which take place in the cell during discharge. As in the study of the reactions of charge, we will proceed to consider first the voltage curve in studying the discharge reactions.

Starting then with the cell in a fully charged condition it will be noted from the curve that the instant the cell is cut in on discharge the cell voltage very rapidly drops from the normal full charge value (2.65 to 2.70 volts) to from 2.10 to 2.00 volts, after which the drop is comparatively slight over the

discharge period; but, during the latter stages of the discharge, that is, when the cell is from 60 to 75 per cent discharged, the voltage begins to drop off more rapidly until approximately 1.70 volts is reached and at which time the cell may be said to be for all practical purposes in a discharged condition. Of course, the discharge could be continued until complete discharge is accomplished, that is, until the cell voltage drops to zero, but for reasons which will later be explained, it is both inadvisable and uneconomical from an operating point of view to continue the discharge below 1.70 volts, especially for discharges at the 3-hour rate and lower. For discharges higher than the 3-hour rate the discharge may be carried slightly below 1.70 volts.

In analyzing the characteristic voltage curve of discharge let us first consider the conditions which obtain in the fully charged cell at the instant just preceding that of placing the cell on discharge. The pertinent conditions which obtain at this stage are that the pores of the active materials composing the plates are filled with high density acid, which is practically uniform in density with the bulk or main volume of electrolyte contained in the cell, and that the entire active surfaces of the plates are in intimate contact with the electrolyte.

Now, at the instant that the cell is cut in on discharge and depending upon the magnitude of the discharge current rate, there is a certain immediate or initial drop in the cell voltage from the full charge value—in general the higher the current rate the greater the voltage drop, and vice versa; the amount of this initial drop in voltage may also be said to be a function of the internal resistance of the cell, the rate of formation of a thin layer of sulphate on the surfaces and in the pores of the plates, and the abstraction of the acid from the electrolyte which is in immediate contact with all portions of the active materials of the plates.

After this initial drop in the cell voltage is effected, the drop thereafter is relatively slight over a considerable period of the discharge, and during this time the acid radical ( $\text{SO}_4$ ) of the electrolyte is combining with the active materials of the plates thus converting them into lead-sulphate. Also, during this period inasmuch as there is an abundant supply of both acid and active materials contained in the cell, the rate of diffusion of the acid into the pores of the plates and the consequent combining of this acid with the active material is comparatively rapid, thus maintaining a relatively constant cell voltage.

However, as the discharge progresses there is a gradual drop in the voltage which is accounted for by the fact that the internal resistance of the cell gradually increases by virtue of the formation of the lead-sulphate in the plates, and also through the fact that the remaining uncombined active

material being located in the interior or core of the plates, it accordingly becomes more and more inaccessible to the action of the electrolyte and, since the density of the electrolyte is in turn gradually growing weaker, it follows that the rate of diffusion of the electrolyte into the pores of the plates is decreased; diffusion of the electrolyte into the pores of the plates is further retarded as a result of the clogged or congested condition of the pores of the active material incident to the formation of the mass of sulphate in the plates.

This condition continues throughout the remainder of the discharge, with the exception that the drop in cell voltage becomes more rapid after the cell reaches a stage of from 60 to 75 per cent discharged, and from which time on due to the fact that the mass of lead-sulphate is steadily increasing while the density of the electrolyte is growing weaker, there is an increasing rate to the drop in cell voltage. As has been stated, the discharge should be discontinued when the cell voltage is reduced to 1.70 volts, as any discharging beyond this point is uneconomical, and also owing to the fact that lead-sulphate is less dense than either lead-peroxide or sponge lead, there is danger of overstraining the grids and cracking or "buckling" them if it be attempted to convert all of the active material into lead-sulphate. Therefore, it has been found that 1.70 volts is the safe limit of the discharge such that an excessive strain will not be put upon the grids through over-expansion of the sulphated mass of active material. However, the rate of discharge establishes the minimum final voltage limit during discharge, and each battery manufacturer establishes this limit for his own particular make of battery. This subject of minimum final voltage limit on discharge will be taken up in more detail in a later chapter.

A study of the specific gravity and the temperature characteristic curves in conjunction with the analysis of the voltage curve as outlined above will serve to form a clear idea of the prime reactions which take place in the cell during discharge. It will be noted that during a normal discharge there is a comparatively slight rise in the cell temperature, this rise being not as great as during charge.

Referring to the characteristic curve of specific gravity it will be noted that the drop in the specific gravity of the electrolyte is practically directly proportional to the ampere-hours of discharge, and for this reason the specific gravity readings are in general more to be relied upon in determining the true state of discharge of the cell than are the voltage readings. However, in order to intelligently operate the storage battery cell routine readings should be taken of the voltage as well as the specific gravity.

## CHAPTER III.

### DEFINITIONS AND NOMENCLATURE OF PARTS.

**Acid.**—The active component of the electrolyte as used in the lead-acid storage battery cell, and consists of chemically pure sulphuric acid ( $H_2SO_4$ ).

**Acid Testing Outfit.**—The accessories used for testing the specific gravity of the electrolyte. These testing outfits usually consist of beakers, hydrometers, hydrometer syringes and thermometers.

**Alternating Current.**—A current which alternates regularly in direction. Should never be used for charging storage batteries unless some form of rectifier is used with it to convert it into direct current.



FIG. 4.—Storage Battery Ammeter.

**Ammeter.**—An instrument used for measuring the rate of current in amperes flowing through an electrical circuit. As used with the storage battery these meters measure the rate of charging current passing through the battery, and also for measuring the rate of current passing from the storage battery on discharge. The ammeters used with storage batteries are usually of the two-way reading type; that is, the zero mark of the ammeter is placed in the center of the arc of the scale and the graduations are made to the right and to the left of the zero mark. Thus, on charge the needle registers on that portion of the scale to the right of the zero mark, while on discharge it registers to the left of the zero mark. This type of meter facilitates using either during charge or discharge of the battery without changing the terminal leads to the instrument, as would otherwise be necessary to compensate for the change in direction of current in the circuit if it

contained only one scale of graduations. Fig. 4 contains an illustration of this type of ammeter.

**Ampere.**—The practical unit of electric current.

**Ampere-Hour.**—A unit of quantity used in measuring the quantity of electric current passing through a circuit, and is obtained by multiplying the rate in amperes by the time. Thus, 10 amperes flowing for 5 hours equals 50 ampere-hours.

**Ampere-Hour Meter.**—An instrument used for measuring the quantity of current (ampere-hours) passing through an electrical circuit. Ampere-hour meters are used in connection with storage batteries for two purposes, which are as follows: First, for recording the ampere-hours discharged from the battery, thus indicating the degree of discharge of the battery. Second, for recording the ampere-hours of charge put into the battery, thus indicating the degree of charge of the battery.

**Antimony.**—A metal extensively used in the manufacture of lead-acid storage batteries. It is used principally for combining with lead to produce the lead-antimony alloy of which the grids for the plates are cast. The antimony adds rigidity to the grid.

**Average Voltage.**—The average value of the electromotive force of a given charge or discharge, and is an essential factor in computing the number of kilowatts developed on a given charge or discharge.

**Battery.**—Any number of complete cells assembled in one or more trays.

**Boosting.**—A term applied to a special charge given to one or more cells whose state of charge has, through any cause, fallen below that of the other cells of the battery. Thus, such cells are given a “boosting” charge to restore them to the same degree of charge as the other cells of the battery.

**Buckled Plates.**—Plates which have become distorted in shape as a result of excessive overcharging and discharging. High temperatures in the cell and over-sulphation of the active material of the plates constitute the chief factors which produce buckled plates.

**Capacity.**—The capacity of a storage battery cell is rated in terms of ampere-hours, which means that the plates in the cell, when fully charged, are capable of delivering a given number of amperes for a given length of time, the time usually being stated in hours. The capacity of a storage battery varies with the rate of discharge; in other words, a battery will deliver more ampere-hours when discharging at a *lower* rate in amperes than it will deliver when discharging at a *higher* rate. Capacity of storage batteries is also expressed in kilowatts.

**Cell.**—The battery unit, consisting of a jar containing completely assembled element and electrolyte, and with cover and vent.

**Cell Connector.**—The metal link used for connecting the positive post of one cell to the negative post of the adjacent cell. These connectors are of various types and designs, but, generally speaking, they consist of a strip of pure copper around which is either cast or plaited a pure lead envelope. For the small portable types of batteries these connectors are usually cast from lead-antimony alloy.

**Characteristic Curves.**—The curves showing the various factors of the normal charge and discharge of the battery, and are essential to an intelligent operation of the battery. These curves show the various rates of charge and discharge, with the corresponding initial, average and final voltages, as well as the kilowatts developed at the various rates. The specific gravity of the electrolyte at full charge and upon which these various factors are based is also included in these characteristic curves.

**Charging.**—The process of passing direct current through a battery in the direction opposite to that of discharge in order to restore the energy used on discharge.

**Charging Curve.**—The curve prepared by the battery manufacturer and showing the starting, intermediate and finishing rates for charging the particular type battery to which it applies.

**Charging Rate.**—The proper rate of current to use in charging a battery. It is expressed in amperes and varies with the size and number of the plates in the cell.

**Chemical Action.**—The joint action taking place between the electrolyte and the active material composing the electrodes of the storage battery cell.

**Corrosion.**—The result of the action of the acid of the electrolyte on the metal parts of the battery, and is principally due to lack of care in cleaning the battery.

**Coulomb.**—The practical unit of quantity of electricity, and is that quantity of electricity conveyed by one ampere in one second; sometimes referred to as the ampere-second.

**Cross Bar.**—The portion of the cross-bar, strap and terminal post casting to which is lead-burned the lugs of the plates of the cell.

**Cell Cover.**—The hard rubber cover which closes each individual cell. These covers contain the various fittings, such as filling cylinders, vent plugs, etc., and are securely sealed to the jar by means of sealing compound.

**Cycle.**—The complete operation of discharging a fully charged cell and again returning it to a state of full charge. It is usual to reckon the life of a battery in cycles.

**Direct Current.**—An electrical current whose direction of flow is constant. Habitually used for charging a storage battery.

**Discharge.**—The flow of an electric current from a battery through a circuit as a result of closing this circuit, and is in the opposite direction to “charge.”

**Faure Plates.**—Commonly known as “paste plates,” and named after their inventor, Camille Faure. The active material of these plates is held in a framework or “grid.”

**Filling Plug.**—The hard rubber plug which fits into and closes the orifice of the filling cylinder in the cell cover.

**Final Voltage.**—The electromotive force of a cell or battery at the end of a discharge.

**Finishing Rate.**—The reduced charging rate used when nearing the completion of the charge of a battery, and is such as to produce a minimum amount of gassing in the cell at this stage of the charge.

**Flooding.**—The act of filling to overflowing a cell when adding water or electrolyte and should be prevented as much as possible, as it is conducive to rotting of the trays, short circuits, etc.

**Freshening Charge.**—A charge given to a battery, which has been standing idle, to insure that it is maintained in a fully charged and healthy condition. On batteries which are subjected to protracted periods of idleness it is good practice to give them a “freshening charge” at least every two weeks if possible.

**Gassing.**—The bubbling of the electrolyte incident to the evolution of gas formed by electrolysis of the water in the electrolyte when nearing the end of the charge.

**Gravity.**—A contracted term used in reference to the “specific gravity” of the electrolyte.

**Grids.**—The lead-antimony alloy castings which form the lattice-work frames for holding the active material of paste plates. Many types and designs of grids have been developed and used by the various storage battery manufacturers.

**Ground.**—A connection made between an electrical circuit and the earth. If such a ground occurs on both the positive and the negative legs of a circuit a “short circuit” is the result. It is especially important to a satisfactory operation that all storage battery circuits be kept as clear as possible of such grounds.

**Group.**—A complete set of positive or negative plates joined to the corresponding cross-bar and strap. Such a group of negative plates is called a “negative group,” and a similar group of positive plates, a “positive group.” Groups do not include separators.

**Hold-Downs.**—The brackets and rods attached to the ends of a tray for securing the battery in position.

**Hydrometer.**—An instrument used for checking and measuring the specific gravity of the electrolyte.

**Hydrometer Syringe.**—The glass barrel and attached rubber bulb used for drawing up electrolyte for test with the hydrometer.

**Hydrogen Gas.**—Liberated at the negative plate of a storage battery during charge. A 3 per cent mixture of hydrogen in air is dangerous, and it is essential to safety in operating storage battery cells to keep the hydrogen mixture below 2 per cent.

**Initial Voltage.**—The electromotive force of a cell or battery at beginning of discharge.

**Intake Vent.**—An orifice located in the hard rubber cover of a cell and through which air is drawn into the cell for ventilation purposes.

**Internal Resistance.**—The resistance to the flow of current offered by the plates, separators and electrolyte in the storage battery cell.

**Jar.**—The container for the element and electrolyte of the storage battery cell. Hard rubber is now used for the jars of lead-acid storage battery cells to the practical exclusion of all other materials, except, however, glass is sometimes used for certain limited services.

**Kilowatt.**—One thousand watts; 746 watts equals one horsepower.

**Lead.**—The basic metal forming the voltaic couple as applied to the lead-acid storage battery cell.

**Lead Drops.**—Drops of molten lead which become detached from the main bulk of the metal during the process of lead-burning the plate lugs to the straps, etc. In order to lessen the likelihood of short circuits it is very essential that none of these lead drops be allowed to lodge between the plates.

**Lead-Peroxide ( $PbO_2$ ).**—The active material composing the positive plates of the lead-acid storage battery cell.

**Lead-Sulphate ( $PbSO_4$ ).**—The compound formed as a result of the action of the sulphuric acid on lead.

**Lead-Burning Outfit.**—An outfit consisting of the various accessories used in the process of lead-burning the various parts of lead-acid storage batteries. These outfits consist essentially of hydrogen or oxygen generators for supporting the flame used in melting the lead or lead-alloy used in this process.

**Lean Plates.**—A term applied to plates in which, through shedding, either normal or abnormal, the amount of active material has been reduced to the point such that little efficiency is obtained with further working of the plates. In other words, plates which have become "lean" have practically reached the end of their useful life. There is shown in Fig. 5 an illustration of a "lean" plate.

**Maximum Gravity.**—The highest specific gravity attained by the electrolyte of the cell through continued charging, thus indicating that no acid remains in the plates and constitutes an important factor in determining when the cell is fully charged.

**Minimum Final Voltage.**—The minimum permissible value of the voltage reached by a cell on discharge.

**Negative Plate.**—The sponge lead (Pb) component of the voltaic couple as used in the lead-acid storage battery cell. A fully formed negative plate is of a "battleship" gray color.

**Negative Group.**—The unit formed by burning the complete set of negative plates of the cell to their corresponding straps, cross-bars and terminals.

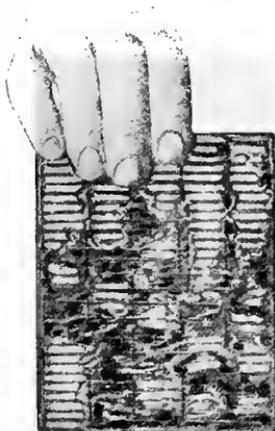


FIG. 5.—Lean Plate.

A negative group contains one more plate than does the corresponding positive group.

**Ohm.**—The practical unit of resistance.

**Ohm's Law.**—The law which expresses the relation between electromotive force, current and resistance in a closed electrical circuit in which the current is continuous. This law takes its name from its enunciator, Georg Simon Ohm, a German mathematician, and states that the current is directly proportional to the electromotive force and inversely proportional to the resistance, and is symbolically expressed as follows:

$$C = \frac{E}{R}, \text{ where}$$

$C$  = Current,  $E$  = Electromotive Force, and  
 $R$  = Resistance.

**Oil of Vitriol.**—Concentrated sulphuric acid, the specific gravity of which is about 1.835.

**Parallel Grouping.**—The method of connecting together the several cells of a battery, such that the positive terminals of all cells are connected to a common bus, and similarly the negative terminals of all cells.

**Planté Plates.**—Plates which are formed from pure lead by Planté's process, and are named after their discoverer, Gaston Planté, a Frenchman, who discovered the reversible voltaic couple in 1860.

**Plates.**—The electrodes of the storage battery cell, the positive plate consisting of lead-peroxide ( $\text{PbO}_2$ ), and the negative plate of metallic sponge lead ( $\text{Pb}$ ).

**Plate Lugs.**—The lug or neck formed at the upper corner of the plate, and which is used for lead-burning the plate to its terminal post strap. The plate lug thus serves to conduct the current to and from the plate to its terminal post.

**Porcelain Insulators.**—The porcelain skids on which the cell trays rest, and which act as an insulating medium to prevent moisture grounds, etc.

**Positive Plate.**—The lead-peroxide component of the voltaic couple as used in the lead-acid storage battery cell. A fully formed positive plate is of a velvety "chocolate fudge" color.

**Positive Group.**—The unit formed by burning the complete set of positive plates of the cell to their corresponding cross-bars, straps, and terminals. A positive group contains one plate less than does the corresponding negative group.

**Rating.**—The measure of the current in amperes capable of being delivered by a storage battery cell for a specific interval. Thus, if a cell is capable of producing 14 amperes continuously for 10 hours, to the specified final voltage, its "10-hour rate" is 14 amperes. Similarly we speak of the 1-hour rate, 3-hour rate, 5-hour rate, etc.

**Rectifier.**—An electrical apparatus used for converting alternating current into direct current. As applied to the storage battery, it is used for converting alternating current into direct current for charging purposes.

**Resistance.**—Any material of relatively low conductivity, such as lamp banks, wire, carbon, water, etc., which is inserted in a circuit for the purpose of retarding the flow of current. By varying the resistance, the amount of current can be regulated. As applied to the storage battery, these various types of resistances form a part of the charging and discharging panels for these batteries.

**Reversed Cell.**—A cell whose voltage reading has become reversed through charging in the wrong direction. Under ordinary operating conditions, cells should never be allowed to become reversed.

**Rubber Separators.**—The perforated sheets of hard rubber placed between the plates to prevent the positive and negative plates from coming in contact with each other. For most batteries used in the naval service these rubber separators are used in conjunction with treated wood separators, one such rubber sheet and one wood separator forming the insulation between each adjacent positive and negative plate. In such a combination the perforated rubber sheet is habitually placed against the positive plate.

**Sealing Compound.**—The thick, black, acid-proof compound used for sealing and making a tight joint between the jar and cover of the unit assembly type storage battery cell.

**Sediment.**—Particles of active material which have become detached from the plates and deposited on the bottom of the jar. This sediment has a thick, muddy appearance and is frequently referred to as “mud” by the operating personnel.

**Sediment Space.**—The clearance space between the bottom of the jar and the bottoms of the plates for receiving the sediment which is “shed” from the plates. This sediment space should be sufficient to receive all sediment shed from the plates during the useful life of the cell and without causing any short circuits across the bottom edges of the plates.

**Separator.**—An insulator placed between the plates of opposite polarity in the storage battery cell to prevent the plates from coming in contact with each other. For batteries of the naval service they usually consist of specially treated sheets of wood, perforated sheets of hard rubber or a combination of both of these types. Separators are generally corrugated or ribbed to insure proper plate separation and to facilitate ample circulation of the electrolyte.

**Separator Supports.**—Usually of hard rubber and placed in the bottom of the jar for supporting the separators in the element. In the small navy type portable batteries, the “bridges” in the bottom of the jar act as separator supports as well as supporting the plates of the element.

**Spray.**—Fine particles of electrolyte carried up by the bubbles formed as a result of the evolution of gas in the cell.

**Series Grouping.**—The method of grouping the cells of a battery such that the positive terminal of one cell is connected to the negative terminal of the adjacent cell and so on throughout the entire circuit. The effect obtained by grouping the cells in series is that the terminal voltage is the sum of the voltages of all cells so connected; hence, the power developed is increased over that of a single cell. However, when so connected, the ampere-hour capacity of the entire battery is that of a single cell.

**Series-Parallel Switch.**—A specially constructed switch for connecting the cells of a battery either in series or parallel grouping, depending upon the power required or other conditions to be met in operation.

**Shedding.**—The normal act of the loosening and falling away from the plates of the worn out particles of active material incident to the working of the cell. This shedding of the active material occurs in a degree with every charge and discharge of the storage battery cell and continues throughout the useful life of the cell; in fact, “shedding” is a function of the life of the cell.

**Short Circuits.**—As applied to the storage battery, it is usually a condition of metallic connection between the positive and negative plates of a cell. The plates may be in actual contact or material may bridge across the plates. A defective separator constitutes the most frequent cause of such a short circuit. With proper assembly of the cell, if the separators are maintained in good condition, the occurrence of such a short circuit is unlikely.

**Silver Nitrate Solution.**—A solution used for making a qualitative test for chlorine in water intended for use in storage batteries. When a few drops of silver nitrate solution are placed in water containing chlorine, the water instantly becomes cloudy and milky; whereas, when placed in water free from chlorine, the water remains clear.

**Specific Gravity.**—The density of the electrolyte of the storage battery cell as compared with water as a standard, the specific gravity of pure distilled water being unity. Usually referred to as “gravity.” An important factor in operation of the storage battery.

**Sponge Lead (Pb).**—The active material of the negative plate in the lead-acid storage battery cell.

**Starting Rate.**—The rate used in beginning the charge of a battery by the constant current method, and varies with the size and type of the battery. It is usual for the battery manufacturer to assign a “starting rate” for each type of battery, and to place this starting rate on the battery name-plate for the information of the operating personnel. The “starting rate” is usually approximately twice the “finishing rate.”

**Strap.**—The lead-antimony casting composing the terminal post and cross-bar and to which the lugs of all plates of like polarity in the cell are burned. In the larger type cells these straps are of copper, the lead-antimony being cast around the copper as a protective coating to prevent the copper from entering the cell.

**Sulphate.**—As applied to the lead-acid storage battery cell it refers to lead-sulphate ( $\text{PbSO}_4$ ), and is the substance into which the active material of both the positive and negative plates is converted during discharge.

**Sulphated.**—A term used in describing the character of the plates containing an abnormal amount of lead-sulphate ( $\text{PbSO}_4$ ) as a result of the cell being in an undercharged condition, from either overdischarging without

correspondingly long charges or from standing idle for protracted periods and becoming self-discharged.

**Sulphate Reading.**—A peculiarity of cell voltage attained when charging a cell, the plates of which are considerably sulphated. In this case the charging voltage shows abnormally high before gradually dropping to the normal charging voltage.

**Temperature Coefficient.**—The amount of the increase or decrease in the electromotive force of the cell as a result of an increase or decrease in the temperature of the cell. The temperature coefficient is positive for increased temperatures and negative for decreased temperatures. Practically speaking, it manifests itself in an increase or decrease in the ampere-hours given out by a cell to a stated final voltage. For example, all storage battery data of the naval service are based on the electrolyte having an initial temperature of 80° Fahrenheit; thus, if the initial temperature of the electrolyte is above 80° F., an increase in the ampere-hour capacity obtained from the cell to the normal final voltage, based on 80° F., will result. Conversely, if the initial temperature of electrolyte be below 80° F., a decrease in ampere-hour capacity obtained from the cell will result. Appropriate curves, called "Temperature Coefficient Curves for Capacity," are supplied by the battery manufacturers, and usually include temperatures ranging from 40° F. to 110° F., the 80° F. point on these curves representing the rated 100 per cent of capacity of the battery at the particular discharge rate as shown on the curve.

**Terminal Post.**—The portion of the positive or negative group which extends through the cell cover and by means of which the cell is connected to other cells or the required service circuits.

**Terminal Post Gaskets.**—The soft rubber gaskets used by some battery manufacturers for making an acid-tight joint around the terminal post where it passes through the hole in the cell cover.

**Terminal Post Nuts.**—The alloy or hard rubber nuts used by some battery manufacturers for securing the cell cover to the terminal post. In addition to assisting in making an effective seal between the cell cover and the terminal post, it also serves to prevent the element from shifting position in the jar.

**Terminal Volts.**—The combined voltages of all cells of a group connected in series. For example, if a tray contains five cells, all of which are connected in series, the terminal voltage of this tray of batteries is the sum of the voltages of these five cells.

**Tray.**—The container or case which holds the cells. The tray and cells which it contains are usually assembled as one complete unit. A battery may consist of one or more such trays.

**Tray Cover.**—The cover provided for closing the battery tray, as described above, and is designed primarily for protecting the tops of the cells against damage when working around the battery as well as keeping it free as possible from dirt, dust, foreign substances, etc.

**Tray Terminals.**—The attachments installed on each end of a battery tray, by means of which the positive terminals of one end cell and the negative terminals of the other end cell are connected to another tray, or the regular service line.

**Trickling Charge.**—When the storage batteries are connected across the supply mains and the conditions are such that the batteries are at all times receiving just enough current to counteract local action and thus keep them in a full charged condition, they are said to be receiving a “trickling charge.” A fraction of an ampere only is required for this “trickling charge,” and aside from the advantages obtained in counteracting local action in the cell the battery at all times has its entire capacity available for instant use if required. All batteries which are assigned primarily for stand-by circuits should be so connected up to the supply mains that they constantly receive a “trickling charge” as described above.

**Vent Trap.**—Consists of a series of perforated rubber sheets or baffle discs placed in the exhaust vent of a cell having forced ventilation, and is designed to trap the acid of the electrolyte which has been thrown up by the spray and return it to the cell.

**Voltage.**—Electrical potential or pressure, the unit of which is the volt.

**Watering Battery.**—The act of adding distilled or other pure water to the storage battery cell in order to replenish the water which has been lost through spraying and evaporation of the electrolyte. The batteries should be watered regularly as necessary. The level of the electrolyte should never be allowed to get below the tops of the plates before watering.

**Water Rheostat.**—A rheostat consisting of a box or barrel of water into which are placed two metal plates; one plate is connected by a wire to the positive terminal and the other one to the negative terminal of a storage battery. This type of rheostat is frequently used for test discharges of storage batteries. The water should be slightly acidulated in order to increase its conductivity. By varying the distance between the plates, the current regulation during discharge may be adjusted. Other types of water rheostats consist of pipe coils through which water is circulated under pressure. By making connections at various points along the length of the coil the resistance is varied and the desired current regulation is obtained.

**Wood Separator.**—A sheet of specially treated wood used for insulating from each other the positive and negative plates of the storage battery cell. Various kinds of wood are used for the separators, including bass wood, redwood, cypress, white cedar and Douglas fir.

## CHAPTER IV.

### DESCRIPTION OF UNIT ASSEMBLY TYPE CELLS.

#### The Unit Assembly Type Cell Defined.

The unit assembly type of cell, as its name implies, is one in which the jar, element, electrolyte and cover are assembled and sealed as one complete unit, and is such that it may be transported or handled entirely as a separate unit if desired, or it may be connected up in series or parallel grouping with other cells if required. Various features of design applying particularly to cell ventilation and non-spillage of electrolyte are characteristic of this type cell.

#### Application to the Naval Service.

Although in some few instances other types of cells are used for certain special services, principally on shore stations, the modern application of the lead-acid storage battery on board ship and in the general naval service is confined practically entirely to the unit assembly type of cell and the descriptive matter of this chapter will be confined to cells of this type. However, description of the other types, the so-called "open" or "tandem" types, will be covered in another chapter.

#### Component Parts of Unit Assembly Type Cell.

The unit assembly type cell in its modern application to our naval service is composed of the following parts, all of which are shown in Fig. 6:

- |                          |                            |                                       |
|--------------------------|----------------------------|---------------------------------------|
| I. Element.              | (a) Positive Group . . . . | Positive Plates.                      |
|                          |                            | Cross-bar, Straps and Terminal Posts. |
|                          | (b) Negative Group . . .   | Negative Plates.                      |
|                          |                            | Cross-bar, Straps and Terminal Posts. |
| (c) Separators . . . . . | Wood.                      |                                       |
|                          |                            | Rubber.                               |
|                          | (d) Separator Hold-downs.  |                                       |
- II. Electrolyte.  
III. Jar.  
IV. Cell Cover and Parts.  
V. Connectors.  
VI. Sealing Compound.

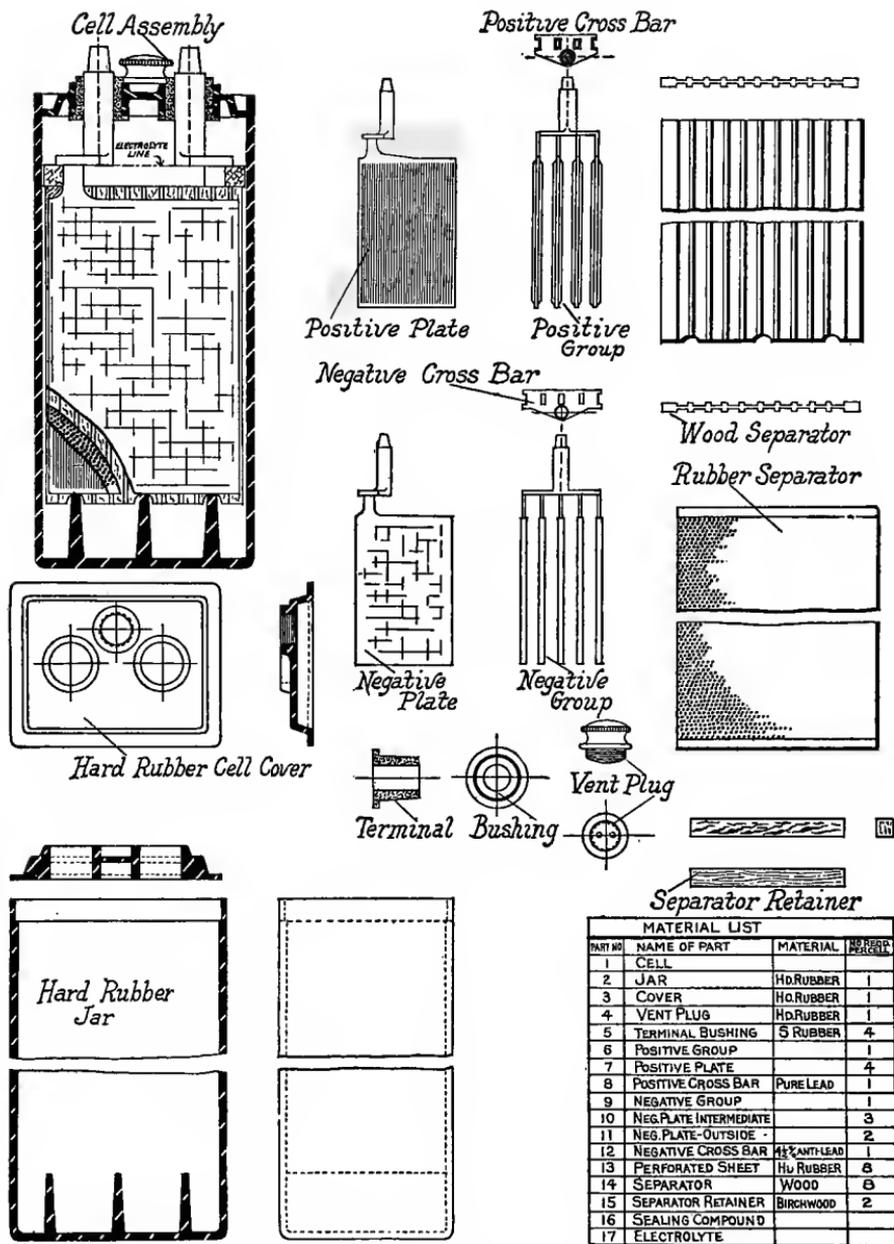


FIG. 6.—Details of Unit Assembly Type Cell.

### I. The Element.

It will thus be seen in the above topical outline that the combination formed by assembling a positive group, a negative group and the corresponding separators is technically termed the "element" of the cell. It is usual practice to assemble the entire element before placing in the jar.

**Positive Group.**—The positive group consists of all positive plates of the cell together with the corresponding cross-bar, strap and terminal posts. The lugs of all positive plates are lead-burned to the positive cross-bar, and this cross-bar is usually cast integral with the corresponding strap and terminal posts.

The positive plates are of a characteristic dark brown or "chocolate" color and are usually thicker than the corresponding negative plates used with them.

**Negative Group.**—The negative group likewise consists of all negative plates of the cell together with the corresponding cross-bar, strap and terminal posts. As in the case of the positive group, the lugs of all negative plates are lead-burned to the negative cross-bar, which is also usually cast integral with the corresponding strap and terminal post.

The negative plates are of a "battleship" gray color, and the negative group contains one more plate than does the corresponding positive group. Also, the end or "outside" negative plates are in some installations not so thick as the other negative plates of the group; this will be understood from the fact that practically only one surface of the "outside" negative plate is used, which surface is that which faces the adjacent positive plate. Thus, by decreasing the thickness of the outside negative plates, a reduction in the weight of the cell is obtained. However, this small decrease in the weight obtained is not considered sufficient by some battery manufacturers to justify the additional mould equipment which is necessary for casting these thin outside negative plates, and unless the question of weight of the battery is of special importance, it may be said that the present tendency is to cast all negative plates in the cell of the same thickness.

**Separators.**—The plates of opposite polarity in the cell are insulated from each other by means of interposing separators between them. For batteries designed for the naval service these separators consist of thin ribbed sheets of treated wood and highly perforated sheets of hard rubber; taken together they are spoken of as "wood-and-rubber combination" separators, since each wood separator is used in combination with a rubber separator, there being one such combination placed in the space between each positive and negative plate. Due to the deleterious effects of the active material of the positive plate on wood, the peroxide of lead tending to decay

and oxidize the wood, the wood separator is habitually placed next to the negative plate and the perforated rubber separator next to the positive plate. To date, the one exception, however, to the use of the "wood-and-rubber combination" separators, in batteries for the naval service, is in the case of the "Ironclad" type of storage battery; on account of the hard rubber tubes used for holding the active material of the positive plates in this type of construction, the perforated rubber separator is unnecessary; therefore, a single wood veneer sheet only is used in these batteries.

The subject of separators, however, will be taken up at length in a separate chapter.

**Separator Hold-Downs.**—The separator hold-downs are the special attachments placed on top of the separators in the cell and are for the purpose of maintaining the separators in their proper relative positions with the plates. If some such expedient is not resorted to, the wood separators will have a tendency to "float" up out of position.

These separator hold-downs are made of wood or rubber and are usually positioned between the tops of the separators and the under side of the cross-bar. Some manufacturers cast a projection on the cross-bars, which projections serve as the separator hold-downs. Various types of these separator hold-downs will be taken up in the descriptions of the several designs of batteries.

## II. Electrolyte.

The electrolyte in this type of cell, as in all other lead-acid storage battery cells, consists of a mixture of pure sulphuric acid and distilled or other pure water, and is the solution required to enable the chemical action to take place during charge and discharge.

## III. Jar.

The jar is the containing vessel in which are assembled the plates, separators and electrolyte. Hard rubber is now used practically entirely for the jars of all storage batteries used in the naval service, although in some few instances, principally on shore stations, glass jars are sometimes used. The subject of jars will be taken up with more detail in a later chapter.

## IV. Cell Cover and Parts.

The cell cover usually consists of a dome-shaped hard rubber lid so designed as to fit closely around the top edges of the jar, there being a channel-way thus formed between the dome of the cover and the walls of the jar in which is poured sealing compound for securely sealing the cover in position. Appropriate holes are cut in the top of the cover through which

pass the cell terminal posts; acid-tight joints are made between the cover and the terminal posts by means of rubber or alloy sealing nuts engaging in suitable threads on the terminal posts. Soft rubber gaskets are placed between the cell cover and these sealing nuts; thus, when the nuts are screwed home an acid-tight joint is obtained. Some manufacturers prefer to obtain this acid-tight joint between the terminal posts and the cell cover by use of sealing compound, but for batteries of the naval service this method is considered very undesirable, and the specifications provide that no sealing compound shall be used in making the joint between the terminal posts and cell covers of batteries designed for the naval service.

The cover fittings consist of intake vents, hydrometer plugs, sealing nuts, gaskets, ventilation system baffle discs and other such parts. The designs of these covers and parts vary in detail in accordance with the special features incorporated in the various types of batteries as manufactured by the several battery manufacturers. The subject of cell covers and parts will also be taken up in detail in a later chapter.

#### **V. Connectors.**

The cell connectors are used to connect the positive terminal of one cell with the negative terminal of the adjacent cell or with the regular service lines. These connectors are composed of lead-alloy or lead-coated copper strips or bars and are usually secured to the cell terminal posts by means of a lead-burned joint or some form of threaded or bolted connection. There are many types of these connectors used on the storage batteries of the naval service, descriptions of which will be taken up in a separate chapter.

#### **VI. Sealing Compound.**

The thick, black, acid-proof compound used for sealing and making an acid-tight joint between the jar and the cover of the unit assembly type storage battery cell.

## CHAPTER V.

### APPLICATION OF THE STORAGE BATTERY TO THE NAVAL SERVICE.

#### Battery Service Divided Into Two Classes.

The application of the storage battery to the naval service may be divided into two general classes, as follows:

1. Main power service.
2. Auxiliary power service.

**Main Power Service.**—The storage batteries designed for main power work in the naval service meet their principal application in submarine boat installations, it being understood that, in the submarine service, whereas the oil engines constitute the prime movers for surface operations, the storage batteries constitute the main source of power for submerged operations. It may also be stated authoritatively that although many other methods of developing power have been proposed, such as the various types of underwater internal combustion engines, etc., to date nothing has proved the equal of the storage battery for this particular form of undersea operation. Also, although there are many undesirable features and inconvenient conditions which are involved in the application of the storage battery to this service, from present outlook in the field of future development in the art of submarine construction and design, it is believed that the storage battery will continue to maintain its present paramount position as prime source of power for submerged operations for many days.

Moreover even though the application of the storage battery to this service does create many inconveniences and unavoidable conditions which must be met and accommodated, it may also be said that in no other branch of storage battery engineering has the development within comparatively recent years in our country been so rapid and reached such a high degree of reliability and perfection. Great credit is due to our own battery engineers and to the personnel of our submarine service in bringing the submarine storage battery to its present high state of efficiency and development in this country. It is also considered that our American storage battery engineering talent, both naval and civilian, is equal to, if indeed it does not surpass, similar talent in other countries. It is also believed that our modern stage of development in this art has attained a degree of perfection which is not surpassed in any other country.

There are various types of assemblies used in the submarine storage battery, all of which types will be fully described in a later chapter.

**Auxiliary Power Service.**—The batteries designed for auxiliary power service are commonly known as portable type batteries, and are in most cases used primarily as stand-by agents for many of the electrical circuits on board ship and in the general naval service; in fact, practically every electrical circuit on board ship now has a storage battery stand-by circuit. This has been brought about by the rapid strides made in comparatively recent time in the development of the storage battery cell of the unit assembly type. A brief historical outline of the development of the unit assembly type cell should here be considered in the study of this subject.

In the first place, as has been characteristic of the developments in many other lines of engineering endeavor, as, for instance, that of the gasoline engine, it may be said that to the automobile industry is due a large part of the credit for the present highly developed stage attained in the art of storage battery construction and design, and particularly is this true of the development of the so-called portable types of storage batteries. In respect to this feature of the subject the rapid strides made in the field of ignition, lighting, electrical propulsion and self-starting systems, as applying to the automobile industry, are familiar examples illustrative of this phase of storage battery development.

In brief, it is therefore seen that the development of the storage battery to meet the demands of the modern automobile industry has contributed materially to its present extensive and increasing application to the naval service. In the early days of the art the principal application of the storage battery on board ship was confined practically entirely to gun-firing circuits, and in some few instances to interior communication installations, but, as has been stated, the present application of the storage battery now embraces practically every electrical circuit on board ship.

The rigid requirement of the United States radio laws applying to marine installations has also served the purpose of assisting in the development of a suitable type of storage battery cell for installation on board ship. These radio laws provide that all steam vessels of the United States or of any foreign country navigating the seas or the Great Lakes and carrying or licensed to carry 50 or more persons, including passengers or crew or both, shall not leave or attempt to leave any port of the United States without being equipped with a stand-by or auxiliary power supply, independent of the vessel's main electric power plant, which will enable the sending set of the radio apparatus to send messages over a distance of at least 100 miles, day or night, and for a period of at least four hours.

This auxiliary supply for modern installations consists usually of a storage battery and the necessary switchboard and other electrical apparatus. The

storage battery is maintained in a charged condition through the main power circuits of the vessel, and is designed to operate the motor-generator set of the wireless equipment, should the main electrical plant for any reason become unavailable. This storage battery installation may also be advantageously used for operating the emergency lighting circuit of the ship in event of failure of the main generating plant. However, under such conditions, the capacity of the battery should be such that it will carry the combined load of the wireless motor-generator set and that of the rated full load of the lighting circuits for a period of at least four hours. It is also usual practice to install the storage batteries for these marine wireless equipments as high as practicable in the superstructure of the ship, in order that the batteries may be available for sending messages as long as possible, should the ship be taking on water and about to sink.

In summarizing the application of the storage battery on board ship and in the general naval service the following circuits should be included:

1. Ship's auxiliary lighting.
2. Turret auxiliary lighting.
3. Interior communication.
4. Telephone reserve supply.
5. Motor-boat ignition and lighting.
6. Motor-boat self-starting systems.
7. Turret auxiliary power.
8. Auxiliary steering power.
9. Speed boat searchlights.
10. Trench lighting outfits.
11. Submarine chasers, ignition, lighting and self-starting.
12. Gyro-compass installations.
13. Gun-firing.
14. Radio.
15. Wireless telephones.
16. Hand lanterns.
17. Portable searchlights.
18. Signalling apparatus.
19. Aeroplane...
 

{	Ignition.
{	Lighting.
{	Self-starting.
{	Radio.
{	Wireless telephone.
20. Shore station radio equipment.
21. Portable radio sets for landing force.

### Method of Obtaining Approved Types.

In obtaining suitable batteries for the naval service it is the present policy to require the various storage battery manufacturers to submit samples of their batteries for a rigid series of tests before they are finally approved as satisfactory and acceptable for service requirements. These tests are at present conducted in the testing laboratory of the New York Navy Yard, and are designed to ascertain the characteristics of these batteries as to life, capacity, durability and other general requirements, such as regular operating service conditions demand.

After a type of battery manufactured and submitted in accordance with current specifications has satisfactorily withstood all prescribed tests, the manufacturer's name is then placed on the eligible list for approved types, whereupon he may then submit, through the usual channels, his bids for supplying his types of batteries on government contracts.

### Method of Conducting Tests.

A general outline of the procedure and tests and the methods of conducting them in order to ascertain the suitability of various types of storage batteries for naval use is as follows:

Those battery manufacturers desiring to obtain approval of their batteries for naval use are required to make application accordingly to the Bureau of Engineering, Navy Department, prior to January first of the year in which they wish their batteries tested. Having obtained the Navy Department's approval of their request for tests on their batteries, they are then required to submit for test prior to January fifteenth samples of their batteries to the testing laboratory. These sample batteries must be manufactured in accordance with current approved specifications. The tests on all batteries thus submitted are begun on January fifteenth or as soon thereafter as practicable.

The laboratory tests consist of running successive cycles of charge and discharge at the specified rates of these batteries, and these tests are divided into three classes, as follows:

- (a) Capacity tests.
- (b) Life tests.
- (c) Durability tests.

**Capacity Tests.**—It is the object of the capacity tests to determine the electrochemical characteristics of these batteries and to ascertain whether or not they are capable of developing their standard rated capacities within the specified period of time.

During the capacity tests the present specifications require that these batteries develop at least 90 per cent of their rated capacity within the first three cycles of charge and discharge. They must also develop 100 per cent of rated capacity within the first eight cycles of charge and discharge. These capacity tests thus insure that proper plates are used. These tests also serve to determine the ampere-hour capacity per unit of weight for the various types of cells.

**Life Tests.**—The life tests of these batteries consist in determining, through successive cycles of charge and discharge, the amount of useful work that may be expected from them before their capacities are reduced to a certain percentage of their original normal rated capacities.

The present specifications require that the flat paste-paste assembly type batteries must retain at least 80 per cent of their normal rated capacity at the end of 200 cycles of charge and discharge, while the Planté-paste and the Ironclad-paste types are required to retain at least 80 per cent of their normal rated capacity at the end of 400 cycles of charge and discharge.

During these life tests, the batteries will be charged at the normal rates as submitted by the battery manufacturers, but for uniformity in conducting the tests the specifications require that the maximum time of charge at these rates shall not exceed 12 hours. Also, the discharges on these tests are run at the rates specified, which for these batteries are the one-, three-, and ten-hour rates.

Relative to the above-mentioned difference in life required of the paste-paste assembly type and that of the Planté-paste and the Ironclad-paste types, it should be understood that in a storage battery cell it is, generally speaking, an inherent characteristic that the positive plate disintegrates more rapidly than the negative plate, and hence is possessed of shorter life. Furthermore, with the present stage of development of the art, a positive plate of the paste type, that is, a positive plate having its active material in the form of a paste and contained within a grid, is of somewhat shorter life than either the Planté or the Ironclad type.

**Durability Tests.**—Having completed the capacity and life tests, the durability features of these batteries are next considered in order to determine their suitability for general naval work. It will here be appreciated that in many instances under service operating conditions these batteries are liable to be subjected to very severe and strenuous treatment; therefore, it is necessary that the specifications require that these batteries be of such rugged construction as to satisfactorily withstand hard mechanical service usage, as well as remaining idle for long periods of time, and, in addition, exposure to salt air.

The durability test consists in reviewing the general behavior of the battery during the capacity and life tests, as shown by the daily log kept during these tests. Also the battery is completely disassembled and all parts thoroughly examined and noted. This examination consists in noting the amount of sediment in the jars, condition of separators, plates, straps, terminal posts, connectors, hard and soft rubber parts, including jar, jar cover, etc. Also, the tray and all parts thereof are examined in order to ascertain the manner in which they have withstood the handling incident to running the tests, as well as the action of the electrolyte through spraying and spillage during the tests. Thus, it is seen that the durability test is a very important one and plays a large part in the final acceptance and adoption of a type of battery for naval use.

#### **Types of Assemblies.**

Depending upon the special type of the plates used in the assembly of these batteries, they are divided into four general classes as follows:

1. Paste type assemblies.
2. Planté type assemblies.
3. Planté-paste type assemblies.
4. Ironclad type assembly.

The special characteristics and details of construction of each of the above types will be described in other chapters.

## CHAPTER VI. PASTE TYPE ASSEMBLIES.

### General Description.

In this type of assembly both the positive and the negative plates are of the "pasted" or Faure type and are of various designs which depend mainly upon the shape and construction of the lead-antimony alloy framework or *grid* supporting the active material of these plates.

In the manufacture of this type of plate the active material is mixed in the form of a plastic mass called *paste* and applied to the grids, after which this paste hardens or *sets* in very much the same manner as cement. This operation is termed *pasting the grids*, and may be done by hand or machinery, depending upon the special methods employed by the various individual storage battery manufacturers.

### Types of Paste Plates.

Depending upon the character of the active material of which they are composed, storage battery plates of the paste type may be divided into three general classes, as follows:

- (a) Soft plates.
- (b) Hard plates.
- (c) Medium plates.

**Soft Plates.**—These plates derive their name from the comparatively soft consistency of the paste constituting the active material. Possessing a high degree of porosity the active material of these plates facilitates rapid diffusion of the electrolyte, which therefore results in a consequent rapid electrochemical action taking place in the cell. Cells having plates of this type are thus capable of producing a large quantity of current at high rates, but owing to the increased degree of chemical action which accompanies such a discharge, these plates are of comparatively short life. Although this type of plate has been used extensively in the commercial world where such service is required, as, for instance, in the field of automobile starting systems, this type is not suitable for general naval use on account of its short life.

**Hard Plates.**—These plates likewise derive their name from the hard consistency of the paste as combined in the active material. The porosity

of these plates as compared with that of the *soft* type plates is relatively low; hence, the rate of diffusion of the electrolyte is reduced and the corresponding rate of the electrochemical action which takes place in the cell is accordingly reduced. Therefore, it follows that these plates are less responsive to high-rate current demands and are thus incapable of producing such large quantities of current at high rates as is characteristic of *soft* plates. However, long life is a characteristic of these hard plates, and they give satisfactory results for service of this kind where comparatively low-rate discharges and long life are required. On account of their comparatively low discharge rates this type of plate is not suitable for general naval use.

**Medium Plates.**—As between two extremes there is a medium or middle ground in the classification of storage battery plates—between the *soft* plate and the *hard* plate described above there is also a *medium* plate, and it is the medium plate which has been adopted and is meeting with extensive application in the naval service. This type of plate possesses a fair degree of porosity, and the rate of diffusion of the electrolyte and the consequent electrochemical action which takes place in the cell is such as to make it capable of producing quantities of current at rates consistent with the demands of the various uses required of it in this service. Moreover, the character of the paste is sufficiently hard to resist *shedding* and to maintain contact with the grid over a considerable period of its life under service conditions of operation, and, therefore, a reasonable amount of useful life can be expected from this type of plate. Consequently, the present storage battery specifications have been so constructed as to require these *medium* plates in the cells designed for naval use.

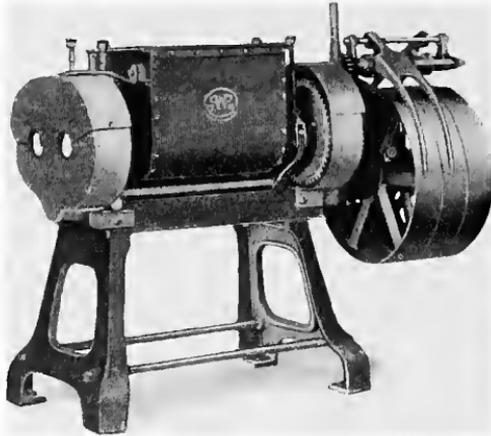
### Mixing the Paste.

In producing the active materials for these paste plates many combinations have been employed, but after a long and exhaustive series of tests with various combinations, litharge ( $\text{PbO}$ ) now constitutes the base of practically all combinations used for forming the active material of the negative plates, whereas, red-lead ( $\text{Pb}_3\text{O}_4$ ) is similarly used for the positive plates. Furthermore, as was explained in the preceding paragraphs, the type of plate produced depends largely upon the consistency of the paste and the subsequent treatment of the plate after *pasteing* and prior to giving it the *formation* charge.

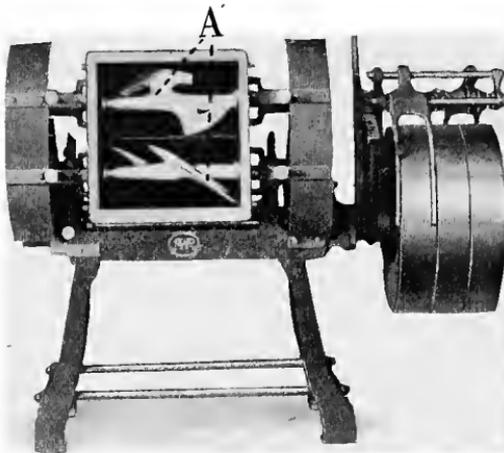
In general, a soft, mushy paste produces a *soft* plate; a firm paste produces a *hard* plate, and, depending upon the degree of variation in consistency between these two limits, the *medium* plate is produced.

**Paste Mixing Machine.**

The paste for storage battery plates is either mixed by hand or mechanically operated machines, and although there are several types of machines used for this purpose, practically all of them operate upon the "dough-



Upright Position.



Tilted Position.

FIG. 7.—Storage Battery Paste Mixing Machine.

mixing" principle, which consists of a trough-like receptacle in which is installed a series of revolving cranks or eccentric arms for agitating and thoroughly mixing the paste.

There is shown in Fig. 7 a photographic illustration of a type of machine commonly used in mixing the paste for storage battery plates. The top

view in this illustration shows the mixing machine in the upright position, which is the normal position for operation during mixing of the paste. The lower view in the illustration shows the mixing trough or receptacle tilted over on its side for dumping the paste out of the machine after mixing and to be served out to the workmen for pasting the grids. The revolving cranks, shown at *A*, of this machine serve to agitate and thoroughly mix the various particles composing the paste; these cranks revolve in opposite directions when the machine is in operation and receive speed of rotation through a system of gears driven from the main shaft of the machine. These machines are designed either for independent motor-drive or with pulley and shaft with belt-drive, as desired.

### Paste for Negative Plates.

The paste for the negative plates is formed by combining litharge ( $\text{PbO}$ ) with dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ), and then working it up to the desired putty-like consistency for applying to the grid. Also, owing to the tendency of litharge to contract and form a metallic mass of lead when subjected to the electrochemical action which takes place in the cell, it is necessary to utilize an *expander* when combining the litharge and the sulphuric acid in order to prevent such contraction and to thus assist in preserving the "spongy" state of the lead in the plate; this expedient is necessary for maintaining the porosity of the active material, which is also a very essential function in preserving the capacity of the negative plates. Furthermore, this expander assists in maintaining good electrical contact between the grid and the active material, which is also an essential feature in the proper working of the plate.

Barium sulphate ( $\text{BaSO}_4$ ) in various proportions depending upon the special formulæ used by the different battery manufacturers is a substance largely used for this expander; manganese sulphate, lamp-black, graphite or carbon in some other form is also used by some battery manufacturers for this purpose.

### Paste for Positive Plates.

The paste for the positive plates is formed by mixing suitable proportions of red-lead ( $\text{Pb}_3\text{O}_4$ ) with dilute sulphuric acid and working it up to the desired consistency. However, an entirely different problem from that of the negative plates presents itself in combining the paste for the positive plates, for, whereas the litharge used in the negative plates has a tendency to contract and compact itself, due to the incoherent nature of lead-peroxide ( $\text{PbO}_2$ ), it is necessary to utilize a *binder* in mixing the red-lead for the

positive paste. Ammonium sulphate  $(\text{NH}_4)_2\text{SO}_4$  is largely used for this purpose. Even though a *binder* is used in mixing the positive plate, lead-peroxide is possessed of comparatively little mechanical strength, and when subjected to the conditions existing within a storage battery cell, it gradually becomes soft or "muddy," and with each cycle of charge and discharge, a portion of the lead-peroxide becomes loosened from the surface of the plate and washes away and falls to the bottom of the cell, henceforth serving no useful purpose in the action of the cell. This wearing or washing away of the particles of active material, known as *shedding*, is a natural occurrence in the operation of the cell, the theory being that whereas at full charge the positive active material consists of lead-peroxide, which is amorphous in consistency, upon discharge the lead-peroxide is converted into lead-sulphate, which is of crystalline structure, and it is due to this transition from amorphous to crystalline structure that particles at the surface of the plate become detached and fall to the bottom of the cell. Gassing of the cell during charge tends to aggravate this action of *shedding*, and it is essential to the life of the positive plate that gassing be reduced to a minimum in operating the cell.

Under ordinary operating conditions of a lead-acid storage battery cell having flat type paste plates, it may be said that, as a general rule, the positive plate is the limiting factor in the life and usefulness of the cell.

### Pasting the Grids.

After the grids are cast and have satisfactorily passed inspection, they are next carried to the *pasting room* to be pasted with the active material. There are two general methods employed in pasting grids, viz.: by hand, and by machine.

**Pasting by Hand.**—When the grids are pasted by hand the workmen, called "pasters," use large specially designed knives, which are very similar to large putty-knives, and wooden paddles for spreading the plastic, putty-like, active material over the grid and working it thoroughly between the lattice-work members of the grid.

The grids are placed flat on the pasting table and pasted thoroughly on one side and then turned over and pasted on the other side. When pasting of a plate is once begun, it is necessary to proceed with the pasting as rapidly as possible in order that the paste will not *set* before pasting is completed, and in order to obtain the proper bond between all particles of the active material, as it is very essential that the active material be thoroughly compacted as an homogeneous mass into the lattice-work of the grid in order to effect good electrical contact between the active material and grid bars, as well as the adjacent active material. The firm grip or bond

thus obtained between the active material and grid bars insures proper conductivity, thus lowering the resistance to the flow of current through the plate and with the consequent increased efficiency in absorbing or delivering energy during charge and discharge; in other words, the cell has a better voltage characteristic. Moreover, the bond thus obtained between active material and grid also prevents unnecessary or abnormal sloughing-off or "shedding" of the active material during the normal working of the plate, thereby increasing its useful life.

After the plates are pasted they are stacked in piles, one on top of the other, with sheets of coarse blotting paper or canvass placed between them.

**Pasting by Machine.**—In the manufacture of machine-pasted plates, the active material is applied to the grid mechanically, after which the plate is passed by means of a belt conveyor under a series of pressure rolls which compacts the active material into the grid. This method of pasting produces a very uniform plate, since all parts of the plate are subjected to the same pressure in passing through the rolls. This method of pasting is especially suitable to the so-called "thin" types of plates.

When the pasting operation has been completed, whether by hand or machine, the plates are next dipped in dilute sulphuric acid of about 1.160 to 1.170 specific gravity in order that a slight sulphating action may be produced in the plate for *cementation* purposes in further locking the particles of active material together preparatory to conducting the *forming* charge. This cementation process is effected through the action of the sulphuric acid on the lead in the paste, thus forming lead-sulphate, the crystals of which interlock with each other and form a crystalline network for supporting and binding together the mass of active material.

### Drying Rooms.

After the plates have been pasted and dipped, as described in the preceding paragraphs, they are next carried to the *drying rooms* where they are hung on racks located in suitable ovens, or in some instances they are hung in the air and allowed to dry out preparatory to receiving their *forming* charge. These drying rooms are usually fitted out with a special series of blowers for circulating the air over the plates for accelerating the drying process. This process requires from one to three days to complete, depending upon the type of plate to be produced.

The plates having been thoroughly dried in this manner, they are next carried to the *forming rooms* where they receive their *forming* charge. This is one of the most important stages in the fabrication of the plate, and special care is taken during the "forming" charge to produce the correct type of plate.

### “Forming” Charge.

The *forming* charge consists in converting the paste of the positive plates into lead-peroxide ( $\text{PbO}_2$ ), and that of the negative plates into sponge lead ( $\text{Pb}$ ). The plates are assembled and *formed* in lead-lined wooden tanks or glazed earthenware crocks, called *forming tanks*, which contain electrolyte of dilute sulphuric acid used in the *forming process*. The plates are usually suspended from racks in the sides or tops of the tanks and are immersed in the electrolyte. The plates are also connected up in several rows in their normal position as regards polarity; that is, a positive plate is grouped with a negative plate, and so on throughout the entire series of rows. No separators are used between the plates while receiving the *forming* charge, as the plates are amply spaced to prevent their coming in contact with each other during this operation.

It is also usual practice to connect all positive plates of a tank in parallel with each other, and likewise the negative plates. The plates may also be formed by using *dummy* electrodes in conjunction with them. This procedure is often resorted to when it is desired to form more positive plates than negative ones, or vice versa, the *dummy* electrodes being used to make up for the shortage in either set of plates. As stated, this *dummy* takes the place of the opposite electrode and may be composed of sheet or cast lead; frequently an ordinary lead-antimony cast grid is utilized for this purpose.

Having assembled and connected up all plates in the *forming tanks*, as outlined above, the positive and the negative terminals of the groups are connected to their respective charging buses and direct current passed through the groups. It is thus that the plates receive their *forming* charge.

At the beginning of the *forming* charge the positive plates are constituted approximately as follows, depending upon the special type of plate to be obtained:

Lead-oxide ( $\text{PbO}$ ) .....	from 50 to 60 per cent.
Lead-peroxide ( $\text{PbO}_2$ ) .....	from 20 to 30 per cent.
Lead-sulphate ( $\text{PbSO}_4$ ) .....	from 15 to 25 per cent.

Upon starting the charge the lead-oxide is converted into lead-peroxide, and as the charge progresses the lead-sulphate is gradually converted into lead-peroxide until at the end of the *forming charge* the composition of the plate is about as follows:

Lead-oxide ( $\text{PbO}$ ) .....	from 6 to 10 per cent.
Lead-peroxide ( $\text{PbO}_2$ ) .....	from 80 to 90 per cent.
Lead-sulphate ( $\text{PbSO}_4$ ) .....	from 2 to 5 per cent.

The plates are then removed from the *forming tanks* and sent to the store rooms for further transfer to the assembly rooms where they are fabricated into the cells.

The composition of the negative plates before beginning the *forming* charge is about as follows:

Lead-oxide .....	from 75 to 85 per cent.
Lead-sulphate .....	from 15 to 25 per cent.

Upon beginning the forming charge the litharge is converted into sponge lead, and as the charge progresses the lead-sulphate is gradually converted into sponge or metallic lead, and upon completion of the forming charge the composition of the negative plates is approximately as follows:

Sponge lead (Pb) .....	from 90 to 95 per cent.
Lead-oxide (PbO) .....	from 3 to 5 per cent.
Lead-sulphate (PbSO <sub>4</sub> ) .....	from 1 to 2 per cent.

In forming the positive and negative plates various degrees of current rates and regulation are used, depending upon the size and type of plate to be produced; also, variations in density of the electrolyte and periods of rest during the charge are used, depending mainly upon the special formations used by the various battery manufacturers.

#### GRIDS.

##### Construction and Design of Grids.

As has been stated, other than in the character of the paste used, the various designs of pasted type plates depend mainly upon the shapes and details of construction of the grids as designed and adopted by the various storage battery manufacturers. These grids are of lead-antimony alloy and are cast in appropriately designed "open and shut" type moulds.

During the process of casting the grids, these moulds and the molten metal pots are maintained at an even temperature in order to produce a uniform lot of castings. Also, before each "pour," the interior surfaces of each half of the moulds are dusted with a linen bag containing pulverized soapstone or talcum powder, which is conducive to producing a smooth, even surface in the casting and also serves to prevent sticking of the casting in the mould, thus making it easier of extraction. This is necessary to prevent damage to the grid bars, which on account of their comparatively small cross-sectional area are frail and do not permit of much rough handling in extracting the casting from the moulds. Some battery manufacturers deposit a thin layer of carbon on the inside surfaces of the moulds in order to prevent the casting from sticking and also to give it a smooth surface; this layer of carbon is deposited by playing the flame and the accompanying smoke

from an oil torch on the inside surfaces of the moulds. These moulds should also be fitted with ample gates and risers in order that an homogeneous grade of castings may be obtained.

In order to increase their rigidity, the alloy used in the manufacture of these grids usually contains from 4 to 10 per cent of antimony, although, in the larger grids, as for instance the submarine types, the alloy contains as high as 12 to 14 per cent of antimony.

It should here be noted that the antimony used in these grids, particularly those of the submarine type, should be of a very highly refined grade, especially as regards arsenic content; this precaution is necessary to prevent the injurious effects from arsine poisoning due to inhaling the gas given off from the electrolytic action of the arsenic, which if present in the grids enters into solution with the electrolyte and is liberated with hydrogen at the negative plate. In respect to this feature, the maximum amount of arsenic present in storage battery grids should not exceed 100 milligrams per kilogram of grid, and for the paste used in these plates it should not exceed 45 milligrams per kilogram.

The positive and negative grids for these batteries are, in most cases, practically identical in design, with the exception, however, that the grid for the positive plate is usually cast slightly heavier for strength in order to withstand the *forming* action, which is to a certain extent characteristic of all positive grids, since it is at this electrode that the oxidizing agency is manifested as a result of the normal electrochemical action which takes place in the cell.

The present specifications for these batteries require that all positive plates of the flat pasted type shall not be less than  $\frac{1}{4}$  inch in thickness, as positive plates of this size and their corresponding negatives have been found to give satisfactory results for the various uses required of them in the naval service.

However, for some special services, such as war emergency batteries for submarines and the batteries used for the aviation service, where maximum capacity per unit of weight is a governing factor, the plates are considerably thinner than  $\frac{1}{4}$  inch. Some of the special types of portable storage batteries designed for the naval service contain plates of  $\frac{1}{16}$  inch thickness. Generally speaking, however, such batteries are of the so-called "short life" type, and are not representative of the types designed for general use in the naval service.

After casting the grids, they are next trimmed and inspected. This inspection consists in examining the grids for broken bars, cracked lugs, blow-holes and other such imperfections in casting. After discarding the imperfect grids as a result of this inspection, the perfect ones are then

delivered to the pasting room where the active material in paste form, as has been described, is applied to them. The defective grids are usually melted up and recast, but in some instances, if the blow-holes and other imperfections are not too bad, these grids may be reclaimed by flame-puddling the blow-holes, lead-burning, etc.

Also, owing to the oxidization which takes place on the grids when they are exposed to the air for a considerable length of time, they should be pasted as soon as practicable after casting, in order to obtain a satisfactory contact between the grid and paste; if the grids are oxidized to a considerable extent the proper bond or contact between the paste and the grid is not obtained.

### Requirements of a Satisfactory Grid.

In regard to the constructive features of these grids, the design should be such as to fulfill the following requirements:

(a) The grid should be of sufficient cross-section and so proportioned as to carry, without undue loss, the current generated by the battery under operating conditions and also obtain uniform current distribution over the entire surface of the plate.

(b) The grid should be so designed as to offer maximum electrical contact with the active material throughout the life of the plate, and also form a receptacle for the active material, such that sloughing-off or shedding of the active material is reduced to a minimum.

(c) The composition of the grid should be such as to not be injuriously affected by the electrolyte. Also, this composition should be such as to afford a minimum of local action between itself and the contained active material.

(d) The grid should be so designed as to allow maximum diffusion of electrolyte through the active material.

(e) The grid should be as light as possible consistent with the function which it has to perform.

(f) The grid should be of sufficient rigidity to resist *buckling*, as a result of oversulphating of the active material which it contains.

### Grid Casting Equipment Should Be Maintained at Uniform Temperature.

In order that uniformity may be obtained in the grade of castings produced from the moulds, it is necessary when casting the grids that these moulds, as well as the molten metal used in these castings, be maintained at an even temperature during this process. This is especially important in casting the larger types of grids, such as are used in submarine storage batteries and other battery installations requiring plates of this size. Therefore, in order to maintain this even temperature in the melting pots and

mould equipment, and thus assist in securing uniform castings, it is customary practice in the leading storage battery manufacturing plants to operate this equipment continuously throughout the entire 24 hours per day until the casting of the particular lot of grids has been completed, thereby preventing the fluctuations in the temperature of this equipment, which would otherwise occur, if allowed to remain idle and cool off during the casting process.

Also, as a further expedient in maintaining this equipment at even temperatures, various types of thermo-electric pyrometers, thermometers and other temperature recording instruments are installed for the guidance of the workmen operating this equipment.

### **Description of Thermo-Electric Pyrometer Equipment as Applied to the Operation of Grid Casting.**

A form of temperature indicating apparatus used extensively with storage battery grid casting equipments is known as the thermo-electric pyrometer, and consists essentially of a thermo-couple in circuit with which is connected a millivoltmeter having its dial graduated in degrees Fahrenheit instead of in electrical units. The principle upon which the operation of this form of apparatus is based is that of the electrical current which is generated when the junction of two dissimilar metals, that is, a thermo-couple, is submerged in a pot of molten metal; as the temperature of the molten metal rises and falls, the temperature of the thermo-electric couple accordingly rises and falls, and the thermo-electric current thus generated accordingly increases or decreases, and is indicated on the millivoltmeter, which, as stated, has its dial graduated in degrees of temperature instead of in electrical units.

This form of apparatus has proved very successful in maintaining the melting pots at a uniform temperature. In some storage battery manufacturing plants this system is elaborated upon somewhat, in that in addition to the indicating apparatus installed in the immediate vicinity of the melting pot for the guidance of the operator in controlling the temperature of his pot, there are also central stations connected up with the thermo-couples installed in the several melting pots, and by a suitable master switch the temperature of each individual pot may be readily read upon the central station instrument. There are also various types of recording devices incorporated in this apparatus by which an accurate record of each individual melting pot may be obtained throughout the entire run.

In some plants there are unskilled operators of the mould equipment who cannot read the temperature indicating apparatus, and for the benefit of these men a series of colored lights are installed in the circuits with the thermo-couples for their guidance in controlling the temperature of the

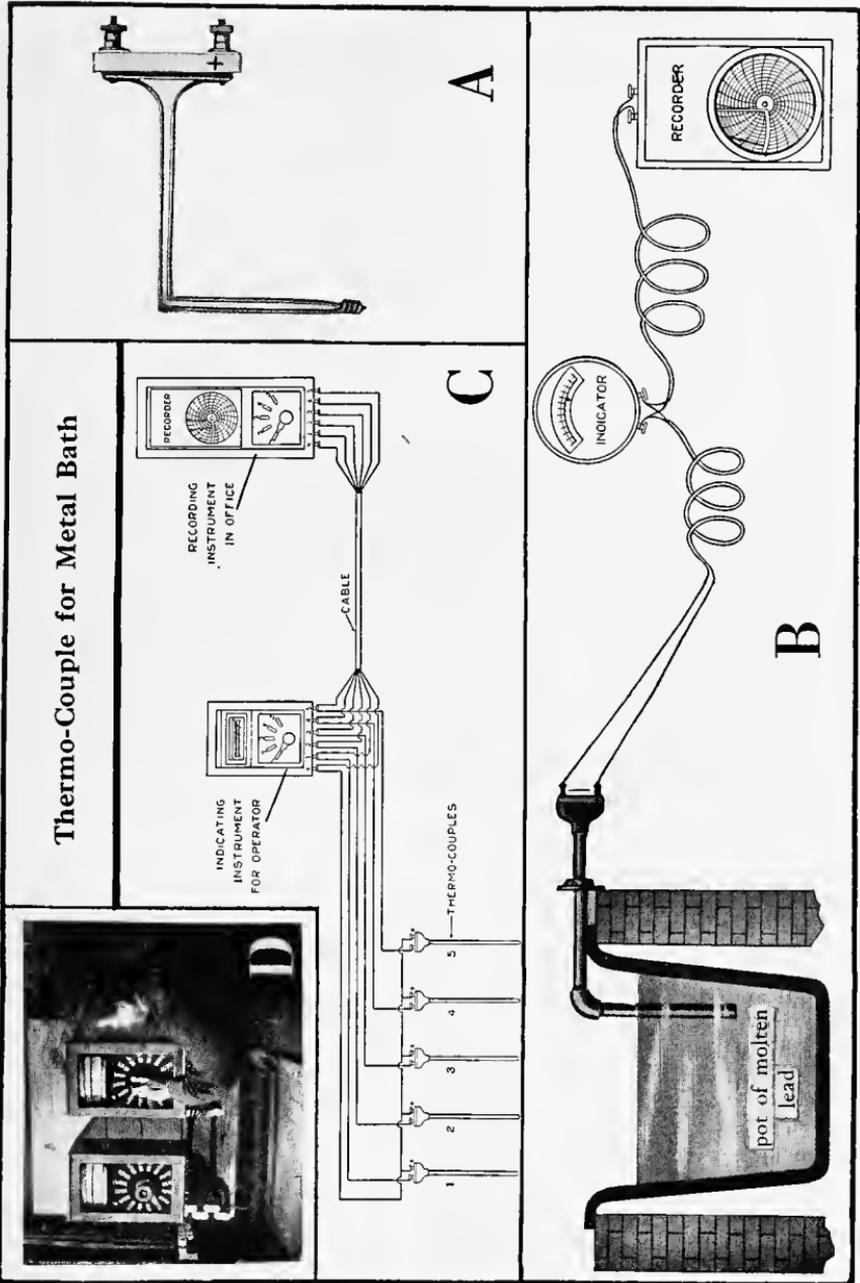


Fig. 8.—Thermo-Couple Apparatus Used in Grid Casting.

melting pots. For instance, in a certain plant the series of colored lights consists of a green light, a red light and a white light; correct working temperature of the molten metal is indicated when the white light is on, temperature too low when the green light is on, and temperature too high when the red light is on. It is thus only necessary for the operator to keep his white light burning in order to maintain his pot of metal at the correct temperature.

Fig. 8 contains a series of illustrations representing the pyrometer equipment, such as is used in connection with the casting of storage battery grids and other parts. Referring to this illustration, the various parts are shown as follows: *A* represents the thermo-couple proper; *B* shows the thermo-



FIG. 9.—“Exide” Type Grid and Plates.

couple submerged in the molten lead pot, the connections to the indicator and the recording instruments being clearly shown in this section of the illustration; *C* shows the wiring diagram and the method of connecting the recording and indicating instruments with the several melting pots, and *D* shows the head moulder reading the temperature of the several pots.

#### Various Types of Grids.

With present stage of the art, the designs of the grids used in storage battery plates may be divided into two main classes, as follows:

(a) Those whose members are arranged in *rectangular* relation with each other.

(b) Those whose members are arranged in *rectangular* and *diagonal* relation with each other.

Of the former class the following types are examples:

“Exide” grid.

“Gould” grid.

“U-S-L” grid.

“Willard” grid.

Of the latter class the following types are examples:

“Diamond” grid.

“Herring-Bone” grid.

“Titan” grid.

**The “Exide” Grid.**—In Fig. 9 is shown an illustration of an “Exide” grid, which is the trade name adopted for it by the Electric Storage Battery Company. There is also shown in this figure illustrations of positive and negative plates using this type of grid.



FIG. 10.—Section of “Exide” Grid.

Referring to the illustration it will be noted that this grid consists of a skeleton framework or lattice-work composed of a series of vertical and horizontal bars. The vertical bars are of the full thickness of the grid and thus extend from side to side of the grid, while the horizontal bars, which are staggered on opposite sides of the grid, are of just sufficient thickness to form a cage for the active material and also to collect the current from the adjacent active material and conduct it to the vertical bars.

In Fig. 10 is shown a cross-section of this grid. Referring to this figure it will be noted that when the active material is properly compacted into this grid, it is then in the form of a ribbon which “zig-zags” from side to side of the grid, the width of this ribbon being the width of the space between the two adjacent vertical bars. By thus staggering the horizontal bars on opposite sides of the grid, they form an interlock for holding the active material in position, and also allow ample space for proper diffusion of the electrolyte into the active material.

The horizontal bars, although individually of parabolic cross-section in shape, are uniform in cross-section throughout the entire grid, while the vertical bars are taper in cross-section from top to bottom of the grid, the larger cross-section being at the top, since this is the location of maximum current density.

**The "Gould" Grid.**—There is shown in Fig. 11 a photographic illustration of a paste type plate manufactured by the Gould Storage Battery Company, and in which plates the "Gould" type grid is used. Both positive and negative plates are shown in this illustration.

In Fig. 12 is shown a photographic illustration of a "Gould" grid such as is used in submarine storage batteries. The details of the vertical and horizontal bars are clearly shown in this illustration.

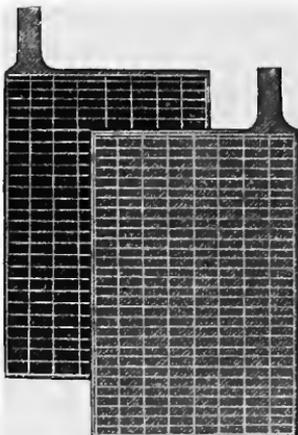


FIG. 11.—"Gould" Type Grid and Plates.

**The "U-S-L" Grid.**—There is shown in Fig. 13 an illustration of plates and grids of the "U-S-L" type and as manufactured by the U. S. Light and Heat Corporation. Both positive and negative plates as well as grids are shown in this illustration. The assembly of a "U-S-L" type group is also shown in this photograph. Special attention is directed to the taper post strap of this group, the detailed method of assembly of which will be described in another part of the text.

**The "Titan" Grid.**—Another type of grid containing the rectangular and diagonal feature of design is the "Titan" grid, an illustration of which is shown in Fig. 14, and as manufactured by the General Lead Batteries Company. In this illustration is also shown a positive and a negative plate composed of this grid. A notable feature of this grid is that it can be bent double on either side of the vertical axis without being broken in twain, for whereas the vertical members of the grid will part during this

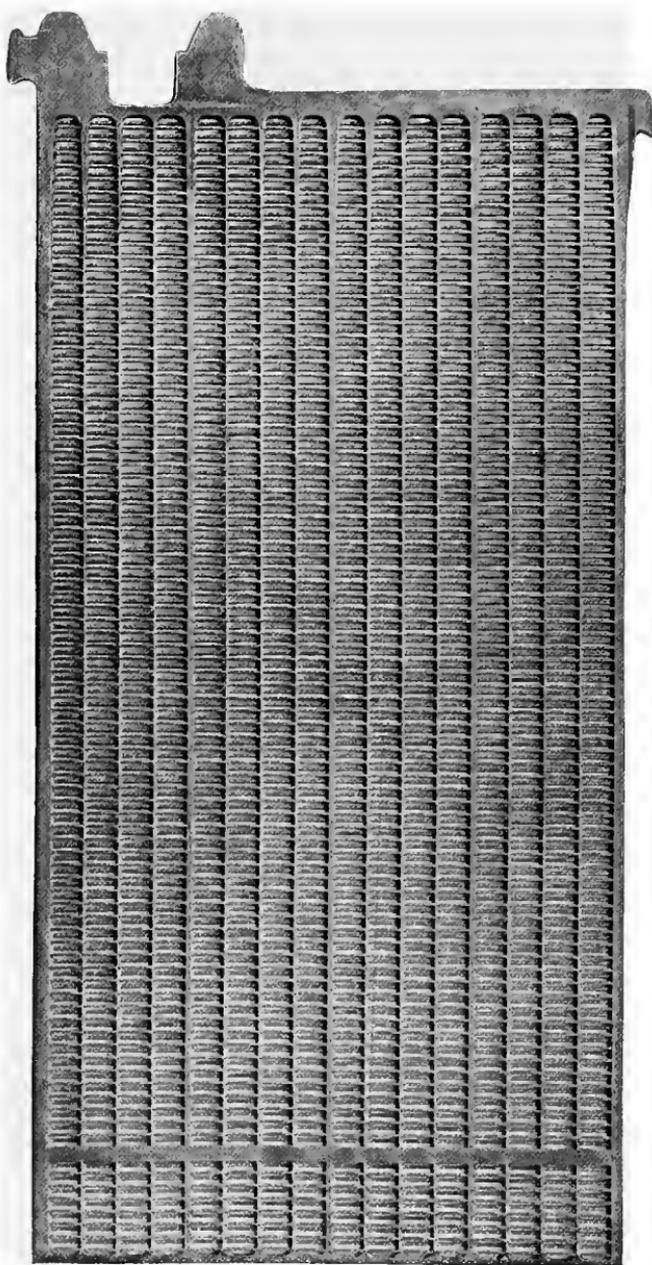


FIG. 12.—“Gould” Grid—Submarine Type.

operation, the diagonal members will not part and accordingly act as stringers in holding the grid together. This feature is conducive to offering resistance to *buckling* of the plate, which is especially desirable for the so-called "thin" type of plates.

**The "Diamond" Grid.**—There is shown in Fig. 15 an illustration of a "Diamond" grid, the trade name as given to it, on account of its shape, by the manufacturers, the Philadelphia Storage Battery Company.

In developing this grid, it will be noted that the designer has made use of certain features of the principle of bridge truss construction in that the

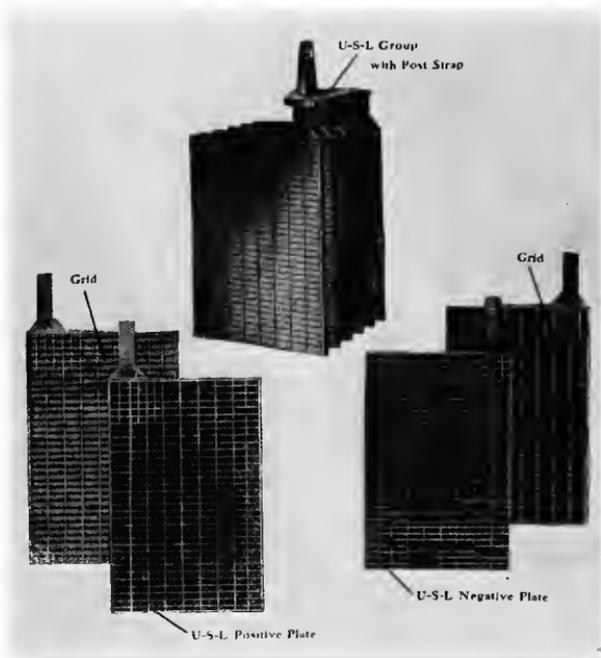


FIG. 13.—"U-S-L" Type Grids and Plates.

framework consists of a series of vertical and diagonal bars. The diagonal bars form a series of "diamond" crosses, which crosses are staggered on opposite sides of the grid in order to produce an effective interlock for maintaining the active material in position.

The vertical bars are of the full thickness of the grid and thus extend from face to face of the plate. Also, these vertical bars are of taper cross-section from top to bottom, the larger cross-section being properly at the top of the grid, the location of maximum current density.

This type of grid has many excellent features, chief among which are the strength and rigidity obtained through the network of truss construction, in

which each member helps to support every other member. Referring to Fig. 15, consider, for instance, the diagonal member, shown in dotted line, starting at the lower left-hand corner of the grid at *A*; this member runs diagonally across to the other side of the grid at *B*, thence back to other side at *C*, and finally, across the grid again to the upper diagonally opposite corner at *D*. Each other diagonal member follows a similar and parallel

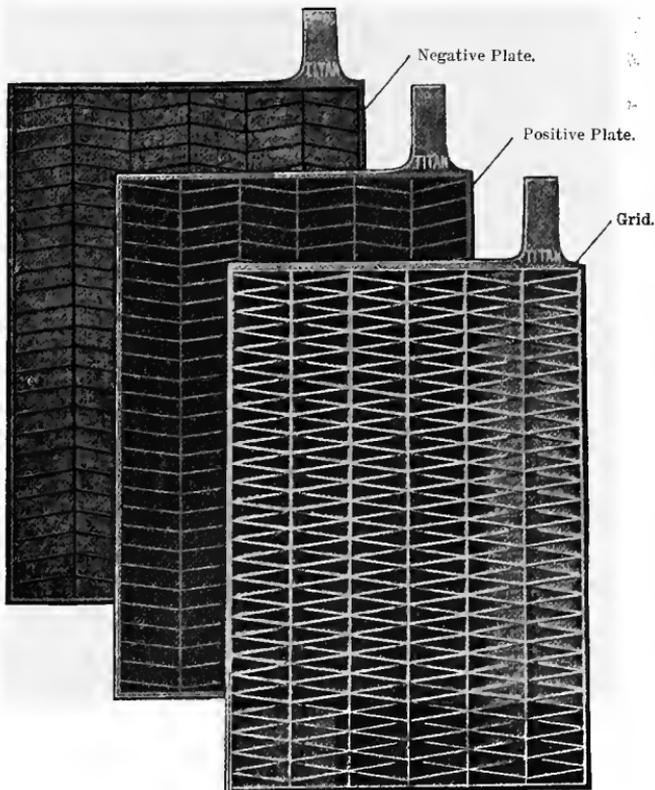


FIG. 14.—“Titan” Type Grid and Plates.

path. Thus a strain on any member of the grid is transmitted to and resisted by every other member of the grid, a feature which is very desirable in resisting any tendency to *buckling* of the plate when installed in the cell.

In Fig. 16 is shown a detailed section and cross-section of this grid, which gives a clear idea of its construction.

In considering further the construction of this grid, it will be noted in Fig. 16 that the face of each diamond on one side of the grid is backed-up by

a cross formed by the members of four diamonds on the opposite side of the grid. Furthermore, on each diamond there are four places where members on one face of the grid cross members on the opposite face. Thus it will be noted that every particle of active material contained within this grid is close to a conductor, which feature not only serves to assist in maintaining the active material in position, but, in addition, forms many short paths for

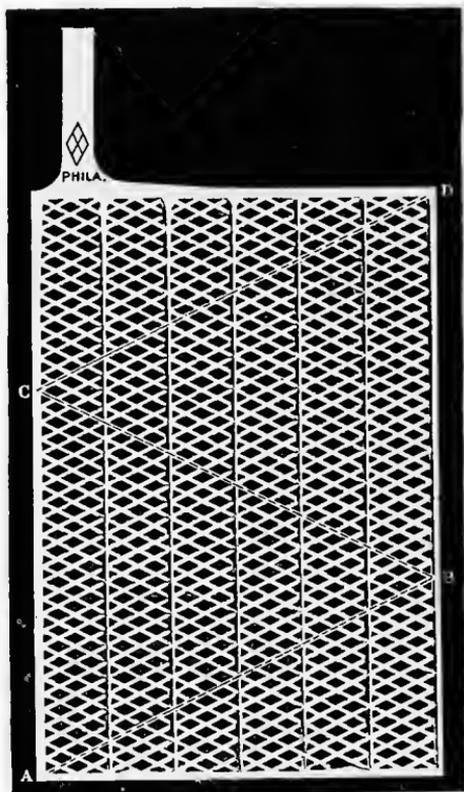


FIG. 15.—Philadelphia "Diamond" Grid.

collecting the current and conducting it to the vertical members of the grid, thereby increasing the efficiency of the plate in absorbing and delivering energy. Therefore, it is seen that this grid contains three prime requisites of a good grid; namely, *strength*, *locking ability*, and *conductivity*, and is considered one of the best grids at present used in storage batteries for the naval service.

Although these grids as used in batteries for the naval service are in most cases  $\frac{1}{4}$  inch thick, the manufacturers supply them for special services and to

the commercial trade in much thinner units. In fact, this grid was one of the pioneers in the field of the so-called "thin plate" batteries.

In Fig. 17 there is shown a complete plate made up from one of these grids. This grid is used only for positive plates, since that plate is the one

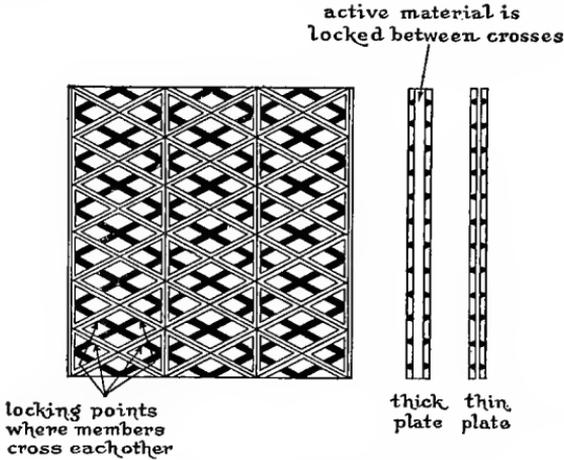


FIG. 16.—Section of "Diamond" Grid.

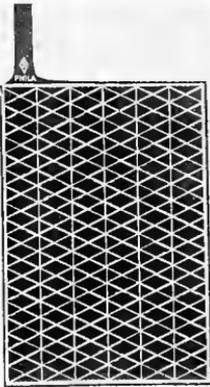


FIG. 17.  
"Diamond" Grid,  
Positive Plate.

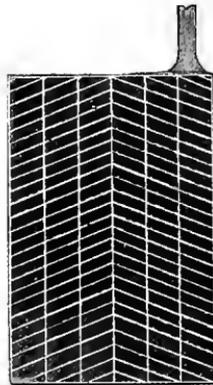


FIG. 18.  
"Herring-Bone" Negative  
Grid and Plate.

which requires the greater structural strength. The negative plates used with this grid are of a different design and are known as the "Herring-Bone" grid. In Fig. 18 there is shown a photographic illustration of the "Herring-Bone" grid as used by the Philadelphia Storage Battery Company.

The "Ironclad" Type Assembly.—Within comparatively recent time another type of paste assembly has been developed in this country and is meeting with extensive application both in the naval service and in the commercial trade. This type of assembly is known as the "Ironclad-Exide" assembly, and derives its name from the special construction of the positive plate which is used in conjunction with the "Exide" type pasted grid. This

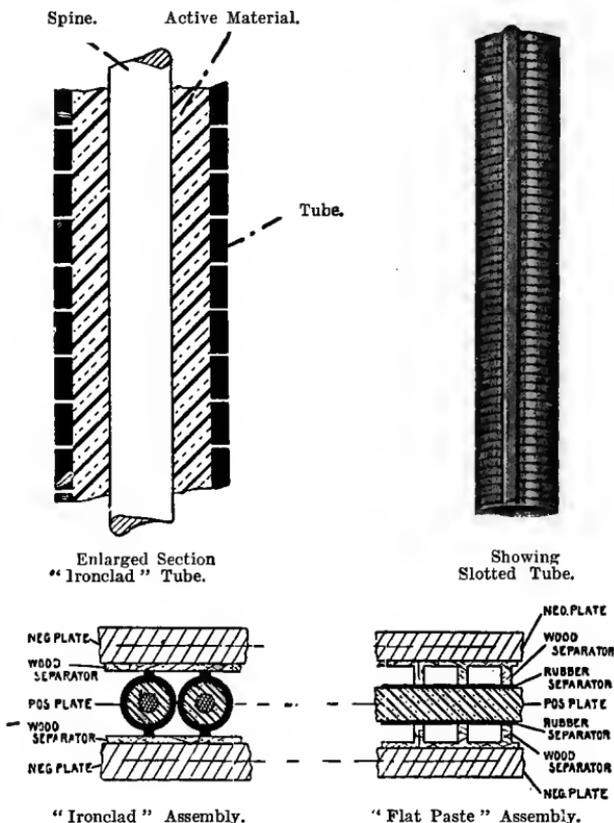


FIG. 19.—Details of "Ironclad" Assembly.

type of assembly is founded upon the principle developed in France about the year 1898 by Phillipart, and which principle has been commercially developed in this country by the Electric Storage Battery Company.

The positive plate consists of a number of hard rubber tubes which are filled with the paste active material. Running through the center of each tube is a lead-antimony core or *spine*, which is firmly anchored in the paste by means of semicircular leaves equally spaced along the length of the spine. This spine is lead-burned to the top bar and bottom bar forming

the frame of the plate, and acts as a conductor for transmitting the electrical energy to and from the plate. The hard rubber tubes are "slotted" circumferentially by fine saw-cuts of about  $1/100$  of an inch in width; these slots are designed to effect diffusion of the acid of the electrolyte into the pores of the active material, and serve the same purpose as the perforations in the hard rubber separators used in the ordinary flat paste type assembly. An unribbed veneer separator only is used with this type of assembly, there being

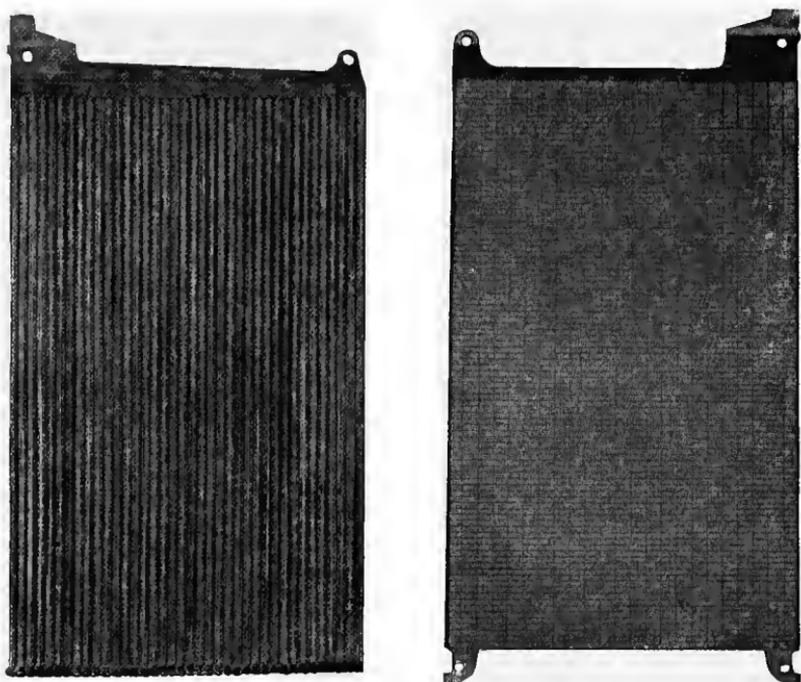


FIG. 20.—"Ironclad" Plate and "Paste" Negative—Submarine Type.

vertical ribs on diagonally opposite sides of the tubes to effect proper plate separation.

There is shown in Fig. 19 a sectional plan view of the regular "flat paste" type assembly and the "Ironclad" type assembly. The essential differences in designs of the two types of assemblies are plainly shown in this drawing. A section of an "Ironclad" tube and the slotted hard rubber tube are also shown in this drawing.

Fig. 20 contains a photographic illustration of an "Ironclad" positive plate and the corresponding "Exide" type negative, such as are used in submarine batteries. Long life of the positive plate is especially characteristic of this type of assembly.

## CHAPTER VII.

### PLANTÉ TYPE ASSEMBLIES.

#### Methods of Manufacture and Types of Planté Plates.

As was explained in Chapter I, the method originally employed by Planté in forming his plates consisted in placing two plain sheets of pure lead in a jar containing sulphuric acid, and then by connecting the terminals of these lead sheets to direct current buses and passing direct current through the cell the respective surfaces of the lead sheets were thus converted into lead-peroxide and sponge lead, thereby *forming* the positive and negative plates.

Also, as has been previously pointed out, such plates, on account of their comparatively limited surface areas exposed to the action of the electrolyte, were possessed of correspondingly limited capacity. Moreover, in order to obtain even this small amount of capacity it was necessary to subject the plates to numerous cycles of charge and discharge, including many reversals, which extended over a considerable period of time and was otherwise a comparatively expensive method of producing these plates. Therefore, the general trend of development in the art of manufacturing this type of plate has accordingly been along the lines of effecting a reduction in the time element required for the *forming process*, which includes the various modern *forming agents* now employed, as well as that of increasing, by various improved manufacturing methods, the plate surface areas in contact with the electrolyte.

In general, the various modern types of Planté assemblies depend mainly upon the methods employed in constructing the plates prior to subjecting them to the *forming process*. In some instances, however, the *forming process* or special *formation* used by the manufacturer governs the type of plate produced.

Mechanically considered, the principal methods now used in Planté plate construction may be classified as follows:

- (1) Casting.
- (2) Building-up.
- (3) Spinning.
- (4) Ploughing.
- (5) Swedging.

Each of the above classifications refers to the particular mechanical method employed in increasing the surface area of that portion of the plate in con-

tact with the electrolyte and which constitutes the so-called *active* portion of the plate. Representative types of Planté plates constructed by each of the above-named methods will be described.

**Cast Type.**—The plates manufactured by the casting method are known as *cast type* plates, and are cast under pressure in appropriately designed moulds, pure soft lead being used in the casting process. Of this particular type of plate the “Tudor” type is a familiar example, this type having been commercially developed and used extensively in European countries.

Fig. 21 contains a detailed illustration of a cast “Tudor” plate. Referring to this illustration it will be noted that the plate construction consists of a series of numerous, thin, vertical leaves, and also of a smaller

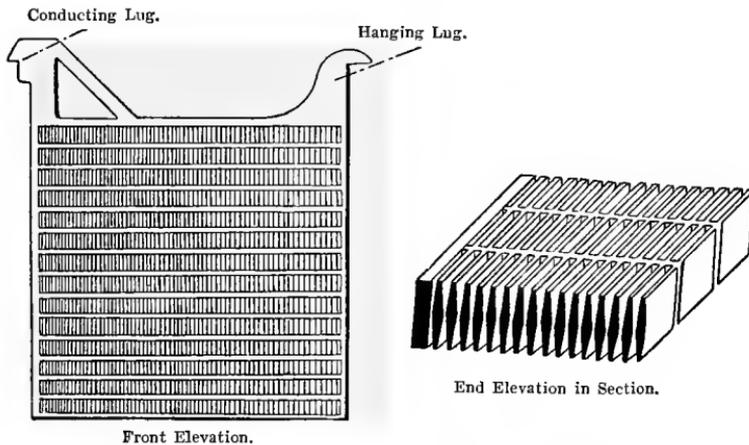


FIG. 21.—Cast Type “Tudor” Planté Plate.

number of horizontal bars or ribs which are integrally joined to the vertical leaves; these particular features of construction being clearly shown in the end elevation of a section of the plate on the right-hand side of the illustration. Consistent with proper mechanical strength required for supporting the plate, this grid-like construction is designed to produce maximum surface area of the plate in contact with the electrolyte. The construction of the hanging and the conducting lugs is also plainly shown in the illustration of this plate.

After these plates are cast they are next subjected to a *forming* process, whereupon thin layers of lead-peroxide and sponge lead are formed on the respective surfaces of the positive and negative plates. It will thus be seen that the number of leaves in such a plate constitutes a function of the

capacity of the plate. For reasons which will be explained later, the negative plates of the Planté type are usually cast slightly heavier than the positive ones. In *forming* these plates, all plates are usually formed as positives after which the required number are reversed and converted into negatives.

It may be said that the cast type "Tudor" plate has never met with extensive application in this country, due primarily to the manufacturing difficulties encountered in the casting process, as it appears that the molecular construction of the lead obtained in this country is not conducive to the same degree of uniformity in the casting of these plates as that obtainable from European leads. Other types of Planté plates have therefore been developed in this country, all of which types will be fully described in the succeeding text.

**"Built-Up" Type.**—There are several types of Planté plates manufactured by the *building-up* method of construction; these plates are usually referred to as the *built-up* type. Although the details of constructing this type of plate vary somewhat, generally speaking, all of them consist of a lead-antimony alloy casting or grid which constitutes the supporting framework for the pure lead *active* members of the plate; these pure lead members being of various shapes and types, principally as regards surface area, depending upon the particular details as worked out in the design of the plate.

Due to the fact that an alloy composed of lead and antimony is practically unattacked by the acid of the electrolyte, the cast grids or frameworks used for these plates take no part in the primary working of the plate other than that of conducting current to and from the plate. These grids should be sufficiently rugged in design as to withstand the strain put upon them as a result of the *growing* action incident to the normal Planté formation which takes place on the pure lead members of which the grids form a support; this feature resolves itself into a function of resisting *buckling* of the plate.

It may be said that, as a general rule, plates of this type find chief application in stationary storage battery installations and other classes of service where the subject of weight is relatively unimportant, as due to the large percentage of the plate as regards weight devoted to the grid, the weight efficiency of plates of this type is comparatively low as compared to other types of Planté and paste plates. However, this type of plate is noted for its ruggedness and its capability to withstand much repeated abuse in the operation of the battery.

The following are familiar examples of *built-up* type Planté plates as manufactured in this country and used in modern storage battery installations requiring plates of this type:

- (a) "Manchester" positive.
- (b) "U-S-L Unit" positive.

Each of the above types will be described in detail in the succeeding text.

(a) "**Manchester**" Positive.—The "Manchester" positive Planté plate was one of the pioneers in the commercial application of storage batteries in this country, and is also now used extensively for certain classes of storage battery installations, principally on shore stations for radio equipment, stationary "stand-by" installations, isolated farm lighting sets, etc.

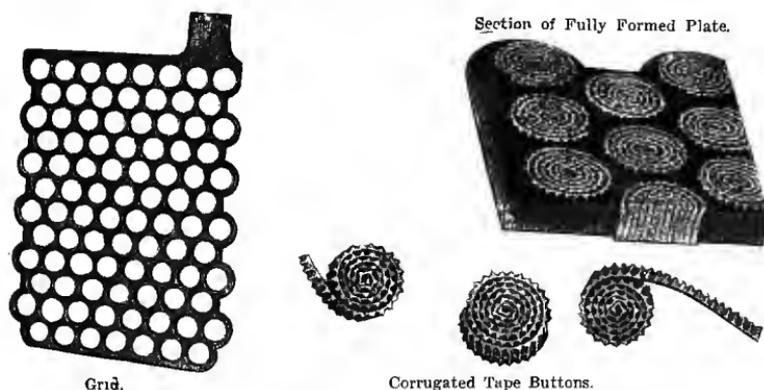


FIG. 22.—"Manchester" Positive Planté Plate.

This type of plate consists of a lead-antimony casting or grid containing numerous holes and into which are hydraulically pressed pure lead "buttons" or "rosettes," which are made up from corrugated strips of pure lead tape. The holes in the grids are slightly bevelled or countersunk on each face of the grid in order that when the buttons expand or *grow* due to the *forming* action which takes place during the operation of the cell, this expansive action will tend to rivet the buttons in position, thereby maintaining good electrical contact with the grid as well as preventing them from becoming detached from the grid.

Fig. 22 contains an illustration which clearly shows the details of the component parts of this plate. Referring to this illustration, the construction of the lead-antimony grid will be readily understood, as will also that of the corrugated tape "buttons" or "rosettes." The section of the fully *formed* plate gives a clear idea of the method of installing the buttons

in the grid. The corrugations in the tape from which the buttons are made are designed primarily to assist diffusion of the electrolyte into the active material of the plate.

Due to the large percentage of grid comprising this type of plate, the weight efficiency is comparatively low, but for certain classes of service, such as stationary stand-by installations where the question of weight is not a

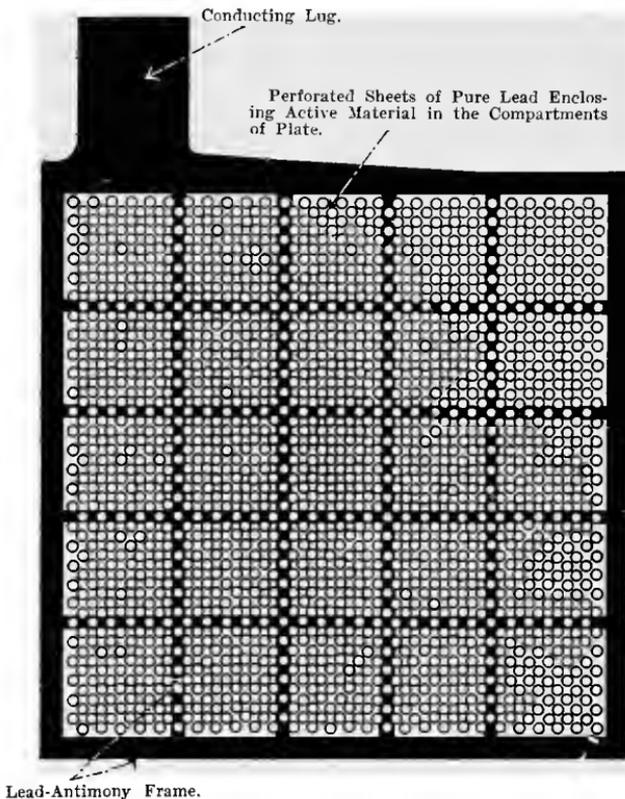


FIG. 23.—“Box” Negative Plate.

governing factor, these plates render highly satisfactory service; ruggedness is an especially characteristic feature of this type of plate. This plate has been commercially developed in this country by the Electric Storage Battery Company, and was used in some of the early submarine storage battery installations in our naval service.

**“Box” Negative.**—Although, properly speaking, the “box” negative type plate does not belong to the Planté group, it being a special type of “paste” plate, it will nevertheless be here described inasmuch as it is now

chiefly used in conjunction with the "Manchester" type positive Planté plate described in the preceding paragraphs.

This plate is of the so-called *built-up* type construction and derives its name from the cellular or "box-like" features of design. Fig. 23 contains a sketch of this type of plate and from which a clear idea of the various details of construction may be had. The frame composing the supporting members of this plate consists of a lead-antimony casting in the form of a series of crossed bars, all of which are integrally joined together, thus producing the compartmentation or cellular construction for holding the *paste* active material. These cells or compartments are closed on each face of the plate by means of perforated sheets of pure, soft rolled lead held in position by riveting to the lead-antimony casting forming the frame of the plate. The perforations in the lead sheets comprising the two faces of the plate are designed to afford proper circulation of the electrolyte in and around the *paste* active material compacted into the several compartments of the plate.

The paste for this type of plate consists of litharge and lampblack, or carbon in some other finely divided form, in order to increase its conductivity as well as to maintain the proper degree of porosity in the paste. Although this type of plate produces good results for certain classes of service, it may be said that, due to the very advanced stage which has been attained in the art of *paste* plate construction, it is gradually being superseded by other later types. After these plates are made up they are given a *forming* charge in the same manner as was described in the preceding chapter applying to paste type assemblies.

(b) "**U-S-L Unit Positive**" Planté Plate.—Another typical example of the built-up type of Planté plate is known as the "U-S-L Unit Positive," an illustration of which is shown in Fig. 24. This plate is manufactured by the U. S. Light and Heat Corporation and consists of a lead-antimony framework or grid casting which supports the pure lead units constituting the active members of the plate. The lead-antimony grid is cast under pressure and is sufficiently rugged in design as to afford ample strength and rigidity during the life of the plate. The lead units which compose the active members of the plate are *swedged* from blank slabs of chemically pure rolled lead; this swedging process consists in working up the surfaces of the blank slabs into leaves or laminations in order to increase the surface areas of the active units in contact with the electrolyte.

The pure lead units are secured to the grid by means of lead-burning, and in order to prevent *buckling* of the plate, as a result of the normal *growth* or expansive action which takes place to a certain degree in all positive Planté plates, ample clearance space is left between the sides and bottoms

of the lead units and the inside edges of the grid to accommodate this growth. This feature of design is plainly shown in the illustration, Fig. 24. The lead-antimony grid used with the paste type negative which operates in conjunction with the Planté positive plate described herein is also shown in this illustration.

In the manufacture of these plates it is essential that a good electrical contact be obtained in lead-burning the pure lead units to the grid; these lead-burned joints should also be of sufficient cross-section and current-carrying capacity as to accommodate the various rates capable of being developed by the active members during the operation of the plate. After

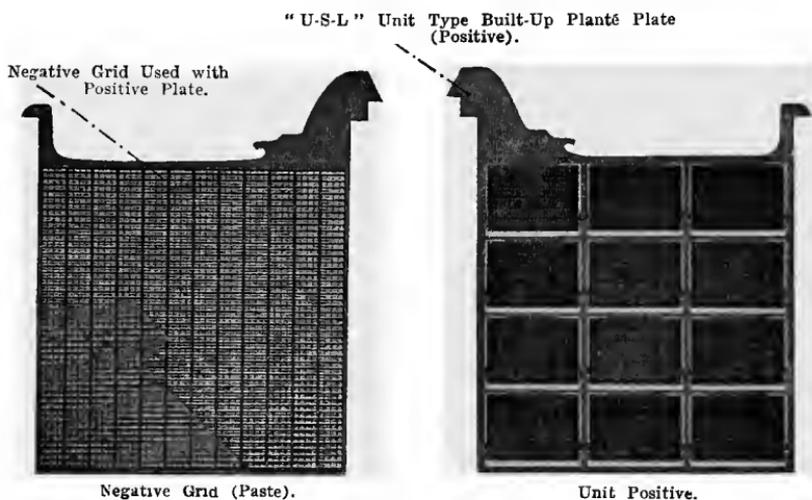


FIG. 24.—“U-S-L” Unit Type Planté Plate.

the units are lead-burned to the grid the plates are then placed in the *forming tanks* and given their formation charge. This type of plate is now used mostly for stationary battery installations and where weight is not a governing factor. This is considered a very rugged and durable plate and for its particular line of service gives good results.

**“Spun” Type Planté Plate.**—This type of plate is manufactured by the *spinning* method of construction and is a type largely used in this country, both in the naval service and commercial fields. Fig. 25 contains a photographic illustration of this type of plate and as manufactured by the Gould Storage Battery Company. Increasing the surface area of this type of plate is effected by passing a pure lead blank through a *spinning machine*

specially designed for this purpose by the manufacturers. The general details entering into the manufacture of this plate are as follows:

The pure lead blank is formed by casting a flat ingot of pure lead of from 4 to 5 inches in thickness, and then passing this ingot back and forth between the steel pressure rolls of a *rolling mill*, and in this manner is rolled until the desired thickness of the lead blank is obtained; this thickness in practice varies from 0.186 to 0.288 inch. It will therefore be seen that when the lead blank is removed from the rolling mill it has been transformed into an

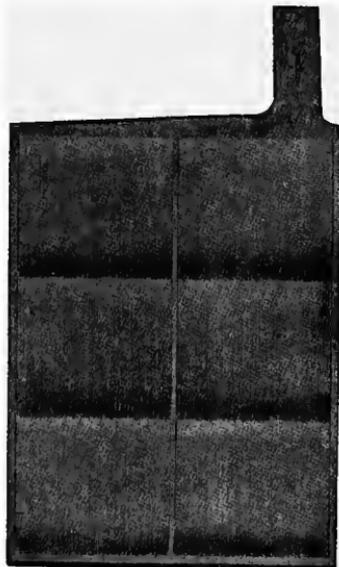


FIG. 25.—“ Spun ” Type Planté Plate.

exceedingly dense and homogeneous sheet of pure lead, qualities which are especially to be desired in the manufacture of Planté plates.

These lead sheets having been removed from the rolling mill are next carried to the *punching machine* where they are die-punched into blank plates of the desired size and form, with hanging and conducting lugs attached. The next operation is that of the *spinning process*, which is as follows:

The blank plates after being punched out as outlined above are next set-up in the frame of the *spinning machine*; when the machine is put in motion this frame carrying the blank plates reciprocates between a series of revolving mandrels, one set located on each side of the plate, each of which is fitted out with steel discs separated from each other by spacing washers.

As the frame carrying the blank plate passes back and forth between these discs a uniform pressure is continuously exerted against these discs and in turn against the blank plate by means of compressed air, and ridges or *ribs* and grooves accordingly begin to appear on each face of the plate. As the spinning operation progresses the discs are thus fed and depressed

"GOULD" TYPE SPUN PLATE.

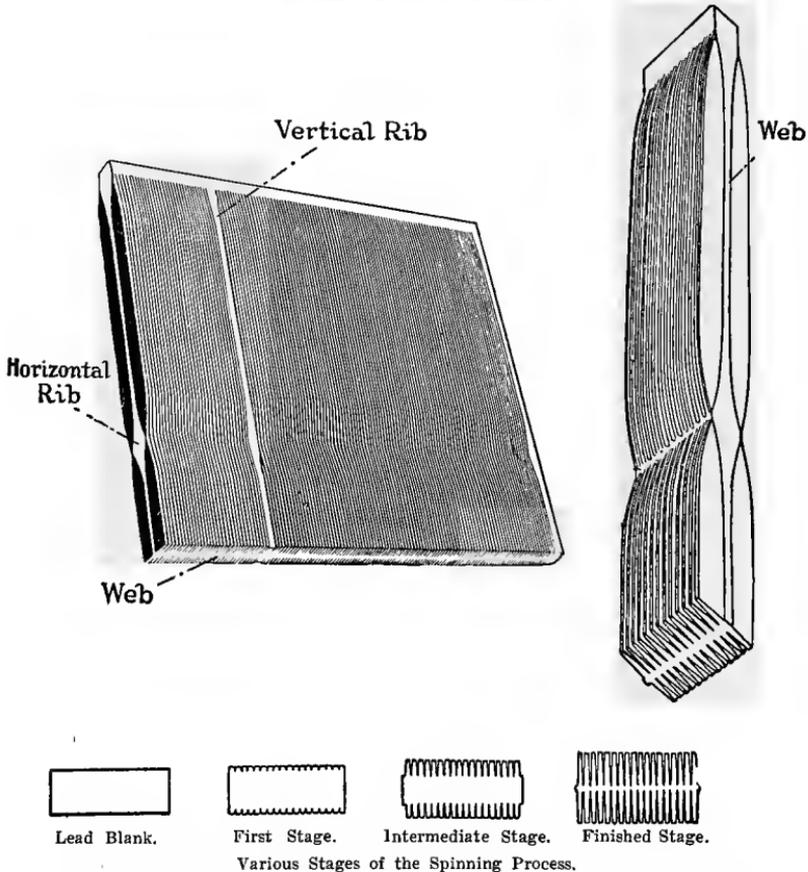


FIG. 26.—Showing Various Views of "Gould" Type Spun Plate.

deeper and deeper into the plate, thus causing the lead to flow into the spaces between the discs, forming the ribs on each face of the plate. It is therefore apparent that the thickness of the ribs thus spun on the plate is governed by the width of the spacing washers interposed between the discs, and that the amount of space between the ribs is governed by the thickness of the discs on the mandrels.

Fig. 26 contains a set of illustrations which clearly show the various stages of the spinning process in the manufacture of these plates, as well as sectional views of the plate after the spinning operation is complete.

The series of drawings at the bottom of this illustration show the various stages of the spinning operation from the pure lead blank to the completely spun plate; the development of the grooves and ribs are plainly indicated in this portion of the illustration.

In plates of large size manufactured by this method, it is desirable to leave a certain portion of the blank plate intact to form horizontal and vertical ribs for strengthening and current-conducting purposes.

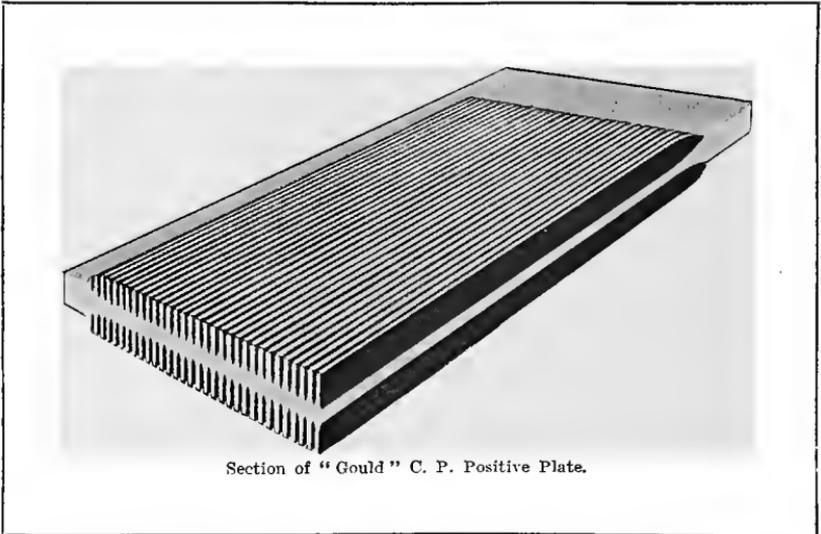
The horizontal ribs are obtained by spinning the plate in sections, thus leaving between the spun sections a diamond shaped cross-bar of solid metal extending the full width of the plate. This feature of the design as worked out on this plate is shown in the upper views of Fig. 26.

The vertical ribs are obtained by means of the heavier washers, periodically spaced along the mandrel, which subdivide each section, thus forming the heavier vertical ribs, these ribs varying in number and size according to the dimensions of the plate. These heavier vertical ribs are also shown in the drawings, Fig. 26.

By limiting the depth that the discs are fed into the blank plate a *web* of solid metal of any desired thickness remains as a central conductor, plate support, and current equalizer; the *web* thus formed is shown in Fig. 26.

It will thus be noted that the spinning of the ribs on the plate resolves itself into a *flowing* process; that is, due to the pressure exerted upon the discs as they are fed into the plates, the metal *flows* into the spaces between the discs, thus forming the ribs on the surface of the plate and increasing the surface area of the plate many times that of the original blank plate. In this regard, it is claimed by some storage battery engineers that this method of rib formation is superior to other methods, such as gouging, cutting, bending, etc., in that on account of the crystalline structure of lead those methods open up the pores of the lead in some of the ribs, thus allowing penetration of the electrolyte into those pores with the result that on account of the Planté action which takes place in the pores, abnormal *shedding* or sloughing-off of the lead ribs is produced; whereas, on the other hand, it is claimed that ribs formed by the *spinning* process are manifestly more dense than the original blank lead plates, thus excluding abnormal penetration of the electrolyte into the lead. It is apparent that any such difference, if there be a difference, in character of the ribs formed by the two methods resolves itself into a function of the useful life of the plate.

After the spinning operation is complete, the plates are next thoroughly cleaned of all oil and other foreign substances preparatory to conducting the



Section of "Gould" C. P. Positive Plate.

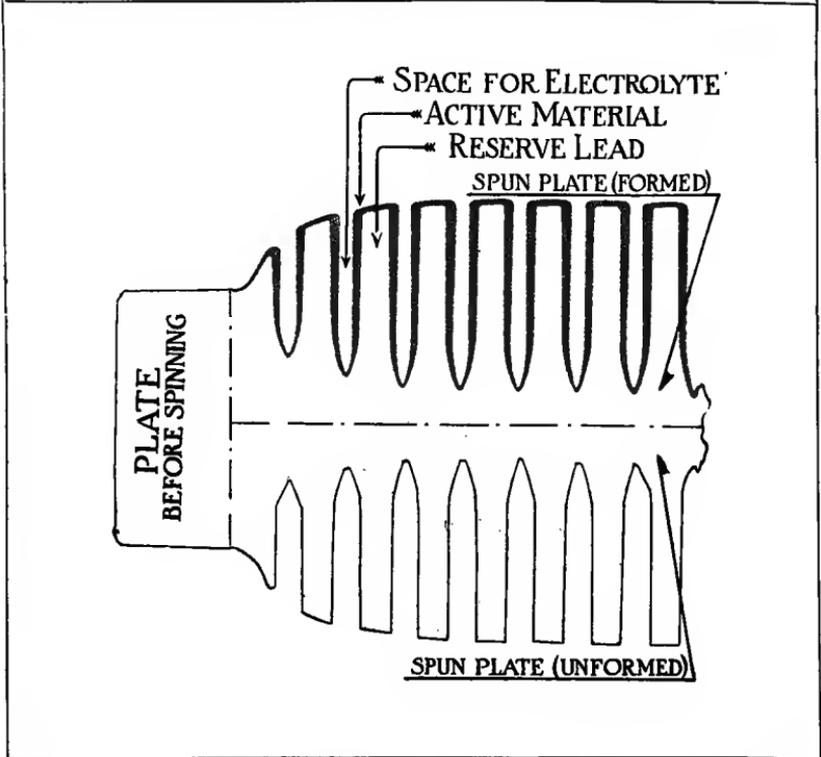


Fig. 27.—Showing Sections of Completely Spun and Formed "Gould" Planté Plate.

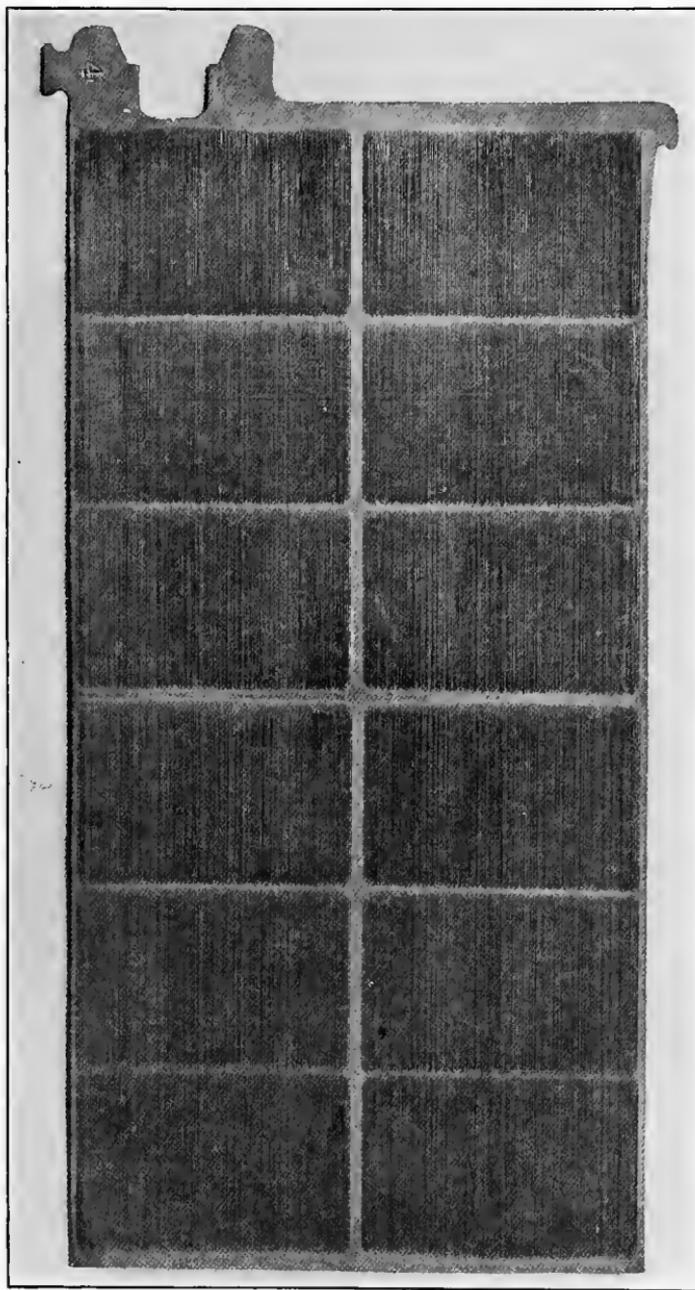


FIG. 28.—“Gould” Type Spun Plate—Submarine Type.

*formation charge.* This charge consists in connecting the plates up in the forming tanks containing the forming solution or lead corroding agents, and then passing direct current through the plates, thus depositing a thin layer of active material on the surfaces of all ribs of the plates. Fig. 27 contains a set of illustrations from which a clear idea of the plate in the various stages of fabrication may be obtained, these stages including all operations beginning with the lead blank to the fully formed plate. The lower view in this illustration shows a section of a plate magnified about five times. This type of plate as manufactured by the Gould Storage Battery Company is known as the "C. P." plate, deriving its name from the "chemically pure" (C. P.) characteristics of the *forming* solution used in the formation charge. Fig. 28 contains a photographic illustration of this type of plate as designed for submarine storage batteries. The unspun sections forming the vertical and horizontal conducting and strengthening ribs are clearly shown in this photograph.

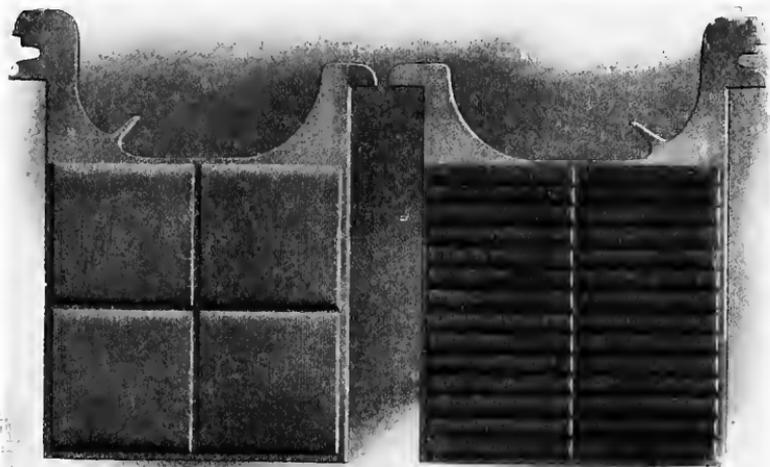
**Ploughed Type.**—Planté plates of this type are manufactured by a *ploughing* process, which process derives its name from the plough-shaped tool used in developing the leaves on the surface of the plate. This method consists in placing a sheet of pure rolled lead in a machine, called a *ploughing machine* and resembling an ordinary shaper, and *ploughing up* leaves or laminations from the surface of the lead sheet, thereby increasing its surface area.

The ploughing tool of this machine is of such design as to produce a leaf of the desired form and size when the machine is put in operation; this tool is mounted in the head of the shaper arm, and at each stroke of this arm a leaf is ploughed up from the flat surface of the sheet of lead. An automatic feed carries the tool across the width of the plate, this feed properly spacing the leaves apart at the end of each stroke. The strengthening and conducting ribs of the plate are formed by *jumping* the feed the proper amount at the desired positions along the width of the plate, thus leaving unploughed sections of the plate which constitute these ribs.

This method of manufacturing Planté plates is featured by the Willard Storage Battery Company. After the ploughing operation is completed, the plates are next placed in the forming tanks and given their formation charge, after which they are ready for assembling in groups and installing in the jars. Generally speaking, jars for this type of plate consist either of glass or lead-lined tanks.

**Swedged Type.**—This type of plate is manufactured by the *swedging* process, which consists in gradually developing the flat surface of a chemically pure, rolled sheet of lead into ribs or leaves by means of progressive and equally distributed pressure applied to the master forming or *swedg-*

*ing.* block of the swedging machine. This block consists of a steel slab having laminations, leaves, grooves, and strengthening ribs very accurately machined on its surface such that the desired form of the surface of the plates is impressed or developed on the rolled lead sheet when the machine is put in operation and pressure applied to the swedging block; obviously, the developed or machined surfaces of the swedging block is the reverse of that of the plates formed from it; that is, a groove on the swedging block develops a rib or leaf on the rolled lead sheet and vice versa. This swedging process is accomplished through the swedging block of the machine being suc-



Planté Negative.

Planté Positive.

FIG. 29.—“U-S-L” Swedged Type Planté Plates.

cessively passed over the surface of the lead sheet; an automatic feeding arrangement is provided such that the swedging block is progressively fed into the lead sheet until the desired depth has been attained, thus developing the increased surface area of the lead sheet. This method of manufacturing Planté plates produces very uniform and homogeneous plates.

Fig. 29 contains a photographic illustration of a pair of plates as manufactured by this method by the U. S. Light and Heat Corporation. It will be noted that the plates in this illustration are practically identical in form with the exception that the design of the negative plate dispenses with all vertical and horizontal ribs, except the center ones, thus increasing the active area of the negative plates. This special feature of design in respect to the increased surface area of the negative plates over that of the corresponding

positive plates may be said to be characteristic of all types of Planté plates, the reasons for which will be explained in another part of the text.

As in the case of other types of Planté plates, these plates are used in installations where the subject of weight per unit of power developed is not an important one.

After the *swedging* process is completed, the plates are next placed in the forming tanks and given their formation charge, which consists in *forming* a thin layer of sponge lead and lead-peroxide on the respective surfaces of the negative and positive plates.

### Special Characteristics of Planté Plates.

**Capacity and Weight.**—As was stated in the preceding paragraphs, the capacity of Planté assemblies per pound of battery is considerably less than that for paste type assemblies, which also accounts for the fact that paste plates are now used practically entirely for the so-called portable types of storage batteries and wherein the subject of weight is of necessity a very important one.

This feature of increased weight of Planté assemblies over that of the paste type is due primarily to the fact that it is necessary to initially provide a reserve of lead in both the positive and negative plates of the Planté type in order to produce a well-balanced unit; the reasons for this may be briefly summarized as follows:

**Positive Plates.**—Inasmuch as the active material of Planté plates is *formed* or produced from the original lead constituting the plates, and due to the fact that it is an inherent characteristic of all types of positive plates to *shed* a certain amount of this active material with each successive cycle of charge and discharge, it is therefore apparent that it accordingly becomes necessary to provide a reserve amount of base metal to compensate for that amount of active material shed from the plates during their normal operation in order that their rated capacity may be maintained throughout their useful life; in other words, this reserve amount of base lead must be provided in order that new active material may be progressively *formed* from it as necessary to replace that lost as a result of *shedding*.

**Negative Plates.**—Although after the original formation of active material is completed on the negative plates, practically no further *forming action* takes place on the basic lead of these plates, yet in view of the fact that all sponge lead has a tendency to contract or shrink during the normal action which takes place in the cells, thereby effecting a reduction in the capacity of the negative plates, it therefore becomes necessary to initially provide an excess of active material in order that when this shrinkage occurs the service

capacity available in the plates may balance that of the corresponding positive plates. As a general rule, it may be said that this shrinkage of the negative active material takes place at a comparatively rapid rate during the early operating days of the battery, after which it gradually decreases until practically no further shrinkage occurs. It is for this reason that Planté negative plates are designed with more initial surface area than the corresponding positive plates. This feature of design is plainly illustrated in Fig. 29, where the number of horizontal ribs is reduced in the negative plate as compared to that of the positive plate in order to increase the surface area of the negative plate.

In further consideration of the subject of reserve metal provided for Planté type plates, it should be noted that whereas in the positive plates the reserve lead is provided in the form of *basic lead* in order to replace the active material lost in *shedding*, in the negative plates the reserve lead is provided in the form of *active material* in order to compensate for *shrinkage* in the original amount provided. In other words, the capacity of the positive plate remains practically constant from the beginning of and during its useful life, whereas an excess of *capacity* (active material) must be initially provided in the negative plate in order that at the end of the shrinkage period ample capacity to balance that of the positive shall remain. This distinction between the two forms of the reserve metal as provided in these plates should be clearly drawn in the mind before passing on to the succeeding text, as a thorough understanding of this feature of the subject is necessary to a proper study of Planté plates.

CHAPTER VIII.  
**CAPACITY AND EFFICIENCY,**  
**Capacity Defined.**

In order that storage battery installations may be intelligently and satisfactorily operated it is necessary that the term *capacity*, as relating to storage battery engineering, be thoroughly understood.

Capacity when considered in this sense may be defined as the amount of electrical energy capable of being delivered by a cell or battery from the beginning of discharge until the gradually diminishing electromotive force of the cell reaches some predetermined value, which value depends upon the rate of the discharge as well as the design of the particular battery in question. The above definition assumes that the discharge is a continuous one, and that it is begun when the battery is fully charged and at a standard initial temperature. The standard initial temperature upon which the capacity of storage batteries for the naval service is based is 80 degrees Fahrenheit.

**The Unit of Capacity.**

The unit of capacity is the ampere-hour, which represents the product obtained by multiplying the rate of discharge in amperes by the time of discharge in hours. Thus, if a cell is capable of delivering 50 amperes steadily for 10 hours, to the predetermined final voltage, the capacity of this battery is 500 ampere-hours at that rate.

**Watt-Hour Capacity.**

Considered from a storage battery engineering point of view, the real energy capacity or true measure of a battery's energy producing capabilities is known as the *watt-hour capacity*, and is obtained by multiplying the ampere-hour capacity of the battery by the average value of the voltage during the discharge and is represented by the expression,  $CtE_a$ , where:

$C$  = Rate of discharge in amperes.

$t$  = Time of discharge in hours.

$E_a$  = Average voltage during discharge.

Thus, considering the same battery as outlined in the preceding paragraph, if this battery is discharged at the 10-hour rate (50 amperes) for 10 hours,

and the average voltage obtained during this discharge is 1.85 volts, then the watt-hour capacity of this battery is:

$$500 \times 1.85 = 9.25 \text{ watt-hours.}$$

### Capacity Varies with Rate of Discharge.

Other things being equal, the capacity of a battery may be said to vary inversely as the rate of discharge; that is, the number of ampere-hours capable of being delivered by a battery when discharged at low rates is greater than that obtainable when discharged at higher rates.

Theoretically considered, the capacity of a battery should be the same for all rates of discharge inasmuch as there is a definite amount of active material contained in the plates as well as a definite amount of sulphuric acid in the electrolyte, which combination should produce a definite number of ampere-hours irrespective of the rate of discharge.

Practically considered, however, such is not the case, for, as has been pointed out, it is an established fact that the number of ampere-hours produced by a battery during a continuous discharge does vary with the rate of discharge.

Considering that the ampere-hour capacity of the battery is 100 per cent at the 1-hour rate, the following tabulation gives the relative percentage of ampere-hour capacity at other rates up to and including the 20-hour rate:

Rate of discharge.	Ampere-hour capacity.
1-hour .....	100 per cent
3-hour .....	135 " "
5-hour .....	150 " "
10-hour .....	172 " "
15-hour .....	193 " "
20-hour .....	197 " "

This variation in capacity for different rates of discharge is due primarily to the fact that as the discharge progresses the acid concentration in the electrolyte becomes progressively less by virtue of its combining with the active material of the plates to form lead-sulphate, and since the ampere-hours delivered by a cell on discharge is a function of the rate of diffusion of the acid into the pores of the plate and the consequent combining of this acid with the active material with which it comes in contact, it follows that the sulphating action is greatest at the surface of the plate where the active material is readily accessible to the acid. Obviously, therefore, at higher rates of discharge, since the sulphating action is greatest at the surface of the plate, the sulphate crystals tend to clog up or congest the outer pores of the plate, thus retarding the diffusion of the acid into the interior of the

plate, with the result that the electrochemical action between the electrolyte and the interior active material of the plate is retarded, thus effecting a reduction in the number of ampere-hours delivered by the battery. Also, as has been stated, since the capacity is established by the end or final voltage, when the surface pores of the active material become congested and reduce the rate of diffusion of the acid into the interior pores, it is apparent that the acid which is entrained in the pores becomes weak, thus increasing the internal resistance of the cell, which is reflected by a reduction in the cell voltage, until the end or minimum final voltage for this rate is reached.

On the other hand, however, at lower rates of discharge the diffusion of the acid into the pores of the plate is more even, and consequently sulphate is not formed so rapidly at the surface and the acid has a better chance of access into the inner pores of the plate, consequently the voltage remains higher, and the number of ampere-hours obtainable at low rates of discharge is greater than at high rates.

Another interesting feature in regard to the capacity of storage batteries is that although when discharged at high rates to the minimum final voltage, if allowed to stand for a short while, the voltage comes up or recovers itself again and the battery is then capable of producing an appreciable number of ampere-hours at lower rates of discharge; this additional capacity obtainable at lower rates after a higher rate discharge is commonly referred to as *recuperative capacity*.

#### Capacity Established by End or Final Voltage.

The low voltage limit reached by the cell at the end of discharge and as referred to in the preceding paragraphs is usually fixed by the battery manufacturers and is based primarily upon the degree to which the plates of the cells may be sulphated without injury during the discharge. This condition arises from the fact that lead-sulphate is less dense than either lead-peroxide or sponge lead, the prime constituents of the active material of the positive and negative plates. Therefore, during a discharge, the active material of both sets of plates expands as it is converted into lead-sulphate, thus making it necessary to discontinue the discharge when a definite degree of sulphation has been attained in order to not subject the grids, adjacent active material and other parts of the plates to excessive strain incident to such expansion. The relative densities of sponge lead, lead-peroxide, and lead-sulphate are approximately as follows:

Sponge lead .....	10.5
Lead-peroxide .....	8.0
Lead-sulphate .....	6.5

Generally speaking, the following tabulation represents the low voltage limits capable of being safely reached by a battery of good design without injury to the plates during a continuous discharge at the designated rate:

Rate of discharge.	Final volts per cell.
1-hour .....	1.50
3-hour .....	1.70
5-hour .....	1.72
10-hour .....	1.75
15-hour .....	1.77
20-hour .....	1.80

It will be noted in the above table that the limiting final voltage has a smaller value at the higher rates of discharge than at the lower rates. This feature is accounted for by the fact that inasmuch as at the higher rates of discharge the number of ampere-hours obtainable from a cell is smaller than at the lower rates, the degree of sulphation in the plates is therefore less at the higher rates and the expansive action of the sulphated active material is accordingly not as great.

#### Factors Which Affect Capacity.

Other than the rate of discharge, the factors which directly affect the capacity of storage batteries may be summarized as follows:

- (a) Quantity of active material.
- (b) Arrangement of active material.
- (c) Condition of active material.
- (d) Quantity and density of the electrolyte.
- (e) Circulation of the electrolyte.
- (f) Temperature.
- (g) Age of the cell.

Each of the above factors may be briefly commented upon as follows:

**Quantity of Active Material.**—Inasmuch as the lead-peroxide of the positive plates and the sponge lead of the negative plates are each converted into lead-sulphate during a discharge, and also since it is as a result of this electrochemical action that electrical energy is produced on discharge, it follows that the greater the amounts of these active materials contained in the plates the greater the capacity of the battery.

The relation between the quantity of active material used in a cell and the quantity of electricity obtainable from it may be determined from the application of Faraday's electrochemical law, which law states that:

1. The amount of a substance liberated at an electrode is proportional to the total quantity of electricity passed through the cell.

II. The amount of a substance liberated by a given quantity of electricity is proportional to the electrochemical equivalent of the corresponding ion.

III. The amount of a substance liberated is equal to the electrochemical equivalent of the corresponding ion multiplied by the total quantity of electricity.

In brief, the above law states in effect that the amount of each substance performing a function in an electrochemical reaction is proportional to the quantity of electricity which passes through the circuit. And when various substances enter into an electrochemical reaction, their amounts are proportional to their chemical equivalent weights.

In the application of this law it is necessary that certain electrical units be utilized, principal among which are the ampere and the coulomb, the former being the unit of current and the latter the practical unit of quantity of electricity, one coulomb being the quantity of electricity which passes through a circuit when a current of 1 ampere has been flowing constantly for 1 second.

The electrochemical equivalent or the chemical equivalent weight of a substance as used in the above law is the ratio of quantity, by weight, of a substance which is decomposed by 1 ampere-hour (3600 coulombs) of electricity, to the quantity of hydrogen liberated by the passage of 1 ampere-hour of electricity. Numerically considered, it is equal to the atomic weight of the substance divided by its valency. Inasmuch as the atomic weight and valency of hydrogen are each equal to 1, the electrochemical equivalent of hydrogen is unity.

As a result of a series of very accurately conducted experiments it has been established that when 1 ampere of current has been flowing constantly for 1 second through a voltameter or an electrolytic cell in which silver is being deposited from a silver nitrate solution ( $\text{AgNO}_3$ ), under standard specifications, this quantity of electricity (1 coulomb) deposits 0.001118 gm. of silver.

The atomic weight of silver is 107.93; silver ion being univalent, the electrochemical equivalent or the chemical equivalent weight of silver is therefore

$$\frac{107.93}{1} = 107.93 \text{ gm.}$$

Then, since 1 coulomb of electricity deposits 0.001118 gm. of silver, the number of coulombs required to deposit 107.93 gm. will be

$$\frac{107.93}{.001118} = 96,540 \text{ coulombs.}$$

Therefore, since this same number of coulombs will deposit the electrochemical equivalent or the chemical equivalent weight of any other metal which can be electroplated in the same manner as described above for silver,

this quantity of electricity (96,540 coulombs) has for convenience been adopted as the electrochemist's unit of quantity of electricity and will be used accordingly in the succeeding text and calculations relating to this subject.

Now, in calculating the amount of active material required to produce a given quantity of electricity in the lead-acid storage battery cell, the procedure is as follows:

$$\text{Active materials..} \begin{cases} \text{Pb, negative plate.} \\ \text{PbO}_2, \text{ positive plate.} \end{cases}$$

The atomic weight of lead is 206.9 and, since it is bivalent, its electrochemical equivalent or chemical equivalent weight is  $\frac{206.9}{2}$  gm.

Hence, if 96,540 coulombs of electricity will deposit  $\frac{206.9}{2}$  gm. of lead, then 1 coulomb or 1 ampere-second of electricity will deposit

$$\frac{206.9}{2} \times \frac{1}{96,540} = .00107 \text{ gm. of lead;}$$

and since 1 ampere-hour is equal to 3600 coulombs, then 1 ampere-hour of electricity will deposit

$$3600 \times .00107 = 3.89 \text{ gm. of lead.}$$

Therefore, 3.89 gm. of lead will be required in the negative plates for every ampere-hour of electricity produced by the battery.

Next, considering the positive plate, the atomic weight of lead-peroxide ( $\text{PbO}_2$ ) is 206.9 + 32, and its electrochemical equivalent or chemical equivalent weight is

$$\frac{206.9 + 32}{2} = \frac{238.9}{2} \text{ gm.}$$

Then, since 96,540 coulombs of electricity will deposit  $\frac{238.9}{2}$  gm. of lead-peroxide, 3600 coulombs, or 1 ampere-hour of electricity will deposit

$$\frac{238.9}{2} \times \frac{1}{96,540} \times \frac{3600}{1} = 4.45 \text{ gm. of lead-peroxide;}$$

or, 4.45 gm. of lead-peroxide will be required in the positive plates for every ampere-hour of electricity produced by the battery.

Although the above calculations represent the theoretical amounts of active materials required in the plates for each ampere-hour of electricity produced by the battery, when practically considered, it is found that from two to five times the theoretical amounts of active material are required, depending upon the type of plates used, for the reason that the porosity of

the active material is necessarily limited in all types of plates, and therefore some of the active material is inaccessible to the action of the electrolyte. Furthermore, for other reasons which have been stated elsewhere in this chapter, the discharge is discontinued when a predetermined minimum final voltage is reached, thus accounting for a certain amount of the active material present in the plates and which is not utilized in producing ampere-hours. These facts taken in conjunction with other characteristic features of design of storage batteries satisfactorily explain why the theoretical amounts of active materials contained in the plates are exceeded.

**Arrangement of Active Material.**—Since it is essential to the production of electrical energy in the cell that the acid of the electrolyte and the active materials of the plates be in contact with each other, it is readily apparent that the arrangement of the active materials in relation to that of the electrolyte constitutes a very important factor in respect to the capacity of the battery. In other words, the greater the degree of contact between the electrolyte and the particles of active materials contained in the plates, the greater the capacity of the battery. Also, it is essential to a proper design of the battery that the active materials be so arranged in the plates as to produce uniform working over all portions of the plate in order to prevent *buckling* and undue strain over any part of the plate.

Therefore, in point of design, the battery engineer strives to produce a battery, the plates of which present maximum surface area in contact with the electrolyte in order that an increase in capacity as outlined above may be effected. Moreover, by installing in the cells a large number of thin plates having surface areas as great as is consistent with good design, the capacity of the battery is accordingly increased. Especially is this true of batteries designed for high discharge rates, as, for instance, in submarine storage batteries, automobile starting batteries, and other batteries designed for similar classes of service.

On the other hand, however, since the rate of diffusion of the electrolyte into the pores of the plate is a function of the capacity of the plate, it may be said that for batteries designed for low rate discharge work, thick plates with smaller surface areas are more practicable, inasmuch as low rates of discharge do not require such a rapid rate of diffusion of the electrolyte into the pores of the plates as is necessary in the case of high rates of discharge; thick plates, therefore, afford ample rates of diffusion for the required low rate capacity. Furthermore, thick plates are in general possessed of longer life than is characteristic of thin plates.

In further consideration of the subject of the arrangement of the active materials in the plates and the effect of such arrangement upon capacity, it

may be said that Planté type plates present striking examples, as in these plates the active materials are *formed* or deposited in very thin layers over a comparatively large surface area of plate, with the result that they respond rapidly to very high rates of discharge; that is, the layers of active materials being relatively thin, the rate of diffusion of the acid into the pores of the plates is correspondingly rapid, thus making the plate capable of readily responding to the high rates of discharge. Also, due to the perfection attained in the contact between the active material and the conducting members of Planté plates, the conductivity is high, the internal resistance of the cell is correspondingly low, and with the result that the voltage of the cell during discharge is high, thus increasing the watt-hour capacity of the cell. Moreover, since the internal resistance of the cell is reduced as a result of the good contact between the active material and the conducting members of the plate, it is apparent that the ampere-hour and the watt-hour efficiencies of Planté plates are relatively high in comparison with paste plates.

**Condition of Active Material.**—Inasmuch as it is impossible for all particles of active materials composing the plates to be assembled at the surface, it obviously becomes necessary that some means be provided whereby the acid of the electrolyte may be readily accessible and plentifully supplied to the particles of active materials located in the interior of the plate in order that full capacity may be obtained during a discharge. This feature or expedient resolves itself into effecting a sufficient degree of porosity in the active material through the use of other agents, such as carbon, barium sulphate and other substances, during the mixing of the paste and the manufacture of the plate.

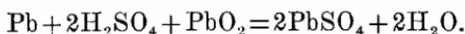
In general, it may be said that the greater the degree of porosity of the active material the greater the capacity of the plate; that is, a porous plate is capable of producing greater capacity, especially at high rates of discharge, than a dense, hard plate. However, there is a practical limit to the degree of porosity which is to be desired in a plate, as too much porosity is conducive to excessive *shedding* of the active material and a consequent short life of the plate.

After a proper degree of porosity has once been obtained in the active material during the manufacture of the plates, it is essential to satisfactory operation of the battery that this porosity be maintained as far as possible throughout the useful life of the plates. In order to maintain this porosity it is therefore necessary that the battery be kept in a state of practically full charge, especially when lying idle and subjected to protracted periods of inactivity, since if it is allowed to remain in an uncharged condition the lead-sulphate crystals become hard and it is with difficulty that such crystals are

reduced during charge, if indeed at all in cases of excessive sulphation. Hence, in such cases the internal resistance of the cell increases, the pores of the active material become clogged or congested, thus preventing proper diffusion of the electrolyte and with the consequent result that the capacity falls off, the efficiency is reduced and the battery deteriorates rapidly in general. Furthermore, if this condition is allowed to exist without taking steps to remedy it, it then becomes only a matter of a comparatively short while until the capacity is beyond restoration, at which time the battery is ready for the scrap heap. The subject of the *trickling charge* and its relation to maintaining the active material of the plates in proper condition as regards capacity is covered fully in a later chapter and should be carefully studied.

**Quantity and Density of the Electrolyte.**—Having considered the active materials composing the plates and their relation to the capacity of the storage battery cell, we will next consider the electrolyte and its relation to capacity. In the beginning it should be thoroughly understood that the electrolyte plays equally as important a part in the operation of the cell as do the active materials of the plates, for if it were not for the presence of the electrolyte no electrochemical action would take place in the cell and, consequently, no electricity could be produced by it.

The necessity for the presence of the electrolyte having thus been established, the next point to be considered is the amount of electrolyte required in the cell to produce a given capacity or quantity of electricity; this can be ascertained through the application of Faraday's law, the procedure being similar to that followed in determining the amounts of the active materials contained in the plates. In this connection let us therefore again review the fundamental equation of the chemical reaction which takes place in the lead-acid storage battery cell. This equation is written as follows:



In applying Faraday's law to the above equation, such that the amount of electrolyte can be ascertained, it becomes necessary to obtain the electrochemical equivalent of the  $2\text{H}_2\text{SO}_4$  member. Therefore, since the atomic weight of sulphur is 31.83, the atomic weight of the electrolyte as chemically expressed above is

$$2[2 + 31.83 + (4 \times 16)] = 195.66,$$

and being bivalent the electrochemical equivalent or chemical equivalent weight is  $\frac{195.66}{2}$  gm.

As has been previously pointed out, since 96,540 coulombs of electricity will deposit the chemical equivalent weight of any substance entering

into an electrochemical reaction, then the amount of  $\text{H}_2\text{SO}_4$  deposited by 1 ampere-hour or 3600 coulombs of electricity will be:

$$\frac{195.66}{2} \times \frac{1}{96,540} \times \frac{3600}{1} = 3.64 \text{ gm.};$$

and therefore 3.64 gm. of  $\text{H}_2\text{SO}_4$  will be required in the cell for every ampere-hour of electricity produced by it. In summarizing the theoretical amounts of active materials used up in the lead-acid storage battery cell in the production of 1 ampere-hour of electricity, it will be seen that these amounts are as follows:

Lead (Pb) .....	3.89 grams.
Lead-peroxide ( $\text{PbO}_2$ ) .....	4.45 grams.
Electrolyte ( $\text{H}_2\text{SO}_4$ ) .....	3.64 grams.

As was stated in the case of the active materials composing the plates, that for a given capacity the actual amounts of these materials required exceed the theoretical amounts, so also does the actual amount of electrolyte required in the cell in practice exceed the theoretical amount. In point of design the chief reasons for exceeding the theoretical amount of electrolyte in actual practice may be stated as follows:

(a) It is necessary that the tops of the negative plates be covered with electrolyte in order to prevent them from oxidizing and drying out and thus losing their capacity. Strictly speaking, in so far as the actual production of ampere-hours is concerned, all acid which is positioned above the tops of the plates is not utilized, although, as will be later described, the additional *acid head* resulting from the acid above the tops of the plates constitutes a function of the rate of diffusion and circulation of the electrolyte in the pores of the plates.

(b) All acid in the space below the bottoms of the plates, which is commonly known as the *sediment space*, plays no useful part in the production of ampere-hours.

Next, in considering the subject of density of the electrolyte, it may be said that this factor has a considerable effect upon the capacity of the storage battery, as within certain limits the voltage of the cell increases with the density of the electrolyte, thus manifesting itself accordingly in an increase of capacity obtainable from the cell. Another necessary consideration to be given to the density of the electrolyte is that of the effect it has upon the life of the cell. In respect to this feature of the subject, it has been found that the chemical activity of the electrolyte at densities above 1.300 is such as to rapidly attack and seriously injure the grids and other parts of the battery, making it impracticable to use acid of a higher specific gravity than 1.300.

As stated above, within certain limits the voltage of the cell increases with an increase in the density of the electrolyte; this is due primarily to the fact that the conductivity of the electrolyte varies with the density of the acid, it being greatest at a density of about 1.220, as shown on the curve in Fig. 30. It will also be noted from this curve that the conductivity decreases from this point as the density of the electrolyte is increased or decreased; that is, the resistance of the electrolyte in the cell increases as the density is increased or decreased from 1.220. However, owing to the increased chemical activity, and therefore capacity, especially at high rates of discharge, which results through the use of high density acid, a compromise has therefore been effected, and the normal full charge gravity reading adopted for batteries of the naval service and designed for high rates of discharge ranges from 1.250 to 1.280; whereas, those designed for intermittent service at comparatively low discharge rates use acid of 1.220 specific gravity at full charge. These limits are considered satisfactory for batteries designed for this service.

**Circulation of the Electrolyte.**—The circulation of the electrolyte also bears an important relation to the subject of capacity obtainable from the storage battery cell. In order that the chemical action may be ample and continuous in supporting the discharge it is necessary that the facilities for affording circulation of the electrolyte be such as to allow the stronger acid to replace the weaker acid in contact with the active material of the plates. Mechanically considered, this feature resolves itself into providing and installing separators containing sufficient porosity; necessary acid space between the plates and the separators, as well as ample space between the separators—these having been very fittingly termed the *breathing spaces* of the cell; necessary height of the electrolyte above the tops of the plates as to produce a sufficient *acid head* for assisting in increasing the capacity of the battery through increased rate of diffusion, hence circulation, of the electrolyte into the pores of the plates; and such other mechanical expedients as will tend to improve, generally, the circulation of the acid in the cell.

**Temperature.**—The subject of temperature is important with regard to capacity in that the rate of diffusion of the electrolyte is quite appreciably increased by virtue of a rise in temperature, and since the diffusion of the acid into the pores of the plates is a function of capacity, it follows that the capacity is increased by a rise in temperature in the cell. The increased diffusion is brought about by expansion of the acid, as well as the increased size of the pores in the separators and plates resulting from this rise in temperature of the cell, all of which tends to assist in improving the circulation of the electrolyte. It has been found that the density of the electrolyte varies inversely by approximately one point (.001) for every 3 degrees

Fahrenheit; in other words, for every 3 degrees Fahrenheit rise in temperature, the density of the electrolyte will register .001 point lower on the hydrometer scale. Therefore, in taking specific gravity readings of a cell, the correction for temperature should be made in order to ascertain the true state of charge or discharge of the battery with respect to the standard temperature upon which the capacity is based. The standard temperature upon which the capacity of all storage batteries for the naval service is based is 80 degrees Fahrenheit.

Moreover, all chemical action is accelerated by a rise in temperature, and the chemical activity of the storage battery cell is thus increased as a result of rise in temperature, which manifests itself in an increase in capacity developed by the battery. It may also be said that the voltage of the cell is increased on discharge by a certain amount as a result of increased temperature in the cell, and since capacity is established by end or final voltage, it follows that the capacity is accordingly increased by a certain amount.

Under normal operating conditions 110 degrees Fahrenheit has been adopted as the maximum permissible limit to be reached by a battery, as on account of the increased activity of the chemical action at temperatures above this point, it is considered detrimental to the battery to exceed this limit; particularly is this true in respect to the wood separators, as the acid at high temperatures has a very bad effect upon them. For occasional discharges, however, this limit may be safely raised to 135 degrees Fahrenheit.

At low temperatures the capacity of the battery falls off rapidly, and for temperatures of 50 degrees Fahrenheit and below the capacity approaches 50 per cent of normal, and the efficiency at low temperatures is correspondingly reduced.

It is customary to require the battery manufacturers to supply temperature coefficient curves for variation in capacity on all types of batteries supplied to the naval service for the guidance of the operating personnel. The 100 per cent capacity point on this curve is the normal capacity obtainable at 80 degrees Fahrenheit. The effect of temperature upon capacity may be said to vary with the rate of discharge, it being greatest at the lower rates of discharge.

**Age of the Cell.**—The age of the cell is another factor which should be considered in the general discussion of the subject of capacity of storage batteries. When operated under normal conditions it is an inherent characteristic of the storage battery to increase in capacity over a certain period of its early life until a maximum has been attained; from this point there is a gradual decline in the capacity until it is so low as to not justify further operation.

Owing to the fact that in the manufacture of storage batteries all of the active material of the plates is not fully *formed* during the initial charge and discharge, it therefore requires several cycles of charge and discharge, depending upon the type of battery, to place all of the active material in condition for supporting the discharge; or, in other words, the battery has not been developed to the point of producing its maximum capacity. On the other hand, however, after all of the active material in the plates has been developed, such that the cell is capable of producing maximum capacity, it is also an inherent characteristic for the plates, especially the positive ones, to *shed* a certain amount of their active material with each cycle of charge and discharge, thus accounting for the gradual decline in the capacity of the battery.

Generally speaking, a battery may be said to be worn out and unsuitable for further operation when its capacity has been reduced to from 60 to 70 per cent of its normal rated capacity. It is usual practice to require the battery manufacturers to guarantee a certain period of operation of the battery (in years) before the capacity is reduced below a certain per cent of its normal rated capacity. For batteries supplied to the naval service the guarantee is drawn up on basis of 80 per cent of the normal rated capacity, the time factor depending upon the type of battery supplied.

### Efficiency.

**Efficiency Defined.**—The efficiency of a storage battery is the ratio of output to input; that is, for a given cycle the ratio of the amount of the discharge to that of the preceding charge. Efficiency may be properly divided into two classes, viz.:

- (1) Quantity efficiency.
- (2) Energy efficiency.

Where:

$$\text{Quantity Efficiency} = \frac{\text{Ampere-hours given out on discharge}}{\text{Ampere-hours put in on preceding charge}}$$

$$\text{Energy Efficiency} = \frac{\text{Watt-hours given out on discharge}}{\text{Watt-hours put in on preceding charge}}$$

The *quantity efficiency* runs very high, which for batteries of good design may be as high as 95 per cent, though the average value is around 90 per cent.

The *energy efficiency*, which is the true measure of a battery's efficiency from a storage battery engineering point of view, does not run as high as the quantity efficiency, in that the average charging voltage is higher than the average voltage produced by the battery on discharge, due primarily to the resistance offered by the battery to the flow of charging current, as a result

of polarization. An 80 per cent watt-hour efficiency is considered very good, the average running around 70 per cent.

Owing to the loss of charge as a result of local action or *self discharge* taking place in the cell, and which is characteristic of all storage batteries, it may be said that the elapsed interval of time between the discharge and the preceding charge is necessarily a function of the efficiency of the cell, the longer this interval the lower the efficiency. Moreover, inasmuch as the capacity of a battery is also a function of its efficiency, the remarks contained in the preceding text in respect to capacity bear an important relation to efficiency.

The actual operation of determining the efficiency of a battery requires a very accurately calibrated set of instruments as well as uniform conditions, in respect to temperature, rates of charge and discharge, etc., and in order to determine an average value for efficiency at a given rate of discharge, the data taken on several cycles conducted under uniform conditions should be used.

## CHAPTER IX.

### ELECTROLYTE.

#### Electrolyte Defined.

Any non-metallic liquid possessed of electrical conductivity and which is chemically decomposed, or whose component elements are disassociated when an electrical current is passed through it is called an *electrolyte*.

#### Composition.

Electrolytes are composed of metallic salts, acids and bases when in solution with water; such aqueous solutions of salt, sulphuric acid, potassium hydrate, sodium hydrate, etc., are familiar examples of this class of electrolytes. Also, many metallic salts, acids and bases when maintained in a molten state perform equally well the functions of an electrolyte.

#### Ionic Theory as Applied to Electrolytes.

As has been stated, an electrolyte must be possessed of relatively good electrical conductivity and its component parts must also be in a stable equilibrium. Moreover, in order that such a substance may be possessed of good electrical conductivity, it must be very susceptible to ionization, since a current can only pass through a solution when two ions are available to convey it. Relative to this feature of ionization, although water in itself is not a conductor, or if it be one, due to its high resistance it is an exceedingly poor one, it nevertheless possesses a remarkable power for aiding in the ionizing of substances held in solution with it, and for this reason it therefore meets with extensive application for forming numerous solutions of high conductivity and may be said to constitute the basis of all electrolytes used in the storage battery cell.

The electrolyte which is used to the practical exclusion of all others in the lead-acid storage battery cell consists of a relatively concentrated solution of sulphuric acid in water. It, therefore, contains concentrations of hydrogen ions (cations) and  $\text{SO}_4$  ions (anions), and these ions in passing back and forth through the solution between the electrodes convey the current to the electrodes and from thence the electricity passes out through the circuit.

It should, therefore, be thoroughly understood that the electrolyte plays a relatively important part in the action of the storage battery cell, and in order that its purity and effectiveness of action may be safeguarded it is deserving of a just amount of attention in the operation of the storage battery cell.

### Navy Specifications for Electrolyte.

In order to insure that a pure grade of sulphuric acid is obtained for the electrolyte of lead-acid storage batteries, the present specifications require that the concentrated acid shall be of the highest grade of commercial sulphuric acid. It must be water white in color, and of at least 1.835 specific gravity (or 65.7 Baumé) at 15.5 degrees Centigrade (or 60 degrees Fahrenheit). It should average at least 76.27 per cent of  $\text{SO}_3$  (sulphuric anhydride), or 93.43 per cent  $\text{H}_2\text{SO}_4$  (sulphuric acid).

Also, it must not contain the slightest trace of platinum and but the smallest trace of copper, selenium, arsenic, tin, manganese, thallium. Cadmium and magnesium are permissible. It must not show more than one one-hundredth of 1 per cent zinc; one twenty-fifth of 1 per cent antimony; one one-hundredth of 1 per cent iron; one one-thousandth of 1 per cent chlorine; one one-thousandth of 1 per cent nitrogen in any form, as ammonia, nitrate, etc.; one six-hundredths of 1 per cent copper. The acid must not contain appreciable quantities of the sulphates of calcium, sodium, potassium, or aluminum, nor of sulphur, sulphur dioxide, or pyrosulphuric acid. It should further be free from organic matter, acetates, chlorates, citrates, and from silicates or sediment in any sensible quantity.

### Composition of Electrolyte Used in the Lead-Acid Storage Battery Cell.

The electrolyte used in the lead-acid storage battery cell is composed of dilute sulphuric acid,  $\text{H}_2\text{SO}_4$ , and pure water, preferably distilled. This electrolyte should be prepared from concentrated acid (oil of vitriol) of 1.835 specific gravity and having a purity which conforms with the specifications as outlined in the preceding paragraph. The so-called "commercial acid," which is ordinarily obtainable at drug stores, etc., is not satisfactory for use in storage batteries, and it is essential that "chemically pure" (C. P.) acid only be used for this purpose. It is also essential that the special precautions for handling and mixing the acid for the electrolyte, and as outlined elsewhere in this chapter, be rigidly adhered to in order that satisfactory results in operation of the battery may be obtained. Too much emphasis cannot be put upon the subject of purity of the acid and water used in making up the electrolyte for the storage battery, as it is especially true in this case that "an ounce of prevention is worth a pound of cure."

### Effects of Impurities in Electrolyte.

In order that the importance of safeguarding the purity of the electrolyte may be realized, a brief outline of the effects that certain impurities have

upon the operation of the storage battery cell will be given. These impurities may in general terms be stated under three headings, as follows:

I. Foreign metals, or salts of such metals, especially those which appear after lead in the electrochemical series; or, in other words, those which are less electronegative than lead; for example, copper, silver and platinum. Due to the electrochemical action which takes place in the cell, these metals are immediately transferred to the active material of the negative plate where innumerable electrical couples are formed, and at which points local action is produced, with the result that the spongy lead of the negative plate is converted by this action into lead-sulphate ( $\text{PbSO}_4$ ), and free hydrogen is evolved at the foreign metal. This action is more pronounced in proportion to the increase in the quantity of the metallic impurity contained in the electrolyte, and consequently the more readily is hydrogen gas evolved from the surface of the foreign metal.

The result of this local action, as described above and caused by such impurities in the electrolyte, is manifested by a gradual decrease in the capacity of the negative plate. Generally speaking, it may be said that platinum, as a rule, is the worst of the metals in this respect.

Another instance of the decrease in capacity of the negative plate as a result of the local action which takes place in a cell due to impurities is in the case of antimony. Antimony is soluble in sulphuric acid; hence, is carried over and deposited on the sponge lead of the negative plate with the consequent local action and loss of capacity of the negative plate caused by the sponge lead-antimony couple thus formed. This antimony is deposited or plated on the negative plate by the electrolytic action, and not only causes a reduction in capacity of the negative plate by local action, as described above, but the pores of the sponge lead active material become filled up and congested with the antimony, thus causing a further loss in capacity through restricted and decreased diffusion of the acid of the electrolyte. In this regard, although the grids of pasted plates contain a certain proportion of antimony, which probably is responsible for some local action taking place in the cell, yet it is practically negligible, inasmuch as it is alloyed with the lead. Furthermore, the surfaces of the grids, especially the positive ones, become corroded by the action of the acid of the electrolyte, and this coating acts as a protection to a certain extent against the antimony content going into solution.

II. Metals, such as iron or manganese, whose salts are readily oxidized or reduced; for example, iron or ferrous sulphate when in contact with lead-peroxide ( $\text{PbO}_2$ ) of the positive plate is readily oxidized to ferric sulphate, while this ferric sulphate, when it comes in contact with the sponge lead (Pb) of the negative plate is again reduced to ferrous sulphate. Each of

these reactions is accompanied with loss of charge of the corresponding plate, with the consequent formation of lead-sulphate ( $\text{PbSO}_4$ ) on each plate. It will, therefore, be understood that the presence of a considerable quantity of iron or manganese in the electrolyte will rapidly discharge a battery in accordance with the reactions outlined above.

The presence of iron in the electrolyte of a storage battery cell when placed on charge is indicated by heating of the cell, as well as by the fact that the specific gravity and voltage will not attain their normal maximum.

III. Foreign acids or salts of these acids or acid forming substances. The presence of these substances in the electrolyte is manifested by a rapid corrosion of the grids. The presence of even the minutest quantity of such acids or substances should, therefore, be avoided.

#### **Relation Between Density and Conductivity of Electrolyte.**

The density of the electrolyte is an important factor in the operation of the storage battery cell. Owing to its high resistance, concentrated sulphuric acid, which is a heavy, oily liquid, does not form a satisfactory electrolyte, and this constitutes one of the chief reasons why the electrolyte used in the lead-acid storage battery cell consists of dilute sulphuric acid and pure water. The conductivity of dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ) is greatest at a density of about 1.220.

In Fig. 30 is shown a graphical representation of the relative conductivity of electrolyte of various densities ranging from that having a specific gravity of 1.030 to that of concentrated sulphuric acid of 1.835 specific gravity. It will be noted that the curve is parabolic in shape, the relative conductivity decreasing as the density is increased or decreased from 1.220.

#### **Specific Gravity Defined.**

The specific gravity of a liquid or any substance is its relative density or weight as compared with water as a standard. It expresses numerically how much heavier or how much lighter any volume of liquid or substance is than an equal volume of pure water. The specific gravity of pure water is therefore considered as unity, usually written 1.000 and spoken of as "ten hundred." Therefore, concentrated sulphuric acid, which is a solution with a specific gravity of 1.835, is one and eight-hundred and thirty-five thousandths times as heavy as an equal volume of pure water, and in terms of specific gravity is spoken of as "eighteen thirty-five." In other words, sulphuric acid being heavier than water, its presence in electrolyte accounts for the fact that the specific gravity of the electrolyte used in the lead-acid

storage battery cell is greater than 1.000. The specific gravity of the electrolyte is obtained by the use of a special instrument called an *hydrometer*, the description of which and method of using will be taken up later.

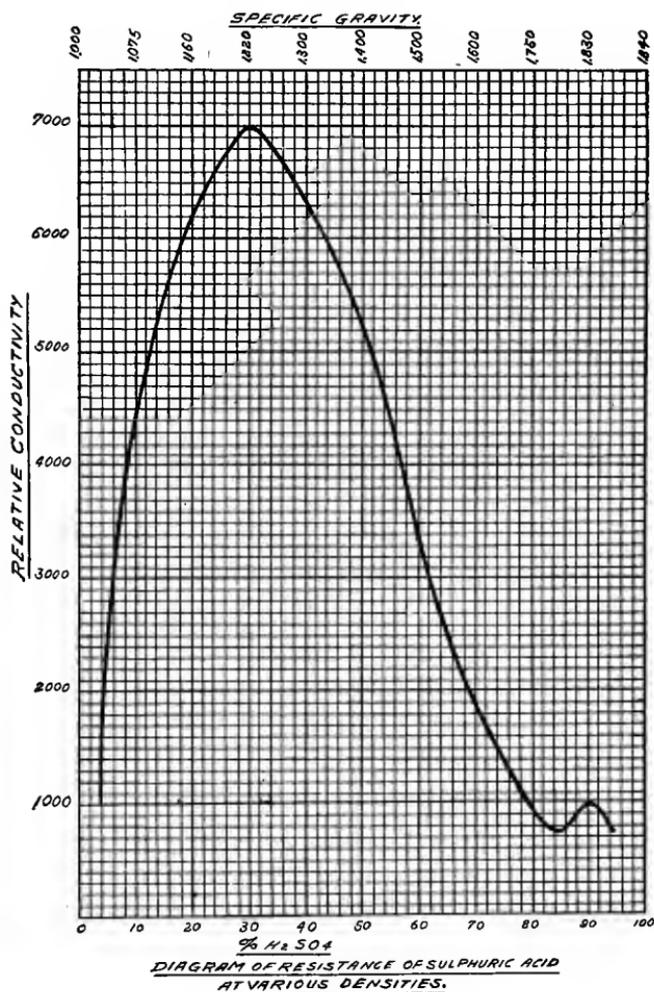


FIG. 30.—Resistance of Sulphuric Acid at Various Densities.

### Specific Gravity of Electrolyte Used in Lead-Acid Storage Batteries—Navy Type.

The specifications for the "Navy Type" lead-acid storage batteries require that the specific gravity of the electrolyte used in these batteries shall be from

1.210 to 1.220 (average 1.215) when fully charged and at a temperature of 80 degrees Fahrenheit.

In view of the fact that the portable storage batteries used in the naval service are, as a general rule, subjected to intermittent periods of duty, they thus remaining idle for protracted periods, the low specific gravity (1.215) of the electrolyte has been adopted, since it affords ample capacity and satisfactory operation of the batteries used on this type of service. By using electrolyte of this low specific gravity, local action, or self-discharge in the cell is reduced, the effect of over-sulphation is minimized, the effects of impurities in the electrolyte are not so pronounced, and the effects of high temperatures attained under regular service conditions of operation are not so injurious as would be the case if electrolyte of greater density were used. In other words, the life of the battery is increased as well as its reliability of operation, by using electrolyte of the low density. High specific gravity electrolyte increases local action within the cell as a result of the increased activity of the chemical action. There is also a progressive increase in the capacity of a storage battery cell through increasing the specific gravity of the electrolyte within given limits.

#### **Specific Gravity of Electrolyte—Submarine Cells.**

Since the main storage batteries of the submarine resolve themselves into the prime movers or source of power when operating submerged, it is thus necessary that the specific gravity of the electrolyte be increased over that used in the portable types of batteries described above. Under ordinary peace time conditions of operation, the electrolyte used in the submarine service is of 1.250 specific gravity at end of full charge and at a temperature of 80 degrees Fahrenheit. However, for boats operating in tropical waters, electrolyte of 1.215 specific gravity at end of full charge and at 80 degrees Fahrenheit is used. For the same reasons as given in the preceding paragraph relative to the portable types of storage batteries, the low specific gravity of electrolyte for tropical service is used in order to counteract the deleterious effects due to high temperature.

Also, under conditions of war time operations, since it is necessary that maximum capacity be available in the storage batteries of this service, it is advisable to increase the specific gravity of the electrolyte to 1.280 or 1.300.

In regard to increased capacity as a result of increasing the specific gravity of electrolyte, it may be said that this applies more particularly to batteries of the paste-paste type, since this increase in capacity is not so pronounced with the storage batteries having Planté plates. The difference in the character and distribution of the active material in the two types of

plates, which is also a function of the rate of acid diffusion during discharge, accounts for this difference in capacity through increasing the specific gravity of the electrolyte.

### Method of Preparing Electrolyte.

In order to properly prepare electrolyte from sulphuric acid of 1.835 specific gravity, it is necessary that certain essential precautions be observed, as follows:

(a) Use a glass, china, glazed earthenware, lead or rubber vessel for mixing the acid and the water. Never use a metallic vessel other than lead, since practically all other metals readily dissolve in sulphuric acid, and if allowed to enter the cell would ruin the plates.

(b) Use only sulphuric acid of known purity and which rigidly conforms with the specifications as previously outlined in this chapter.

(c) Use only pure water, preferably distilled water if obtainable. It is especially important that pure water be used, in view of the fact that certain organic acids or chemical compositions frequently found in water of some localities will attack the plates and ruin them in a comparatively short time.

(d) Carefully pour the acid into the water and never the water into the acid, since during this process of dilution a chemical combination is produced and not an ordinary mechanical mixture; therefore, heat being liberated, the solution accordingly becomes hot. Care should be taken to prevent splashing, as strong acid will cause painful burns. Should the water be poured into the acid, the accompanying chemical combination between the larger volume of concentrated acid is much more rapid and pronounced than if the acid be poured into the water. Fig. 31 contains a photographic illustration of the operation of mixing sulphuric acid with water to form electrolyte. Note that the workman is pouring the acid into the water.

(e) Stir thoroughly with a wooden paddle and allow the solution to cool before taking the specific gravity with the hydrometer. Sulphuric acid and water do not mix readily; the water, being lighter than the acid, tends to remain on top. When mixing, the density of the solution cannot be accurately measured until both the acid and the water are thoroughly mixed. However, having once been thoroughly mixed they remain so.

(f) Since all storage battery data for the naval service are based on an electrolyte temperature of 80 degrees Fahrenheit, the specific gravity of the solution after mixing should be taken at this temperature, or corrected to this temperature, in order to obtain the required density of the mixture.

(g) Provide the personnel mixing the electrolyte with rubber boots, rubber aprons, rubber gloves and goggles.

### Mixing Large Quantities of Electrolyte.

In mixing large quantities of electrolyte, such as for a renewal of electrolyte in a submarine battery, putting a new submarine battery in commission

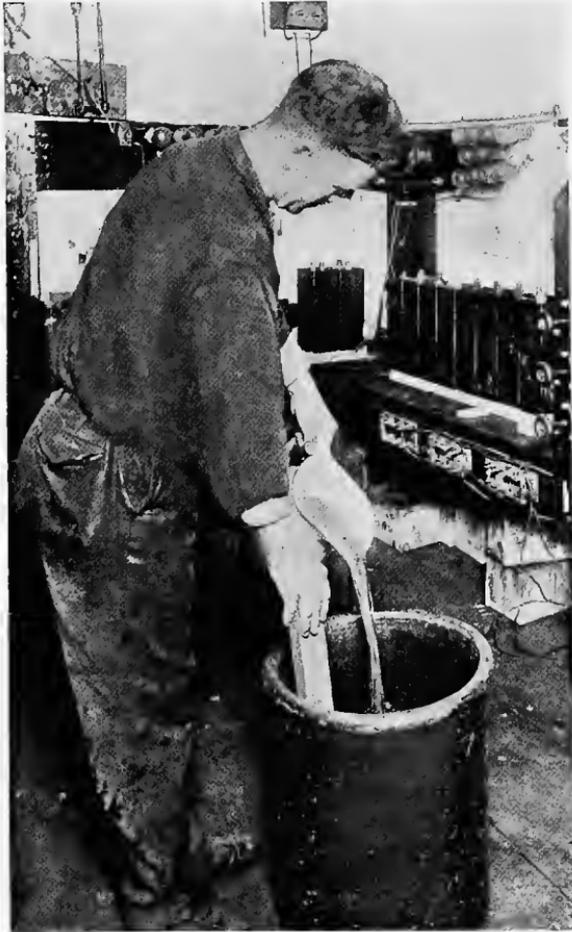


FIG. 31.—Mixing Sulphuric Acid with Water to Form Storage Battery Electrolyte. Acid Poured from Pitcher into the Crock Containing the Water, and Stirred with Wooden Paddle During Process of Mixing.

or preparing electrolyte for a large number of small batteries, a large lead-lined tank is preferred, but should such a tank not be available, a tank of sufficient size to accommodate the required quantity of electrolyte to be

prepared should be constructed of well-seasoned lumber and, after completion, given a couple of coats of asphaltum or other acid-proof paint on the inside in order to protect the electrolyte from the contaminating effects of the injurious acids contained in the wood of the tank. This coating of the interior of the tank with acid-proof paint is especially important should the water be placed in the tank while hot, as in the case of water made on board ship, submarine tenders, etc., where it is customary to pump the water direct from the distillers to the mixing tank, since on account of the increased activity of the chemical action at high temperatures, the water is thus more susceptible to contamination by the injurious wood acids. The effect when using cold water is, therefore, not so marked.

Should neither a lead-lined tank nor acid-proof paint be available, the wood tank should be constructed as described above and filled with water containing caustic soda or other alkali and the solution brought to a boiling point by means of a steam coil or other method, and thus allowed to boil for five or six hours in order to neutralize the injurious wood acids on the inside lining of the tank. This having been done, rinse out the tank thoroughly with pure water and again fill with the necessary amount of cold water and proceed with mixing the electrolyte as outlined in the preceding paragraphs.

#### Table for Preparation of Electrolyte of Various Densities.

The following table may be conveniently used in the preparation of electrolyte of various densities when using acid of 1.835 specific gravity, as well as that of 1.400 specific gravity. This table gives the parts of pure water to be added to one part of acid of each of the above-mentioned specific gravities, at 80 degrees Fahrenheit, to form electrolyte of a given density, as shown in the left-hand column of the table; this table is also made up on a basis of parts of acid by volume as well as by weight.

In most cases it will be found that the table of 1.400 specific gravity acid will suffice, as it is now customary for battery manufacturers as well as the various navy yards and shore stations to carry a supply of 1.400 specific gravity acid for use in mixing storage battery electrolyte, and the acid for this density is now commonly known as *battery acid*. The purity of the 1.400 acid should be equal to that outlined elsewhere in this chapter, and no acid should be used for storage battery electrolyte until it has been tested and found satisfactory. Neither should water be used in mixing the electrolyte until it has been analyzed and found suitable for the purpose. A rigid adherence to these simple directions will do much towards a satisfactory operation of the battery.

TABLE FOR MIXING ELECTROLYTE.  
 (Specific Gravity Ranging from 1.200 to 1.300.)  
 BASED ON 1 PART SULPHURIC ACID  
 (1.835 S. G. ) AND (1.400 S. G. ) AT 80° F.

Specific gravity of mixture desired at 80° F.	Parts of pure water to one part of acid at 80° F.			
	1.835 acid.		1.400 acid.	
	Parts by volume.	Parts by weight.	Parts by volume.	Parts by weight.
1.200	4.33	2.36	1.14	.83
1.205	4.15	2.30	1.09	.79
1.210	4.07	2.22	1.04	.75
1.215	3.90	2.15	.99	.71
1.220	3.84	2.09	.94	.68
1.225	3.70	2.05	.89	.65
1.230	3.60	1.97	.85	.61
1.235	3.48	1.92	.81	.58
1.240	3.40	1.86	.77	.55
1.245	3.30	1.80	.73	.52
1.250	3.22	1.76	.69	.50
1.255	3.10	1.70	.66	.47
1.260	3.05	1.66	.63	.44
1.265	2.95	1.65	.59	.42
1.270	2.90	1.57	.56	.40
1.275	2.80	1.55	.52	.38
1.280	2.75	1.49	.49	.35
1.285	2.68	1.48	.46	.33
1.290	2.60	1.41	.43	.31
1.295	2.55	1.40	.40	.29
1.300	2.47	1.34	.37	.27

### The Hydrometer.

The specific gravity or density of the electrolyte is measured with an instrument called the *hydrometer*, which consists of a closed hollow glass tube or bulb float, the top end of which terminates in a long, narrow stem which contains the graduated scale for measuring the specific gravity of the solution. The hydrometer floats upright in the electrolyte and the point on the graduated scale which coincides with the surface of the liquid measures its density or specific gravity, and it is usually spoken of as "gravity." There is shown at *C*, Fig. 32, one of these hydrometers as described above.

### The Hydrometer Syringe.

For greater convenience in testing the electrolyte, the hydrometer has been combined with other parts, the complete combination of which is called a *hydrometer syringe*. In Fig. 32 is shown one of these hydrometer syringes,

which consists of the following parts, as indicated in the figure: *A*, rubber bulb; *B*, glass barrel; *C*, hydrometer; *D*, rubber suction tube; *E*, suction tube plug valve; *F*, hydrometer scale.

### Method of Using the Hydrometer Syringe.

When it is desired to test the specific gravity of the electrolyte, take the hydrometer syringe and squeeze the rubber bulb *A*, insert the end of the

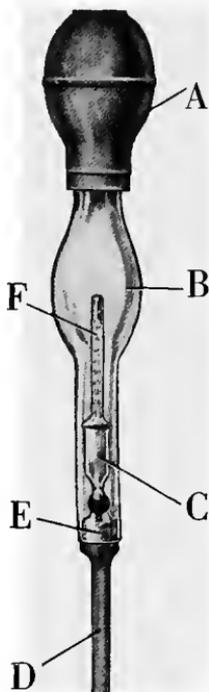


FIG. 32.  
Hydrometer  
Syringe.

rubber suction tube *D* in the electrolyte, and well below the surface of the liquid. Then, by slowly releasing the rubber bulb *A*, the electrolyte is drawn through the plug valve *E*, and up into the glass barrel *B*, until the hydrometer *C* floats freely and clear of the plug valve *E* in the bottom of the glass barrel. The point on the hydrometer scale *F* at which the stem emerges from the solution is the measure of the specific gravity of the solution.

In order to get an accurate reading and to prevent the hydrometer from sticking to the side of the glass barrel, it is necessary that the hydrometer syringe be held in a vertical position. Also, the reading should be taken

when there is no compression on the rubber bulb. The accuracy of the calibration of the hydrometer should be ascertained before using by checking against another hydrometer known to have correct graduations.

It should also be understood that before taking the hydrometer reading the acid and water of the electrolyte should be thoroughly mixed, since the water being lighter than the acid will tend to remain on top, and if it has not been thoroughly mixed with the acid, a reading taken under these conditions will be misleading and incorrect.

#### **Effect of Temperature on Specific Gravity Readings.**

Since electrolyte, like most other substances, expands when heated, and contracts when cooled, its specific gravity is accordingly affected by a change in temperature. This variation in specific gravity as a result of temperature change amounts to approximately .001 points of gravity for every 3 degrees (Fahrenheit) change in temperature. Thus, if electrolyte has a given specific gravity at a temperature of 80 degrees Fahrenheit and then be heated, the heat will cause the electrolyte to expand, and, although the actual strength of the solution will remain unchanged, yet the expansion will cause it to register a lower specific gravity of approximately one point (.001) for each 3 degrees rise in temperature.

For example, if electrolyte has a specific gravity of 1.215 at 80 degrees Fahrenheit and the temperature be raised to 89 degrees Fahrenheit, this increase in temperature will cause the electrolyte to expand and the specific gravity to drop three points ( $3 \times .001 = .003$ ); hence, the specific gravity of the electrolyte would then be 1.212 instead of 1.215. Similarly, if the temperature of the electrolyte be lowered from 80 degrees Fahrenheit to 71 degrees Fahrenheit, this would cause the electrolyte to contract and the specific gravity would then rise from 1.215 to 1.218.

Therefore, since the change of temperature does not affect the actual strength of the electrolyte, the specific gravity only being changed, in order to refer all specific gravity readings to an adopted standard, these readings should be corrected one point for each 3 degrees change in temperature. Eighty degrees Fahrenheit is the adopted standard for all battery data of the naval service; therefore, all specific gravity readings should be corrected to this point as a standard.

#### **Sea-Going or Practical Tests for Storage Battery Electrolyte**

Although it is realized that under operating conditions and those which obtain in general on board ship, the testing of storage battery electrolyte cannot be obtained with the same degree of accuracy as is possible in a well-

equipped chemical laboratory, yet it is considered that with a little detailed care and attention to this subject a practical working test may be obtained with a fair degree of accuracy by establishing a "sea-going laboratory" in the battery service stations on board ship and on submarine tenders.

**Laboratory Equipment Required.**—The equipment for this "sea-going laboratory" should consist essentially of the following:

- 1 Test tube rack.
- 12 Test tubes, size 6 inches by  $\frac{5}{8}$  inch (approximately).
- 2 Test tube cleaners.
- 2 60-c. c. glass flasks.
- 2 250-c. c. glass flasks.
- 2 10-c. c. glass graduates.
- 2 100-c. c. glass graduates.
- 12 Glass stirring rods, 6 to 7 inches long.
- 1 Dropping bottle for potassium permanganate.
- 1 Chemical balance.
- 1 Bunsen burner.
- 1 Iron tripod.
- 1 Wire gauze for tripod.
- 1 250-c. c. beaker.
- 1 4-inch watch glass (for covering beaker).
- 1 1-liter flask with glass stopper.
- 1 Reagent bottle with glass stopper and ground glass label for each of the following reagents:
  - Silver nitrate.
  - Potassium ferrocyanide.
  - Lead acetate.
  - Nitrate acid (C. P.).
  - Sulphuric acid (C. P.).
  - Starch solution.
  - Standard iron solution.
  - Standard iodine solution.

**Reagents Required.**—The following reagents for making practical tests of the electrolyte should be included in this laboratory equipment:

- Silver nitrate ( $\text{AgNO}_3$ ), 5 per cent solution.
- Sulphuric acid ( $\text{H}_2\text{SO}_4$ ), 1.835 specific gravity, chemically pure.
- Nitric acid ( $\text{HNO}_3$ ), 1.400 specific gravity, chemically pure.
- Granulated zinc (Zn), 20 mesh, chemically pure.
- Lead acetate, 10 per cent solution.
- Potassium permanganate, 0.3 per cent solution.
- Potassium ferrocyanide ( $\text{K}_4\text{Fe}_2\text{Cy}_6$ ), 4.0 per cent solution.

**Ferrous Sulphate (Saturated Solution).**—This reagent is made up by dissolving the chemically pure crystals of ferrous sulphate in a small quantity of distilled water in a test tube, care being taken to use an excess of crystals in order to insure that the solution is saturated. A fresh supply of the reagent as outlined above must be made up each day as used, hence a supply of chemically pure ferrous sulphate crystals should be kept on hand.

**Starch Solution.**—To prepare this reagent, place 200 c. c. of distilled water in a 250-c. c. beaker and bring to the boiling point over a Bunsen burner, the beaker being supported by iron wire gauze resting on an iron tripod. Next, 1 gram of ordinary starch mixed to a thin paste with cold distilled water is slowly poured into the boiling distilled water. Continue boiling this mixture for two minutes after the starch is added, then cover the beaker and allow to stand overnight. Then pour into the starch reagent bottle the clearer portion of the solution, discarding the thick portion found collected in the bottom of the beaker.

**Standard Iodine Solution.**—In preparing this reagent mix 2.4 grams of chemically pure iodine and 15 grams of potassium iodide in 1 liter of distilled water.

**Standard Iron Solution.**—This reagent should be made up to contain the maximum allowable amount of iron for comparative tests. Therefore, a sufficient amount of pure iron wire to give the allowable limit of iron in 1 liter of solution is carefully weighed and dissolved in chemically pure sulphuric acid of 1.250 specific gravity (or any other gravity of acid as required for the test). Next, an excess of hydrogen peroxide (5 c. c. 3 per cent) solution is added and then the entire solution boiled until gas ceases to be evolved, the beaker being covered with a watch glass to prevent loss. When cold, transfer the solution to a 1-liter measuring flask, care being taken to wash all of the solution out of the beaker in which it was boiled, and the flask then filled up to the mark with chemically pure sulphuric acid of 1.250 specific gravity (or any other specific gravity, depending upon the specific gravity of the electrolyte to be tested).

### Electrolyte Tests.

The tests outlined below apply primarily to the testing of new electrolyte of 1.250 specific gravity. If it is desired to test electrolyte of higher specific gravity, it should first be diluted or cut back to 1.250 by the addition of distilled water. In diluting acid of any strength higher than 1.400 specific gravity, care should be taken that the acid is poured into the water and not the water into the acid; this to avoid excessive heating and possible injury to personnel resulting therefrom. If electrolyte of lower specific gravity

than 1.250 is to be tested, the proper allowance for the maximum allowable impurities should be made.

When electrolyte from a cell which has been in use is to be tested, the standard iron solution should be made up to correspond to the increased amount of iron allowable in old electrolyte.

**Color.**—The sample should be clear and practically colorless. A small amount of lead-sulphate, which shows as a white sediment, will do no harm. Oil of vitriol (1.835 specific gravity) is sometimes dark in color as a result of the presence of traces of organic matter, and this is not cause for rejection unless the color is very dark.

**Odor.**—Electrolyte which is suitable for storage batteries should be odorless. To test the odor, shake up a closed flask or bottle partially filled with electrolyte and then uncork and note whether or not there is any odor. Sometimes sulphurous or nitric acid can be detected in this manner and further testing eliminated.

**Iron.**—To 100 c. c. of the electrolyte in a test tube add the potassium permanganate solution, drop by drop, stirring each time. As each drop enters the test sample a pink color will be observed, which may disappear as the permanganate solution becomes mixed with the sample. Continue adding the permanganate solution until a slight pink color becomes permanent; then add 2 c. c. of potassium ferrocyanide solution, when the presence of iron will be indicated by a blue color. Next, make a comparative test by using 10 c. c. of the standard iron solution instead of the electrolyte being tested.

If the sample being tested shows a deeper blue color than the standard iron solution, the sample should be rejected.

Owing to the disastrous effect of iron upon a cell, the test for iron is a very important one, and furthermore, on account of the ever-present likelihood of iron entering the cell through the use of contaminated water, or other cause, a periodic test for iron should be made on the electrolyte from time to time.

**Effects of Iron in a Cell.**—Iron being one of the injurious metallic impurities generally found in various quantities in electrolyte, not more than .01 per cent should be allowed in new filling acid, relative to the amount of concentrated  $H_2SO_4$  constituting the solution. All iron contained in the lead parts and active materials of the cell only gradually dissolve out into the electrolyte, and therefore in old cells the amount may reach the permissible maximum of .01 per cent. Iron is contained in the cells as oxides and as sulphate, the latter condition, however, owing to the electrolytic action in the cells, is not maintained. In sulphuric acid iron cannot exist as metal, although during charge the existing tendency is for it to deposit

as such on the negatives, but owing to its high solubility as metal in dilute  $H_2SO_4$  this is prevented, and the efficiency during the charge is thereby primarily reduced. Moreover, the presence of iron in the electrolyte produces a local action very similar to most of the other metallic impurities, in that it affects both electrodes; that is, the positive and negative plates.

For the reason that the higher oxidized ions on reaching the negative plates give off part of their oxygen, while the lesser oxidized ions, which are in contact with the positive plates, absorb oxygen, it is thus seen that we have to deal with a continuously reversible reaction when iron is present in the storage battery cell.

Also, unlike some other cases of impurities in the electrolyte, it appears that the total amount of iron contained in all parts of the cell, after once going into solution, remains permanent for the life of the cells, and all iron which from time to time enters the cell is cumulative in effect, as nothing is lost by decomposition or liberated in a gaseous state.

The normal amount of charge for cells containing no appreciable quantities of metallic impurities is approximately 105 per cent; that is, the ampere-hour efficiency is approximately 95 per cent. On the other hand, the amount of charge required for cells containing large quantities of iron may reach as high as 135 to 150 per cent, depending upon the amount of iron they contain, and furthermore, such cells may, on open circuit, lose their charge entirely, due to the very active reversible reaction, in from 3 to 6 weeks.

Therefore, the reasons for at all times taking special precautions against iron entering a storage battery cell are readily apparent.

**Chlorine.**—To test for chlorine in new electrolyte, add a few drops of nitric acid, then a little silver nitrate solution to a sample of the electrolyte in a test tube. If pure, the addition of the silver nitrate will have no effect. If slightly impure, the addition of the silver nitrate turns the sample slightly cloudy, and the sample can be passed as O. K. If totally impure, the addition of the silver nitrate turns the sample a very milky color, which is accompanied by a heavy precipitate of silver chloride, and such a sample is unsuitable for storage batteries.

If the electrolyte has been in a cell, the above test will not show chlorine unless recently introduced. Chlorine in a worked cell is changed to perchloric acid, and requires a special method for its detection.

A never failing test for chlorine is by smell.

**Nitric Acid (Oxides of Nitrogen).**—Nitric acid and other oxides of nitrogen are very harmful to the plates of storage battery cells. To make a test for these impurities, to 5 c. c. of the electrolyte to be tested add 15 c. c. of chemically pure sulphuric acid (1.835 specific gravity) and allow to cool.

Then add 2 drops of a saturated solution of ferrous sulphate, and stir with a glass rod until thoroughly mixed. The presence of oxides of nitrogen will be indicated by a pink color. If this color is very pale or slight after standing for 10 minutes, the sample of electrolyte can be passed as suitable for storage batteries. In order to offer contrast in determining the color, the sample should be judged against a piece of white paper in a good light.

**Sulphurous Acid.**—In order to detect the presence of sulphurous acid in electrolyte, first place 15 c. c. of the sample in a small, narrow-necked flask of 60 c. c. capacity, and add a sufficient amount of chemically pure granulated zinc to cover the bottom of the flask. Then moisten a piece of filter paper or other absorbent paper (white blotting paper will answer the purpose) with lead acetate solution, and lay this absorbent paper over the mouth of the flask. The gas evolved by the zinc will strike the paper and turn it brown if sulphurous acid is present. If the paper remains white, sulphurous acid is not present, and the sample can be passed in so far as this impurity is concerned.

If the above zinc-lead acetate test shows a discoloration of the paper, the following test should be made to determine whether or not the electrolyte should be accepted or rejected:

Measure exactly 5 c. c. of standard iodine solution into a 250-c. c. flask and add 3 or 4 drops of the starch solution. This reaction is accompanied by a deep blue color. Now, add 100 c. c. of the sample of electrolyte to be tested and shake until thoroughly mixed. If the blue color disappears, sulphurous acid is present in sufficient quantity to reject the electrolyte. If any blue color remains after a thorough shaking, sulphurous acid content is low enough to be passed.

The above tests cover the detection of impurities most likely to be found in electrolyte and which are more or less a common source of trouble in the operation of storage batteries, particularly incident to the naval service.

It has been found very convenient to place all of the reagents and laboratory equipment as outlined in the preceding text in a cabinet constructed very much on the order of the boiler testing cabinets now supplied to vessels. In time it is hoped that a regular standard equipment for such a laboratory will be supplied to all submarine tenders and other ships.

CHAPTER X.  
PLATE INSULATION AND SEPARATORS.

Function of Separators.

In developing the storage battery to meet the requirements of its various modern applications, it has been necessary to install in the cells a maximum number of plates, consistent with proper mechanical strength, life and durability, in order to obtain maximum capacity in current per unit of space.

Therefore, in so doing, the thickness of the plates has been necessarily reduced and the plates have been placed closer together, much more so, in

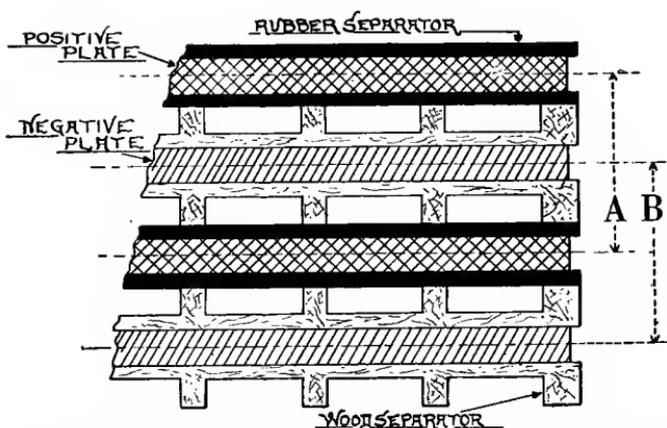


FIG. 33.—Showing Plate Centers and Arrangement of Plates and Separators.

fact, than in the early days of storage battery construction and design; or, in the words of the battery engineer, when speaking of placing the plates closer together, "the plate centers have been decreased," which means in effect that the distance between the vertical axes of two adjacent positive or negative plates has been decreased. This point is illustrated in Fig. 33, which shows a portion of the plan view of a cell with positive plates, negative plates and the corresponding separators. In this figure the positive plate centers are indicated at *A* and the negative plate centers at *B*. Obviously, if both positive and negative plates are of the same thickness, then their plate centers are the same, or *A* would then equal *B*.

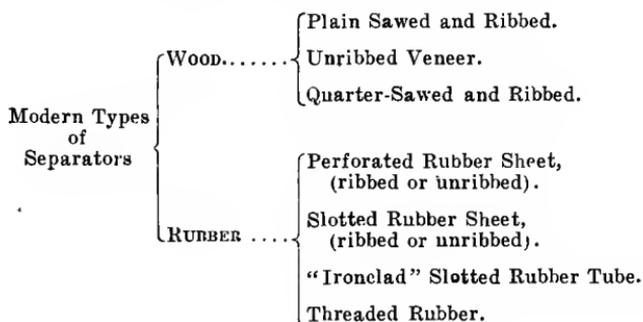
By thus placing the plates closer together it will therefore be appreciated that for a proper functioning of the cell and in order to safeguard it against damage as a result of internal short circuits, it is necessary that the insulating medium or separators placed between the plates of the cell be of a high order of perfection. In addition to serving as an insulating medium, these separators must fulfill the following requirements:

- (a) They must be impervious to the action of the acid of the electrolyte.
- (b) They must be strong enough to withstand the mechanical chafing and compression incident to the normal expansion and contraction of the plates while working.
- (c) They must be unaffected by the temperatures attained by the cell during ordinary conditions of operation.
- (d) They must also contain no substances which have a deleterious effect upon any portion of the cell.
- (e) They must possess a fairly high degree of porosity in order to facilitate proper circulation and diffusion of the acid of the electrolyte into the plates during a discharge and, conversely, form paths for the return of the acid to the electrolyte on charge.
- (f) Although requiring a high degree of porosity, the individual pores of these separators should be so minute as to prevent as much as possible the entraining of gas bubbles therein, thus reducing the effects of polarization to a minimum.

### Modern Types of Separators.

It is therefore apparent that many problems present themselves in obtaining an insulator which fulfills all of the foregoing requirements, and much time, thought and ingenuity have been devoted to this subject by battery engineers. Many different combinations of as many different kinds of materials have been tried and used for these insulators or separators, but with the present stage of the art it may be said that in so far as the naval service is concerned nothing has been found quite so good for the purpose as the combination consisting of a sheet of specially treated wood when used in conjunction with a thin, finely perforated sheet of hard rubber, which type is known as the "wood and rubber combination" separator. However, at the present writing another type of separator, known as the "Threaded Rubber Separator," has been placed on the market by the Willard Storage Battery Company, and this new type is said to be producing good results for certain classes of service; this type will be described elsewhere in this chapter. Also, the "Ironclad" type assembly uses a thin wood veneer separator in conjunction with the slotted rubber tubes of the positive plates; this type will also be described.

The following topical outline represents in a general way the various types of separators used in modern storage battery installations:



It will be noted in the above outline that these separators consist of either wood or rubber, or both, and that each of these two types is further subdivided into other types, differing mainly in the methods of manufacture as well as the particular type of battery in which they are installed. The methods of manufacture and special characteristics of each of these types will be described in detail.

**WOOD SEPARATORS.**

**Historical.**—In the comparatively early days of the commercial application of storage batteries, as for instance in the large central power station installations, untreated cherry wood separators placed between two thin sheets of asbestos were used for the plate insulating or separating medium; these cherry wood separators as used in such installations also contained a series of large auger holes drilled through them in order to reduce the internal resistance of the cell and to facilitate proper circulation and diffusion of the acid of the electrolyte into the plates. For many years this combination of separators was used for this service and until they were superseded by other wood separators which incorporated improved methods of treating the woods and which methods with the present stage of the art have reached a high degree of perfection.

The circumstances leading up to the development of the wood treating process, which now forms the basis of all treatment of separators by this method, is of interest in the study of the general subject of wood separators. It appears that one day while working in the laboratory, one of the research engineers of one of the large storage battery manufacturing companies had on hand some old storage battery cells, the plates of which were supposed to have lost their capacity, and as judged from the standards at that time.

were due for the scrap-heap; however, while he was examining these old cells the idea occurred to him to place some thin sheets of cherry wood, containing no auger holes, between the plates of these cells and to charge them up and conduct a series of tests upon them. This he did, and as a result he was very much surprised to find that these old, apparently worn out cells gave a considerable amount of their original rated capacity and, in fact, much more than they had given when they were turned in to him as being worn out. This result was responsible for his continuation of research along this line and with the view of ascertaining, if possible, just what caused this rejuvenation of the old, apparently worn out plates.

After an extensive series of experiments along this line it was finally concluded that the wood acids (acetic) contained in these cherry wood separators were helpful to the active material of the negative plates and tended to accelerate the sulphating action upon the negative active material during a discharge, which satisfactorily accounted for the noted increase in capacity of these old cells.

The next stage in the development of this subject came when it was attempted to use woods other than cherry for these separators, as on account of the scarcity of cherry wood and the expense attached to its use for this purpose, other more abundant and less expensive woods were to be preferred if they could be satisfactorily used.

The next wood which suggested itself was poplar, as this wood was plentiful, less expensive than cherry, belonged to the soft-wood family, and, containing a comparatively small amount of resinous matter, its use for separators effected a reduction in the internal resistance of the cell as compared to that of other available woods.

Accordingly, many batteries were manufactured and equipped with poplar wood separators, but after these batteries had been in service for a short while it became readily apparent that something was radically wrong with the cells. Upon opening these cells and removing the elements it was found that the grids, lugs, and other lead parts had been seriously attacked, and in some instances the grids fell apart and the lugs were so badly attacked that they disintegrated, thus allowing the plates to fall away from the cross-bars and straps. After much research it was finally established that the acetic acid contained in these poplar wood separators was responsible for the destructive attack as noted upon the lead parts of these cells.

Therefore, the next important problem which presented itself in the development of this subject was that of devising some method of treating these wood separators such that portions of the injurious wood acids should be removed, but allowing to remain such of them as proved beneficial to the negative active material. The first logical step in the solution of this

problem was that of neutralizing the undesirable amount of wood acids contained in the wood; another series of tests on these separators was accordingly arranged with this end in view, until finally a method of treating the wood was evolved which, as has been stated, now forms the basis of the general scheme of treating practically all wood separators by this method. This method was known as the *alkali treatment*. The details of this treatment will be described later.

**Woods Used; Relative Life, Conductivity, Etc.**—Of the various woods which, after receiving the proper treatment, have been found suitable for storage battery separators and which are now more or less generally used, the following may be included:

- (a) Basswood.
- (b) Poplar.
- (d) Douglas fir.
- (d) California redwood.
- (e) White cedar.
- (f) Cypress.

The above list is given in the approximate relative order of life of each of the woods when operated under uniform conditions in the storage battery cell; considering the life of basswood as 100 per cent, the following table represents approximately the relative lives of the other woods when used as separators:

Wood.	Life.
Basswood .....	100 per cent.
Poplar .....	100 " "
Douglass fir .....	175 " "
California redwood .....	180 " "
White cedar .....	190 " "
Cypress .....	200 " "

It will be noted in the table that cypress is possessed of about double the life of either basswood or poplar; however, it may be said that cypress, on account of its dense, close grain, has a higher factor of internal resistance, hence less conductivity, than basswood or poplar, and for a given battery installation the voltage characteristic is not as good when using cypress as when basswood or poplar is used.

Other things being equal, it may be said that the conductivity factor in woods used for separators varies inversely as the life; that is, the longer the life the less the conductivity, and vice versa.

The subject of selection of woods for separators therefore resolves itself into choosing between life and conductivity, and in making such selection the particular type and design of the battery as well as the special services for which it is intended must necessarily be taken into consideration. In other

words, if a battery is designed for very high discharge rates and the requirements of the service demand a high voltage characteristic even at the expense of life of the separator, then one of the soft woods, such as basswood or poplar, should be used. On the other hand, if long life and reliability against deterioration of separators, with the consequent sacrifice of a certain amount of voltage characteristic, is desired, then one of the coniferous woods should be used. Furthermore, it may be said that, as a general policy, the coniferous woods as outlined in the above table are considered better suited to the requirements of the naval service than the softer woods; it is also believed that, with present stage of the art, the trend in commercial applications of storage batteries is in favor of the coniferous woods.

With further reference to the general subject of selection of woods for separators, it should be stated that air-dried lumber produces better separators than kiln-dried stock, for the reason that the process of kiln-drying destroys a certain amount of the strength and endurance qualities of the wood, thus shortening its life, and air-dried lumber should therefore be used for this purpose when obtainable.

Hence, it follows that timber to be used for separator stock should be cut in the autumn or winter seasons, as at such time the sap is "down," and the lumber obtained from such stock is capable of air-drying more quickly, and can be fabricated into separators at an earlier date after cutting. By air-drying is meant the reduction, without the use of heat, of the percentage of moisture contained in the stock to that of the normal humidity of the surrounding air. By kiln-drying is meant the reduction of the moisture through the application of heat to the stock, as from a kiln, etc.

Moreover, by cutting the separator stock during the seasons when the sap is "down," many of the so-called impurities, gums, resins, and other constituents which increase the resistance of the separator and have a deleterious effect upon the cell are eliminated. This feature of the subject will be later considered in more detail in connection with the *treating processes* used in the manufacture of separators.

**Method of Sawing Wood for Separators.**—The manner of sawing the wood used for separator stock constitutes an important factor in the efficiency of the separator produced. Generally speaking, there are two approved methods of cutting this stock for use in the manufacture of wood separators, these methods referring to the manner of sawing the stock out of the logs at the saw mill rather than the subsequent sawing, grooving or other machining done in the fabrication of the finished separator. For convenience these methods may be classified as follows:

- (a) Quarter-sawed.
- (b) Plain sawed.

In describing these methods and the relative efficiencies of the separators produced, it is necessary to consider certain fundamentals which are characteristic of tree growth, inasmuch as the principles upon which these methods are based depend upon these fundamentals.

In this regard, the prime feature to be considered is that of the annual growth ring, or *annual ring*, as commonly referred to in plant anatomy; each year of a tree's growth is marked by a cellular formation which constitutes an integral part of the main trunk structure and by which the diameter of the trunk is increased from year to year. This ring is concentric with the main axis of the trunk and is circumferentially divided into two sections, one of which is highly porous and of light fibrous structure, while the other is of a dense resinous consistency; these ring-like sections of the annual ring are often referred to as winter and summer growth rings. It is with reference to these rings and their relative positions in respect to the plane of sawing the separator stock that the above-mentioned methods of sawing are classified.

**Quarter-Sawed Method.**—Fig. 34 contains a set of drawings which are intended to illustrate the principles embodied in this subject. The circular drawing to the left of this illustration represents a section taken diametrically across the trunk of a tree to be cut up for separator stock. Each annual ring is represented by a plain and a shaded circle, the resinous section being shown as shaded, whereas the lighter and more porous section is unshaded. The cross-section of the trunk is divided into quadrants, each of which is numbered for clearness in illustrating the text.

Referring to quadrant 3, the dotted lines on each side of and parallel to the 45-degree radius represent saw cuts taken through the trunk. Now, it will be noted that the annual rings in the block included between these two dotted lines, as indicated at *c*, make right-angles with these dotted lines or the plane of the saw cuts; this angle is known as the *annual ring angle*. Also, this method of cutting the stock out of the trunk is called *quarter-sawed method*, and all separators produced from the block *c* are of the quarter-sawed type. As will be later explained, this method produces the best type of separators.

**Plain Sawed Method.**—It will be further noted, as shown in the parallel lines of quadrant 4, that as the cuts are taken beyond the limits of the dotted lines of block *c*, the angles made between the annual rings and the plane of sawing decrease. All sawing beyond the limits of block *c* is called *plain sawing*, and stock produced from this portion of the quadrant is known as plain sawed stock. Quadrant 2 shows a modification of each of these methods in which the plane of sawing is taken parallel to the diameters instead of the 45-degree radius; this method of sawing produces a maximum

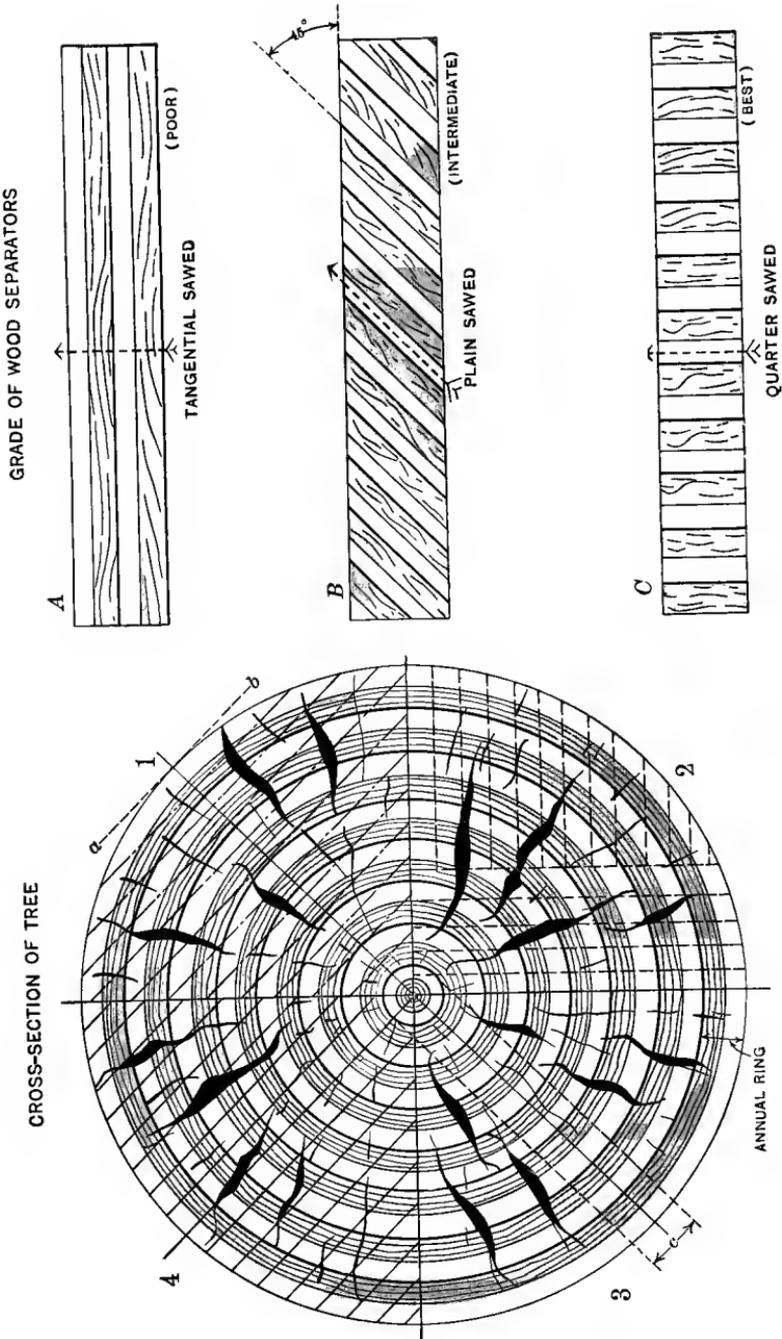


Fig. 34.—Showing Methods of Shaving Wood for Separators.

number of large pieces of stock having annual ring angles less than 45 degrees. In the plain sawed method of sawing, no stock having annual ring angles less than 45 degrees should be used in the manufacture of separators.

Quadrant 1 represents the poorest method of sawing wood as far as separator stock is concerned, and wood sawed by this method should not be used for separators. This particular method of sawing is known as the *tangential method*, the plane of the saw cuts being parallel to the dotted line *ab*, which is perpendicular to the 45-degree radius of this quadrant, hence tangent to the annual ring; or, in other words, the annual ring angle in this stock is zero.

#### Characteristics of Separators Obtained from Each Class of Stock.

The portions of the illustration shown at *A*, *B*, and *C* in Fig. 34 represent enlarged and exaggerated cross-sections in end elevation of wood separators. Owing to the thinness of the separators, the arcs of the annual rings are projected as straight lines.

*A* represents a separator manufactured from stock cut by the tangential method, and as shown in quadrant 1. In this case it will be noted that the annual ring runs practically parallel with the sawing plane or effective face of the separator. Moreover, as shown by the arrow, in order for the electrolyte to diffuse through this separator it is necessary for it to traverse both the resinous and the lighter fibrous sections of the sheet, poor facilities for aiding diffusion of the electrolyte being especially characteristic of the dense resinous section. Therefore, this type of separator offers the greatest resistance to the diffusion and circulation of the electrolyte in the cell which accordingly manifests itself in a reduction of the cell voltage with a corresponding reduction in efficiency. As has been stated, such stock should never be used in the manufacture of separators.

*B* represents a separator produced from stock obtained by the plain sawed method, such as has been described in connection with quadrants 2 and 4. The path of the acid in diffusing through the sheet is also shown by the arrow, and it will be noted that this separator was obtained from a block, the annual ring angle of which is 45 degrees. Although the diffusion and circulation of the acid through this sheet is improved to a great extent over that shown in *A*, owing to the longer path which the acid has to traverse in passing through the sheet, the rate of diffusion is not as rapid as is that for the separator shown in *C*. As the annual ring angle increases from 45 degrees to 90 degrees (quarter-sawed type), the efficiency of the separator increases in direct proportion.

*C* shows a separator produced from stock obtained by the quarter-sawed method, and such as shown in block *c* of quadrant 3, the similarity of the

cross-section of this separator and block *c* being readily apparent. The path of the acid in diffusing through the sheet is also shown by the arrow, and inasmuch as this path is the shortest possible distance across the sheet, it follows that the rate of diffusion through this separator is greatest, and hence its efficiency is likewise greater than that of *A* or *B*. This method produces the ideal separator in so far as diffusion and circulation of the electrolyte are concerned.

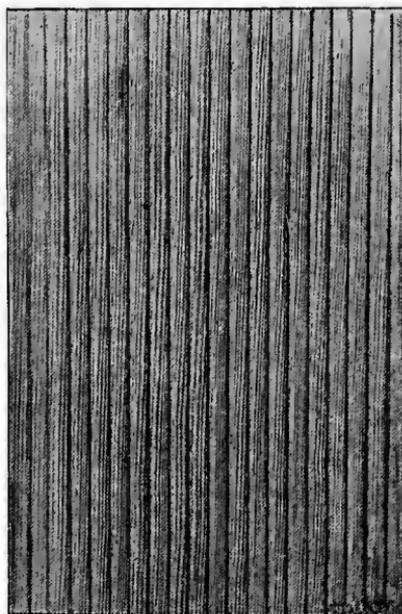


FIG. 35.—Quarter-Sawn Wood Separator.

Fig. 35 contains a photographic illustration of a quarter-sawn separator as manufactured by the Philadelphia Storage Battery Company. The alternate light and dark streaks in this photograph represent the light and the resinous sections of the annual ring, and due to the uniformity of spacing of these sections and the short path of the acid through the sheet, it is evident that this separator is conducive to uniform working of the entire area of the plates for which it forms an insulator. Owing to the toughness of the resinous section of the annual ring it also follows that the strength and durability of the separator are increased through disposing these resinous sections so uniformly across the width of the sheet.

### Methods and Object of Treating Wood Separators.

Having considered the types of wood suitable for use as separators and the methods of sawing the stock from the logs, we will next consider the methods of treating the wood used for this purpose and the object of the treating process.

In brief, the object of treating the wood used as separators may be stated as follows:

1. To neutralize a portion of the acetic or other wood acids which have a deleterious effect upon certain parts, especially those of lead, in the cell.
2. To dilate the fiber and thus increase the porosity, which accordingly decreases the resistance and aids in accelerating the circulation and the diffusion of the electrolyte into the pores of the plates. The treating process saponifies the fats, dissolves the resins, gums, etc., thus developing to a considerable extent the porosity of the wood.

In producing the effects outlined above, various methods have been used, but with present stage of the art the following methods may be said to constitute the ones now most generally used, and although some of the processes may vary slightly in detail from those stated below, the general principles involved are the same:

- (a) Acid-alkali bath.
- (b) Steam bath.

**Acid-Alkali Bath Process.**—The process of treating wood separators by this method consists of three stages, viz:

1. Acid bath.
2. Alkali bath.
3. Washing.

(1) *Acid Bath.*—The separators, having been planed, grooved or machined by other approved methods, are placed in a vat containing a sulphuric acid water solution of about 1.200 specific gravity and at a temperature of from 70 to 80 degrees Fahrenheit, and are allowed to thus soak for a period of from 2 to 4 days. However, if higher temperatures of the bath are used, such as from 100 to 110 degrees Fahrenheit, the specific gravity of the solution may be reduced to 1.100, but the duration of the treatment remains practically the same in either case.

(2) *Alkali Bath.*—The separators after receiving the acid bath described above are next placed in a second set of vats containing an alkaline bath consisting of a 3 per cent solution of caustic potash, or another such alkali in water, and at a temperature ranging from 70 to 80 degrees Fahrenheit; the separators are allowed to thoroughly soak in this bath for a period of from 24 to 48 hours.

(3) *Washing*.—The last stage of the process is that of washing the separators and thoroughly clearing them of all acid or alkali absorbed in the preceding stages of the treating process. This is usually done by placing them in a third series of vats and allowing them to soak for from 12 to 24 hours in running water; or if this arrangement cannot be had, the separators should be washed in not less than 15 changes of water, the separators being allowed to remain in each change of water for from 3 to 5 hours. Also, the water used for the washing process should be of approved quality suitable for storage batteries, in order that water containing impurities detrimental to the battery will not be introduced in the cells when installing the wood separators.

After the separators have been treated as outlined above, they are placed in the trimming machine where they are trimmed to the exact size; this is necessary in view of the fact that the treating process has a tendency to soften and swell the fiber, thus rendering the separator in most cases larger than before beginning the treatment. The separators are now ready for installing in the cells. If they are not required upon completion of the treating process, they are packed up in boxes containing excelsior which has been thoroughly moistened with approved battery water to prevent the separators from drying out. If they are to be stored for a considerable period before using, the excelsior should be again moistened periodically by pouring the water into the packing cases. It is also advisable to store the packing cases in such manner that the separators are horizontal, as this prevents to a certain degree the water from draining out of the pores of the wood. If allowed to dry out, the separators become shrunken, buckled, or cracked, and are thus rendered unfit for installation in the cells.

**Steam Bath Process.**—Some authorities maintain that the amounts of wood acids and other acid-forming materials usually contained in the lignone are not present in sufficient quantities in certain of the coniferous woods, such as white pine, Douglas fir, and the common species of cedar, as to cause any injurious effects upon the positive plates or any other portions of the cell, but, on the other hand, these materials are actually helpful to the negative plates. Therefore, no attempt is made to eliminate or neutralize such materials contained in the wood by the treating process herein described; however, the internal resistance of the above-mentioned woods is relatively high, and this treating process, known as the *steam bath process*, is designed primarily to lower the resistance of the wood through the elimination of certain of its gums and resinous constituents, thus increasing the porosity of the wood as a result of softening and swelling of the fiber.

This process consists in subjecting the wood, after it has been sawed, grooved and fabricated into the separator sheet, to a steam bath treatment

under pressure for a period of from 12 to 18 hours. The same results may be obtained, however, by boiling the wood in a bath of pure, fresh water, preferably at atmospheric pressure, for a period of from 24 to 48 hours. In order to reduce the time of the treating process some manufacturers prefer to boil the wood under a pressure of from 80 to 90 pounds per square inch, the time required to complete the process under these conditions ranging from 5 to 10 hours; in general, however, the duration of the process will vary with the type of wood and the pressure employed.

In conducting the above described treating process the separators are usually packed vertically in tiers in large vats, the steam being admitted at the bottom of the vat.

The advocates of this method of treating separators maintain that a better quality of separator is produced than in the alkali acid process previously described, in that the removal of the acetic acids and acid-forming materials from the lignone tends to weaken the structure of the wood fiber, thus weakening and impairing the insulating qualities of the separator; whereas, in the steam bath process they claim that such is not the case since practically none of these materials are removed from the wood. However, in so far as the batteries for the naval service are concerned, the experience has been that each of these methods of treating the woods is equally satisfactory.

#### **Notes on Design and Manufacture of Wood Separators.**

In manufacturing wood separators the stock is usually received at the separator plant in planks, the thickness of which ranges from  $\frac{3}{8}$  inch to 1 inch, while the length and width vary with the type and size of the separator to be produced. After these planks have been inspected for knots, cracks, and other imperfections, they are then passed through the rip-saw machine where they are worked up in sheets of the desired thickness; they are then ready to be passed through the grooving and ribbing machines, which machines resemble in general an ordinary planer and the knives or saws which effect the grooving and ribbing process are mounted on a revolving mandril, the spacing of these cutters depending upon the desired width of grooves and ribs. In order to protect the leading edge of the sheet, which is relatively thin, from splitting as it passes under the cutters, the ends of the sheets or boards are usually dipped in molten paraffin before passing them through the grooving and ribbing machine. Fig. 36 contains an illustration of a type of wood separator commonly used in battery installations, the details of the ribs and grooves being plainly shown. The thin portion of the sheet included between the ribs is known as the *web* of the

separator. In order to give added strength to the separator it is usual practice to design the outboard or marginal ribs slightly wider than the intermediate ribs. When used in conjunction with a ribbed rubber separator the ribs on the rubber sheet are positioned such that they will rest

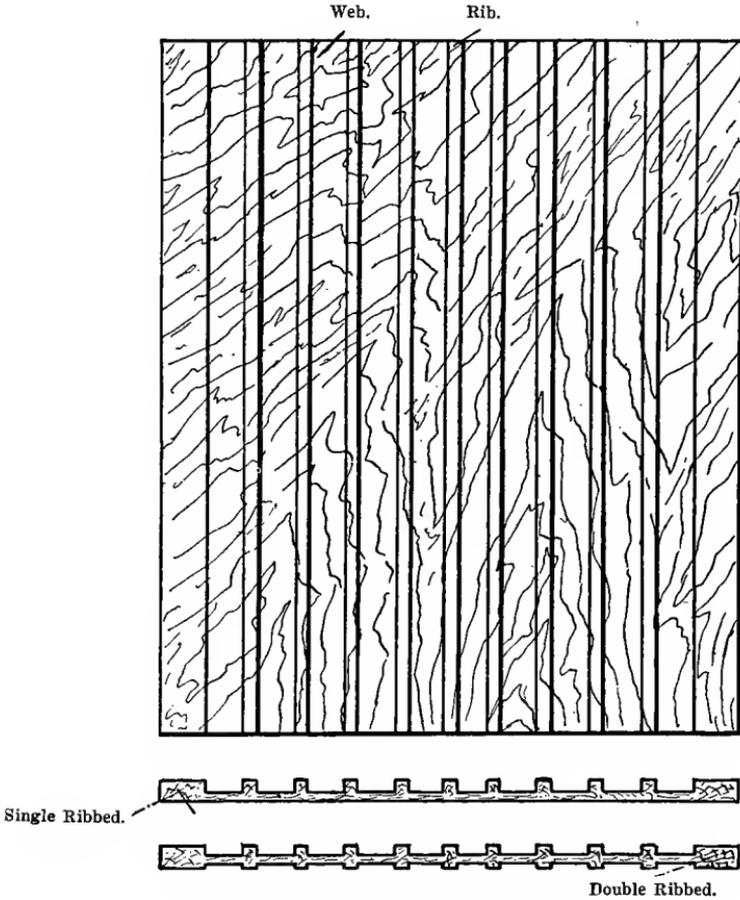


FIG. 36.—Treated Wood Separators (Single and Double Ribbed).

against that portion of the web of the wood separator lying midway between two wood ribs; also, the wood separator usually contains from two to three times the number of ribs as does the corresponding rubber separator. If an unribbed rubber separator is used the number of ribs on the wood separator is increased and they are placed closer together to increase the strength of the combination.

It will also be noted that the lower portion of the drawing in Fig. 36 contains end elevations in section showing a wood separator which is ribbed only on one side (*single ribbed*), and one which is ribbed on both sides (*double ribbed*). Both types are commonly used, though it may be said that the single ribbed type is more generally used. The advantage in using the double ribbed type rests in the fact that a great volume of acid and correspondingly better circulation of the electrolyte is effected around the negative plates, which is conducive to improved characteristics of the negative plates in point of capacity, especially at high rates of discharge. However, it may be said that special precautions are necessary in mixing the negative paste for plates used in such installations in order to guard against over-expansion of the negative active material in service, as on account of the expanding agent contained in the paste there is a tendency for over-expansion to take place and thus cause this active material to be forced out from the grid and into the grooves of the separators, and which in time results in a gradual decrease in the capacity of the negatives. The chief reason for this loss in capacity of the negative plates is that such active material which is forced out into the grooves of the separators loses proper contact with the grid and the adjacent active material and with the consequent result that on account of the poor conductivity offered it fails to receive the proper amount of charging current to reduce the sulphate, and thus in time becomes inactive and contributes nothing towards the capacity of the plate on discharge. Such plates may be detected by a cadmium test, as they will be found to have a gradually increasing cadmium reading on succeeding charges.

For batteries of the naval service it may be said that the single ribbed type are considered preferable to the double ribbed type, inasmuch as the flat side of the single ribbed type is placed in contact with the negative plates, which tends to maintain the negative active material in position in the grid, thus reducing the likelihood of loss of capacity as outlined above.

As to the method of installing separators in storage battery cells it may be said that for batteries containing a single wood separator, the ribs are placed next to the positive plates and the plain or ungrooved side next to the negative plates for the reason that, as has been stated, the wood has a healthful effect upon the capacity of the negative plates; furthermore, the positive active material oxidizes the wood and accelerates decay, and since the ribs are the strongest portions of the separator they are placed in contact with the positive plates.

In batteries equipped with the "wood and rubber combination" type separators, the wood separator is also placed in contact with the negative plates, while the flat side of the rubber separator is placed in contact with the

positive plates. Fig. 37 contains a photographic illustration of a complete cell assembly in which the "wood and rubber combination" method of plate insulation is used; the relative positions of positive plates, negative plates,

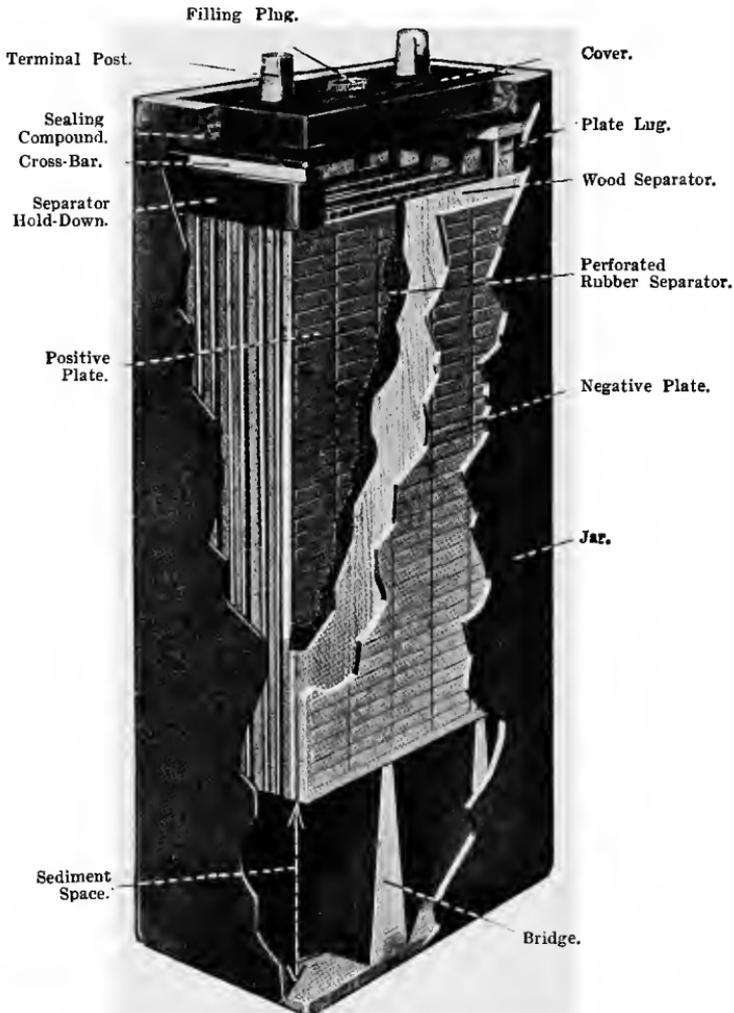


FIG. 37.—Assembly of Cell Showing Wood and Rubber Separators Installed.

wood and rubber separators, and other portions of the cell are plainly shown in this illustration. As to the deterioration of wood separators in service, it may be said that, other things being equal, high temperatures have the greatest effect in shortening their life.

### Wood Veneer Separator.

A special form of the "wood and rubber combination" separator is used in the "Ironclad" type paste-paste assembly cell. The wood member of this combination consists of a treated veneer or unribbed sheet, which is placed next to the negative plates, the thickness of this sheet being about the same as that of the *web* portion of the ordinary ribbed type wood separator. Fig. 38 contains a detailed illustration of this assembly and from which a clear idea of the relative positions of the plates and separators may be had. It will be noted that the hard rubber tubes of the positive plates

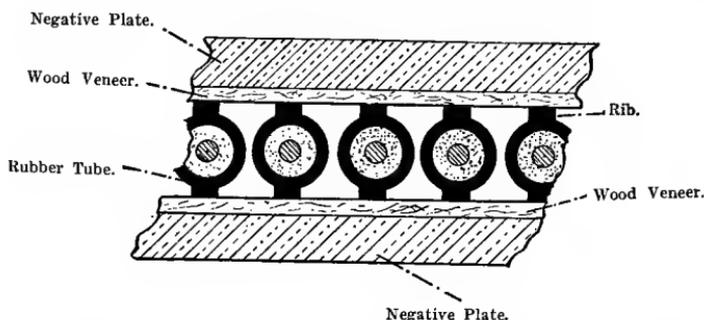


FIG. 38.—Showing Wood Veneer Separator in "Ironclad" Assembly.

contain projections on each side which serve as ribs for maintaining proper plate separation and spacing, these ribs extending the full length of the tube.

### HARD RUBBER SEPARATORS.

**Perforated Rubber Separators.**—In the "wood and rubber combination" method of plate insulation or separation, the rubber member consists of a thin, finely perforated sheet of hard rubber, and the arrangement of this combination is such that there is one such rubber sheet placed against each face or surface of each positive plate in the cell; and, although thus serving primarily as an insulator, this separator also acts in a secondary capacity as a support for retaining in position the active material of the positive plate, since in addition to possessing little or no mechanical strength, the lead-peroxide of these plates becomes softened or "muddy" during the normal operation of the cell, this would otherwise cause it to fall away from the grid in comparatively large lumps if it were not held in place by the rubber separator.

Furthermore, in order that the internal resistance of the cell may be reduced to a minimum, thereby increasing the voltage characteristic of the

cell and with the consequent increased electrical efficiency, the porosity of these rubber separators is made as high as possible consistent with proper mechanical strength and stability of the sheet. Moreover, the fineness of the porosity of these rubber sheets constitutes an essential factor in retaining the active material of the positive plates in position, as has been described above. This porosity, as used in the rubber separators for the naval service, runs from 25 to 35 per cent, which means that in every square inch of surface area of the separator sheet, the perforated area in this square inch amounts to from 25 to 35 per cent. There is shown in Fig. 39 an illustration of a pair of separators such as are used in the "wood and rubber combination" type.

There are various types of these rubber separators, some of which contain vertical reinforcing ribs, while others contain no ribs. It may be said that,

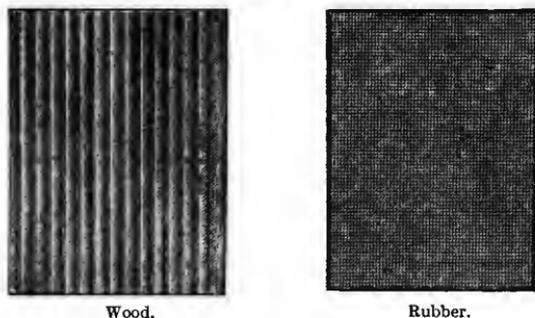


FIG. 39.—Pair of "Wood and Rubber Combination" Separators.

as a general rule, the separators for the small portable types of batteries contain no ribs, whereas some of those used in the larger cells, such as the submarine type, contain the vertical reinforcing ribs. Fig. 40 contains a detailed illustration of a type of rubber separator containing the vertical reinforcing ribs; these ribs consist of narrow strips of hard rubber which are vulcanized to the hard rubber sheets after they have passed through the perforating machines. The portion of the perforated sheet located between the vertical ribs is known as the *web* of the separator. The strength and durability of these separators is increased by leaving an unperforated margin of from  $\frac{1}{8}$  to  $\frac{3}{8}$  of an inch all around the sheet; this feature is also shown in the drawing.

In the manufacture of rubber separators it is very essential that all impurities, particularly as regards metals, be not present in the separator stock. Some manufacturers make a practice of passing the separator stock, after it comes from the calendering machines, through a high voltage

dielectric testing machine in order to detect the presence of any conducting substances or any other defects which cause a breakdown in the insulating qualities of the stock, and all such pieces are discarded. This is considered an excellent procedure and is recommended for all plants manufacturing separators.

Also, some manufacturers cure the rubber separator stock between sheets of tin-foil in order to effect a smooth, polished surface in the finished sheet,

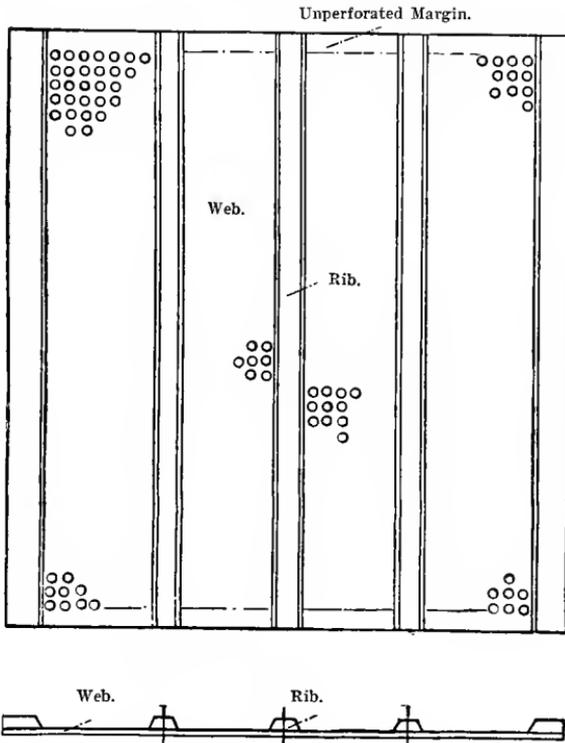


FIG. 40.—Perforated Hard Rubber Separator (Ribbed).

and although it is considered that this method produces an excellent separator and one which is to be desired, great care should be taken when inspecting the separators to see that none of the tin-foil adheres to the sheet, and to thus guard against any particles of tin-foil entering the cell when the separators are installed; this in order that the likelihood of short-circuits resulting from the presence of the tin-foil may be eliminated.

**“Slotted Rubber” Separator.**—Another type of hard rubber separator which has recently made its appearance in storage battery installations is

known as the "slotted rubber" type, and has been developed and brought out by the Philadelphia Storage Battery Company. This separator differs mainly from the ordinary perforated type just described in that instead of perforations this rubber sheet contains fine rectangular *slots*, the die which is used in the punching or *slotting* machine being of rectangular cross-section instead of round; otherwise, the general design, method of installing in the cell and process of manufacture are practically identical with the perforated type.

However, certain merits are claimed for this separator as against those of the perforated type. These claims may be summarized as follows:

1. Increased life of positive plates; the slots are much more efficient than the perforations in preventing the loss of active material from the plates, thus materially increasing the life of the positive plates without any decrease in capacity or efficiency of the cell.

2. Increased life of wood separators; owing to the fact that all positive active material which comes in contact with the wood separators has a tendency to disintegrate and decay the wood, it is claimed that inasmuch as this separator retards *shedding* of the positive active material to a greater degree than does the perforated type, a smaller amount of positive active material therefore comes in contact with the wood separators, with the consequent increase in their life.

3. The combined effect of the increased life of positive plates and wood separators as a result of using slotted rubber separators is that the life of the battery is increased 25 per cent or more.

The theory upon which the merits claimed for this separator are based is that whereas the perforations in the ordinary separator are on the order of .045 to .050 of an inch in diameter, the slots in this new type separator are  $\frac{3}{16}$  of an inch long by .012 of an inch wide, the porosity running about 27 per cent; and, inasmuch as it is claimed that the particles of active material which are "shed" or flake off from the positive plates during the normal operation of the battery have a diameter of approximately  $\frac{1}{50}$  of an inch (.020"), these particles are therefore small enough to pass through the perforations in the ordinary separator, but too large to pass through the slotted rubber sheet. In other words, the *shedding* of the positive plates is retarded and the size of the particles of active material which do pass through the slots is so small as to cause them to readily fall to the bottom of the cell without lodging on the wood separators and disintegrating them, the net results being that the life of the battery is increased by 25 per cent or more through the use of the slotted rubber separators. Tests are now in progress in our navy to determine the comparative merits of this separator when operated under regular service conditions.

**Slotted Rubber Tube for "Ironclad" Assembly.**—The rubber member of the "wood and rubber combination" separator, as used in the "Ironclad" type paste-paste cell assembly, consists of a slotted hard rubber tube into which is packed the active material of the positive plates. The slots in this tube are on the order of  $1/100$  of an inch wide, and they extend circumferentially around the tube from rib to rib. These ribs are placed diametrically opposite each other and take up against the wood veneer separator, thus acting as a spacing rib for maintaining proper plate separation and spacing. Each tube also contains an unslotted

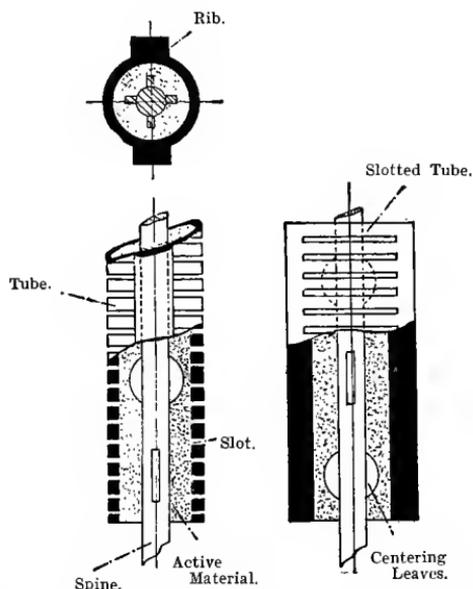


FIG. 41.—Showing General Principles of "Ironclad" Tube Construction.

margin or cuff of from  $\frac{3}{16}$  to  $\frac{1}{4}$  inch wide at the bottom and the top for the purpose of reinforcing and protecting the ends of the tubes. These tubes are made of a very high grade of hard rubber stock and are die-pressed in very much the same manner as the process used in the manufacture of fountain pen stock. After the tubes come from the die-pressing machine they are next placed in the vulcanizers and are cured to the proper degree. The next step in their manufacture is that of the slotting operation, which consists in passing them through a slotting machine, after which they are ready to be filled with the active material and fabricated in the plate. Fig. 41 contains an illustration which shows the general principle upon which this type of plate is based. The drawing is slightly exaggerated

as to size in order that the principles incorporated in the design may be clearly shown. The relative positions of negative plates, wood veneers, and slotted tubes are shown in the illustration of Fig. 38.

**“Threaded Rubber” Separator.**—Another type of separator or insulator which has comparatively recently made its appearance in the storage battery world and which is now being used extensively in the commercial field, especially in the automobile industry, is known as the “threaded rubber” separator, and is a product developed by the laboratories of the Willard Storage Battery Company.

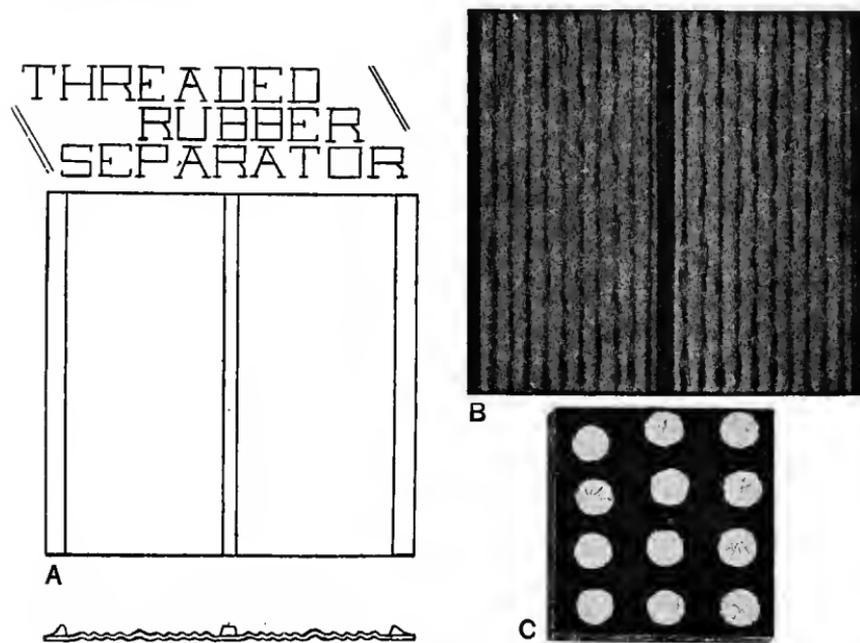


FIG. 42.—Threaded Rubber Separator or Insulator.

This separator takes its name from the great number (about 200,000 per separator) of small cotton strands which pass through the rubber sheet from face to face, and by which circulation and diffusion of the electrolyte in the cell is effected. Fig. 42 contains a group of illustrations of this separator. Referring to this illustration, *A* represents a detailed line drawing of the separator and which gives a clear idea of the shape of the sheet and strengthening ribs. It will be noted that the sheet is of corrugated cross-section in order to afford proper circulation and contact of the electrolyte with and around the plates; also the corrugations act as channels for the liberation of gas bubbles formed in the plates. The hard rubber spacing

and strengthening ribs which extend the full length of the sheet are vulcanized to it. These ribs are designed to maintain proper plate spacing and also to act as reinforcing strips for the threaded sheet. Three ribs are shown in this particular illustration, but the number varies with the width of separator used; *B* shows a photographic representation of this particular size of separator using three ribs; *C* is a greatly enlarged micro-photograph of a section of the separator. The white spots in this photograph represent the numerous cotton strands which thread through the sheet. Each of these threads is about  $\frac{1}{32}$  of an inch in length and of so small a diameter as to be practically invisible to the naked eye.

During the late war this type of separator was used extensively for storage batteries in the aviation branch of our service, and are said to have proven entirely satisfactory. One of the chief merits claimed for this separator is that it affords a much higher voltage curve than a wood separator, particularly at low temperatures, for the reason that at low temperatures the pores of the wood contract and increase the internal resistance of the cell which manifests itself in a reduction in the cell voltage, whereas no such action is apparent with the threaded rubber. The contractors claim to have made some very conclusive comparative tests in starting automobile engines with the surrounding air around freezing, and in each case the voltage characteristic of the batteries equipped with threaded rubber separators was higher than similar batteries of identical design and equipped with wood separators.

Another very important feature claimed for this separator is that batteries when assembled with this separator can remain practically indefinitely, and with no deterioration of the plates or separators, without the necessity of pouring electrolyte and periodically charging the battery, such as is characteristic of all other types of current separator installations. If this claim be correct, it would appear that, other things being equal, this separator should prove especially suited to the requirements of the naval service, wherein it is necessary to maintain a large stock of storage batteries in store at navy yards, shore stations, etc. Tests are now in progress to determine the suitability of this separator for the general naval service, and with present stage of the tests it may be said that the results are considered favorable to the separator.

#### Methods of Installing Separators.

Depending upon the type of battery, method of shipment, and length of time which will elapse before the battery is put in commission after assembly, various methods of installing separators have been adopted, chief among which may be included the following:

**“Wet” Method.**—In this method the treated wood separators and the rubber separators are installed in the battery at the time of assembling the plates and lead-burning them together. Also, the electrolyte is poured practically immediately, or within a space of a few hours, after the element is installed in the jar. The cell is then placed in the charging room and given its *initial charge* and test discharge, specific gravity of the electrolyte equalized, height of the electrolyte adjusted as necessary, and the battery thoroughly cleaned up preparatory to packing for shipment. This method, in so far as the naval service is concerned, is the one most commonly used. Batteries shipped by this method require a periodic *freshening charge* at least every 100 days when not in use, but better results will obtain if batteries shipped by this method are placed on *trickling charge* and maintained in a state of practically full charge at all times. The subject of trickling charge will be taken up in detail in a later chapter.

**“Unfilled” Method.**—This method consists in installing the treated wood separators and the rubber separators in the battery in the same manner as was described in the preceding paragraph for the *dry* method with the exception, however, that the cell is hermetically sealed and no electrolyte is poured. The object of hermetically sealing the cell is to prevent the wood separators from drying out.

Batteries shipped by this method will remain for at least 10 months without filling with electrolyte and conducting the initial charge. After the electrolyte is poured in the cell it is then treated in the same manner as regards charging, etc., as a *wet* cell.

**“Dumped” Method.**—This method consists in assembling the cell with treated wood and rubber separators, pouring electrolyte and conducting the initial charge and test discharge, after which the battery is fully charged and then the cells turned upside down and the electrolyte *dumped* out. The cells are then thoroughly rinsed out with fresh water, care being taken to remove as much of the acid as possible. All of the water having been removed from the cells, they are then sealed up, with the exception of a small pin-hole left in the filling plug for *breathing* purposes to allow any gases which may be evolved in the cell to escape.

When it is desired to put the battery in commission it is necessary to pour the electrolyte and recharge it. This is considered a very undesirable method of preparing batteries for shipment and is not recommended for the naval service.

**“Dry” Method.**—This method consists in installing untreated wood separators and the regular rubber separators in a battery and not pouring the electrolyte until it is desired to give the battery its initial charge and place it in commission at a later date. This method is known as the *dry*

method, as both wood separators and plates are dry when installed in the jar. This method is rarely used, the objection being in the fact that the wood separators have not been treated, thus causing the likelihood of the following:

1. Excessive amount of acetic acid contained in the wood and ill effects incident to this.

2. Wood has not been treated to increase its conductivity; hence the internal resistance is higher, and cell voltage will be reduced thereby.

3. Possibility of warping, drawing, cracking or buckling of wood separators due to drying out through lack of moisture in the jar. When this occurs, it is necessary to remove the separators and replace them with good ones. In any event, it is always advisable, when time permits, to remove such elements from a jar and examine the separators for cracks, etc. Better still, if the time and treated separators are available, it will pay in the long run to remove the dry untreated separators and replace them with the treated separators before pouring the electrolyte and running the initial charge.

**“Bone Dry” Method.**—This method is used by the Willard Storage Battery Company in conjunction with their “threaded rubber” separator which has been previously described. In so far as the naval service is concerned, to date this method has not been in vogue sufficiently long to form any conclusions, but it is understood that this method is producing satisfactory results in the commercial field. Surely if there is no deterioration to plates or separator for an indefinite period when shipping batteries by this method, it would appear that this method constitutes a very desirable one, especially when it is desired to store batteries for long periods of time and at places where proper charging facilities, etc., are not available for taking care of batteries filled with electrolyte.

#### Notes on Shipping Separators.

The methods of packing and shipping separators, particularly those of wood, are very important in respect to preserving them and maintaining them in suitable condition for installation in the cells. It is especially essential that precautions be taken against allowing treated wood separators to dry out, since in drying out they become warped, shrunken, and cracked and are thus rendered unfit for installation in the cells. It is the present policy in supplying separators for spare cells, especially those of the submarine type, to require the battery manufacturers to pack such separators in hermetically sealed cases; this method will preserve them for practically an indefinite period without further attention. However, whenever the case is once unsealed it is then necessary to pour fresh water in the packing

case periodically to keep the separators moist. The cases should therefore be not unsealed until ready to install the separators. It has been found very convenient to pack the separators for each spare submarine cell in a separate case and to allow 25 per cent in excess for breakage in handling incident to installation, etc. In such cases the boxes containing the separators should be appropriately marked with the name of the submarine, individual cell number, the type of cell, and other identification markings which will facilitate expeditious handling in the store rooms at navy yards and on board ship. These cases should also be marked: "Treated wood separators"; "Do not open until ready to use," etc.

In shipping spare submarine cells it is also usual practice to install the rubber separators in the element and to use dry wood spacing boards to take the place of the treated wood separators until desired to install them and put the cell in commission.

For the smaller types of batteries the wood separators are usually packed in boxes containing moist excelsior, and then pouring fresh water in the cases from time to time to prevent the separators from drying out. Also, at battery service stations on board ship and at navy yards it has been found very satisfactory to provide an earthenware jar or crock equipped with a tight-fitting cover for storing such separators as are required during the regular course of battery repairs and separator renewals, the supply in the crock being replenished from the main supply in the packing cases as required.

### **History of Separator Development in the Naval Service.**

The history of the development of the wood separator as used in the naval service dates back to the early days of storage battery applications to submarines, and in which the old tandem type battery installations were used, which period also antedates the development in this country of the unit assembly type such as is now used practically entirely in these installations.

In those days a single basswood separator was used, as no perforated separators were designed for use with them; also, these basswood separators contained no vertical ribs, such as is now current practice, but "straddle" type hard rubber pins or ribs were placed between the separator and the plates to protect the separator from the chafing action caused by the movement of the plates in the cell which was an especially characteristic feature in these old, loose assembly tandem installations. However, these hard rubber pins or ribs proved of little if any value, as the chafing action resulting from the movement of the plates in the cells was sufficient to grind through the wood separators, thereby causing no end of serious battery troubles through short-circuiting of the plates. Moreover, basswood being

of admittedly short life in electrolyte, this wood proved especially unsatisfactory for this service.

Therefore, on account of the very unsatisfactory results obtained through using basswood separators, it was decided by the submarine electrical experts of that time to abandon the use of wood separators and to substitute therefor a thin perforated sheet of hard rubber. These hard rubber separators contained a series of vertical hard rubber ribs vulcanized to the sheets and equally spaced across the width of the separator; these ribs were designed to maintain proper plate spacing and to prevent short-circuiting of the plates. This method of plate separation proved little if any better than the single wood separators, as experience proved that it was only a question of time before the active material of the plates bridged across the separating space and through the perforations in the rubber separators, thus producing the damaging short-circuits in the cell.

It was at about this time that the first unit assembly type cell for submarines was developed in our country, and the electrical experts of the submarine builders concluded that as there would be practically no relative motion between the plates in the cells of this type of assembly, a single, perforated and ribbed hard rubber separator would prove satisfactory as a plate insulating or separating medium. However, such conclusion was destined to bring about sore disappointment, for it was found that although the chafing or grinding actions between the plates and which had proved so disastrous in tandem installations, had been eliminated through adopting the unit assembly type cell, the destructive short-circuits between the plates were not eliminated, as in time, on account of the heat generated in the cell, these separators became soft and pliable, and the web portions of the sheets sagged against the plates thus producing pockets for catching the sediment which was shed from the plates. In time these pockets became loaded up with active material which forced its way through the perforations in the rubber sheets and produced the above-mentioned short-circuits. The author served as commanding officer of one of the first submarines in our navy to be equipped with the unit assembly type cell containing the single rubber separators, and he can offer first-hand testimony as to the very unsatisfactory results obtained with these separators.

The next step in trying to eliminate the short-circuits was to use two perforated rubber separators between the plates. These separators were of practically identical design as the single rubber separators used in these cells and which have been described. Moreover, the double rubber separators proved no better than the single rubber, as experience proved that it was only a matter of time before the short-circuits occurred, since it was impos-

sible to prevent the ultimate bridging across of the active material between the plates and through the perforations in both rubber sheets.

Therefore, the pendulum of separator application having swung between the two extremes, that is, on the one side to that of the single wood separator and on the other to that of the double rubber, and in each case no success against short-circuits having been attained, the next step was to balance the swing of the pendulum. This was done through selecting a wood separator from one side of the field and a perforated rubber separator from the other and to combine these two, thus producing what is known as the "wood-and-rubber" combination. In justice to some of our battery engineering talent it should be stated that there was considerable opposition on the part of a portion of the submarine personnel against ever using the double rubber separators after it was found that the single rubber separator had proved a failure; but this opposition was practically overruled and the decision in favor of trying out the double rubber separators was made, and it was only after experience proved that the double rubber separators produced nothing towards the satisfactory solution of the separator problem that the "wood-and-rubber" combination was finally adopted.

However, since this combination has been adopted and, also, since it is producing the most satisfactory results thus far obtained in the operation of batteries in our service, it is hoped that we will retain this combination as a standard policy, or until such time as it is proved beyond all doubt that a better design has been evolved. Furthermore, it is believed that it can be safely asserted without question that, to date, fully 90 per cent of the serious battery troubles in our naval service can be attributed primarily to separator troubles, and, as stated, since with present stage of the art the "wood-and-rubber" combination is considered the very best yet evolved for this service, let us take care that in the future the swinging of the pendulum of separator application is maintained at the balance.

## CHAPTER XI.

### JARS.

#### Types of Storage Battery Jars.

There are five general types of jars used in lead-acid storage battery installations, which types are as follows:

- (a) Hard rubber.
- (b) Glass.
- (c) Lead-lined wooden tanks.
- (d) Gummite.
- (e) Celluloid.

The designs of each of the above types of jars vary with the special installations for which they are intended, and incorporate the various individual features corresponding with the particular batteries in which they are used and as developed by the various storage battery manufacturers.

#### Types as Applied to the Naval Service.

At the present writing, in so far as the storage battery installations in the naval service are concerned, it may be said that the hard rubber type of jars meets with more extensive application than either of the other types. However, in a few special cases, principally in remote shore stations for stand-by purposes, glass jars are sometimes used; these installations usually comprising the stand-by batteries for radio installations, etc., and in some instances battery installations which were put into operation before the development of the present extensively used hard rubber jar. Also, in the early days of submarine boat construction and design, lead-lined wooden tanks were used, but this practice was discontinued when development of the art of hard-rubber manufacture had reached the stage such that a hard-rubber jar of the type and size used in submarine boat storage battery installations could be satisfactorily manufactured. Also, at the present writing, experiments with the manufacture of "gummite" jars are going on in this country, but as yet this type has not attained the stage of extensive commercial exploitation, though in European countries, principally in France, this type of jar has been successfully manufactured on a broad commercial scale for several years. From present indications, however, it is believed that before these notes are published this type of jar will also have reached the stage of successful commercial manufacture and application in this country.

**HARD RUBBER JARS.****Specifications for Hard Rubber Jars (Small Portable Types).**

The hard rubber jars used for the small portable type batteries in the naval service are very similar in design to the jars used in the regular commercial trade, such as in the automobile starting, lighting and ignition systems, electric vehicle installations, etc. However, it may be said that the naval specifications for these jars are somewhat more rigid in requirements than those for the commercial trade, and especially so in the grade of the hard rubber used.



FIG. 43.—Hard Rubber Jar, Portable Type.

Except for some special jars having a thinner wall, as in gun-firing, aviation and other such special types of storage batteries, the specifications for the jars going into the production of batteries for the naval service require that they be of hard rubber not less than  $\frac{1}{8}$  inch thick, and shall be made of rubber compound with not less than 5000 pounds tensile strength per square inch, with not less than 6 per cent elongation. Also, the specifications require that all such jars shall be given a dielectric break-down test at the works of the battery manufacturer prior to installation of the element in the jar; for the  $\frac{1}{8}$  inch thick jars this dielectric test should be not less than 10,000 volts, and for the thinner wall jars it should be not less than

3500 volts. The object of the dielectric test is to detect foreign conducting matter which may be present in the rubber compound, or cracks, fissures and other such imperfections in manufacture. The specifications also require the rubber manufacturers, as well as the battery manufacturers, to have their names vulcanized on one side of the jar, which is conducive to maintaining a high standard in the manufacture of these jars, as well as serving to assist

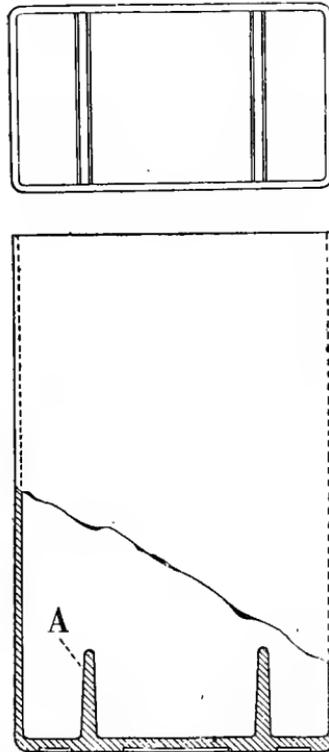


FIG. 44.—Hard Rubber Jar, Portable Type.

the various service stations and the general naval service in detecting and readily identifying a manufacturer's product, whether good or bad.

#### Plain Wall-Bridge Bottom Type Jar.

There is shown in Fig. 43 a photographic illustration in section of a very extensively used design of hard rubber jar going into the production of portable storage batteries for the naval service, which design also meets with extensive application in commercial storage battery installations. This

type is known as the "plain wall-bridge bottom type," and derives this name from the fact that the four walls of the jar are entirely plain, there being no element-supporting ledges attached thereto, while the bottom of the jar contains the element-supporting *bridges*. These bridges are vulcanized to the bottom of the jar during process of manufacture, thus forming an integral part with the bottom. In Fig. 44 is also shown a line drawing of this jar, a portion of which is in section; it will be noted that there are two

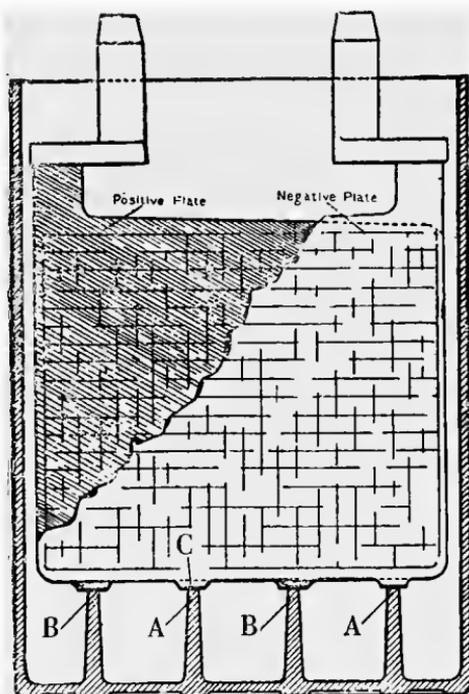


FIG. 45.—Jar Containing Four Bridges.

*bridges* shown at A in this drawing. However, the number of bridges contained in these jars varies in different types of batteries, the width of the plates used in the particular jar usually being a function of the number of bridges which it contains; that is, a narrow plate requires only two bridges, whereas, a wider plates requires more, usually not in excess of four.

#### Jar Containing Four Bridges.

Some battery manufacturers design their elements such that all positive plates in the cell are supported by an individual set of bridges, and likewise

all negative plates in the cell. This is considered a very desirable feature, as it reduces the likelihood of short-circuits occurring between the adjacent positive and negative plates, as a result of sediment collecting on top of these bridges. There is shown in Fig. 45 an illustration of a type of cell containing four bridges and embodying this feature of design. It will be noted

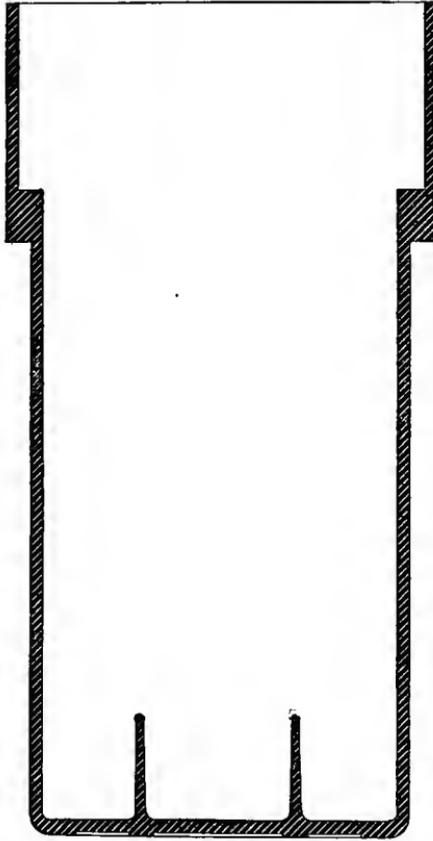


FIG. 46.—Side Wall Element Support Type Jar.

that the two positive and negative supporting bridges shown at *BB* and *AA*, respectively, are "staggered," thus facilitating uniform points of support for the positive and negative plates. Another desirable feature of design illustrated in this drawing is that of the reinforced "feet" on the bottom of the plates, shown at *C*; these feet protect the bottom edges of the plates from damage against the jar bridges cutting through the bottom edge of the grid, as a result of the bumps and knocks which the cell is subjected to under

service operating conditions. Endurance tests conducted on bumping platforms have demonstrated the desirability of casting these reinforced feet on the bottoms of the grids, and especially so for services using comparatively thin plates in their storage batteries.

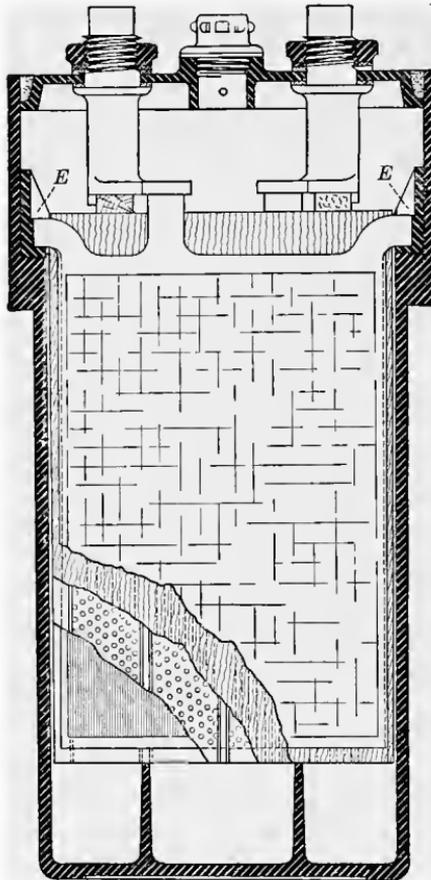


FIG. 47.—Cell Assembly in Side Wall Support Jar.

#### Side Wall Element Support Type Jar.

Another type of hard rubber jar used for storage batteries designed for the naval service is shown in Fig. 46. This jar is known as the “side wall element support” type, and derives its name from the fact that two of the opposite inside walls of the jar are off-set, thus forming ledges for supporting the element. Suitable lugs are cast on the plates, or in some cases, the cross-bars are designed such that they are capable of supporting

the element by engaging on top of the ledges in the jar walls, as described above. The bridges on the bottom of the jar for supporting the separators are also shown in this drawing; however, in some types of installations the separators are supported by hard rubber pins which pass through holes in suitable lugs cast on the bottoms of the plates.

Fig. 47 contains a detailed illustration of a cell assembly using this type of jar and developed by the Gould Storage Battery Company for use in the naval service. All features of this assembly, such as plate support lugs, separator support bridges in the bottom of the jar, wood and rubber separators, separator retainers, etc., are shown in this drawing. Special notice should be had of the method of insulating the plate support lugs from each other on top of the support ledges in the jar walls; this insulation is obtained in this particular installation by use of the hard rubber lug spacing pieces which are plainly shown in the drawing. These lug spacing or separating pieces and method of supporting the element by the plate lugs are plainly shown at *E* in the drawing. It will be noted that the design of these lug spacing pieces is such that each plate lug is separated from the adjacent lug of opposite polarity by a hard rubber partition, each lug thus resting in an individual compartment of its own, and it is thus that proper insulation between the lugs is obtained. It will be further noted that these lug separating pieces are about double the height of the plate lugs, and that the partitions also extend the full height of the separating pieces; this is done to guard against short circuiting of the plate lugs by the lead sponge or mossy growth which collects on top of the negative plates and which is characteristic of all negative plates after they have been in service for some little time.

#### **Specifications for Submarine Type Hard Rubber Jars.**

Owing to the large size of the jars used in submarine storage batteries, as well as the large factors of safety and reliability required for this service, it is necessary that the very best grade of materials and workmanship be used in their manufacture. Although at the present writing these jars are not considered of as high a type in respect to workmanship and materials as is desired for such an important class of service, it should nevertheless be stated that a very great advancement has been made within comparatively recent time in the art of their manufacture, and this advancement is steadily going ahead at a satisfactory rate. Moreover, it is believed that, when the rubber manufacturers have had more experience in the mixing and the fabrication of their stock for this large work, together with the improved methods of manufacture which will doubtless result from the very considerable

amount of research which is now being carried on in respect to this special product, an entirely satisfactory submarine jar will be produced.

The current navy specifications for these jars have therefore been framed to improve this stock and the general character of the product as rapidly as possible, and also to insure that the workmanship keeps pace with any improved characteristics which may be developed in the material; these specifications are therefore subject to change and, like all other specifications and regulations, are really a growth or development in themselves. With present stage of the art, the following constitute the more important features of the current specifications:

**Dimensions.**—Hard rubber jars shall conform to the dimensions shown on drawings specified in requisition or schedule covering the special installation in which the material is to be used; but on account of the high coefficient of hard rubber, a tolerance will be allowed of 0.006 of an inch plus, per 1 inch for width, length, and height on inside dimensions, measurement to be taken at the corners. 0.0095 inch minus tolerance per inch in height may be taken when it is necessary to reheat the jar for straightening purposes after the jar has been finished to the proper height; such jars must then be altered on the underside of the bottom to compensate for one-half the above tolerance, so that the over-all height of the jar will conform to not less than within 0.0047 per 1 inch of height to dimensions shown on the drawings. When jars are supplied with outside reinforcing ribs, they must be made to the tolerance specified on drawings.

**Materials.**—The materials used in the preparation of the hard rubber shall be limited to rubber, reclaimed rubber, sulphur, hard rubber dust and the various ingredients required to produce a material having the physical and chemical properties specified below.

**Specific Gravity.**—Specific gravity shall not exceed 1.50.

**Impurities.**—The hard rubber shall be free from metallic particles, such as copper, brass, and tin; from all granular matter, and from all lumps or aggregations of mineral matter which have not been thoroughly incorporated into the rubber compound during mixing on the compounding mill, and from all other substances soluble in sulphuric acid of 1.4 specific gravity. The iron present as such, and in combination, shall not exceed 0.30 per cent.

**Tensile Strength.**—Rectangular test pieces  $\frac{1}{4}$  inch by  $\frac{1}{4}$  inch by 4 inches, cut from a test slab as described below, shall be turned in a lathe for a space of 2 inches centrally located on the test pieces. These test pieces, when broken in the testing machine at a temperature between 70 degrees and 80 degrees Fahrenheit, shall show a tensile strength of not less than 3000 pounds per square inch.

**Transverse Strength.**—Cylindrical rods 4 inches long and  $\frac{1}{4}$  inch in diameter shall be prepared from a test slab as described below. One test shall be made from these rods maintained at an average temperature of 40 degrees Fahrenheit, and when placed on supports  $2\frac{1}{2}$  inches apart shall be capable of supporting a load (centrally applied) of 23 pounds, showing a deflection of not under 0.07 inch. A second similar test will be made at a temperature of 100 degrees Fahrenheit; the test rods must support 23 pounds, showing a deflection of not over 0.50 inch.

**Test Slabs.**—(a) The test slabs from which the tensile and the transverse strength test pieces are prepared shall be taken from such lots of mixture after the same has been calendered and made ready to build into a jar.

(b) These test pieces shall be vulcanized under the same conditions as the jar itself.

(c) One test slab shall be prepared for each 10 jars, or less, to be manufactured, and the size of each of these test slabs shall be such as to produce at least six test pieces (two for tensile strength test and four for transverse strength test) of dimensions specified above for those test pieces.

**Dielectric Break-Down Test.**—Jars of all types will be subject to the following test:

*First.*—Fill the jar with water, allow same to stand filled from 8 to 10 hours.

*Second.*—A wood block covered with metal (the size of which shall not be less than  $\frac{3}{16}$  of an inch smaller than the inside dimension of the jar) is to be used by inserting it in the jar after the water has been emptied from it.

*Third.*—Water will then be poured in the jar, covering the metal-covered block until there is no air gap between the jar and the block, to within  $1\frac{1}{2}$  inches of the top of the jar.

*Fourth.*—The metal of the block shall then be connected to one terminal of a high voltage transformer of not less than 24,000 volts, and not less than  $\frac{1}{2}$  kilowatt capacity; the other terminal of the transformer shall be connected to a wire brush (the wire brush having bristles, at least 4 inches long, and so constructed that the brushes will readily fall into every corner of the jar). Current shall then be turned on and the wire brush passed very slowly and carefully over every part of the exterior of the jar up to the point where discharge over the top of the jar begins. If the jar should puncture at any point the jar will be rejected, and shall not be presented for retest.

**Hydrostatic Test.**—Jars intended for installation in submarines in which each jar is wedged, shall be filled with liquid up to operating level and containing the weight, 25 per cent in excess of the weight in jar when completely assembled, and kept standing in this position supported on a fair level surface for six hours. This test shall be made in a room where the

temperature is not under 75 degrees Fahrenheit, the temperature of the liquid in the jar being maintained at an average of 120 degrees Fahrenheit by means of electric or steam coils at the option of the manufacturer. At the end of this test, when the jar has assumed the normal temperature of the room, liquid or weight having been removed from the jar, caliper measurements shall be taken on the outside of the ribs on both the length and width of the jar, and no permanent set greater than  $\frac{3}{4}$  of an inch in total dimensions shall be shown. Jars tested under this paragraph shall be limited to five jars. After type of jars has satisfactorily withstood above tests, jars on future orders of same type will be considered satisfactory if material test for tensile strength and dielectric strength are complied with.

**Finish.**—(a) The surface of the jars, both inside and outside, shall present a neat, smooth, and finished appearance, and shall be free from pitting, blow-holes, rough spots, rubber scale, blisters, and other deformations which may be caused by the presence of air pockets in the compound, or other air pockets which may be formed between the rubber and mandrel as a result of improper venting during process of manufacture.

(b) All vertical and horizontal ribs forming and strengthening the outer walls of jars shall be true with the surface of the jar and shall be perfectly joined to each other and to the adjacent surfaces of the jar.

**Marking Jars.**—The following data shall be vulcanized on the outside of each jar near the top so as to be plainly legible:

Name of jar manufacturer.

Date of manufacture.

Government's, battery manufacturer's, or shipbuilder's contract number on which jars were built.

### Types of Submarine Jars.

In respect to the methods of manufacture, hard rubber jars of the submarine type may be divided into two general classes, viz.:

(a) Built-up.

(b) Moulded.

**Built-Up Type.**—In the built-up type the walls, strengthening ribs, bands, etc., are assembled successively around a cast iron mandrel, the shape of which conforms to the shape of the inside of the jar, and after each piece is in turn thoroughly worked into its respective position by means of hand rollers used by the workmen, they are placed in the vulcanizers where they are subjected to the vulcanizing process. After this process has been completed, the jars are removed to the extracting machine where the mandrels are extracted, after which they are sent to the grinding machine where they are ground to the finished size; they are then ready to be finished up prepara-

tory to subjecting them to the inspection and tests in accordance with approved specifications.

Fig. 48 contains a photographic illustration of a built-up jar. The strengthening ribs and bands are plainly shown in this picture, as are also the lifting eyes for use in lifting the cell by means of the lifting device, which is equipped with a series of lifting pins designed to engage in the lifting eyes.



FIG. 48.—Built-Up Type Hard Rubber Jar for Submarine Battery.

In the manufacture of jars by this method it is very essential, when assembling the various pieces of stock around the mandrel, that all air entrapped between the sides of the mandrel and the stock be driven out by means of the hand rollers used by the workmen. It is likewise essential that good adhesion be obtained between all ribs, bands and other parts which are assembled on the stock forming the walls, and also to exercise care in rolling out any air that may have been entrapped between any of these parts during the course of building up the jar. This is necessary for the reason that any air that remains in any part of the stock is converted into steam during the vulcanizing process and hence expands and forms blisters, blow-holes, open

seams, and other such imperfections which render the jar unfit for use. It may be said that this feature of entrapped air and the subsequent injurious effects which it has upon the jar during the vulcanizing process, constitutes one of the chief sources of trouble and difficulty in the manufacture of jars by this method.

**Moulded Type.**—In the moulded type jar, the stock forming the walls, ribs, bands, lifting ears, insulator feet, etc., is placed in a very ruggedly constructed and accurately machined press-mould, after which this press-mould is assembled around a cast iron mandrel, the outside shape of which conforms to the desired shape of the interior of the jar. The various parts forming this press-mould are then forced or pressed by hydraulic pressure, or any other means, against the mandrel, thus forcing the rubber stock into the various compartments of the mould and accordingly effecting the desired formation of the jar. The next operation is that of vulcanizing the jar, which consists in bringing the interior of the mandrel and the parts of the press-mould to the required temperature by means of steam, there being steam leads into the interior core of the mandrel as well as steam jackets around the parts of the press-mould. When the vulcanizing process has been completed the press-mould is disassembled from around the mandrel thus leaving the newly formed jar. The next operation is that of extracting the mandrel from the jar, after which another mandrel is inserted in the jar to preserve the proper form and size during the cooling period. After the jar has properly cooled it is taken to the grinding machine, where all rough edges are removed and any other necessary work done to prepare the jar for the required inspection and tests.

Owing to the very satisfactory grade of jars obtained by this method, it may be said that this process of manufacture is considered superior to the built-up method, the main advantages of the moulded over the built-up type being as follows:

- (a) Greater uniformity in finish, shape and size, which is especially important from the point of view of installation in the submarine.
- (b) No open seams or imperfectly formed seams.
- (c) Fewer blow-holes, blisters, cracks and other imperfections.
- (d) Smaller percentage of loss incident to manufacture.
- (e) Requires less time to manufacture and is especially adapted to quantity production.
- (f) Possible to obtain better lines, fillets, and other finer details of design than in the built-up type.

(g) Requires fewer skilled workmen in the actual fabrication of the jar.

The design shown in Fig. 49 represents a type of jar which has been very successfully manufactured by the moulded method, and contains many improved features of design over the built-up type of jar shown in Fig. 48.

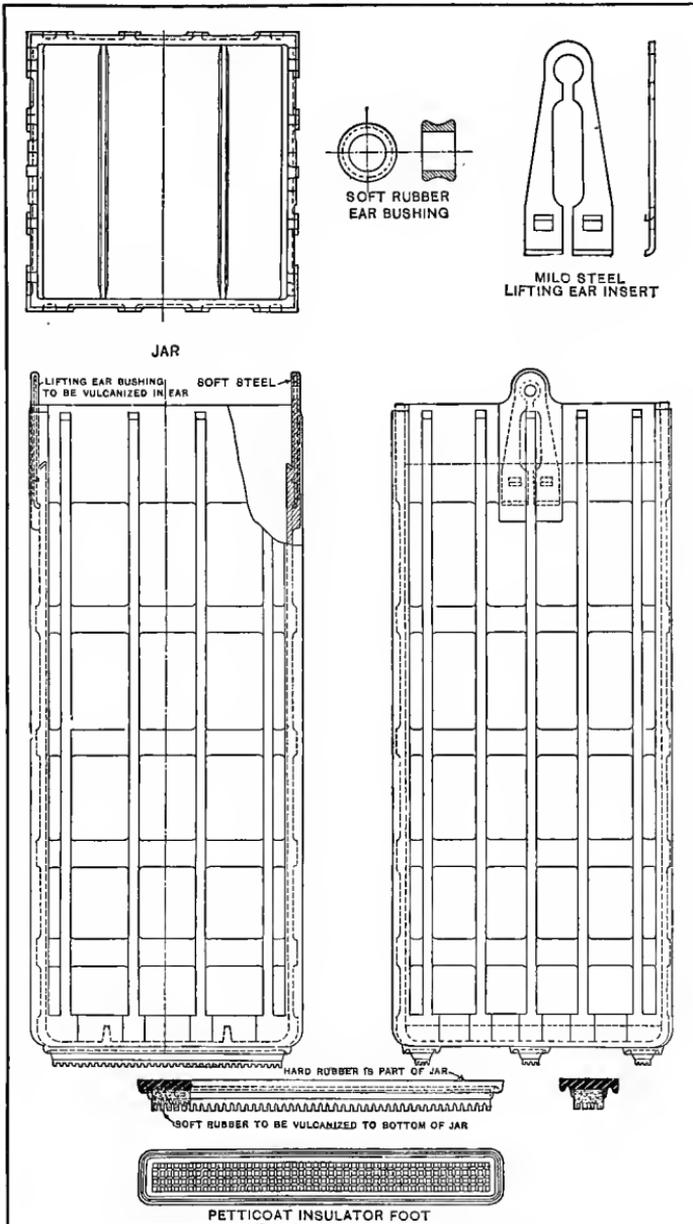


FIG. 49.—Hard Rubber Jar, Submarine Type.

It will be noted that this jar contains a series of horizontal bands progressively spaced from the bottom of the jar in order to prevent excessive bulging of the sides of the jar when subjected to the working temperatures of the cell. This jar also contains a series of vertical ribs, which in addition to increasing the rigidity of the jar, also serve as wedging ribs or guides by which the jars are wedged or secured in position in the battery tank, paraffin impregnated maple wood wedges appropriately grooved to slide over these wedging ribs on the jar being used for this purpose. In respect to this feature it will be further noted that each wedging rib contains a square shoulder or stop at the bottom of the jar in order to prevent the wedge from being driven too far down and injuring the lead lining of the battery tank.

Another improvement which will be noted in the jar under present consideration is that it is equipped with two steel reinforced lifting ears, the eyes of which are fitted with soft rubber bushings designed to equalize the strain of the lifting device pins in the lifting ear eyes when lifting the cell. Although when it is desired to lift the cell, the lifting device is also made fast to the terminal posts of the cell in addition to the lifting ears of the jar, such that the weight of the element is not borne entirely by the lifting ears, the specifications nevertheless require that these lifting ears be strong enough to support the weight of the fully-charged cell when filled with electrolyte and without attaching the lifting device to any other part of the cell.

The details of the soft rubber bushings and the metal inserts for the lifting ears are shown in the upper right-hand corner of the illustration. The steel inserts are plated with a lead-antimony coating to protect them against the corrosive action of the acid of the electrolyte should the inner wall of the jar become cracked or contain other fissures or imperfections which would allow the acid to come in contact with the metal insert; this expedient also serves as a precaution against damage to the cell through the iron going into solution with the electrolyte.

The soft rubber feet on the bottom of the jar are of the petticoat insulator type, the soft rubber strips or cushions being serrated on their under side to compensate for any irregularities of construction in the bottom of the battery tank, thus equalizing the supporting strain across the bottom of the jar. It will be noted that the element is hung from two support ledges formed on the inside walls of the jar. It is considered that this jar incorporates the best features of design of any yet evolved.

#### GLASS JARS.

As far as the battery installations of the naval service are concerned, those using glass jars are confined practically entirely to stand-by batteries at shore stations, principally for radio work. However, in the commercial field

these jars are extensively used for certain classes of service, such as isolated farm-lighting sets, certain types of stand-by batteries, and other such installations which are confined practically entirely to the stationary type. For such classes of service these jars give very satisfactory results, and due to the fact that the element is at all times visible, the height of the electrolyte and general condition of plates, separators, and other parts of the interior of the cells may be readily observed.

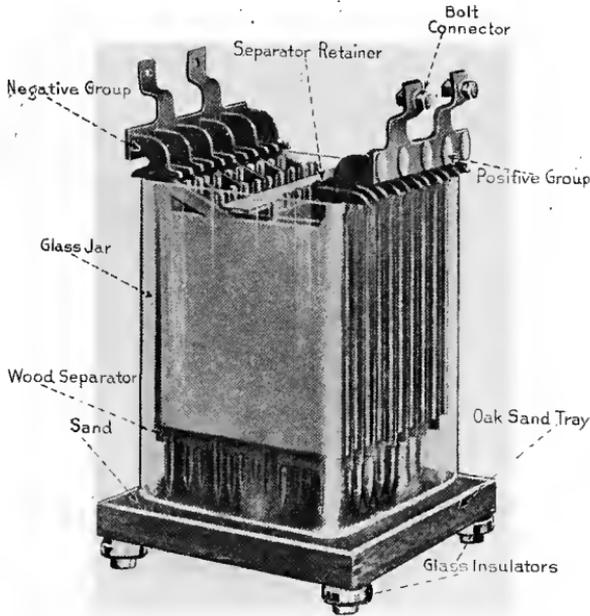


FIG. 50.—Glass Jar Cell Assembly.

There are various designs of elements and plates used in these jars, both the Planté and the paste type assemblies being used as required for the special nature of the service to be performed. Fig. 50 contains a photographic illustration of a common type of glass jar cell assembly. It will be noted that in this particular design the element is supported from the top edge of the jar by means of hanging lugs cast on the plates, the separators being supported from the bottom of the jar by the separator pins which extend below the bottom edges of the separators; the separators are prevented from "floating up" by a glass bar or separator hold-down placed across the top of the element.

For proper insulation this type of cell assembly sets in a bed of sand contained in an impregnated oak tray, which is insulated from the battery rack or platform by means of glass insulators of the petticoat type. The other portions of the cell making up this assembly are plainly shown in the illustration. Fig. 51 contains an illustration of a typical battery installation in which glass jars are used. The method of supporting the cells in racks or tiers is plainly illustrated, as are also the methods of making the inter-cell connections as well as the terminal or end-cell connections with the main service bus bars. The sand trays and glass petticoat insulators are also plainly shown.

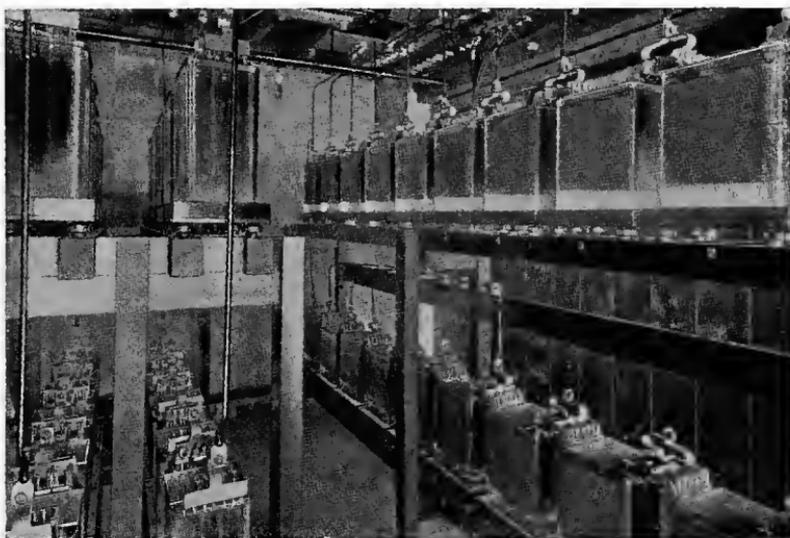


FIG. 51.—Glass Jar Battery Installation.

Some types of glass jar installations provide for the support of the element by means of a set of bridges secured to the bottom of the jar very similar to those described for the portable types of hard rubber jars, with the exception, however, that these bridges are secured to the bottoms of the glass jars by means of sealing compound or other such method. Fig. 52 contains an illustration of a glass jar cell assembly incorporating this feature of design. These particular cells are securely sealed by means of acid-proof sealing compound, the terminal posts passing through this bed of compound. The inter-cell connectors and method of connecting the cells together are also shown.

Fig. 53 contains a disassembled view of a Planté type cell assembly, such as used in glass jar installations. The details of the plates, separators, sand

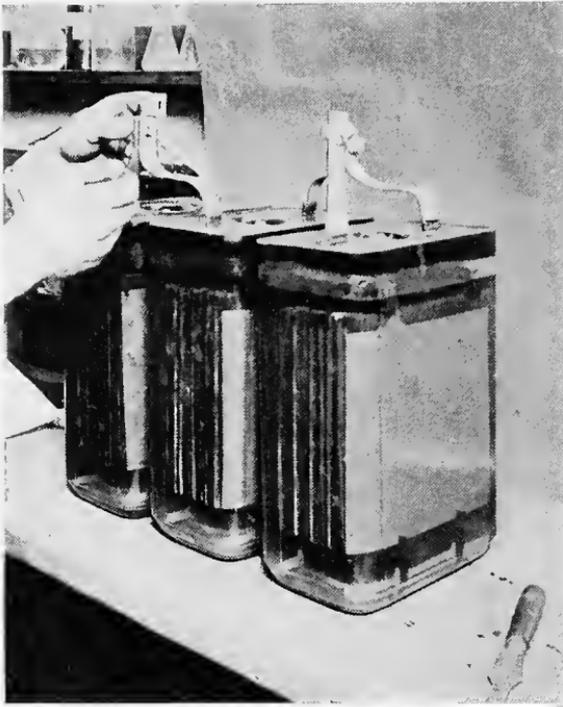


FIG. 52.—Glass Jar Assembly, Showing Bridges for Supporting the Element.

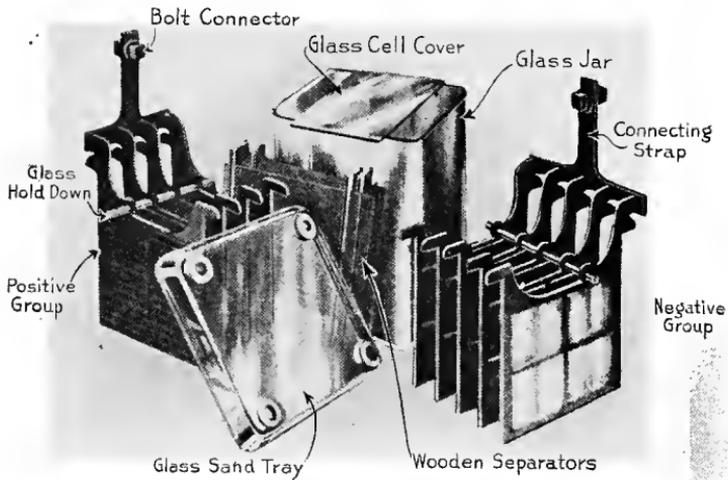


FIG. 53.—Disassembled View of Glass Jar Assembly.

tray, cell cover, glass jar, connectors, etc., are plainly shown in this illustration and from which a clear idea of the various features of construction and design may be obtained.

#### LEAD-LINED WOODEN TANKS.

As has been previously pointed out, in the early days of submarine boat construction and design in this country, and before the hard rubber jar had been perfected for this service, lead-lined wooden tanks were used in the battery installations of these boats. Also, it may be said that no lead-lined



FIG. 54.—Cell Assembly Showing Lead-Lined Wooden Tank.

wooden tanks are now used in any storage battery installations of the naval service.

In the commercial field, however, lead-lined tanks are especially characteristic of certain classes of service, such as stand-by battery installations for the large central power and lighting stations and other plants of this type; also, many of the storage battery installations used with railway car-lighting equipment use lead-lined wooden tanks, as they are especially rugged and can stand considerable abuse.

Fig. 54 contains a photographic illustration of a typical cell assembly using the lead-lined wooden tank, and such as used in the stand-by installations of central power and lighting stations. The method of supporting the plates by means of the bus bars which take up on the top of the tank is clearly shown, as is also the method of insulating and supporting the bottom of the tank. In Fig. 55 there is shown the interior of a section of a stand-by battery installation such as has been described above.

In the manufacture of these tanks a good grade of well-seasoned oak lumber should be used and which should also be given several coatings of an



FIG. 55.—Lead-Lined Wooden Tank Battery Installation.

acid-resisting paint to preserve it against the corrosive action of the electrolyte. Good workmanship in fitting the lead lining to the tank as well as lead-burning the seams is also necessary in the manufacture of these tanks.

#### “GUMMITE” JARS.

The “Gummite” type jar has been extensively used in submarine storage battery installations in both the French and the English navies, the greater portion of these jars having been manufactured in France. It is understood that the material used in the manufacture of these jars consists of an asphaltum base, or some material of similar consistency, the jars being moulded or formed from this material when subjected to high pressures. Owing to the special characteristics of this material it is necessary to make certain variations in the design of the jars as compared to the designs used

in the manufacture of hard rubber jars, as it appears that this material does not run as high in tensile strength as hard rubber. At the present writing preparations are just beginning to be made to manufacture this type of jar in this country, and in view of the fact that we have had little or no experience with this type, there is very little data as to the relative merits of this material as compared to the jars made in this country of hard rubber. However, it is said that these jars are capable of being repaired when fractured, which is a distinct advantage over hard rubber jars, especially in the larger types, such as are used in submarine battery installations, as with the present stage of the art, it is not possible to satisfactorily make such repairs to hard rubber jars. It is understood that these jars have given very good service in European countries, and there appears to be no reason why they should not prove satisfactory in this country, provided the product compares favorably with that of the hard rubber industry in this country.

#### CELLULOID JARS.

Although, to date, celluloid jars for storage battery installations have not been used very extensively in this country, they have for quite some time past been used extensively in European countries, principally in France and Germany. These jars are of the "built-up" type, and are made by cutting out the sides, tops, bottoms, etc., from sheets of celluloid and then assembling these pieces around a hard-wood mandrel, acetone being used as the adhesive agent for holding these parts together. After these parts have been assembled around the mandrel and all seams in the jar securely sealed with the acetone adhesive, the jars are then clamped up or pressed together with a set of cabinet-maker's screw clamps, or other similar devices, and are thus held firmly together until the acetone adhesive has thoroughly set. The chief advantages claimed for these jars, and as put forth by advocates of this type of jar, are that they are transparent, thus enabling the interior of the cell to be observed for height of electrolyte, conditions of the plates, etc., and the capability of this type of jar to withstand sudden shocks without fracture. The latter one, however, may be said to be the chief advantage resulting from using these jars, as the transparent feature is of little if any advantage in service, as it has been found that after these jars have been used for some little time the action of the sulphuric acid of the electrolyte has a tendency to cloud or opaque the walls of the jar. The chief disadvantages in using this type of jar may be said to be that of inflammability and liability to leakage, if an imperfect seam is made in the fabrication of the jar. Moreover, with the present advanced stage of the art in the hard rubber industry in this country, it may be said that the hard rubber type jar is to be preferred to the celluloid type.

## CHAPTER XII.

### HARD RUBBER CELL COVERS AND PARTS.

#### Moulded Type Cell Covers.

All hard rubber cell covers for batteries of the naval service are of the moulded type. The specifications require that these covers shall be made of the same quality of rubber compound as used in the hard rubber jars; that is, this compound shall have a tensile strength of not less than 5000 pounds per square inch with not less than 6 per cent elongation.

These covers are formed and vulcanized in suitable moulds at the works of the rubber manufacturers. The various battery manufacturers have developed their own individual designs to correspond with the special designs of their batteries; the chief points of difference in the designs of these covers are those having to do mainly with the methods of securing and sealing the cover around the cell terminal posts and jars, as well as various features in the designs of filling cylinders, filling cylinder plugs, methods of cell ventilation, etc. Descriptions and illustrations of the various types of cell covers in use in the batteries of the naval service will be taken up later. The general specifications for these covers are as follows:

(a) The cover shall be of the moulded type and must be securely fastened or sealed to the jar.

(b) If a sealing compound is used it must not flow when heated to 120 degrees Fahrenheit. A minimum amount of sealing compound must be used in making the cover gas tight.

(c) The cover shall contain an opening for filling, taking hydrometer readings and to permit the free egress of all gases generated in the cell.

(d) Terminal connections through the cover shall be gas tight, but no sealing compound shall be used for this purpose.

(e) The design of the cover and cell for all batteries to be such that the electrolyte will not spill when the cells are turned through an angle of 50 degrees in any direction, with the level of the electrolyte at least  $\frac{3}{8}$  inch above the tops of the plates. However, for ignition and starter batteries this angle will be 70 degrees. Some special type batteries for aviation and other service have "non-spill" features incorporated in the cover designs of these batteries.

The "Diamond Grid" Cover.—Fig. 56 contains a group of photographic illustrations of a type of hard rubber cover known as the "Diamond Grid" cover and designed by the Philadelphia Storage Battery Company, for use on their type portable batteries. There are many of these covers used on batteries designed for the naval service. This cover is of the moulded type and contains bevelled and flanged edges for effecting an acid-proof seal around the top edges of the jar by means of sealing compound. Also, an acid-proof seal

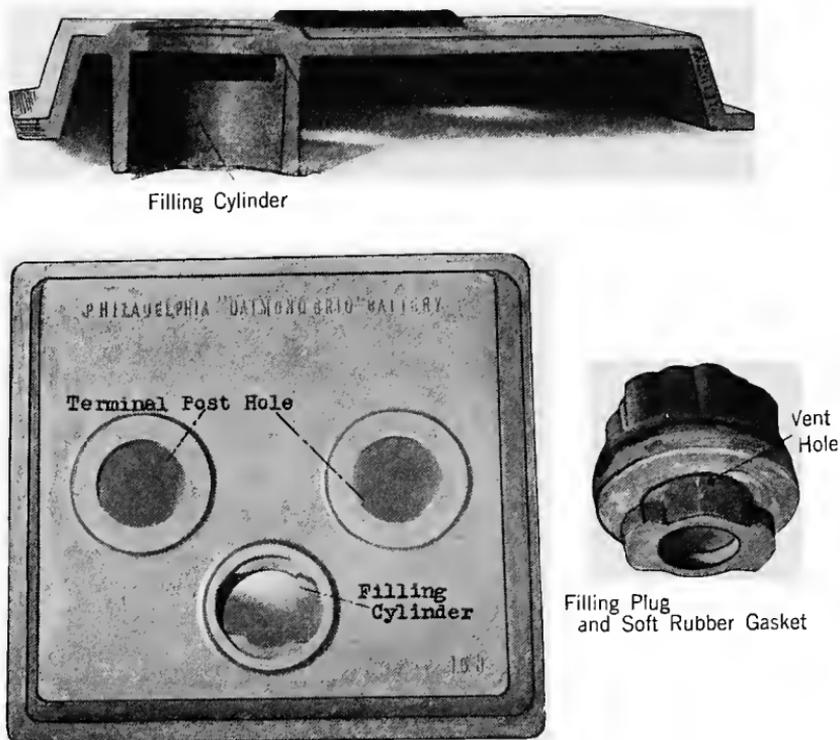


FIG. 56.—"Diamond Grid" Type Cell Cover.

is obtained around the terminal post-straps by means of a soft rubber gasket, a shoulder cast on the post straps, and a hard rubber jam nut which engages the threaded portion of the terminal post; by setting up on the hard rubber nut with a suitable spanner wrench the soft rubber gasket is accordingly compressed between the under side of the cell cover and the shoulder on the post strap, thus forming an acid-proof seal around the terminal posts where they pass through the cover. In setting up on the hard rubber jam nuts care should be taken to not set up too tight on them, in order to guard against stripping the threads or bursting the nuts.

Ventilation of the cell and escape of gases are accomplished by means of small vent holes contained in the filling plug; one of these vent holes is plainly shown in the filling plug, Fig. 56. It will be noted that the filling plug is fitted with a bayonet joint and a soft rubber gasket for locking the plug in position in the filling cylinder and also to effect an acid-proof seal

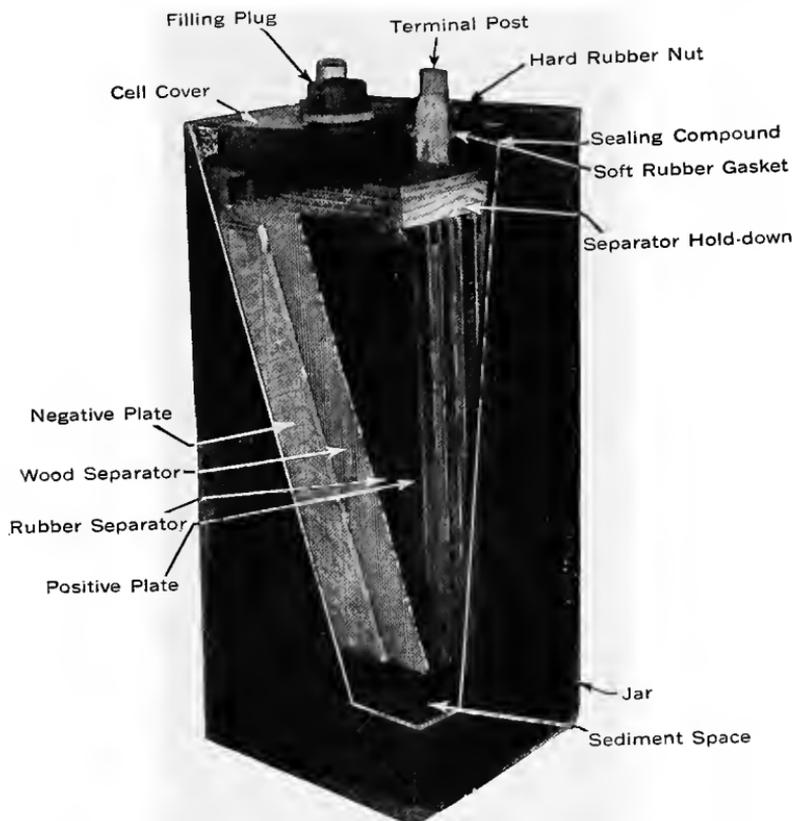


FIG. 57.—Sectional View of "Diamond Grid" Cell, Showing Details of Cell Cover.

around the plug. The filling plug should habitually be kept securely locked in position in order to keep the tops of the cells dry and as free as possible from moisture grounds.

The various details of the design of this cover, including the method of sealing the cover to the jar, securing the cover to the terminal posts, and the ventilation features are plainly shown in the sectional view of the "Diamond Grid" cell contained in Fig. 57.

**The "Exide" Cover.**—A type of moulded hard rubber cell cover which has been found very satisfactory for batteries used in the naval service is the "Exide" cover, a photographic illustration of which is contained in Fig. 58. This cover was designed and developed by the Electric Storage Battery Company for use on their type portable batteries.

The outer edges of this cover are flanged in such manner as to properly support the sealing compound for making an effective acid-proof seal

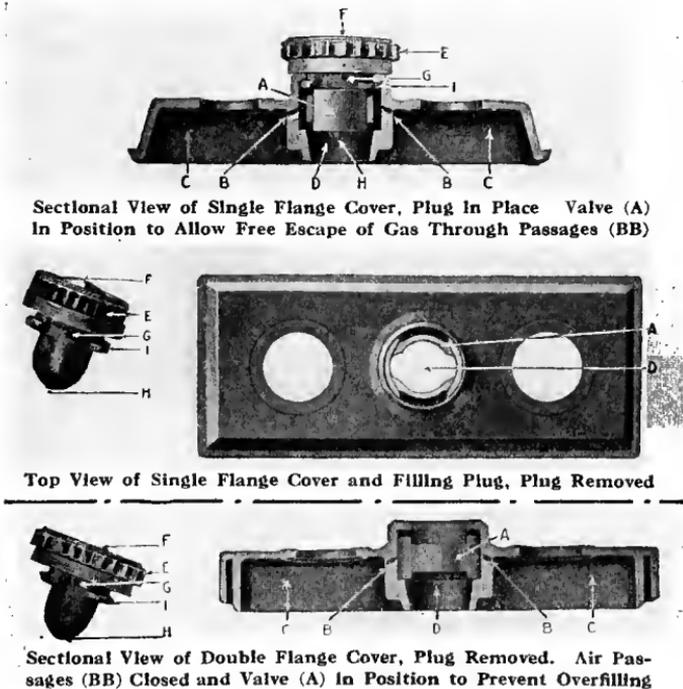


FIG. 58.—Sectional Views of "Exide" Cell Cover.

around the top edges of the jar. An acid-proof seal is also made around the cell terminal posts where they pass through the cover, by means of a soft rubber gasket which seats upon a lead alloy shoulder cast on the upper end of the post strap; by setting up on the terminal post nut the soft rubber gasket is compressed between the under side of the cover and the post strap shoulder, thus effecting the required seal around the terminal post. This cover contains another good feature of design by which the exact amount of water to be added to replace evaporation is automatically controlled. The details of this feature are plainly shown in Fig. 58.

Referring to this illustration, it will be noted that piece *E* is a filling plug for closing the filling cylinder shown at *D* in the central opening in the cover. When piece *E* is secured in position the cell is vented and gas allowed to escape through the vent holes *F*, *G* and *H*. The automatic control of filling when replacing evaporation is effected by means of the hard rubber valve *A*, which is installed in the filling cylinder *D*; the tip of the filling plug *E* engages the valve *A*, as shown in the illustrations. The action of removing plug *E* turns valve *A*, thus closing the air passage *BB*, and forming an air bound chamber *C* in the top of the cell. Now, under these conditions, when water is poured into the cell it cannot rise any higher in the cell than the bottom edge of the filling cylinder *D*, due to the chamber *C* being filled with air; therefore, when the proper level is reached the surplus water rises in the filling cylinder *D* and gives a positive indication that sufficient water has been added. However, should the filling be continued, such that the water in the filling cylinder overflows over the top of the cell, the overflow will consist only of pure water and no acid.

On replacing filling plug *E* after filling, the valve *A* is automatically turned, thus opening the air passage *BB*, leaving the air chamber *C* in the top of the cover available for accommodating the expansion of the electrolyte, which occurs during the normal working of the cell. The bottom views of Fig. 58 represent a double flanged cover, and by means of which another method of sealing the cover of the jar is effected. In this type of cover the space between the flanges of the cover is filled with hot sealing compound and then the cover pressed down on the jar, the top edges of the jar being pressed into the space between the flanges and secured in this position by means of the sealing compound. The action of the automatic filling control feature is identical with that described above for the single flanged cover.

**The "Gould" Type Cover.**—A type of moulded hard rubber cover designed by the Gould Storage Battery Company for a certain type of their storage batteries, some of which are used in the naval service, is illustrated in Fig. 59. The general design of this cover is very similar in many respects to those described in the preceding paragraphs, with the exception, however, that the method of sealing the cover around the post straps is slightly different. In regard to this feature it will be noted that this seal is obtained by means of soft rubber bushings of taper cross-section, and through which the terminal post straps are forced when installing the cover, the compression of the bushings against the corresponding recesses in the cover being sufficient to effect the required acid-proof seal. This type of cover has given satisfactory results and is especially good for installation on batteries which are subjected to severe shocks.

Cell ventilation is obtained by means of small vent holes contained in the bottom and sides of the filling plug; this feature is clearly shown in the detailed drawing of the filling plug. The cross-section of the Gould Planté-paste assembly cell in this illustration also gives a clear idea of the construction and method of assembling this type of cover. This company also sup-

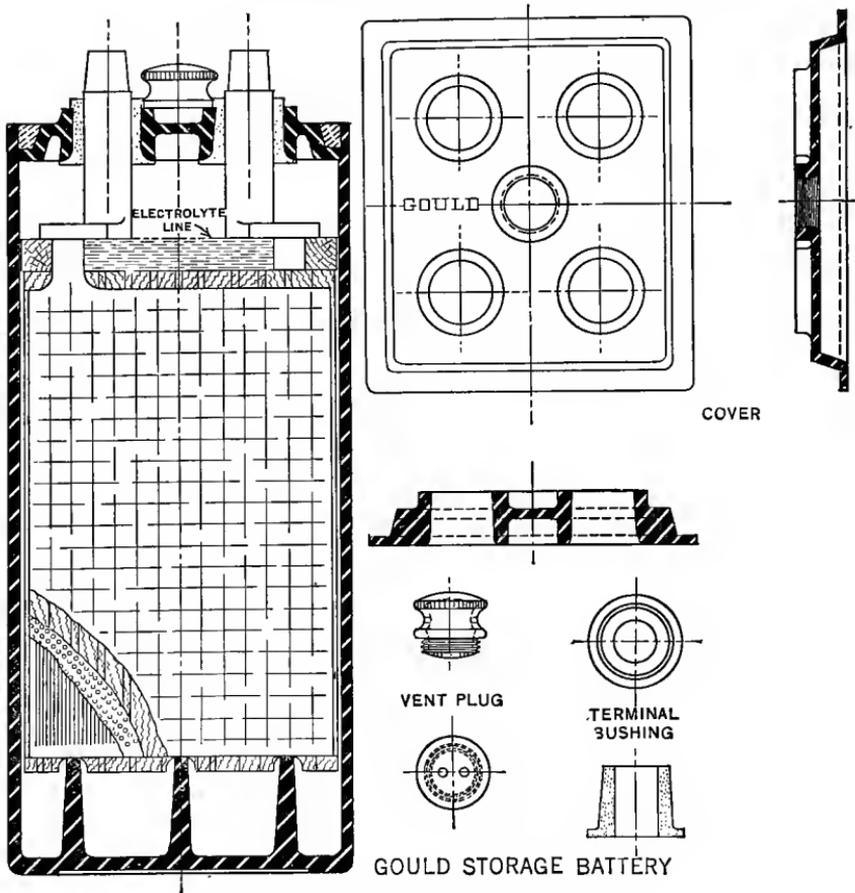


FIG. 59.—“Gould” Type Cell and Cover.

plies a type of moulded cell cover for batteries of the naval service which seats on a soft rubber gasket against a shoulder cast on the post strap, in very much the same manner as other covers containing this feature and which have already been described.

**The “Titan” Cover.**—A type of moulded cover which has comparatively recently been placed upon the market, and which incorporates some novel features of design, is known as the “Titan,” and developed by the General

Lead Batteries Company for use with their portable types of batteries. The principal feature of this cover rests in the method of securing it to the cell terminal posts and effecting an acid-proof seal between the cover and the post strap. Fig. 60 contains some photographic illustrations of the various parts composing the cover.

Referring to these illustrations, the method of sealing the cover around the post straps is as follows: It will be noted that the post strap contains an interrupted cam thread with which the lock nut engages when the cover

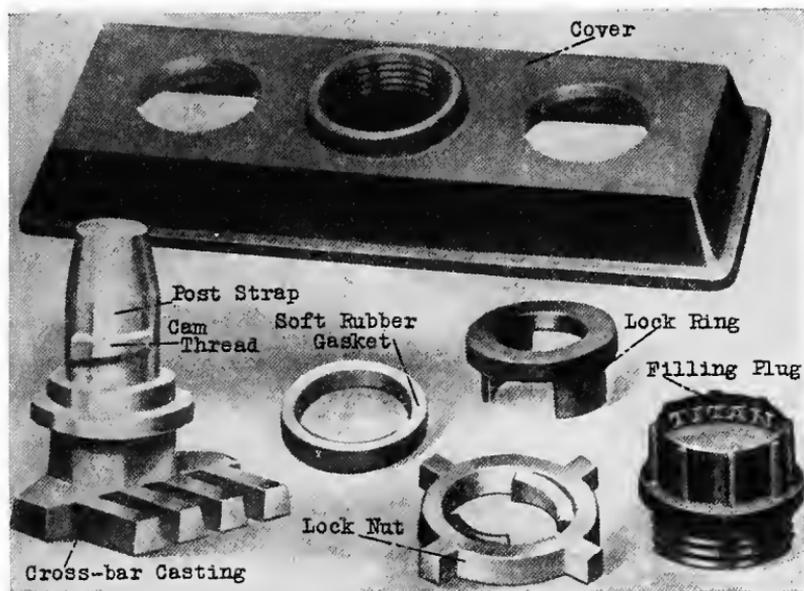


FIG. 60.—Details of "Titan" Type Cell Cover.

is secured in position on the cell; also, there is a shoulder cast on the post strap for supporting the soft rubber gasket and against which the cover seats when in position, there being a circular chamber or tube on the under side of the cover which is concentric with the terminal post hole and into which the soft rubber gasket is compressed when the cover is secured in its normal position.

In assembling the cover on the cell the soft rubber gaskets are placed in position on their respective shoulders of the post straps, after which the cover is placed on the cell and the lock nut engaged with the cam thread and set up on. The thickness of the soft rubber gasket is very accurately gauged, such that when the lock nut is rotated to the required position in relation

to the interruption or opening in the cam thread, the soft rubber gasket is compressed sufficiently against the post strap and the inside walls of the tubular chamber of the cover as to effect an acid-proof seal around the cover at this point. Next, the hard rubber lock ring after being thoroughly coated with vaseline is placed over the terminal post and the projections of this ring seated in the interruptions or openings in the lock nut and cam thread, thus keying the lock nut in position and acting as a keeper in preventing the lock nut from backing off the post strap thread. The next operation in the assembly of the cover is that of lead-burning the cell connector to the ter-

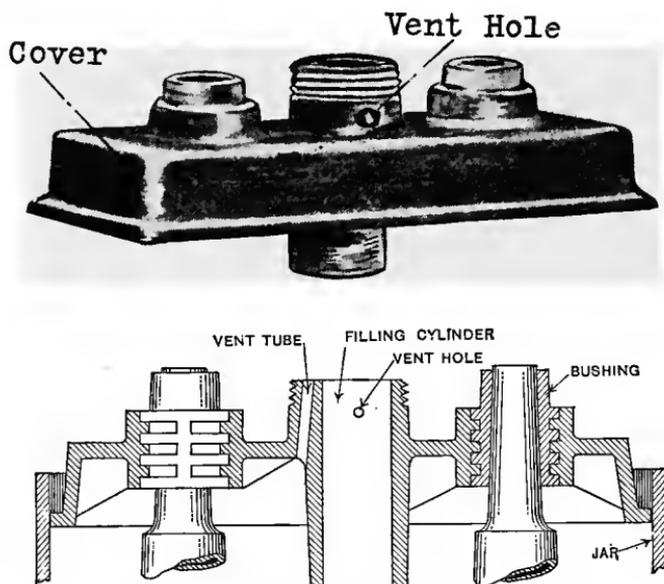
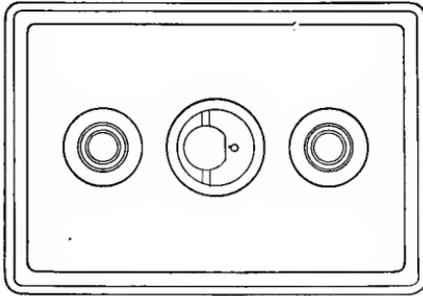


FIG. 61.—Details of "U-S-L" Type Cover.

terminal post. The connector is pressed down over the taper portion of the terminal post such that it prevents the lock ring from getting adrift, and in this position the connector is lead-burned to the terminal post. Ease with which a cover can be renewed is one of the merits claimed for this cover.

**The "U-S-L" Cover.**—Fig. 61 contains an illustration of a type of cover developed by the U. S. Light and Heat Corporation for their type batteries. Particular attention is directed to the manner of effecting the acid-proof seal around the terminal post straps. In respect to this feature it will be noted that each cover contains two lead-antimony bushings through which the terminal posts are passed when securing the cover in position. These bushings are placed in the hard rubber cover mounds and the cover moulded around

them during the process of manufacture; each bushing contains a series of four rings by which it is securely anchored in position in the cover. After the cover is placed in position the cell connectors are placed on the terminal posts



**U-S-L UNIT  
ASSEMBLY  
TYPE CELL**

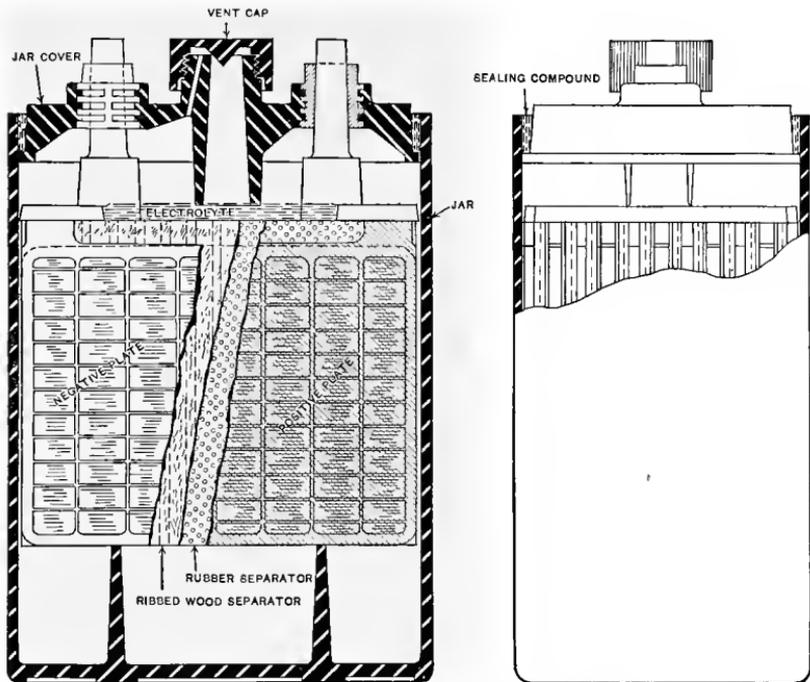


FIG. 62.—“U-S-L” Unit Assembly Type Cell.

and the bushing, terminal post, and connector are integrally lead-burned together, thus effecting a rigid and acid-proof joint. Cell ventilation is accomplished by means of longitudinal vent holes passing through the wall of the filling cylinder, there being an annular space on the under side of the vent

cap to allow any gases to escape when the vent cap is screwed down. A clear idea of the ventilation features as well as the method of securing the cover to the jar and to the cell terminal posts may be obtained from a study of the cross-section drawing of the "U-S-L" unit assembly cell contained in Fig. 62.

Another special feature of this cover is the manner in which replacing evaporation is automatically controlled. This feature may also be seen in the drawings described above.

To replace evaporation of water in the cell remove the vent cap, place a finger over the vent tube, and pour water into the filling cylinder. It has been found very convenient to use an hydrometer syringe for this purpose.

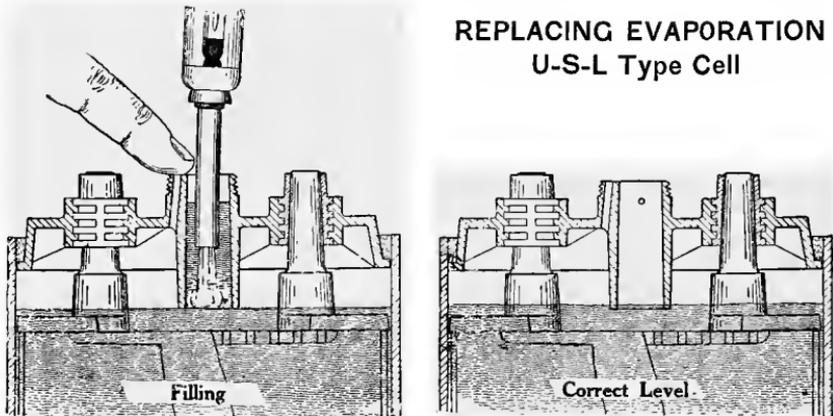


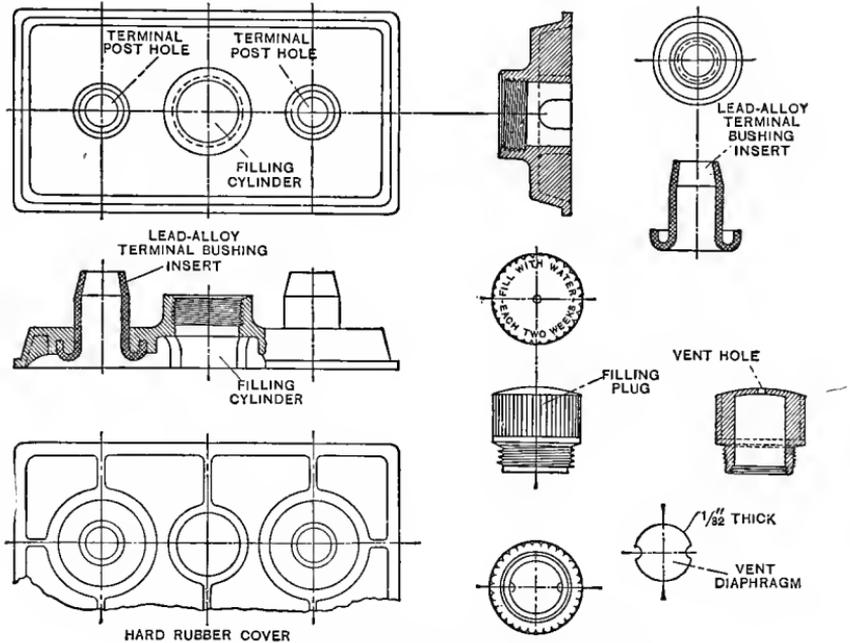
FIG. 63.—Replacing Evaporation in "U-S-L" Type Cell.

Looking into the filling cylinder continue adding water until the level of the electrolyte is just below the horizontal holes in the filling cylinder. When the electrolyte has thus been brought to the level as outlined above, stop adding water and remove the finger from the vent tube. The level of the electrolyte will then fall and you can be sure that sufficient water has been added as to bring the level of the electrolyte the required height above the tops of the plates. The method of replacing evaporation in this type of cell is clearly illustrated in Fig. 63.

**The "Willard" Cover.**—Another type of cover which contains a lead-antimony bushing or insert for making a rigid, acid-proof joint between the post strap and the cover is the "Willard" cover shown in Fig. 64, and developed by the Willard Storage Battery Company. This type of cover is used on many of their batteries supplied for the naval service. It will be noted from the drawing that the alloy insert bushing is anchored in the hard rubber cover

by means of a ferrule-shaped end, and the terminal post, connector, and bushing are integrally lead-burned together when assembling the cell.

Cell ventilation is obtained in this type of cover by means of vent holes contained in the filling cap, this cap being hollow and fitted at the bottom with a thin hard rubber disc or baffle plate, through the holes of which pass the gases evolved from the cell. The details of this feature are plainly shown in the cross-sectional drawing of the filling plug.



DETAILS OF WILLARD TYPE CELL COVER

FIG. 64.—Details of "Willard" Type Cell Cover.

**Submarine Type Cell Cover.**—In view of the fact that submarine storage batteries are designed for forced ventilation, a special type of cover is required to accommodate this system of ventilation. In general, each cover of this type contains an intake vent and an exhaust vent, the present tendency in design being to incorporate both of these fittings in a common chamber or connection located in the center of the cover.

Cell ventilation is usually accomplished by means of a motor-driven suction blower which connects with the main exhaust ducts of the battery compartment, and to which ducts each cell is connected by means of a

flexible coupling leading to the exhaust vent of the cell cover. The combination intake vent and exhaust vent fitting located in the center of the cell cover should also contain the filling cylinder for replacing evaporation as well as the openings for taking hydrometer and thermometer readings. In regard to this feature, the design of these covers should be such that, when it is necessary to remove the filling caps of one or more cells in the battery for replacing evaporation, taking cell readings or for any other purpose, no interference whatsoever is occasioned in the free ventilation of any other cells in the battery. This is an especially important feature of design which should be obtained for submarine batteries.

The exhaust vent of these covers should also be equipped with a series of suitable baffle discs for preventing the acid contained in the electrolyte spray from passing into the main exhaust ducts when ventilation is taking place. The exterior of the cover should be as free as possible from all pockets, indentations, or other such features as would collect moisture, dirt, or other matter, in order to facilitate keeping the top of the cell clean and free from moisture.

It is especially essential that all portions of the interior of the cover be thoroughly ventilated and no pockets, in which hydrogen, or other gases can collect, be permitted in the design of these covers. Covers for this service should be sufficiently rugged in design and composed of a good grade of rubber compound so as to withstand the wear and tear which is especially characteristic of this service.

### **SOFT RUBBER PARTS.**

#### **General.**

The soft rubber parts used in connection with lead-acid storage batteries should be made from a high grade compound and should contain no materials which have a deleterious effect upon any portion of the battery. These soft rubber parts constitute the vent trap gaskets, ventilation system elbows, various washers used about the cell cover, plate spacing washers, soft rubber coaming pieces for submarine cells, soft rubber feet for hard rubber jars, element supporting ledges for hard rubber jars, jar lifting ear bushings, and various other such parts used around the battery.

#### **Specifications for Soft Rubber Parts.**

The soft rubber elbows for vent traps, coaming pieces and soft rubber feet for the jars shall be moulded from a compound that can be readily vulcanized.

The various washers and gaskets used about the cell cover and accessories, and plate spacing washers shall be either moulded from a compound that

can be properly vulcanized, or stamped, or cut on a lathe from a properly vulcanized compound.

The soft rubber element supporting ledges and the lifting ear bushings of the hard rubber jars shall be built on the jars from calendered or tube machine run stock, and be vulcanized in the same heat as the jars themselves.

All soft rubber parts shall be made from and have the characteristics of a compound containing not less than 35 per cent of washed and dried Fine Para rubber (the term "Fine Para" being understood to include the highest grades of plantation Para which by virtue of their physical and chemical characteristics are in strict conformity with these specifications), and not more than 4 per cent of sulphur, with the remainder of suitable dry fillers inert to sulphuric acid. The inert matter may contain barytes, but should be practically free from sulphur in other forms, and from any substances likely to have a deleterious effect on the rubber compound. The sulphur in barytes will not be included in the allowable sulphur content. The compound shall be free from all lumps, and all aggregations not thoroughly incorporated into the compound during mixing in the compound mill.

All parts shall conform in detail with the dimensions specified on the approved drawings.

**Chemical Tests.**—Samples of the finished compound when immersed for a period of 24 hours in sulphuric acid of 1.400 specific gravity and at a temperature of 145 degrees Fahrenheit, shall not show an increase in volume greater than  $2\frac{1}{2}$  per cent.

**Physical Tests.**—A test piece  $\frac{1}{8}$  inch wide, prepared from the compound, shall show the following physical characteristics: Tensile strength, 1200 pounds per square inch; ultimate elongation, 2 inches to 10 inches (2 to 10).

These tests shall be conducted upon samples which the manufacturers guarantee are made from the same material or compound as the soft rubber parts which they represent.

**Inspection.**—The soft rubber parts shall be inspected carefully and rejections made as follows:

- (a) Soft rubber parts not properly cured.
- (b) Soft rubber parts which do not check to dimensions specified within the allowable tolerances by reason of being improperly filled out or otherwise.
- (c) Soft rubber parts which do not meet the required tests.

## CHAPTER XIII.

### CROSS-BARS, STRAPS, TERMINAL POSTS, CONNECTORS, ETC.

#### Cross-Bar, Strap and Terminal Posts.

The cross-bar, strap and terminal post of each respective group of plates installed in the storage battery cell are usually joined together by casting, lead-burning or other such means, thereby incorporating these parts in a single unit; however, it may be said that, with present stage of development of the art, casting of these parts is the method most generally used.

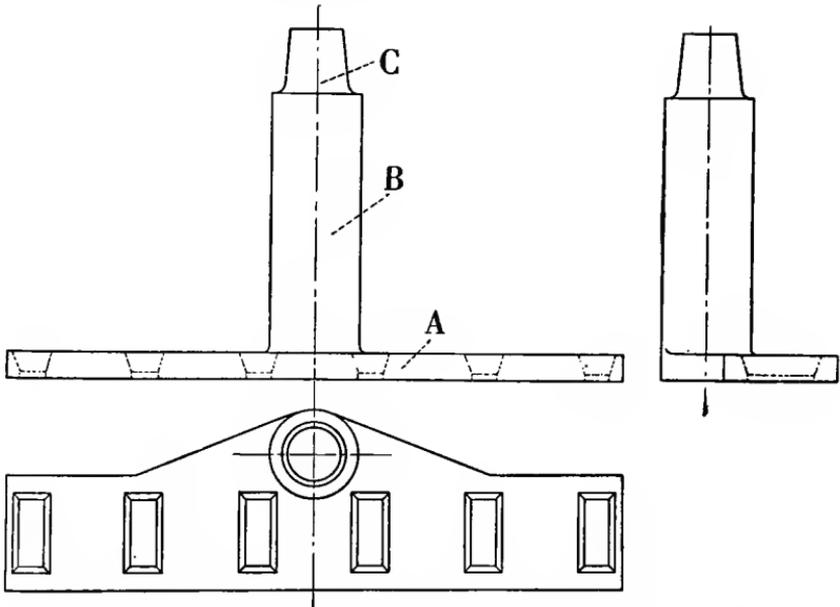


FIG. 65.—Details of Cross-Bar, Strap and Terminal Post Casting.

This piece or casting serves as a connecting medium for conducting the current to or from the service lines to the plates when the battery is being charged or discharged.

In order that a clear understanding may be had of the various parts making up this casting, Fig. 65 contains an illustration of such a casting in which the various parts are clearly shown. The *cross-bar* is shown at *A* and is that portion of the casting to which all plate lugs of the respective group are attached by lead-burning. These cross-bars usually contain openings or slots through which the plate lugs are inserted for lead-burning

to the cross-bar. The *strap* portion of the casting is indicated at *B* and is the part which serves to connect the *cross-bar* with the *terminal post*, which is indicated at *C*. It will be noted that the type of terminal post shown in this drawing is of taper cross-section, and is so designed as to make a cone joint when inserted in the hole of corresponding taper in the end of the cell connector. With this type of terminal post it is the

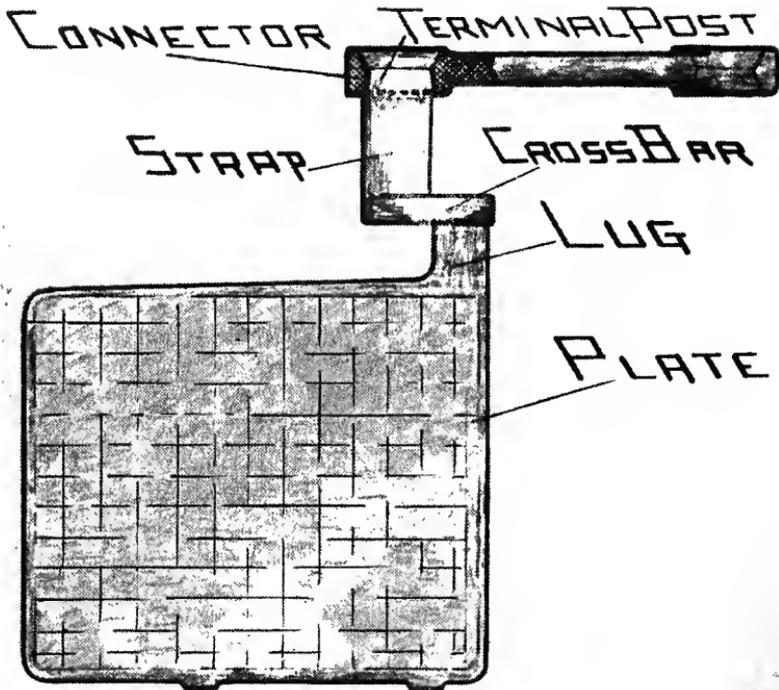


FIG. 66.—Details of Assembly of Plate, Cross-Bar, Strap, Terminal Post and Connector.

usual practice to lead-burn the cell connector direct to the terminal post. This method, however, is only one of the various methods employed in attaching the connectors to the terminal posts, and other methods will be described later on in this chapter.

In Fig. 66 is shown a line drawing of a connector, terminal post, strap, cross-bar and plate, all of which are assembled and joined together in their proper relative positions. Thus in tracing the path of the current from the service line to the plate on charge, it will be seen that the current passes

through these parts in the following order: Service line, cell connector, terminal post, strap, cross-bar, plate lug, plate, and thence into the electrolyte. For batteries designed for the naval service, there is usually one terminal post per group for all batteries whose 10-hour rated capacities are 140 ampere-hours or less, and two terminal posts per group for batteries whose 10-hour rated capacities exceed 140 ampere-hours. However, in the larger type power batteries, such as the submarine cell, where large current rates are required, there are, in some instances, four terminal posts per

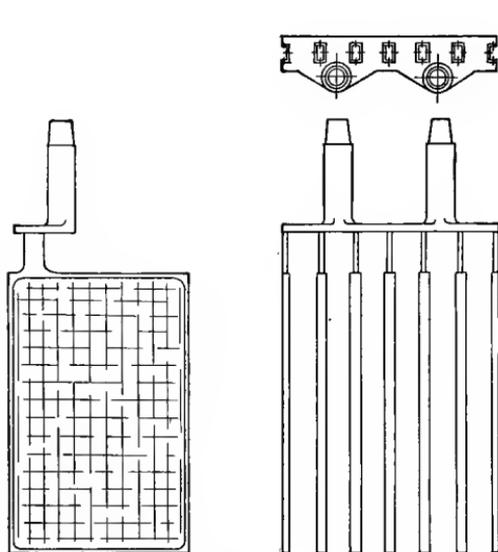


FIG. 67.—Group Containing Two Terminal Posts.

group. There is shown in Fig. 67 an illustration of a type of cell requiring two terminal posts per group.

#### Flanged and Threaded Strap and Terminal Post.

There is shown in Fig. 68 an illustration of a special type of cross-bar, strap and terminal post used extensively in modern storage battery construction and design. It will be noted that the top of the strap portion of this casting is developed and fashioned into a flange, shown at *A*, which serves as a support for the cell cover and also for making an acid tight joint between the cover and the strap. The threaded portion of the strap for receiving the alloy retaining nut *C* is also shown in the drawing. It is the practice of some battery manufacturers to apply the principle of multiple threads, usually quadruple, to this type of strap. The other parts used in

connection with this design are also shown in the figure. *B* is a soft rubber gasket, two of which are used with each strap and terminal post. One of these gaskets is placed directly on top of the flange *A*, thus forming a soft rubber seat and seal between the strap and the cover; the other soft rubber gasket is placed on top of the cover and between the alloy washer *D* and the retaining nut *C*, the alloy washer *D* thus forming a substantial purchase against which the retaining nut is placed when this nut is screwed home. This type of strap and terminal post has given good results under regular service operating conditions, and it is considered to be one of the best

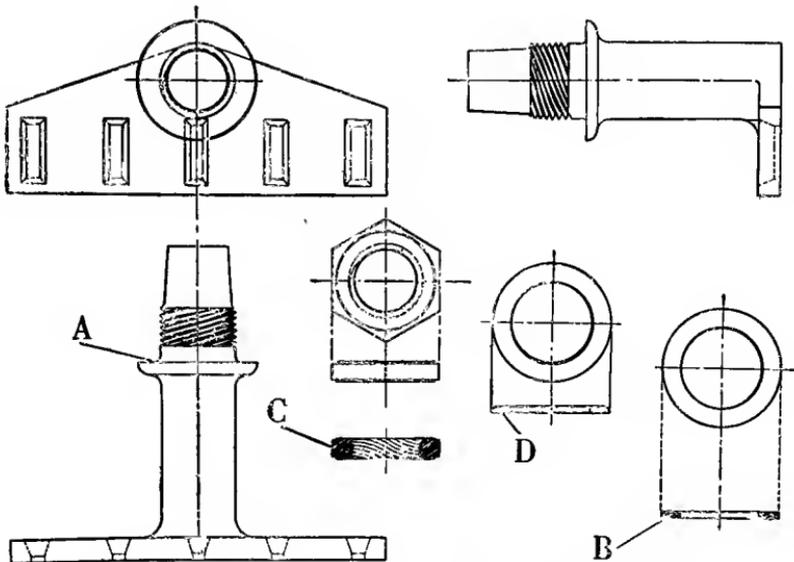


FIG. 68.—Flanged and Threaded Strap and Terminal Post.

methods at present used for attaching and sealing the cover to the strap, as when properly assembled and given the necessary attention, it forms an effective seal against acid *creeping*, which is so prevalent in storage battery installations.

In some modified forms of this design the nut *C* is sometimes made of hard rubber, and in some instances these nuts are made of brass or bronze, usually lead-plated. As a rule, it is considered that the lead-antimony alloy nuts and also those of hard rubber are superior to the brass nuts, in that the use of brass nuts violates the principle of design that the nuts should be composed of a softer material than the threaded portion of the strap. The soundness of this principle is obvious, since it is apparent that the nut can be more readily and easily replaced than the threaded portion of the strap;

therefore, this principle should be adhered to as closely as the particular services for which the battery is designed will permit. In the manufacture of cross-bars, straps and terminal posts of this design, the antimony content of the alloy used in casting these parts runs from 1 to 8 per cent, while that of the alloy used in the manufacture of the nuts is correspondingly smaller in percentage to accord with the principle of making these nuts of a softer material than the straps and posts, as outlined above.

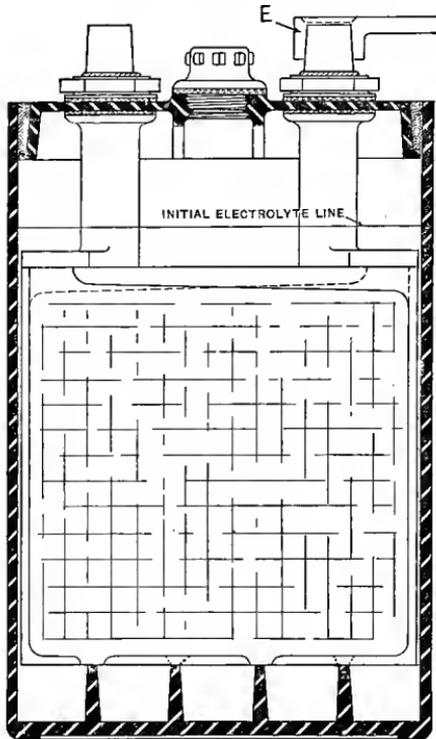


FIG. 69.—Cell Assembly with Flanged and threaded Strap and Terminal Post.

There is shown in Fig. 69 an illustration of a typical cell assembly in which this design of cross-bar strap and terminal post is used. The relative positions of the soft rubber gaskets, alloy washers and nuts are plainly indicated in the drawing. The cell connector shown lead-burned to the terminal post is indicated at *E*.

In assembling this type of cell, it is the usual practice to upset the top of the thread on the strap after the alloy nut has been screwed home, in order to prevent the nut from backing off, thereby maintaining a tight joint between the cell cover and the strap. This upsetting of the thread is done

with a center punch, sharp end of a file, nail, or other such tool. These nuts should be set up on from time to time, after the battery has been put in commission, to compensate for the give and stretch of the soft rubber gaskets.

The particular type of the nuts shown in the drawings, Figs. 68 and 69, are of hexagonal shape for use with a standard wrench; some battery manufacturers also design these nuts for use with a spanner wrench.

### Types of Cross-Bars, Straps and Terminal Posts.

There are two general types of cross-bars, straps and terminal posts used in the construction of the storage battery cell, each of which types have their particular field of usefulness. Also, each of the above types consists of many various designs which have been developed by the battery engineers, the two general types being included under the following headings:

(a) Pure lead or lead-antimony alloy castings.

(b) Pure lead or lead-antimony alloy castings which contain copper inserts.

**Pure Lead or Lead-Antimony Castings.**—This type of cross-bar, strap and terminal post is used practically entirely in the field of small portable storage battery construction where the ampere capacities of the batteries are relatively small, as for instance in the small portable storage batteries designed for the naval service, automobile starting and lighting systems, etc. The types represented and described in Figs. 65, 66 and 68 are typical examples of this type of cross-bar, strap and terminal post. However, it may be said that in the early days of the art of storage battery construction and design, when the automobile starting and lighting systems were first developed, copper inserts were used by some battery manufacturers in the terminal post castings for these small batteries, but experience proved that very little advantage was gained in using these copper inserts in the smaller type batteries. This was especially true of the batteries in which the inter-cell connectors were lead-burned directly to the cell terminal posts, as in removing these connectors for repairs, etc., the copper inserts often became exposed, and it was thus with difficulty that a satisfactory union was again obtained, if at all, between the copper and lead alloy, with the consequent loss in efficiency in the operation of the battery. Moreover, in such instances the paramount advantage and object sought in using the copper insert—that of increased conductivity over that of a solid lead-alloy casting—were not obtained, and in some instances of exceptionally poor contact between the copper and the alloy, the use of copper was actually worse than if the solid alloy casting had been used. Therefore, it may be said that with present

stage of development of the art, no copper inserts are used in the terminal post castings of the small portable storage batteries.

The various designs of this type of terminal post casting, as developed by the battery engineers, conform to the requirements of the special features incorporated in the designs of the batteries to which they apply and manufactured by the various storage battery companies. These special features include the various methods of attaching the cell connectors to the terminal posts, securing and sealing the hard rubber cell cover in position and effecting an acid tight joint between the cover and the post strap, methods of retaining the separators in position in the cell and other features of this order.

The antimony content of the alloy used in these castings ranges from 1 to 8 per cent, depending upon the special services for which the batteries are used. The antimony tends to make the casting more rigid and hard, and also raises the melting point, which is advantageous in lead-burning the inter-cell connectors to the terminal posts, since these connectors and the sticks of metal used in the lead-burning process contain a smaller amount of antimony than the terminal post castings and thus melt at a lower temperature. Pure lead melts at 620 degrees Fahrenheit and antimony at 1150 degrees Fahrenheit.

#### **Terminal Post Castings Containing Copper Inserts.**

In the larger types of storage battery cells designed primarily for high-power work, for example, those used in the submarine service, it is necessary that these cells be equipped with cross-bars, straps and terminal posts of high-current carrying capacity; therefore, this feature of design is obtained by placing copper inserts, possessed of a high factor of conductivity, in these terminal post castings.

Fig. 70 contains an illustration of typical example of such a cross-bar, strap and terminal post. This figure contains three views of the various parts composing this casting, viz.: The copper insert, in end elevation, is shown at *A*; the entire terminal post casting, in end elevation, showing the lead-alloy casting around the copper insert at *B*, and the side elevation of this casting showing the location of the projecting lugs *D*, to which the plate lugs are lead-burned in attaching the plates to this casting. It will be noted that these projections *D* are located on each side of the cross-bar, along its length, to facilitate attaching the plates to the cross-bar by means of a lead-burned joint, there being two corresponding projections on each plate lug for this purpose. However, this particular feature is characteristic only of the design shown in this illustration, as the methods of lead-burning

and attaching the plates to the cross-bars vary with the designs of the various battery manufacturers.

A special feature in the design of the copper insert, and one which is deserving of special attention, is shown at *C* in Fig. 70. In this regard it will be noted that the face *C*, of this portion of the casting, having the greatest surface area is placed normal to the direction of current flow, as indicated by the arrows in the drawing. Thus, it is seen that this face of the casting is so positioned as to facilitate collection of the maximum amount of current at the correct point; that is, as delivered from the plate lugs on

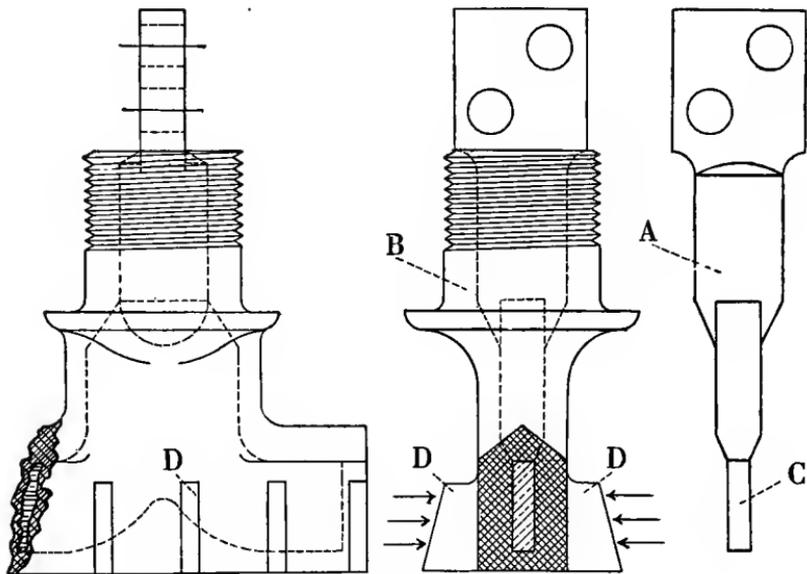


FIG. 70.—Cross-Bar, Strap and Terminal Post Containing Copper Insert.

discharge, or conversely, to properly distribute the current to the plate lugs on charge. In the early days of the art of storage battery construction and design, comparatively little consideration was given to this particular feature in designing these terminal post castings, even by the leading battery engineers, but experience with a large number of these batteries in our naval service has conclusively demonstrated the necessity for properly designing this portion of these copper inserts, as outlined above. A poorly designed insert in respect to this feature is manifested by excessive heating of the terminal post during charge and discharge, as well as undue voltage drop through these castings, with the consequent reduction in efficiency in the operation of the battery. Therefore, the cross-section of this portion of the

copper insert should be designed with an ample factor of safety, in respect to conductivity, commensurate with the demands of the service for which the cell is intended.

### **Proper Electrical Contact Necessary Between the Copper Insert and the Lead-Alloy Casting.**

In the manufacture of this type of terminal post casting, it is also highly essential to satisfactory and efficient operation of the battery that proper electrical contact be obtained between the copper insert and the lead-alloy casting around same. Much of the trouble experienced in the past with this type of terminal post casting has been due to an improper union of the copper with the lead-alloy casting, thus causing excessive heating and undue drop through these parts.

The various steps in the manufacture of these parts by a method which has proved satisfactory in obtaining a proper union between the copper insert and the lead-alloy casting are as follows:

1st. Copper insert cast. This casting should be of a very fine, close-grained quality and free from honeycombs and other such imperfections.

2d. Copper insert casting thoroughly cleaned, and inspected for imperfections.

3d. Copper insert tinned by dipping in molten tin solder. A mixture of 50 per cent tin and 50 per cent lead has been found to constitute a good tinning alloy for this purpose.

4th. This tin-solder coating is next flame-puddled or sweated to the copper insert casting, thus insuring a proper union between the copper and the tin-solder coating.

5th. Copper insert casting, while hot, placed in the moulds and the lead-alloy poured around it, thus coating the lead-alloy portion forming a part of this casting.

6th. The lead-alloy casting is then flame-puddled over its entire surface in order to fill up any holes, shrinkage cracks or other such irregularities and imperfections in the casting.

7th. Casting next tested for millivolt drop between the copper and the lead-alloy covering. This drop should in no case exceed 5.0 millivolts when tested at the designed 1-hour rate of the battery and at a temperature of 80 degrees Fahrenheit. The average drop on satisfactory castings of this type ranges from 0.1 to 3.0 millivolts when tested as outlined above.

8th. Casting is now ready for assembling in the cell and lead-burning to the plate lugs.

Formerly, in the manufacture of these castings, mercury was used to amalgamate the lead-alloy covering with the copper, but this method was found unsatisfactory, for the reason that in casting the lead-alloy around the copper the heat of the molten lead-alloy was sufficient to vaporize the mercury, and the gas thus formed prevented a satisfactory union between the copper and the lead-alloy covering. This method, therefore, has been discontinued for work requiring such a high degree of perfection in the union between the copper and the lead-alloy.

**The Copper Insert.**—The copper inserts designed for this service are usually of cast copper. These inserts should be of a very high grade of fine, close-grained casting, as the density of the casting is a function of its conductivity. With modern methods employed in casting these inserts, a very good grade of casting is now obtained. Before preparing these inserts for receiving the lead-alloy casting around them, they should be thoroughly inspected for all porous spots, honeycombing, shrinkage cracks and other imperfections in casting.

The conductivity of these copper inserts should not run less than 80 per cent perfect, as referred to Matthiessen's Standard for conductors.

#### **Method of Obtaining Millivolt Drop between Copper Insert and Lead-Antimony Casting.**

So much importance attaches to obtaining a satisfactory union between the copper inserts and the lead-antimony casting of terminal posts that it is considered advisable to give the method in detail of checking the millivolt drop through these terminals in order that such a check may be made when desired.

Fig. 71 contains a sketch showing the equipment required and the various connections necessary for making such a check test of the millivolt drop through a cell terminal post. Referring to this sketch, *V* is a millivolt-meter connected in circuit with two prods, *A* and *B*. Prod *A* is placed in direct contact with the copper insert, and prod *B* in contact with the lead-alloy covering. Hence, when current is passing through the terminal post casting, the drop between the copper insert and the lead-alloy casting will be registered on the millivolt-meter. As has been stated, this drop should not exceed 5.0 millivolts when at 80 degrees Fahrenheit, current to the amount of that designed to be carried by the terminal post at the designated 1-hour rate of the battery is passing through the circuit. When tested, as outlined above, the average drop obtained through these castings should range from 0.1 to 3.0 millivolts. Due to the variations in the drop obtained at different temperatures, for uniformity in these tests all terminals should

be at 80 degrees Fahrenheit when the tests are made; care should also be taken to insure that the proper current rate is used when making these tests. These tests can be made while the battery is either charging or discharging. It is also essential to accurate results that clean contacts be made between the cell terminal posts and the busses of the service lines when making these tests.

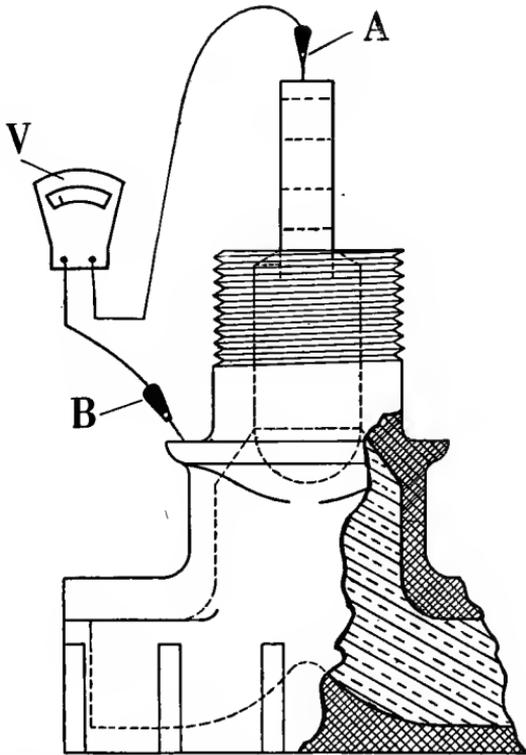


FIG. 71.—Connections for Obtaining Millivolt Drop.

#### Chart of Terminal Post Connections for Millivolt Check Test.

When the cell contains more than one terminal post per group of plates, in order to eliminate any errors through divided circuit calculations, it is advisable to connect only one post per group to the busses of the service lines and to thus check the drop through each individual post separately when the required amount of current is passing through it.

Fig. 72 contains a chart in which is indicated the method of making the connections with the busses of the service lines for checking the millivolt drop through the individual terminal posts for cells having two, three and

four terminal posts per group, respectively. Referring to this chart, the procedure for making the tests is as follows:

Case I, two terminals per group:

$$\text{Current required for test equals } \frac{1\text{-hour rate of cell}}{2}.$$

For checking drop through each terminal post, connect terminals *A* and *A'* only with the busses of the service lines, and with the proper current rate obtain millivolt drop through *A* and *A'* in same manner as was

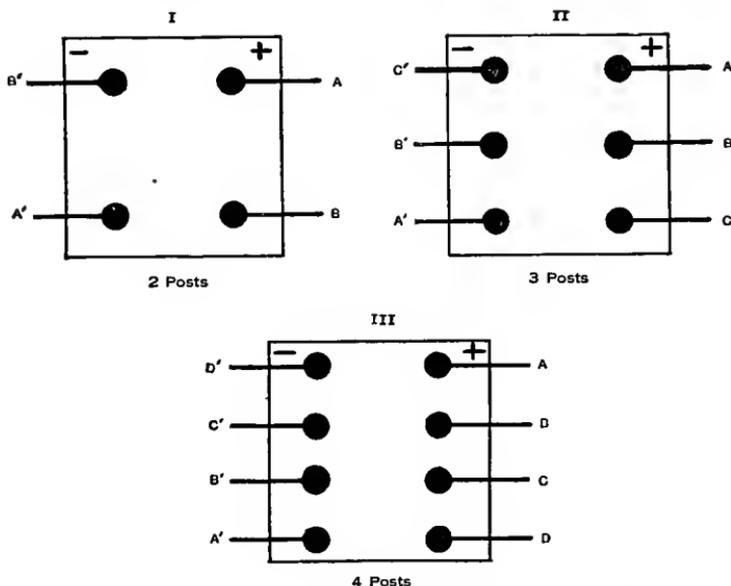


FIG. 72.—Chart for Obtaining Millivolt Drop in Terminals.

described in the preceding paragraph. Having obtained the drop through terminals *A* and *A'*, disconnect from the service busses and connect up terminals *B* and *B'* and proceed as before.

Case II, three terminals per group:

$$\text{Current required for test equals } \frac{1\text{-hour rate of cell}}{3}.$$

For checking drop through each terminal post, connect in order for each individual test terminals *A* and *A'*, *B* and *B'*, *C* and *C'*, and proceed as outlined in Case I.

Case III, four terminals per group:

$$\text{Current required for test equals } \frac{1\text{-hour rate of cell}}{4}.$$

For checking drop through each terminal post, connect in order for each individual test, terminals  $A$  and  $A'$ ,  $B$  and  $B'$ ,  $C$  and  $C'$ ,  $D$  and  $D'$ , and proceed as outlined in Cases I and II.

The above method of making connections between the terminal posts and the busses of the service lines when making the tests insures that the results obtained are based on each terminal post carrying its own designed portion of the current.

### Mattheissen's Standard of Conductivity.

This is the commercial standard of conductivity for conductors as used in this country, and is based upon the specific resistance of a standard copper conductor.

The universally adopted unit of resistance is the international ohm, which is based upon the ohm equal to  $10^9$  units of resistance of the C. G. S. system of electromagnetic units, and is represented by the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice ( $0^\circ$  Centigrade,  $32^\circ$  Fahrenheit), 14.4521 grams in mass, of a constant cross-sectional area, and of a length 106.3 centimeters.

**Specific Resistance.**—In order to obtain the specific resistance of any conductor, let

$l$  = Length of the conductor in centimeters.

$A$  = Cross-section of the conductor in square centimeters.

$R$  = Resistance of the conductor in ohms.

$p$  = Specific resistance of the conductor.

Then,

$$R = \frac{pl}{A}.$$

Hence,  $p = \frac{RA}{l}$  = specific resistance of a centimeter cube of the conductor.

In the above analytical description, when  $l$  is measured in inches, and  $A$  in square inches,  $p$  is the specific resistance of an inch cube of the conductor.

**Specific Conductivity.**—The specific conductivity of a conductor is the reciprocal of the specific resistance. Thus, let

$c$  = Specific conductivity.

$$\text{Then } c = \frac{1}{p} = \frac{l}{RA}.$$

**Relative Percentage Conductivity.**—By relative or percentage conductivity of a conductor is meant 100 times the ratio of the conductivity of the conductor at standard temperature to the conductivity of another conductor of the same dimensions and made of the standard material and at standard temperature.

Therefore, if  $p_o$  is the specific resistance of the conductor at standard temperature and  $p_s$  is the specific resistance of the standard conductor at standard temperature, then

$$\text{Percentage conductivity} = 100 \times \frac{p_s}{p_o}$$

In obtaining the percentage of conductivity of different materials, the specific resistances should always be determined at the standard temperature, which is practically universally taken as 0° Centigrade.

Thus, as stated above, Matthiessen's Standard of Conductivity is the commercial standard to which all conductors are referred, and is a copper wire having the following properties at the standard of 0° Centigrade:

Specific Gravity .....	8.89.
Length .....	1 meter.
Weight .....	1 gram.
Resistance .....	0.141729 ohms.
Specific Resistance .....	1.594 microhms per c. c.
Relative Conductivity .....	100 per cent.

Although, as stated, all copper castings used in storage battery construction, such as the inserts used in the cross-bars, straps and terminal posts, should not run less than 80 per cent in conductivity, as referred to Matthiessen's Standard, the copper inter-cell connectors, which are usually made of a high grade of rolled copper, should not run less than 98 per cent in conductivity, as referred to this standard.

### Connector Bolts, Nuts and Washers.

The connector bolts, nuts and washers used with the larger type power batteries designed for the naval service are made of a good grade of lead-plated phosphor bronze. Formerly, for this service, lead-coated mild steel was used for these parts, but proved unsatisfactory for the reason that it was difficult to obtain a good union between the steel and the lead coating, and from the injurious effects of iron, should any of the bolts, nuts and washers enter the cell.

There is shown in Fig. 73 a typical example of the type of bolts, nuts and washers used for this service. The bolts and nuts are usually of hexagonal shape designed to fit a standard wrench, and for easily handling of these parts the nuts should be of the same size and shape as the bolt heads, thus requiring only one size of wrench to be used with them. Two bolts are usually used with the connector on each terminal post, and each bolt is equipped with two phosphor bronze washers, one of which is placed between the bolt head and the connector, and the other one between the terminal post and the nut, thus protecting the lead plating on the connectors and terminal

posts when setting up on these bolts and nuts in making connections between the cells.

For proper operation of the battery, these connector bolts and nuts should be set up on periodically in order to keep the connectors tight, thus maintaining good electrical contact between the connectors and the cell terminal posts. These parts should also be kept clean and free from sulphate and moisture grounds, and acid "creeping" reduced to a minimum. In order to reduce the corrosion of these parts to a minimum these connectors, bolts, nuts and washers are sometimes coated with an acid-proof paint, in which case they should be regularly inspected, and if there is any sign of corrosion,

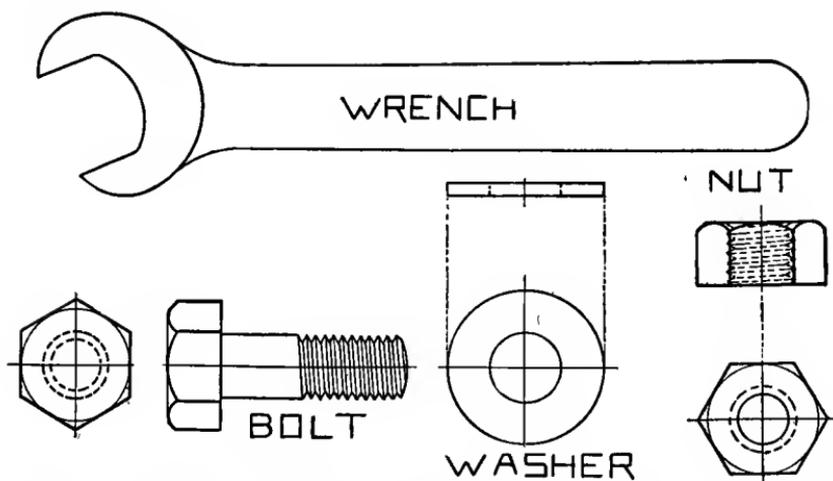


FIG. 73.—Lead-Plated Phosphor Bronze Connector Bolts, Nuts and Washers.

the part thus affected should be thoroughly cleaned and recoated with the acid-proof paint. A strong solution of soda water has proved very effective in cleaning these parts and neutralizing any effects of acid "creeping."

#### INTER-CELL CONNECTORS, TERMINAL CONNECTORS AND PARTS.

##### Types of Cell Connectors.

There are three general types of cell connectors used with storage batteries, as follows:

- (a) Inter-cell connectors or links.
- (b) End cell or terminal connectors.
- (c) Inter-tray connectors.

**Inter-Cell Connectors.**—The inter-cell connectors or links are used for making necessary connections between the cells of a battery. Various

designs of these connectors have been developed by the several battery manufacturers and are in use on the various types of batteries. The specifications for the batteries of the naval service require that these inter-cell connectors shall be made of lead strap, lead-covered copper strap, or lead-alloy strap. For the navy type portable batteries, the specifications also require that these connectors shall be integrally welded to the cell terminal posts and have a cross-section sufficient to carry the total output of the battery when discharging at the highest specified ampere rate, and with a temperature rise of not more than 40 degrees Fahrenheit above the surrounding air. For the larger type of batteries, such as the submarine cells, these inter-cell connectors are secured to the cell terminal posts with lead-coated phosphor bronze bolts, nuts and washers. Steel or iron should never be used for these

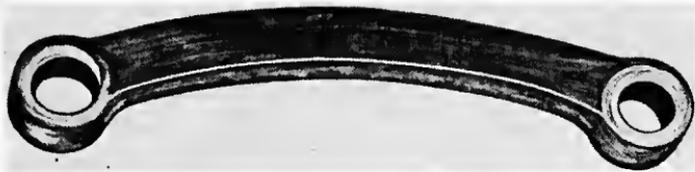


FIG. 74.—Rigid Type Connector.

connector bolts, nuts and washers on account of the liability of damage from the iron of these parts entering the cell.

These inter-cell connectors may be further divided into two general types or designs as follows:

1. Rigid connectors.
2. Flexible connectors.

**Rigid Connectors.**—The rigid connectors are of various designs, depending upon the special types developed by the various battery manufacturers, the different features of the various designs depending mainly upon their shape and method of attaching to the special designs of cell terminal posts. These rigid connectors consist of a solid piece of lead strap, lead-alloy or lead-coated copper bar. The lead-alloy straps are usually made from lead-antimony alloy casting, suitable moulds being provided for this purpose. The antimony content in these connectors ranging from 3 to 6 per cent.

There is shown in Fig. 74 a photographic illustration of a type of rigid inter-cell connector in common use on storage batteries of the naval service,

and in Fig. 75 is shown a line drawing of this type; the ends of this connector are shown in section to illustrate the method of attaching to the cell terminal posts. It will be noted in this drawing that the holes for the terminal posts are of taper cross-section to effect good electrical contact when the connector is forced down over the tapered terminal posts. It will also be noted that the upper portion of the holes in the ends of the connector are developed into a larger reverse taper cross-section, this portion being used for lead-burning the connector to the top of the terminal post. The alloy used for burning these connectors to the cell terminal posts should be of practically the same composition as the terminal posts and connectors. It is very essential to a satisfactory operation of the battery that a good

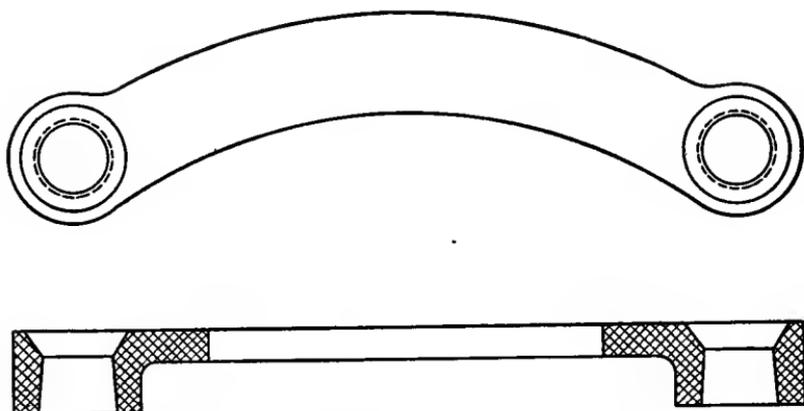


FIG. 75.—Details of Rigid Type Connector.

electrical contact be obtained in lead-burning these parts together. Also, when these connectors are made of lead-coated copper, it is essential that good electrical contact be made between the lead and the copper, as poor contact means a decrease in the efficiency of the battery. In order to prevent the corrosive action of the acid of the electrolyte on the copper and the bad effects resulting therefrom, no blow holes should be present in the lead-alloy covering or copper of these connectors. The conductivity of these copper connectors should be not less than 98 per cent.

**Flexible Connectors.**—The flexible type of inter-cell connectors usually consist of one or more separate layers of thin, narrow strips of lead-plated copper, around the ends of which are cast lead-antimony alloy terminal lugs for attaching to the cell terminal posts, these alloy terminal lug castings being appropriately designed to conform to the special type of terminal posts with which they are used. The copper strips of these connectors are lead-

plated to protect the copper from the corrosive action of the electrolyte. The methods of attaching these flexible connectors to the cell terminal posts are substantially the same as those employed in connecting the rigid types; that is, they are usually lead-burned to the terminal posts. However, in some instances the tops of the cell terminal posts are threaded for



FIG. 76.—Flexible Type Connector.

receiving a corresponding alloy nut, in which case the nut takes up against the connector, holding same in position and in contact with the terminal post. Generally speaking, on account of the liability of the nut working loose, thereby allowing poor contact between the terminal post and the connector, this method is not considered as effective as that in which the con-

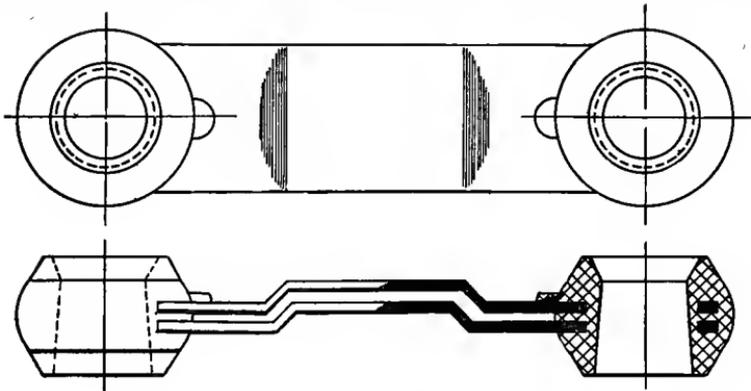


FIG. 77.—Details of Flexible Type Connector.

connector is lead-burned directly to the cell terminal post; especially is this true for services where the battery is subjected to knocks and vibration in service.

There is shown in Fig. 76 a photographic illustration of a common type of flexible inter-cell connector such as has been described above. The lead-antimony terminal lug castings are plainly shown in this illustration, as are also the thin strips of lead-plated copper. In Fig. 77 is given a line drawing

in which the alloy lug casting of this connector is shown in section to illustrate the method by which it is attached to the taper end or "pillar" of the cell terminal post. This type of connector has proven very satisfactory, as the copper affords good electrical conductivity, and, furthermore, on account of its flexibility, it is easy of adjustment for connecting the cells of a tray together, as well as withstanding and absorbing knocks and vibration incident to the service operation of the battery.

In the manufacture of these connectors it is very essential that proper electrical contact be obtained between the lead-plated copper and the lead-antimony terminal castings. In manufacturing these connectors, the copper strips are first cut and trimmed to proper size, then thoroughly cleaned and lead-plated, after which they are inserted in the terminal lug moulds and the molten lead-antimony alloy poured, thus casting the terminal lugs around the ends of these lead-plated copper strips. The connectors are then trimmed up and inspected for blow holes or other defects in the casting or



FIG. 78.—Flexible Inter-Tray Connector.

lead plating; all such defects and imperfections found should be rectified by lead-burning or replating before finally passing inspection for installation on the battery.

**Inter-Tray Connectors.**—The inter-tray connectors are used for connecting together the trays of a set of storage batteries. Various types of these connectors are in use, including both the rigid and the flexible types. However, as a general rule, the inter-cell connectors used on the portable storage batteries designed for the naval service are of the flexible type, consisting mainly of lead and armored cable, although in some cases other types of flexible cable encased in pure Para rubber covering are used.

Various methods are utilized by the battery manufacturers in attaching these inter-tray connectors to the terminal posts of the end cells installed in the trays. These methods include lead-burning the connector lugs of the cable directly to the terminal posts, securing these lugs to the terminal posts by means of bolts, cone joints, set screws or other special designs of connecting attachments. As to these special types and features of attaching the inter-tray connectors to the cell terminal posts, it may be said that

those methods which facilitate readily connecting up or disconnecting a tray without involving the use of lead-burned joints are more desirable for battery installations of the naval service. The various types of connector lugs are usually sweated or soldered directly to the wire conductors of these cables. In making up the inter-tray connectors, at least 6 inches in excess of the distance between the end cell terminal posts of adjacent trays as installed should be allowed for manipulating these cables in connecting up or disconnecting the trays.

There is shown in Fig. 78 an illustration of a type of flexible inter-tray connector which is typical of modern storage battery installations. The connector lugs attached to the ends of this connector are plainly shown in this illustration, as is also the pure Para rubber covering.

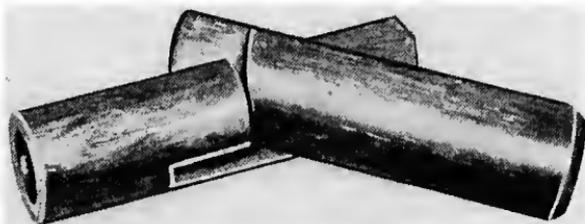


FIG. 79.—Westinghouse Connector.

**Westinghouse Connector.**—Still another type of attachment used with inter-tray connectors is one in which one end of the cable is attached directly to the cell terminal post, while to the other end of this cable is secured a special connecting attachment so designed as to engage with a corresponding attachment installed on the end of another flexible connector similarly attached to the end cell of the adjacent tray. Thus, in bringing together these attachments secured to the ends of these cables, a connection between the trays is effected.

An example of this type of connector and one which meets with extensive application in storage battery installations is known as the "Westinghouse connector," a photographic illustration of which is shown in Fig. 79. It will be noted that this connector is in two parts, consisting of two slotted cam-shaped lugs of brass which dovetail together or enmesh into each other when the connection is made, thus securely joining the ends of the

two cables together. This connector is very satisfactory for services in which it is necessary to readily connect or disconnect the trays of a battery. In Fig. 80 is shown a type of flexible inter-tray connector on one end of which is installed a Westinghouse connector, such as has been described above.

**Taper Lug and Thumb Screw Terminal Connector.**—Fig. 81 contains a line drawing of the various parts making up a type of terminal connector which is used extensively in portable storage battery installations. This type of connector is known as the “taper lug and thumb screw terminal connector.” The functions of the various parts making up this connector will be understood from a study of the drawings of these parts as given in Fig. 81. The terminal connector proper of this type consists of a lead-antimony casting containing two reverse taper holes having their axes running at right angles with each other. The reverse taper hole *C*



FIG. 80.—Flexible Inter-Tray Connector with Westinghouse Connector Attached.

is designed to engage the taper pillar of the cell terminal post and is secured to same by means of a lead-burned joint.

The taper terminal lug is made of rolled brass. One end of this lug is cored out at *A* for receiving the end of the cable connector, which is secured in position by sweating or soldering. A popular method for securing the end of the cable in position in this lug is to fill the core hole *A* with molten soft solder and forcing the end of the cable home in the solder, the end of the cable having been previously and amply stripped of all insulation and other covering.

Thus, in making the connection, it is only necessary to insert the taper end of the brass lug into the taper hole *B* of the terminal connector and securing the lug in position by means of the thumb screw engaging with the female thread in the taper end of the lug. The body and threaded portion of the thumb screw is also composed of brass, while the large head of this screw is composed of lead-antimony and is cast around the brass screw, thus forming a suitable purchase for setting up on or backing off the screw by

hand. The end of the brass screw around which the alloy head is cast is of square cross-section for securely anchoring the screw in position in the casting and thus preventing any motion between the alloy head and the screw. It will also be noted that one end of the brass terminal lug is of hexagonal cross-section for use with a wrench, if necessary, in making or breaking the connection. This type of connector is very convenient for quickly connecting up or disconnecting a battery tray when it is desired to

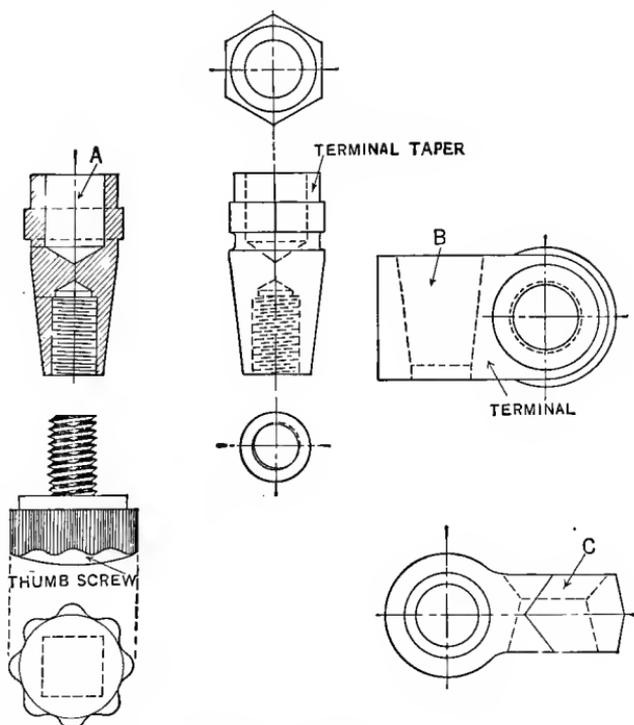


FIG. 81.—Taper Lug and Thumb Screw Terminal Connector.

remove or replace a tray or for making or breaking connection with the service lines. In using this connector, the taper end of the lug should be kept clean and free of foreign substances, in order that a good electrical contact may be had between the lug and the terminal connector, thus enabling the battery to work at maximum efficiency.

**Bolted Top Connector.**—Another method of securing a connector to a cell terminal post, and in which method no lead-burning is required, is shown in Fig. 82. This type of connector is known as the “bolted top connector,” and obtains its name from the screw bolt used in securing the connector to

the top of the cell terminal post. The various parts of this connector, as shown in Fig. 82, are as follows:

*A* is a rolled brass or phosphor bronze screw bolt, usually containing a head of square or hexagonal cross-section for use with a standard size wrench. In some instances the head is of brass and made integral with the screw, while in other instances the head is of lead-antimony alloy and is cast in appropriately fashioned form around the body of the brass screw; both methods meet with extensive application where this type of connector

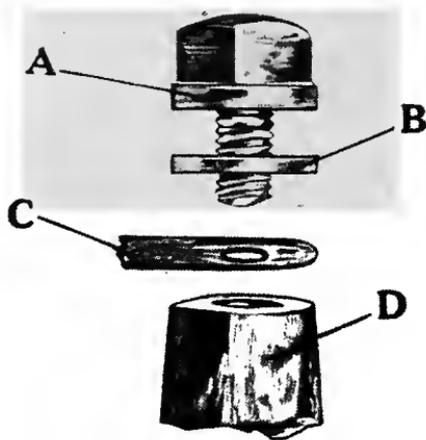


FIG. 82.—Bolted Top Connector.

is used. *B* is a lead-antimony alloy washer which takes up against the connector and the screw. In some instances this washer is made of lead-plated phosphor bronze or brass. The lead-plated copper connector is shown at *C*, and the taper pillar of the terminal post containing a female thread in the top of same is shown at *D*. The method of making a connection with this type of connector will be readily understood from a study of the drawing in Fig. 82. As a general rule, it may be said that for batteries used with comparatively light services where the sustained current rates are small, as in the portable types of batteries, both the screw and the cell terminal posts are of lead-antimony alloy, in which case the terminal post should be composed of a harder alloy than the screw bolt, in order that the thread in the

terminal post will not be easily stripped or will not wear out during the service life of the battery, as a screw bolt is more easily renewed than is a terminal post. For batteries of the larger type, such as power batteries, which are used in services subjecting them to sustained high rates of charge and discharge, the connector bolts are usually made of lead-plated phosphor bronze, and the terminal posts of copper around which is cast a protective coating of lead-antimony alloy.

Although this method of securing the connector to the cell terminal post is used to some extent in this country, it may be said that it meets with more extensive application in battery installations in European countries. The chief objection to this type of connector is that unless they are carefully attended to and kept free from the corroding agencies in the battery, the screw bolt is very liable to "freeze" in position, making it difficult of removal without damaging either the cell terminal post, the screw bolt, or both, with the attending delays and inconveniences incident thereto.

## CHAPTER XIV. CELL TRAYS AND CONTAINERS.

### Types of Cell Trays.

The containers or trays for portable storage batteries are of two general types, as follows:

- (a) Wood.
- (b) Hard rubber.

Except in the designs of a few of the special types of batteries, the cell trays for the portable storage batteries used in the naval service are constructed of well-seasoned wood, oak and ash being extensively used for this purpose. These trays are coated with acid-proof paint to protect them against the action of the acid of the electrolyte.

### Specifications for Construction of Wooden Cell Trays.

In order to insure ample ruggedness in the construction of these wooden trays to withstand service usage, the specifications require that their ends shall be composed of boards not less than 1 inch in thickness and shall be constructed with dovetailed or locked corner joints and tongue and groove joints in the sides. These trays are also provided with handles on each end for lifting or carrying the battery units, and the designs of these handles are such that the tray can be lifted when the cover is on, and when installed alongside other trays. Impregnated wood partition boards of not less than  $\frac{3}{8}$  inch in thickness are placed between the cells installed in these trays.

In order to prevent the sides of the tray from bulging, or becoming otherwise distorted after the cells have been installed, two tie-rods are symmetrically placed near the center of the tray, these tie-rods being capable of drawing the sides of the tray up against the sides of the jars; the specifications also require that when these tie-rods are secured in position their ends shall be flush with the sides of the tray. In order to effect uniformity in construction and installation, all trays of a battery are of the same size. Should a tray be too large for the number of cells required to complete the battery, blank or dummy cell spacers should be installed in the tray to fill up the unused space.

In addition to the features outlined above, each tray shall contain the following parts or features:

(a) A set of at least four enameled porcelain insulator skids placed on the bottom of the tray for supporting and insulating purposes; these por-

celain skids to support and raise the bottom of the tray not less than  $1\frac{1}{4}$  inches from the deck or other surface.

(b) A set of suitable clamps or hold-downs provided on the ends of each tray for securing the tray in position.

(c) Each tray to be provided with a suitable cover. The ends of this cover to be slotted to receive the cable leads connecting to the cell terminals. In connecting these cable leads to the cell terminals, the armor, but not the lead covering, is stripped from the cables from the point where they enter in through the tray cover to the point at which they connect to the cell terminals.

(d) Each tray contains a non-corrosive metal name plate securely attached to its front side. This name plate contains the following data:

- (1) Battery manufacturer's name.
- (2) Type of battery.
- (3) Serial number.
- (4) Ampere-hour capacity at designated rating.
- (5) Normal charging rates.
- (6) Discharge rate.
- (7) Minimum voltage limit.
- (8) Maximum specific gravity.
- (9) Allowable height of electrolyte over tops of plates.
- (10) Guarantee clause, as follows:

"Guaranteed to give useful service, and at least 80 per cent of rated capacity for (.....) years from.....date of shipment."

(e) To the inside of the tray cover is secured a celluloid plate, on which is stamped or printed with acid-proof ink the instructions for the care and maintenance of the battery.

(f) All screws, handles, hold-down attachments and other metal parts used in the construction of the tray are lead-plated to protect them against the corrosive action of the acid of the electrolyte.

**The "Exide" Cell Tray.**—A type of tray designed in accordance with specifications for batteries of the naval service, and which presents a neat and finished appearance, is the "Exide" type tray, manufactured by the Electric Storage Battery Company, an illustration of which is given in Fig. 83. The details of the flexible type inter-cell conductors, porcelain insulator skids, tray tie-rods, lifting handles, and methods of installing and connecting up the individual cells are clearly shown in this illustration. The celluloid instruction plate is shown secured to the inside of the tray cover. It will also be noted that the polarity of the end cell terminals is indicated by a plus and a minus sign stamped on the front side of the tray, the standard method

of assembling all batteries for the naval service being that the positive terminal is to the right-hand side when facing the front of the tray. It is also usual practice to coat the end cell terminals with red and blue enamel, the red indicating the positive terminal. It is especially essential that all trays be plainly marked in this respect in order to prevent damage to the battery through charging in the wrong direction. The non-corrosive white metal name-plate containing various pertinent data in regard to the special characteristics of

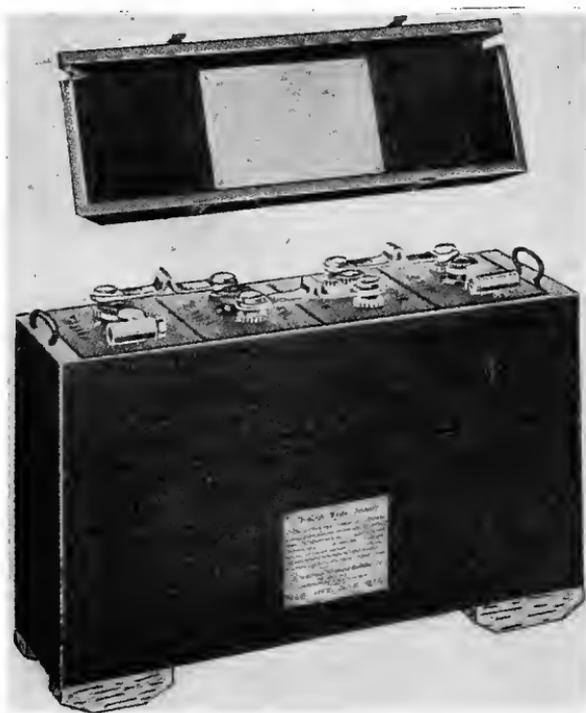


FIG. 83.—“ Exide ” Type Cell Tray.

the battery as regards charging rates, discharge rates, date of manufacture and shipment, as well as the terms of the guarantee is also shown secured to the front of the tray. This tray is fitted with a hold-down device which works on the principle of the eccentric lever. This attachment is not shown in the illustration.

**The “Gould” Type Tray.**—Fig. 84 contains an illustration of a type of combination lifting device, cover retaining clip, and hold-down attachment as developed by the Gould Storage Battery Company for installation on their type of portable storage batteries supplied for the naval service. There is one

set of each combination attachment installed on the ends of each cell tray. This attachment consists of an extension handle of malleable iron, the bottom part of which is pad-shaped and contains a hook or lip into which is engaged the oblong head of the iron hold-down bolt. The hold-down bolt passes through a hole in the deck or battery stowage rack and the tray is thus

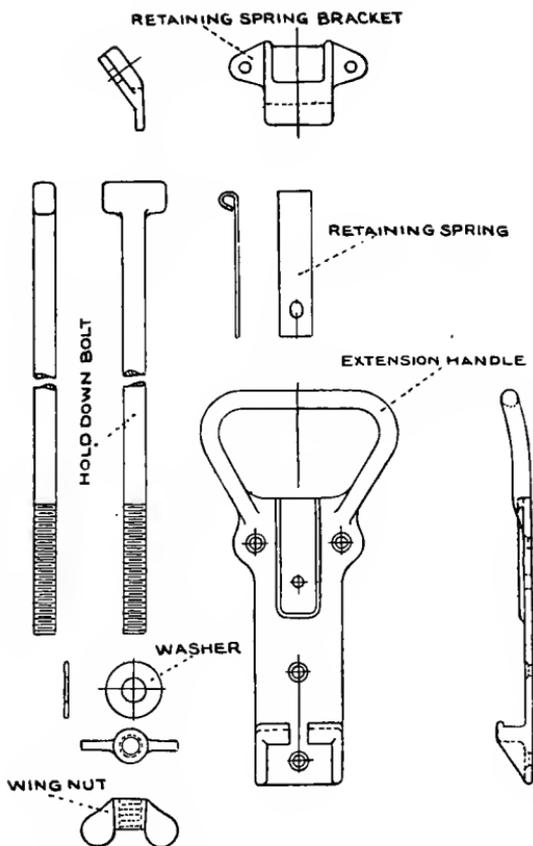


FIG. 84.—Details of Cover Retaining Clip and Hold-Down Attachment.

securely locked in position by setting up on the wing nut, which in turn takes up against the hold-down bolt washer.

The cover retaining feature of this attachment consists of a malleable iron retaining spring bracket attached to the tray cover and into which is engaged the steel retaining spring, as shown in the drawing. The lifting handle pad is recessed for receiving and securing in position the cover retaining spring. All parts of this set, including the screws, are lead-plated

to protect them against the action of the acid of the electrolyte. An assembled view of this attachment as installed on the ends of the cell tray is shown in Fig. 85. The functions of the various parts of this combination attachment will be readily understood from a study of this drawing. It will also be noted that the ends of the tray cover are bevelled to facilitate lifting the cell tray without necessitating the removal of the tray cover. This drawing also shows the details of construction of the cell tray, including the dovetail joints in the corners, impregnated wood spacing pieces placed between the cells, tie-rods for preventing bulging of the sides of the tray, metal name-plates on front side, porcelain insulator skids, etc.

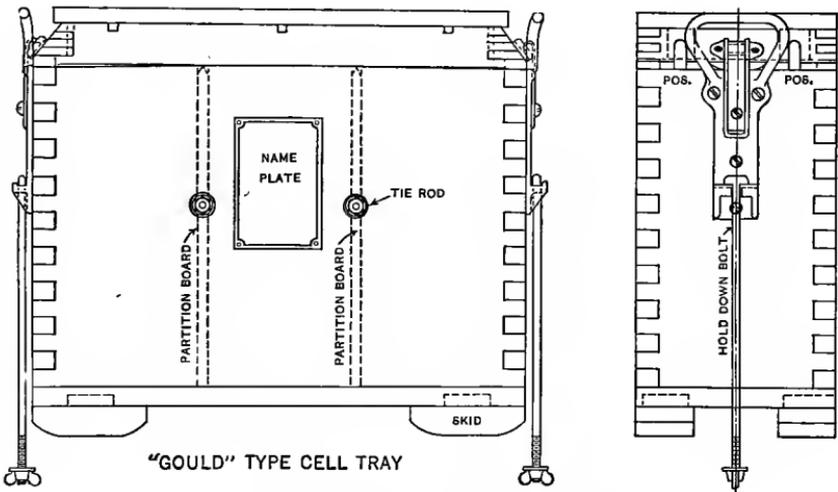


FIG. 85.—"Gould" Type Cell Tray.

**Philadelphia Storage Battery Company Type of Cell Tray.**—There is illustrated in Fig. 86 a type of tray developed by the Philadelphia Storage Battery Company and applied to their type storage batteries manufactured for the naval service. This illustration contains the various details of the tray, such as porcelain insulator skids, tie-rods, name-plate, cover clips for holding the tray cover in position, tray lifting device and hold-down attachment for securing the tray in position, etc. It will be noted that the tray cover is bevelled at each end, thus permitting the tray to be lifted while the tray cover is in position. The vent holes are shown in the side of the tray cover, there being three such holes on each side of the tray cover for allowing the escape of any gas which may be evolved from the cells. In this regard it should be borne in mind that during the regular charging of these batteries the cell trays should be habitually removed, as the evolution

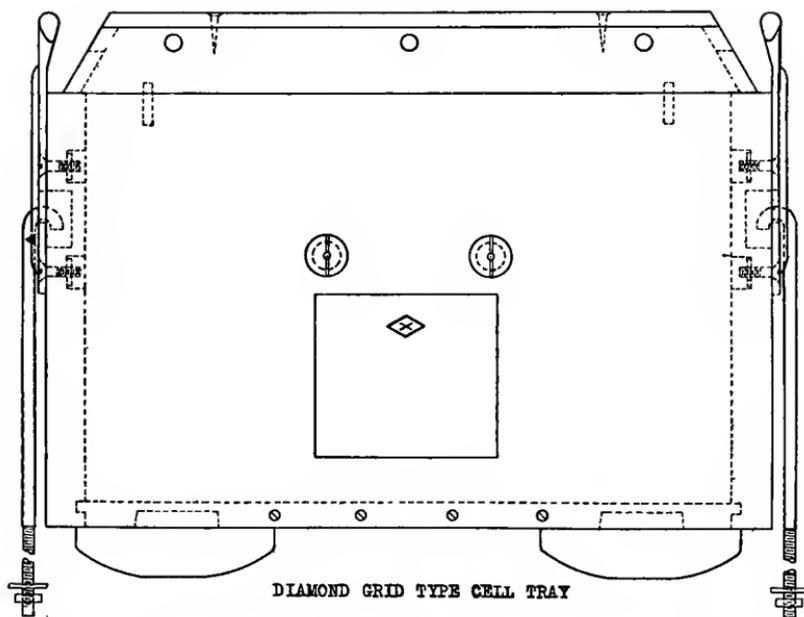


FIG. 86.—Philadelphia Storage Battery Type Tray.



FIG. 87.—Philadelphia Storage Battery Company's  
"Diamond Grid" Cell Tray.

of gas during the latter part of the charge may be considerable. The vent holes in the tray cover, as described above, are therefore designed to allow the escape of any gas which may have been entrained in the cells during the regular charge, or which may subsequently be formed as a result of any local action which may take place while the cell is standing idle or on open circuit. These precautions and expedients to insure proper cell ventilation should be observed in the operation of all types of storage batteries. A photographic illustration of one of these trays, showing also the method of installing the cells and making the cell connections, is given in Fig. 87.

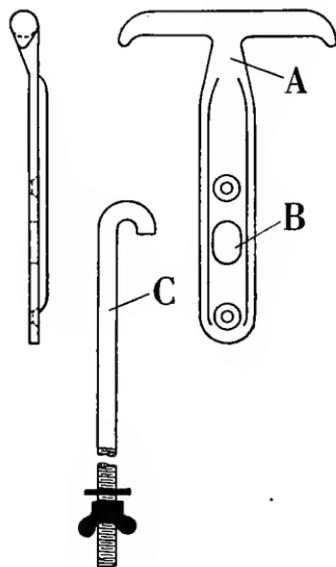


FIG. 88.—Philadelphia Storage Battery Type Hold-Down Attachment.

**Philadelphia Storage Battery Company Type Tray Lifting Device and Hold-Down Attachment.**—Fig. 88 contains a detailed illustration of the tray lifting device and hold-down attachment applying to the type of cell tray described in the preceding paragraph.

This device consists of a malleable iron lifting handle, shown at *A*, the bottom part of which is pad-shaped and designed for attaching to the end of the tray by means of two countersunk screw bolts and lock nuts, these lock nuts fitting in countersunk holes bored in the inside wall of the tray end-boards.

The hold-down portion of this attachment consists of the hold-down bolt, shown at *C*, the upper end of which is hook-shaped and designed to engage

in the oblong hole *B* of the lifting handle pad, the end-board on each end of the tray being counterbored in wake of the oblong hole *B* for receiving the hook of the hold-down bolt. The hold-down bolt is also threaded at the bottom end and equipped with a washer and wing-nut for securing the tray in position at the desired location. One of these attachments is installed on each end of the cell tray. The assembly details of this attachment are clearly shown in Fig. 86. All parts of this attachment are lead-plated to protect them against the corrosive action of the electrolyte.

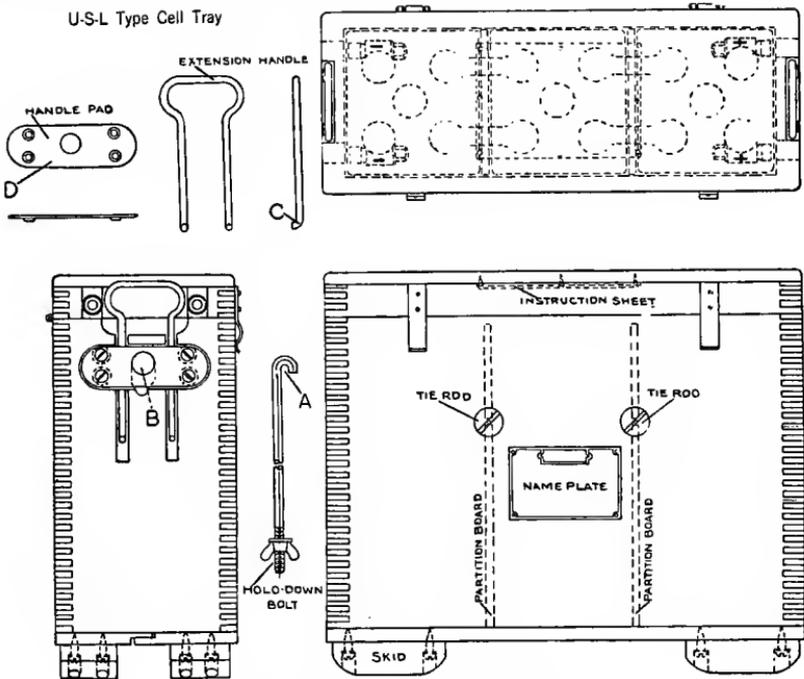


FIG. 89.—"U-S-L" Type Cell Tray.

**The "U-S-L" Type Tray.**—The type of tray manufactured by the U. S. Light and Heat Corporation, for their portable storage batteries supplied in accordance with the navy specifications, is shown in Fig. 89. This drawing clearly illustrates the various features of this cover, including the dovetailed and lock-cornered joints in the tray construction, method of securing the cover to the tray, tray tie-rods, method of installing the cells in the tray, inter-cell connectors, end cell terminals, porcelain insulator skids, impregnated wood partition boards placed between the cell, etc.

The details of the hold-down attachment and tray lifting device are also shown in this illustration. The lifting device consists of a bale-shaped

extension handle which houses down in a recess in the end of the tray cover when not in use. This handle contains two prongs or toes, shown at *C*, which take up against the handle pad secured to the end of the tray, thus facilitating lifting of the tray. The hold-down attachment consists of a hook-shaped hold-down bolt which is threaded at its lower end and fitted with a wing nut, the hook end *A* of this bolt being designed to seat in the hole *B* of the handle pad; the threaded end of the hold-down bolt passes through the deck, battery storage rack, or other such support for the tray,

Willard Type Cell Tray

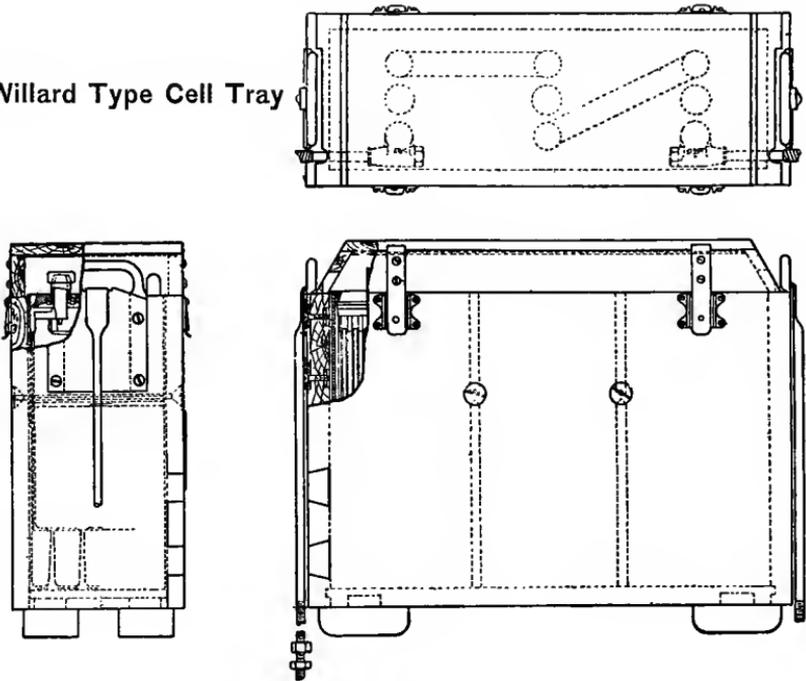


FIG. 90.—Willard Type Cell Tray.

and by setting up on the wing nut the cell tray is thus secured in the desired position. The general design and construction of this tray are considered very satisfactory for the batteries designed for the naval service.

**Willard Storage Battery Company Type Tray.**—There is shown in Fig. 90 a detailed illustration of the tray developed by the Willard Storage Battery Company for their type portable storage batteries supplied in accordance with navy specifications.

This illustration clearly shows the installation of the cells in the tray and the manner in which the cells are connected together, and with the service lines by means of the inter-cell and terminal connectors. The other features

of the tray construction, such as dovetailed or lock-corner joints, cover retaining clips, tie-rods, inter-cell partition boards, name-plate, porcelain insulator skids, tray lifting device and hold-down attachments, etc., are also shown in this drawing.

### Cell Tray Tie-Rods.

Fig. 91 contains an illustration of a type of tie-rod extensively used for holding the sides of the tray firmly against the cells and to thus prevent bulging or other distortion through checking or buckling of the lumber in the tray, or from any other cause. Experience in operating these batteries in our naval services has proved that such an expedient is necessary to enable these batteries to withstand the hard service usage.

These tie-rods are made of steel, lead-plated, and contain countersunk heads and nuts which are slotted for receiving a screw-driver, chisel or other such tool used in setting up on the rods. The holes in the sides of the trap



FIG. 91.—Details of Cell Tray Tie-Rod.

are counterbored to receive the bolt head and nut, such that when set up on the bolt head and nut are flush with the sides of the tray. The specifications for these batteries require that at least two of these tie-rods, symmetrically located, shall be installed on each tray.

In service these tie-rods should be set up on occasionally to insure that the tray is maintained in a rigid condition and thus prevent distortion of the hard rubber jars of the cells which, on account of the heat generated in the cell, would be liable to occur if the tray walls did not hold them firmly in position.

### Porcelain Insulator Skids.

There is shown in Fig. 92 a photographic illustration of the type of porcelain insulator skids used on the bottoms of the cell trays of the portable storage batteries in the naval service. These skids are of various sizes, depending upon the type and size of the batteries with which they are used. Four of these skids usually constitute a set for each tray, one skid being installed at each of the four corners of the tray, and in addition to serving as an insulator for the battery they are also used for sliding or skidding the

trays along the deck or other surface when it is necessary to move them for adjusting in position, etc.

There is also shown in Fig. 93 a line drawing of one of these skids. This drawing shows the method by which these skids are attached to the bottoms

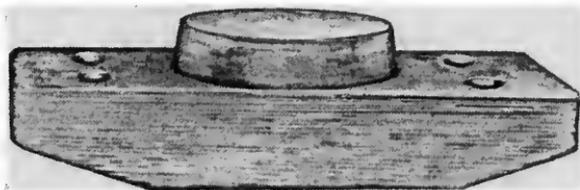


FIG. 92.—Porcelain Insulator Skid.

of the trays. It will be noted in this drawing that there is a boss on the top of the skid which fits into a corresponding hole in the bottom of the tray; there are also four counterbored holes in the skid for accommodating

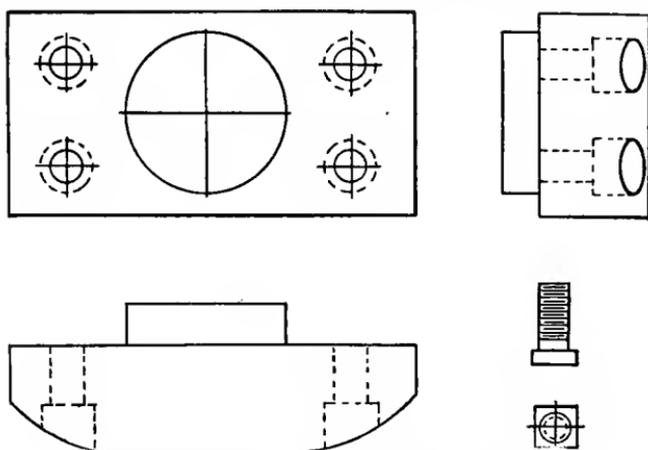


FIG. 93.—Details of Porcelain Insulator Skid.

the four brass screws which hold the skid to the tray. After these screws are driven home it is usual practice to pour sealing compound into the counterbored chambers on top of the screw heads, thus preventing the screws from backing out as well as preventing the collection of dirt, grease,

etc., in these holes. The outside surfaces of these porcelain skids are glazed, which is conducive to preventing them from absorbing moisture, also to assist their sliding over the deck more easily, as well as making them more easily kept clean. In some instances iron screws are used for attaching these insulator skids to the tray, in which case the screws are lead-plated to preserve them against the action of the acid of the electrolyte.

## CHAPTER XV.

### WATERING BATTERY.

**Cells Should Be Watered Regularly.**—It should be thoroughly understood that it is absolutely necessary to a proper and successful operation of the storage battery that the cells be watered periodically, in order to replenish that which has been lost through various causes and to thus insure that the level of the electrolyte is maintained at the proper height over the tops of the plates. The level of the electrolyte should *never* be allowed to fall below the tops of the plates.

The causes which are in general responsible for the loss of water during the operation of the storage battery may be stated as follows:

(a) Evaporation. The natural evaporation of the water in the electrolyte is increased, due to the fact that, as the battery is being charged, heat is generated in the cells. Also, the rate of evaporation varies with the atmospheric conditions to which the storage battery is subjected.

(b) Spillage.

(c) Spray incident to gassing of the cells.

(d) Lost in taking specific gravity and temperature readings. When taking specific gravity readings the sample drawn up in the hydrometer should always be returned to the cell from which it was taken.

(e) Leaky jar. When discovered, immediate steps should be taken to either replace the cell or renew the defective jar.

**Pure Water Only To Be Used.**—Special care should be taken to insure that none but pure water, preferably distilled if obtainable, which has been approved for battery purposes, is used in the storage battery cell.

Never use well water, water from a stream, lake, spring, or from regular water-works supply lines until it has been tested and found suitable for storage battery use. Water which has been boiled does not in itself constitute water suitable for battery use.

If no distilled water is available, clean, filtered rain water, or that obtained from melting artificial ice may be used. Never use rain water which has passed over stained shingles, composite or metallic roofs or gutters.

Certain impurities commonly found in water will seriously interfere with the proper operation of the battery, and in some cases will entirely ruin the cells. It should be borne in mind that all impurities which enter the cell, even in comparatively small amounts, on successive watering of the battery

will prove cumulative in effect and continual vigilance should, therefore, be observed at all times in securing pure water for the battery.

The impurities commonly found in water, and which are injurious to the storage battery, are iron, chlorine, calcium and magnesium oxides, ammonia, nitrates, nitrites, etc. The specifications for water suitable for storage battery use prescribe that the water shall not contain a greater amount of the above-mentioned impurities than outlined in the following table:

SPECIFICATION TABLE FOR STORAGE BATTERY WATER.

Impurities	Maximum Allowable Amount in Per Cent
Color .....	White
Iron .....	0.00005
Chlorine .....	0.0005
Calcium and magnesium oxides.....	0.004
Ammonia .....	0.008
Nitrites .....	0.0005
Nitrates .....	0.001
Organic and volatile matter .....	0.005
Suspended matter .....	Trace

Only in emergency cases of operation should water containing impurities in greater amounts than shown in the foregoing table be used; if used under such emergency conditions it is advisable in safeguarding the future satisfactory operation of the cell that the electrolyte be drawn off or the cells "dumped" at the earliest practicable opportunity and the cells thoroughly flushed or rinsed out with pure, approved battery water.

**Method of Clearing the Storage Battery of Impurities.**—Should the electrolyte become contaminated through the use of impure water, or from any other cause, the following procedure should be carried out:

1st. Discharge the cell completely at the earliest practicable opportunity.

2d. Remove all of the electrolyte from the cell. For small portable cells, the electrolyte may be conveniently "dumped" out and cells flushed several times with pure water. For larger cells, such as the submarine type, it may be necessary to remove the element and syphon off, or otherwise withdraw the electrolyte. Should it be necessary to remove the element for this purpose, it should be reinstalled immediately after flushing or rinsing the jar and element several times with pure water.

3d. Having thoroughly flushed or rinsed the element and jar, the cell should then be filled with new, approved electrolyte of required specific gravity and cell given a complete charge at the normal rate specified for the particular type. This charge should be continued at the specified *finishing* rate until a maximum specific gravity reading is obtained.

4th. Equalize the specific gravity of the electrolyte by raising or lowering, as may be necessary, to correspond with that of the other cells of the battery.

5th. After the cell has been put through from 10 to 15 cycles of operation in the new electrolyte, a sample of this electrolyte should be tested to ascertain whether or not the impurities were removed. If the electrolyte should be found to still contain impurities, the cell should again be dumped of the electrolyte and cell flushed and treated as outlined above until such impurities have been eliminated.

**When to Water Battery.**—In operating the storage battery a good rule of thumb to apply is to inspect and fill the cells with water once every week in warm weather, and once every two weeks in cold weather. However, as has been stated, in every case the prime precaution to observe is that of never allowing the level of the electrolyte to fall below the tops of the plates. For the submarine service, special routine watering and inspection is prescribed.

Best results will obtain if the cells are habitually watered, as necessary, just before starting a charge, as by so doing thorough mixing of the water with the acid is accomplished through the gassing of the cells during the charge. Watering the battery just before starting a charge is also advantageous in cold weather in guarding against freezing, as the mixing of the water with the acid during the charge, as outlined above, prevents freezing.

After watering battery no dependence should be had in hydrometer readings taken before the water and acid have been thoroughly mixed as, due to the fact that the water is lighter than the acid, it will remain on top, and such readings will prove entirely misleading in respect to the true state of charge of the battery.

**Precautions for Handling and Storing Water.**—Pure distilled water has a great affinity for practically all base metals, except lead and tin; therefore, it is necessary when handling, transporting or storing water for battery use that no metallic vessels, other than lead or tin lined, be used for this purpose, in order to avoid the probability of contaminating the water. However, glass, porcelain, earthenware or rubber vessels, when thoroughly clean, may be used for this purpose; clean lead or glass carboys and earthenware jugs make suitable containers for storing small quantities of battery water, but they must be kept tightly sealed with clean corks.

Ordinary wooden water-breakers found on board ship may also be used, but care should be taken, before using them for storing battery water, that they are thoroughly boiled out with a solution consisting of caustic soda and pure water in order to neutralize the wood acids and other organic matter which are injurious to the storage battery plates. After boiling for three or four hours in a 3 to 5 per cent caustic soda solution, they should

then be thoroughly rinsed out with pure water, after which they are suitable for storing battery water.

In storing large quantities of battery water on board ship, submarine tenders, at service stations, etc., large lead-lined wooden tanks containing a closely fitting cover should be used, but all pipes and fittings should be given a substantial coating of tin. Alcohol barrels, which have been thoroughly cleaned by boiling in a caustic soda solution, also make suitable containers. Barrels which have contained oil should not be used for this purpose.

CHAPTER XVI.  
CHARGING AND DISCHARGING BATTERIES.

Charging.

**The Function of Charge.**—We now come to consider the function of charge and its relation to the life and operation of the storage battery cell. First of all, it should be understood that the sole object of charging is that of driving out of the plates the acid radical ( $\text{SO}_4$ ) of the electrolyte which, during discharge, has combined with the active material of the plates, and of restoring this radical to the electrolyte thus completing the battery cycle and putting the cell in condition for responding to subsequent discharge.

At this juncture it should also be understood that the storage battery is in many respects not unlike the human body in that it is necessary that a proper balance be at all times maintained between food administered and work or exercise performed, in order that it may be preserved in a vigorous, healthy state for properly performing its allotted duties. That is to say, if the human body receives too much food without sufficient exercise the result is that sluggishness sets in, which in turn leads to disease and ultimate physical breakdown. So it is with the storage battery, for if it receives too much charge in proportion to the amount of work which it performs, the result is that the battery likewise becomes diseased and unable to respond to its allotted duties.

Then, too, if the human body be worked continually without receiving sufficient nourishment and rest, fatigue followed by disease set in, and in time the body will succumb to exhaustion. Here, also, the same course of reasoning applies to the storage battery, for in order for it to respond to its natural functions it must receive proper nourishment and must not be worked to exhaustion any more than the human body. In battery parlance a starved battery is one which, through lack of charging, is in an abnormally sulphated condition.

Therefore, inasmuch as charging current constitutes the food and nourishment of the storage battery cell, it is obviously of paramount importance to the successful operation of the battery that the various methods and features characteristic of charging be thoroughly understood by the operating personnel, and these methods and features will accordingly be taken up and explained in the succeeding text.

**The Two Systems of Charging.**—Depending upon the manner in which the cells are connected with each other and with the charging buses, there are two systems of charging storage batteries, which are as follows:

- (a) Series.
- (b) Parallel.

**Charging in Series.**—When charging in series all cells are connected in series relation with each other and with the charging buses; that is, the positive terminal of one cell is connected to the negative terminal of the adjacent cell, and so on from cell to cell, while the positive terminal of one end cell in the group is connected to the positive charging bus, and the

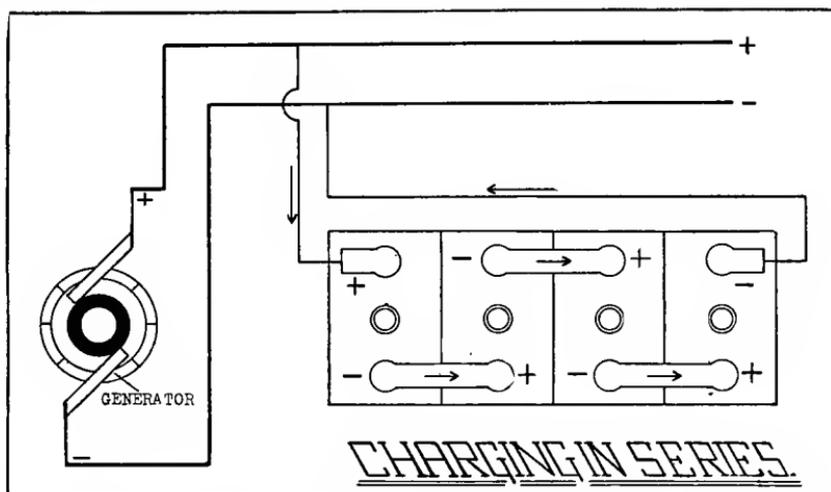


FIG. 94.—Showing Method of Connecting Cells for Charging in Series.

negative terminal of the other end cell is connected to the negative charging bus.

Fig. 94 contains a detailed drawing clearly illustrating the method of connecting up the cells with each other and with the charging buses for charging in series, the direction of the flow of current through the circuit being indicated by the arrows in the drawing.

In order to completely charge a battery when charging in series, the voltage of the charging lines should be not less than 2.65 times the number of cells connected in series. Also, for reasons which will later be explained, it may be said that charging in series is conducive to more uniform results in respect to the condition and operation of the individual cells than when charging them in parallel, and, where the capacity of the generator equipment is sufficient, charging in series is therefore recommended.

**Charging in Parallel.**—When charging in parallel each cell or battery is connected in parallel relation with the other cells or batteries and the charging lines; that is, the positive terminals of all cells or batteries are connected to the positive charging bus, while all negative terminals are connected with the negative charging bus. However, it may be said that as a general rule it is rare that individual cells are charged in parallel, as in most cases of charging by the parallel system the individual cells are assembled in series relation with each other in the trays, while the trays are in turn connected in parallel relation with each other.

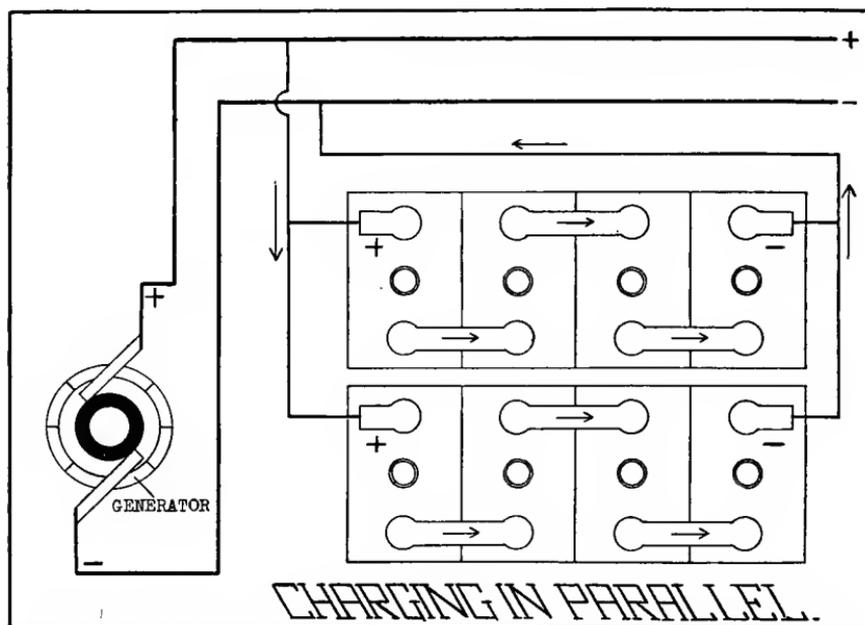


FIG. 95.—Showing Method of Connecting Batteries for Charging in Parallel.

Fig. 95 contains a drawing illustrating the method of connecting up the batteries for charging them in parallel. It will be noted that the cells of each battery tray are connected in series with each other, whereas, the trays are connected in parallel relation with each other as described above. The direction of the charging current passing through the circuits is indicated by the arrows in the drawing.

It may be said that the chief objection to charging batteries by the parallel system is that in case the internal resistance of the cells or batteries in one group is higher than that of another group, the result is that the batteries do not receive a uniform amount of charging current. Manifestly this is true.

since for a given charge the group of cells having the least internal resistance will receive more charging current than the other group or groups.

On the other hand, however, under certain conditions, the parallel system of charging may be used to advantage. One of the advantages to be gained by using this system is where it is impossible or impracticable to reduce the charging line current to the required amount for charging a particular set of batteries. In such a case the charging current which passes through each cell may be reduced to the required amount by connecting the batteries in parallel relation with each other. Thus, if the charging line current be 100 amperes, and there are two sets of batteries to be charged but whose charging rates should not exceed 50 amperes, then the required charging rate may be obtained by connecting the two sets of batteries in parallel relation with each other.

Another advantage obtained by this system is where the voltage of the generator set is insufficient to charge all cells of a given battery installation when connected in series. Under such conditions a full charge may be put into the battery by suitably grouping the trays in parallel relation, such that the available charging line voltage is sufficient for completing the charge when connected in this manner. In this regard it is frequently the practice to design the generator equipment for a given battery installation with just sufficient capacity to fully charge the battery when the trays are connected in parallel with each other, whereas, the batteries are normally discharged in series. In other words, the power supplied for charging is not as great as that normally required on the line when discharging the batteries. This feature is described more fully under the subject of discharging batteries.

**Practical Charging Methods.**—There are in general three practical methods employed in charging storage batteries each method of which depends upon the special operating conditions to which the battery is subjected, as well as the available facilities and charging equipment. These methods may be classified as follows :

- (1) Constant potential method.
- (2) Constant current method.
- (3) Multi-stage current regulation method.

**Constant Potential Method.**—The application of this method is based upon the principle of maintaining the voltage of the charging lines at a predetermined constant value throughout the charge and, as the charge progresses, since the counter-electromotive force developed by the cells increases, the charging current gradually decreases until at the end of the charge the theoretical value of the charging current is equal to zero; in other words, inasmuch as the resistance or counter-electromotive force offered by the

cells at full charge exactly equals the charging voltage, an electrical balance obtains and accordingly no charging current passes through the cells.

However, in actual practice, it may be said that it is both difficult and impracticable to gauge and regulate the charging voltage and current within these narrow theoretical limits, and a slightly modified application of this principle is therefore used in charging by this method.

In this method approximately 60 per cent of the charge can be put into the battery during the first hour, provided, of course, that the generating sets, as well as wiring, connectors, etc., are of sufficient capacity to supply and accommodate the high rate of current which the battery is capable of absorbing during this period. In the case of a completely discharged battery the charging current during this period may run as high as from 5 to 6 times the normal charging rate.

When using this method it is common practice to begin the charge with the generator voltage or charging line voltage equal to 2.30 times the number of cells connected in series in the circuit, and to maintain this constant voltage until the charging current is gradually reduced to the finishing rate of the cells in the circuit; when the finishing rate is reached the generator or line voltage should be raised sufficiently to complete the charge at this rate.

Relative to the above method of computing the value of the constant voltage on the basis of 2.30 volts per each cell connected in series in the circuit, it should be stated that 2.30 volts is sufficiently below the *critical gassing point* of the cell as to prevent damage from gassing, so that, as long as the voltage is kept at or below this value, no harm will be done to the cells. Moreover, it is even possible to allow the battery to remain on charge, under these conditions, without receiving any attention whatever and without any danger of injurious gassing or overcharging incident thereto. As the charge progresses and the voltage of the cells rises, the charging rate is simply reduced until the cell voltage rises to 2.30 volts, at which time an electrical balance obtains between the line voltage and the counter-electromotive force of the cells and no further current passes into the battery.

However, it should also be stated that in general it is impossible to completely charge the cells with this voltage, especially at very low cell temperatures or in case that the cells are in a badly sulphated condition, in either case of which the added internal resistance of the cells necessitates a higher line voltage in order to completely charge the battery.

The *critical gassing point* of a cell on charge occurs at or about 2.35 volts, and generally speaking the finishing rate of charge should always be conducted on a basis of at least 2.35 volts per cell for each cell connected in series in the circuit in order to insure that the cells receive a complete charge.

Especially is this true when giving the cells an *equalizing charge*, in which case it is not uncommon for the charging voltage to average 2.65 volts per cell at the end of such a charge.

When using the constant potential method of charge, and in the event that the generator or line voltage is greater than 2.30 times the number of cells connected in series, and where it is not possible or practicable to reduce the line voltage to the required value by means of generator regulation, it is sometimes very convenient to use counter cells for the purpose of absorbing the surplus line voltage, the number of such cells required in the circuit being computed on a basis of 3.0 volts per cell. Accordingly, from the statements set forth above the following formula may be evolved:

Let

$E$  = Generator or charging line voltage.

$n$  = Number of cells connected in series.

$N_{cef}$  = Number of counter-electromotive force cells required in the circuit.

Then:

$$E = (2.30 \times n) + (3.0 \times N_{cef}).$$

Or:

$$N_{cef} = \frac{E - (2.30 \times n)}{3.0}.$$

*Example.*—It is desired to charge by the constant potential method a set of stand-by radio batteries consisting of 60 cells connected in series. The voltage of the charging line is 225 volts and it is impracticable to reduce this voltage by generator regulation or otherwise. Find the number of counter cells required to be connected in the circuit with this battery in order to charge it by this method.

*Solution.*—Substituting in the above formula we have:

$$N_{cef} = \frac{225 - (2.30 \times 60)}{3.0} = 29 \text{ cells.}$$

Therefore, 29 counter-electromotive force cells are required in series with the 60 cells of this battery in order to charge it by this method.

The counter-electromotive force or counter cells mentioned above consist of cells which are identical in design with the other cells of the battery in every respect with the exception, however, that no active material is contained in the plates, it being the general practice to use unpasted or dummy grids for the plates of such cells.

Although these cells contain electrolyte and should be watered regularly, and should also receive the same attention as to cleanliness and care of connectors as the other cells of the battery, it is unnecessary to take tem-

perature and hydrometer readings of these cells, as practically no change in the specific gravity of the electrolyte is manifested either during charge or discharge.

When such cells are used it may be said that it is in general preferable to connect them on the positive side of the circuit. Fig. 96 contains a detailed illustration of a set of batteries connected up for a charge and in circuit with which is also connected a set of counter cells as described above. The

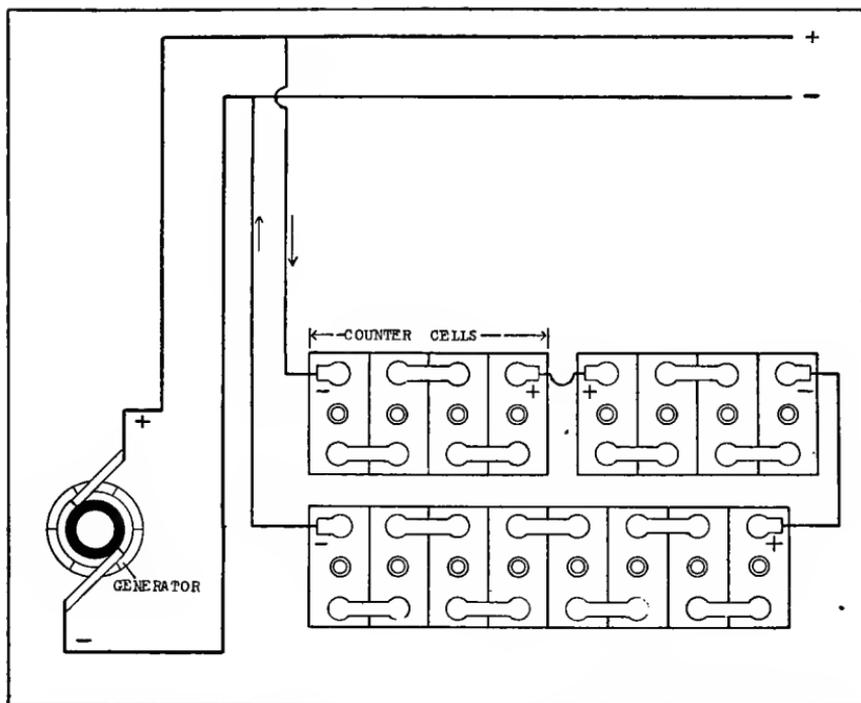


FIG. 96.—Showing Method of Charging with Counter Cells in Circuit.

method of making the various connections in this circuit is plainly shown in this illustration.

Particular attention is invited to the fact that the positive terminal of the battery is connected to the positive terminal of the set of counter cells, and that the negative terminal of the set of counter cells is connected to the positive charging bus. Obviously, this arrangement is necessary to effect the required reduction in the charging line voltage.

Where facilities are available and operating conditions permit, the constant potential method of charging storage batteries is considered an excellent one.

**Constant Current Method.**—In the constant current method of charging batteries the charging rate is set at some specific value at the beginning of the charge, and as the charge progresses and the voltage of the cell rises, the charging line voltage is accordingly raised sufficiently by generator regulation, rheostat, or other means to continue and complete the charge at this specified rate. Depending upon the available facilities for charging, time, operating conditions, etc., the constant current method of charging may be further subdivided into two other methods, each of which will be later described. These methods are as follows:

- (a) Sustained low rate charge.
- (b) Quick or emergency charge.

**Sustained Low Rate Charge.**—In practice it has been found that when operating conditions permit and the necessary facilities are available, a very satisfactory method of charging batteries consists of selecting a very low charging rate, such as the 20-hour or the 24-hour discharge rate, and to continue to completion the charge at this rate. This method is especially conducive to increased life of the battery in that the injurious effects of gassing and high temperatures during charge are reduced to a minimum. Minimum amount of detailed attention required while charging the battery is another characteristic feature of this method; this constitutes a very desirable feature for certain classes of service where there are limited facilities and personnel for taking care of the batteries while charging.

This method of charging is also especially effective and satisfactory when treating a badly sulphated battery in order to restore its capacity.

**Quick or Emergency Charge.**—Under certain conditions of operation, it becomes both necessary and advisable to put into the battery in minimum time a maximum amount of charge consistent with minimum wear and tear on the plates and other parts; such a charge is commonly referred to as a *quick or emergency charge*. This is another constant current method of charging and is based upon the principle that, for any state of discharge, a battery is capable of absorbing current at any rate without injury to the plates and other parts, provided this rate be not high enough to cause gassing or heating.

In general, this method contemplates the use of an ampere-hour meter in order that the exact state of the discharge may be known for computing the charging rate. It should also be stated that this method of charging requires the constant attention of the operating personnel throughout the charge, in order that the charging rate may be reduced at the proper time to prevent injury to the plates should the battery show signs of gassing or heating.

Ordinarily, a charge by this method may be satisfactorily conducted if the following rule is followed:

*Provided the maximum limiting value of the temperature is not exceeded, the charging rate in amperes at any time may equal but must not exceed the state of discharge expressed in ampere-hours at that time, and the "finishing rate" for the particular type of battery may be carried at any time during such a charge.*

The above rule may be analytically expressed as follows:

Let

$C$  = Charging current.

$AH$  = State of discharge expressed in ampere-hours.

$t$  = Time available for charging.

Then

$$C = \frac{AH}{1+t}; \text{ or } t = \frac{AH-C}{C}.$$

*Example.*—The storage batteries of a submarine have been discharged to the amount of 1000 ampere-hours, and there is available one hour for putting in an emergency charge. Find the charging rate such that a maximum amount of charge may be put into the battery within this time limit.

*Solution.*—Substituting in the above formula, we have:

$$C = \frac{1000}{1+1} = 500 \text{ amperes.}$$

Hence, the charging rate under the conditions outlined in the above problem is 500 amperes.

With regard to this method of charging it should be understood that the charging rate as obtained from the above formula must not be continued for longer than the specified time for charging, and should the battery show signs of gassing or heating before the expiration of this time, the rate should be immediately cut to the *finishing rate*. Attention is again invited to the fact that when charging by this method the battery requires constant attention to safeguard it against damage from gassing and heating, and under conditions of hot weather, when the battery has a high initial temperature, this method may prove entirely impracticable, in which case one of the other charging methods should be used.

The following table contains charging rates for use with this method, and these current values apply to all lead-acid type batteries irrespective of size. The other arguments constituting this table are the state of discharge of the battery and the time available for the charge. The method of using this table is self-explanatory.

TABLE OF CHARGING RATES FOR EMERGENCY OR QUICK CHARGE.

Amount of discharge in ampere-hours.	Time available for charging.															
	½ hr.	¾ hr.	1 hr.	1¼ hrs.	1½ hrs.	2 hrs.	2½ hrs.	3 hrs.	3½ hrs.	4 hrs.	4½ hrs.	5 hrs.	5½ hrs.	6 hrs.		
	AMPERES.															
20	16	13	11	10	8	8	7	6	5	5	4	4	3	3	3	3
30	24	20	17	15	13	12	10	9	8	7	6	6	5	5	4	4
40	32	27	23	20	18	16	13	12	11	10	9	8	7	6	6	5
50	40	33	28	25	21	20	17	15	14	12	11	10	9	8	7	7
60	48	40	34	30	26	24	20	18	17	15	13	12	11	10	9	8
70	56	47	40	35	30	26	23	20	19	17	15	14	12	11	11	10
80	64	53	45	40	35	32	26	23	22	20	18	16	14	13	12	11
90	72	60	51	45	40	36	30	27	25	22	20	18	16	15	14	12
100	80	66	57	50	44	40	33	30	28	25	23	20	18	16	15	14
110	88	73	63	55	49	44	37	34	30	27	25	22	20	18	16	15
120	96	80	68	60	53	48	40	37	33	30	27	24	22	20	18	17
130	104	87	75	65	58	52	43	40	36	32	29	26	24	21	20	18
140	112	94	80	70	62	56	47	43	39	35	31	28	26	23	21	20
150	1 0	100	86	75	67	60	50	46	42	37	33	30	28	25	23	21
160	128	106	91	80	71	64	53	49	45	40	35	32	30	26	24	22
170	136	112	97	85	75	68	57	52	48	42	37	34	32	28	26	24
180	144	120	104	90	80	72	60	55	51	45	39	36	34	30	28	25
190	152	126	108	95	85	76	63	58	54	47	42	38	36	31	29	27
200	160	133	114	100	89	80	67	61	57	50	45	40	38	33	31	28
225	180	150	128	112	100	90	75	69	64	56	48	45	40	37	34	32
250	200	167	143	125	112	100	83	76	71	62	55	50	45	41	37	35
275	220	183	157	137	122	110	91	84	78	68	61	55	50	45	42	39
300	240	200	171	150	133	120	100	92	85	75	66	60	55	50	46	42
400	320	266	228	200	177	160	133	123	114	100	88	80	72	66	61	57
500	400	333	285	250	222	200	166	154	142	125	111	100	90	83	76	71
1000	800	660	571	500	444	400	333	307	280	250	220	200	180	160	153	142
1250	1000	830	714	625	555	500	416	384	350	310	275	250	225	200	192	178
1500	1200	1000	857	750	666	600	500	461	425	375	330	300	270	250	230	214
2000	1600	1330	1142	1000	888	800	660	615	570	500	440	400	360	330	307	285
2500	2000	1660	1428	1250	1111	1000	833	769	710	625	550	500	450	410	384	356
3000	2400	2000	1714	1500	1333	1200	1000	923	850	750	660	600	540	500	461	428
3500	2800	2330	2000	1750	1555	1400	1166	1076	1000	875	775	700	630	580	538	500
4000	3200	2660	2285	2000	1777	1609	1330	1230	1140	1000	880	800	725	660	615	571
4500	3600	3000	2571	2250	2000	1800	1500	1384	1280	1125	1000	900	810	750	692	642
5000	4000	3330	2857	2500	2222	2000	1666	1538	1425	1250	1110	1000	900	830	761	714
5500	4400	3660	3142	2750	2444	2200	1833	1692	1570	1375	1220	1100	1000	910	846	785
6000	4800	4000	3428	3000	2666	2400	2000	1846	1710	1500	1330	1200	1090	1000	923	857
6500	5200	4333	3714	3260	2888	2600	2166	2000	1857	1625	1444	1300	1181	1083	1000	928
7000	5600	4666	4000	3500	3111	2800	2333	2153	2000	1750	1555	1400	1272	1166	1076	1000
7500	6000	5000	4285	3750	3333	3000	2500	2307	2142	1875	1666	1500	1363	1229	1153	1071
8000	6400	5333	4571	4000	3555	3200	2666	2461	2285	2000	1777	1600	1464	1333	1230	1142

Should the battery installation be not equipped with an ampere-hour meter, or if the time available for the charge be not definitely known, the following modification of this method may be used:

Consult either the battery data contained on the name-plate attached to the front of the tray, or the characteristic curves supplied with the battery and find the *starting rate* for the particular battery in question. Having

thus ascertained the normal *starting rate*, begin the charge at 50 per cent higher than this value and continue the charge at this rate until the cells show signs of gassing, at which time cut the charging rate to the normal *starting rate* as shown on the name-plate or characteristic curves. Proceed with the charge at this rate until the cells again show signs of gassing or heating, and at which time cut the charging rate to the *finishing rate*, which is also found on the name-plate or characteristic curves, then complete the charge at this rate. If time permits, the *finishing rate* should be carried until the cells are gassing freely to insure that the battery is fully charged. This method is not recommended for general practice, and only in cases of emergency should it be attempted in hot weather. The temperature of the cells should not be allowed to rise higher than 110 degrees Fahrenheit.

**Multi-Stage Current Regulation Method.**—Although this method of charging may be properly classed as a modification of the constant current method described in the preceding paragraphs, it is nevertheless here considered under a separate heading for the reason that there are some special features connected with it which will later be explained as well as the fact that, in so far as the naval service is concerned, next to the constant potential method of charging, this method may be said to meet with more common application than any of the others; in fact, a charge put into the battery by this method is frequently referred to and is commonly known as a *normal charge*, as practically all battery manufacturers now use this method as a basis in constructing their characteristic curves and in making up the name-plate data supplied with their batteries. Moreover, such characteristic curves of charge and name-plate data usually cover a full charge following a complete discharge conducted at the 3-hour rate.

For the small or portable types of batteries this method usually consists of two stages of current regulation, the larger one of which is known as the *starting rate*, and is the rate at which the charge is begun, while the smaller one is known as the *finishing rate*, since it is at this rate that the charge is completed. For practically all types of lead-acid batteries these charging rates approximate very closely the 6-hour and the 10-hour discharge rates respectively.

In using this method the *starting rate* is carried until the cells begin to gas or for a predetermined interval, as shown on the characteristic curve of charge, after which the rate is cut to the *finishing rate* and the charge completed at this rate. This method is especially convenient for charging when it is apparent that there is ample time for charging by this method, or where there is no necessity for an emergency charge, since the rates have been properly established for a particular battery by the battery manufac-



turers, and under normal conditions the battery should therefore be capable of receiving such a charge with practically no likelihood of injury from excessive gassing or overheating.

There is shown in Fig. 97 a typical set of battery characteristic curves, such as are supplied for batteries manufactured for the naval service. The characteristic charging curve is shown at *E*, and it will be noted that this curve is of the 2-stage type which, as stated, is common for portable batteries; the curve of ampere-hour capacity for the various discharge rates is shown at *A*; the curve of final volts is shown at *B*; *C* is the curve of average volts, while *D* represents the curve of initial volts; *F* is the temperature coefficient curve for the 1-hour discharge rate, *G* that for the 3-hour discharge rate, and *H* that for the 10-hour discharge rate. In regard to these temperature coefficient curves it should be noted that the 100 per cent capacity point for each curve is at 80 degrees Fahrenheit, the standard temperature upon which all capacity and discharge data for batteries of the naval service are based. Also, while the set of curves in this illustration include all discharge rates up to 10 hours, which is standard practice for the portable types of batteries, it should be stated that the standard curves for submarine batteries show all rates up to and including the 20-hour discharge rate, since under war-time operating conditions a 20-hour discharge for this service is not uncommon.

**Submarine Charging Methods.**—For the submarine service it may be said that the multi-stage charging method should consist of not less than three stages of current regulation, and, although some authorities advocate the 2-stage method for submarine batteries as well as for the portable types, for reasons which will later be explained, operating experience has nevertheless clearly demonstrated that the 3-stage method is preferable to the 2-stage method for this service.

With further reference to the general subject of charging methods applicable to submarine batteries it should be stated that the *constant potential* method is also an excellent one and is recommended for this service, where operating conditions permit; but it must be borne in mind that this is a very exacting and strenuous service and that it may not always be convenient or even possible to charge by this method inasmuch as this method generally requires the services of two engines, two generators, and their crews, and in the event of disability of either of these units, or when it is considered advisable to keep one of them in reserve for emergency, it is therefore apparent that it may not always be convenient or practicable to charge by the constant potential method.

Therefore, although the constant potential method is extensively used, it may be said that the multi-stage current regulation method constitutes

the standard charging method for submarines, since it can be used at all times as long as one engine and one generator are available. The characteristic charging curves supplied with submarine batteries by the manufacturers are accordingly based upon the multi-stage method of charging, although the sheets upon which these curves are plotted also contain the necessary data for charging by the constant potential method.

As previously pointed out, when using the multi-stage current regulation method of charging for submarines, the 3-stage system of current regulation is considered preferable to the 2-stage method. In arriving at this conclusion it is necessary to take into account certain well-defined principles of submarine boat construction and design.

In the first place, when the design of the submarine is being laid down, a battery of such size and characteristics is selected as will, when used in conjunction with certain other electrical and motor equipment, produce a given submerged speed with the boat for a definite period of time. Moreover, the capacities of the battery, motors, engines, charging equipment, etc., having thus been determined, it next becomes the function of the boat builders, through their subcontractors or manufacturers of these various units, to so co-ordinate the methods and instructions laid down for operating this equipment as will produce maximum efficiency with the boat operating as a whole.

With particular reference therefore to the feature of charging submarine storage batteries, it may be stated that for a given capacity of generator equipment it in turn becomes the function of the battery manufacturer to develop his characteristic curve of normal charge to accord with the capacity of the charging equipment when operating at full efficiency. Furthermore, the boat builders should use this charging curve as a basis for establishing the capacity of the battery ventilation system, and designing this system such that it will properly control the battery temperature and carry off the gases formed during such a charge.

There are four prime factors which bear an intimate relation to the general subject of charging submarine batteries and which must necessarily be considered in designing the ventilation system, as well as in the adoption of a proper charging method. These factors are as follows:

- (1) Evolution and control of gas.
- (2) Control of temperature.
- (3) Time required for charging.
- (4) Consumption of water.

Now, in considering the relative merits of the 3-stage system as against the 2-stage system of current regulation during a charge, of the four factors enumerated above, only the last two need be taken into consideration, since

it is assumed that the first two of them have been properly taken into account in the design of the ventilation system, as they must be satisfactorily provided for no matter what system of charging is used. Time required for charging and consumption of water are then the two factors which must be reckoned with in establishing the superiority of one of these systems of current regulation over the other.

Let us first consider the time available for charging, as it is of strategic as well as of tactical importance that, consistent with proper treatment of the battery, a charge should be completed in the earliest practicable time. It has been found that the time saved in putting in a full charge by the 3-stage system of current regulation over that of the 2-stage system amounts to from 20 to 30 per cent, and other things being equal, this in itself is considered of sufficient importance to justify the adoption of the 3-stage system.

Furthermore, for a given charge the duration of the charging period at the *finishing rate* is less with the 3-stage system than with the 2-stage system; hence, the wear and tear on the engines while charging under the light load of the *finishing rate* is not so great, since the engines operate under this light load for a shorter period. This is considered another distinct advantage in favor of the 3-stage system.

Next, in taking up the consumption of water factor, it follows that since the time to complete the charge by the 3-stage system of current regulation is less than that of the 2-stage system, the time that the ventilation blowers are actually in operation is correspondingly reduced, with the consequent reduction in the amount of water which is carried out of the cells as moisture with the air when the ventilation blowers are in operation. This is another advantage of the first order in favor of the 3-stage system. To summarize the above advantages we have the following:

- (a) Less time required for charging.
- (b) Less wear and tear on the engines.
- (c) Less water consumed.

Hence, it is very apparent that the 3-stage method of current regulation is to be preferred to the 2-stage method for charging submarine batteries. It is usual practice to designate the three stages of this method as *starting rate*, *intermediate rate*, and *finishing rate*.

**The Initial Charge.**—The object of the initial charge is to advance the conversion of the active materials in the plates beyond the stage attained by them during the *formation charge*, thereby placing the plates in condition for developing their maximum capacity within a few succeeding cycles of charge and discharge. The initial charge therefore constitutes a most important period in the life of a storage battery plate in that it is during this period that the particles of active material begin to assume their

proper relative positions in the plates, and upon which feature largely depends the future satisfactory operation of the plates. It should here be said that there are many cases of defects which later develop in a plate that can be attributed directly to not giving proper attention to details during the initial charge. It is manifestly of great importance, therefore, that detailed attention be given to the manner in which this charge is conducted and to observe certain fundamental principles during the course of this charge.

In the first place, the prime precaution to observe is that of insuring that the initial charge is completed in every respect before placing the battery on discharge.

Before beginning the initial charge the element of each cell should be inspected to insure that it is in good condition in respect to separators, plates, etc., after which the cells should be filled with electrolyte, care being taken to adjust the level of the electrolyte at the proper height above the tops of the plates and separators. Owing to the fact that the treated wood separators contain a certain amount of water, the specific gravity of the filling electrolyte should be from 20 to 30 points (.020 to .030) higher than the required specific gravity at full charge. Also, after filling the cells with electrolyte they should be allowed to stand from 10 to 12 hours in order that they may cool down before beginning the initial charge.

After pouring the electrolyte it will be noted that there is an appreciable drop in the specific gravity of the electrolyte, due to the fact that a certain portion of it combines with the active material of the plates. However, upon beginning the initial charge the specific gravity again rises to normal. During the initial charge if the specific gravity rises above the normal full charge value, some of the electrolyte may be drawn or siphoned off and pure distilled or other approved battery water added to reduce the gravity to the desired value.

The initial charge rate is usually supplied by the battery manufacturers with the characteristic curves and other battery data, but in absence of a specific charging rate, the initial charge may be satisfactorily conducted by selecting a rate of from 50 to 75 per cent of the normal *finishing rate* of the particular battery in question.

The length of time required for completing the initial charge will vary with the charging rate, a low charging rate requiring more time than a higher one. In general, it may be said that it requires from 75 to 90 hours to complete the initial charge, but of course this varies with the rate, number and length of interruptions during the charge, etc.

During the charge periodic voltage, temperature, and specific gravity readings should be taken and recorded on all cells. Select certain cells

located in the center of the rows or trays of batteries for pilot cells. The routine readings of pilot cells should be taken at least every hour during the first 50 hours of the initial charge, and an overall set of readings taken on all cells every 5 hours during this period, after which pilot cell readings should be taken every 30 minutes and overall cell readings taken at least every 2 hours.

The initial charge should be conducted until the voltage and specific gravity readings have remained constant for a period of from 10 to 12 hours and all cells are gassing freely. As has been stated, this is a very important feature of the initial charge, and care should be taken in every case to insure that the initial charge is completed before the battery is placed on discharge.

It is especially important that the temperature of the electrolyte be watched closely during the charge in order to detect any signs of overheating in the cells. The temperature of the cells should not be allowed to exceed 110 degrees Fahrenheit, and if it is seen that the temperature is approaching this value the charging rate should be reduced, or the charge discontinued until the cells cool sufficiently for proceeding with the charge at the normal rate. The exception to this rule is when batteries are operated with reduced gravity of electrolyte in the Tropics, in which case the maximum temperature limit is 125 degrees Fahrenheit.

For cells equipped with forced ventilation systems, such as the submarine type, all parts of the ventilation system should be inspected before filling the cells with acid and beginning the initial charge. Be sure that each cell exhaust nipple is properly connected with the main exhaust ducts, and that there are no kinks or other defects in the soft rubber goose-necks and other connections which would impair the ventilation.

Also, before beginning the initial charge all inter-cell and terminal connectors should be carefully inspected for cleanliness and to be sure that they are tight in order to avoid heating during the charge. These connectors should also be regularly inspected for heating during the course of the charge.

**The Equalizing Charge.**—Again referring to certain similarities existing between the human body and the storage battery cell, it may be said that each cell possesses certain individual characteristics as is also the case with human bodies, and it is during the operating as well as the idle periods that these individual characteristics manifest themselves. In general it may be said that the effects of these individual characteristics may be translated directly into terms of various degrees or comparative stages of charge of the individual cells of a battery, and the *equalizing charge* is therefore designed to periodically correct the effects of this individuality and to restore all cells

to as uniform a degree of full charge as is possible under practical operating conditions.

The same charging rates are used for the equalizing charge as are used for a normal charge; in fact, the only difference between a normal charge and an equalizing charge is that the equalizing charge is continued at the finishing rate for a longer period, and as shown by no rise in the specific gravity of the electrolyte of the pilot cells for eight successive readings taken at 15-minute intervals. In other words, the equalizing charge is continued at the finishing rate for at least two hours after no rise in the specific gravity of the electrolyte is apparent, and it is during this period that uniformity in the state of charge of the individual cells is attained.

Ordinarily, best results will obtain if the routine for the equalizing charge be fixed at once every two weeks, but it must be borne in mind that the operating conditions to which the battery is subjected must be taken into account in establishing any routine in respect to the equalizing charge. However, under average operating conditions it has been found that satisfactory results will in general be obtained if the equalizing charge be conducted at approximately bi-weekly periods. The precautions as to temperature limits, gassing, etc., as pointed out elsewhere in the text, should be observed in conducting this charge.

In view of the fact that the gassing period during the equalizing charge is longer than that of a normal charge, it is good practice to water the cells before beginning the equalizing charge.

**The Boosting Charge.**—It frequently happens that a cell which has developed defects, such as short circuits through breaking down of the separators, etc., requires special treatment to restore its capacity after such defects have been eliminated. One form of treating such cells is to give them a special charge, commonly known as a *boosting charge*. This charge is usually conducted at the finishing rate, or lower, of the particular type cell in question, but the time required to complete such a charge is greater than for a normal charge. Such cells are usually disconnected from the other cells of the battery during this charge, although in some instances they may receive the necessary treatment during a normal charge of the other cells of the battery, provided, of course, that the other cells are cut out when fully charged, in order that they may not be damaged through overcharging while continuing the boosting charge on the cells receiving the treatment.

Special attention should be given to accurately taking and recording the individual cell readings of the voltage, specific gravity, and temperature during the boosting charge. These readings may also prove useful in observing the future performance of such cells.

**Pilot Cells.**—In order to maintain a constant check on the performance of a battery it is necessary that certain cells be selected for use in obtaining voltage, temperature, and specific gravity readings. In other words, such cells are intended to serve as a guide in judging the condition of the other cells of the battery.

At least three pilot cells should be selected for each tray of batteries. These cells should be located near the center of the tray, as such location is usually conducive to producing average temperature readings with the other cells of the battery. Do not select cells located in the ends of a tray, as the temperature of such cells is likely to be influenced by better air circulation, hot terminals, etc.

It is also important that the specific gravity of the electrolyte in the pilot cells be uniform with the other cells of the battery, or if it is not uniform with them, the error plus or minus in points of gravity should be known. In general, it may be said that it is difficult to maintain a fine degree of uniformity in the specific gravity of the electrolyte of pilot cells, as these cells are subjected to fluctuations in gravity due to loss of electrolyte when taking readings, more frequent watering, etc.; however, as stated, the errors plus or minus in points of gravity should at all times be known.

**Battery Log Book.**—It is essential to intelligent care and operation of a storage battery that a permanent record be kept of its performance. This record should be in the nature of a log book in which an entry is made of all pertinent data incident to the operation of the battery. Such entries should include individual cell voltage, temperature, and specific gravity readings for each cycle of charge and discharge, with the dates of all charges and discharges and amounts of each, dates of equalizing charges, and of watering battery, and other remarks, such as defects noted, nature and description of any repairs made, etc.; in fact, this log book should form a complete life history of the battery beginning with the initial charge and discharge.

Special forms adapted to a particular battery installation should be provided in this log book and a few specimen forms are shown in Figs. 98, 99 and 100 for guidance in making up a record book as described above. By noting comparative performances of the cells as entered in this book from time to time, defects can often be detected in the cells and rectified before serious damage results, and for this reason all entries in the log should be both accurate and systematic. This record book will also be found especially useful when any change occurs in the battery operating personnel.

If no battery log books are supplied with the battery, a blank ledger book in which appropriate forms have been ruled off may be conveniently used for the purpose.



STORAGE BATTERY LOG

DAILY READINGS OF PILOT CELLS

Month of.....19..... Type of Battery.....

Day	Pilot Cell No. _____											
	Volts	Sp. Gr.	Temp.									
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												

REMARKS:

FIG. 99.—Form for Daily Pilot Cell Record.

STORAGE BATTERY LOG

RECORD OF DISCHARGE

Date { Started .....  
 Finished .....  
 Time { Started .....  
 Finished .....  
 Temperature of Room { Start .....  
 Finish .....

Total Battery Voltage { Start .....  
 Finish .....  
 Average Discharge Rate.....Amperes  
 Ampere-Hours taken Out.....  
 Type of Battery.....

Cell No	Volts		Sp. Gravity		Temperature		Time	Pilot Cell No			Pilot Cell No		
	Start	Finish	Start	Finish	Start	Finish		Volts	Sp.Gr.	Temp.	Volts	Sp.Gr.	Temp.
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13							Time	Pilot Cell No			Pilot Cell No		
14								Volts	Sp.Gr.	Temp.	Volts	Sp.Gr.	Temp.
15													
16													
17													
18													
19													
20													
21													
22													
23													
24													
25													
26													
27													
28													
29													
30													

REMARKS:

Readings taken by.....

FIG. 100.—Form for Discharge Record.

**Precautions to Observe in Connection with Charging.**—In order that satisfactory results may be obtained in operating the storage battery, it is necessary that certain well-defined fundamentals be observed in connection with charging. These fundamentals, including brief remarks upon each of them, may be outlined as follows:

(1) The battery should be charged practically immediately following a discharge, especially if the low voltage limit for the given rate of discharge has been reached. In general, it may be said that when the voltage of the battery has fallen to 1.70 volts per cell the battery should be considered as completely discharged and should then be recharged without delay; however, at discharge rates higher than the 3-hour rate, the voltage may be allowed to fall as low as 1.50 volts per cell before considering the battery as completely discharged.

If a battery be allowed to stand in a completely discharged condition for more than a few hours (not over 24 hours) the plates become sulphated to such a degree that recharging is effected with difficulty, and if this practice is repeated frequently the wear and tear on the plates is very pronounced and the life of the battery considerably shortened.

As regards this feature of excessive or *injurious degree of sulphation* in the battery, it should be stated that at the end of a discharge the normal lead sulphate crystals which are formed in the plates are of a soft, small, and finely divided variety, and are easily reduced by the normal charging current for the particular type and size of battery in question; on the other hand, however, upon standing it is an inherent characteristic of such crystal formations to become agglomerated, this agglomerated mass being in turn transformed into another crystalline structure, the crystals of which are formed from the smaller crystals, and are much harder, larger, and more difficult of reduction with the normal charging current than are the smaller crystals of the original formation. Moreover, the sulphate composed of these hard, large crystals possesses very marked insulating qualities, and accordingly offers considerable resistance to the flow of the charging current; also, since this form of sulphate is reduced with difficulty, the portions of the plates containing these hard crystals become hot, owing to the resistance offered to the charging current, and there is a strong tendency for the plates to warp or buckle at these points and which is further conducive to the active material becoming loose and falling away from the grid. Furthermore, since comparatively little of the charging current, especially at the initial stages of the charge, is utilized in reducing this sulphate, electrolysis of the water of the electrolyte in contact with such spots occurs, and the evolution of the gas thus formed has a tendency to blow out or blast, wash out, or otherwise detach from the grid the adjacent particles of sul-

phate and active material, thereby reducing the capacity and shortening the life of the plates. Plates in this condition require a very long, low-rate charge in order to reduce the sulphate. In extreme cases where the plates are too far gone it is even in favor of economy to scrap the battery. Obviously, with these facts in hand, care should therefore be taken to safeguard the battery against damage from this cause by charging before the injurious degree of sulphation has been attained.

If sufficient time is not available to complete the charge, at least a partial charge should be put into the battery, and every effort put forth to prevent the battery from standing in a completely discharged condition. A good rule to observe, if operating conditions permit, is to never allow the battery to stand less than one-half charged.

In cases of emergency, where the charge cannot be started immediately following a complete discharge, but little harm is done in allowing the battery to stand from 12 to 18 hours without charge, provided such practice is infrequent and is only permitted in cases of emergency; in other words, such practice should not become by any means general.

As has already been pointed out, should a battery become badly sulphated, as outlined above, in order to restore its capacity and put the plates in good condition, best results will be obtained by dumping out the old electrolyte from the cells and replacing with low-gravity acid (about 1.180 to 1.190 specific gravity) and then placing the cells on a long, low-rate charge, on the order of the 20-hour discharge rate or lower. This charge should be continued until the specific gravity of the electrolyte ceases to rise and remains constant for a period of at least from 3 to 4 hours, at which time the cells should be gassing freely. The time required to complete such a charge in extreme cases may run as high as a week or 10 days. Care should be taken to keep the cells replenished with water, as electrolysis and evaporation during such a charge are usually abnormal. Following such a charge the battery should be given a let-down discharge and then recharged in order to assist the particles of active material to again adjust themselves in the plates and to restore the proper degree of porosity.

(2) Direct current only can be used for charging batteries.

Therefore, if the only available supply of current is alternating, it must be converted into direct current by means of some form of rectifier or a motor generator set before passing it through the battery. To pass alternating current through the battery will result in serious harm to the plates.

(3) Due regard for polarity should be had when connecting the battery to the charging lines.

Always connect the positive terminal of the battery with the positive charging bus or lead and the negative battery terminal with the negative

charging lead. Charging in the wrong direction will result in serious injury to the battery, if not complete ruin.

If in doubt as to the polarity of the charging lines and there is no suitable voltmeter available, the polarity may be determined by dipping the two ends of the charging leads into a glass of water which has been made slightly acidulated by the addition of a few drops of sulphuric acid or a teaspoonful of salt; with current flowing under these conditions electrolysis of the water is manifested by the evolution of hydrogen bubbles at the negative terminal. In making this test care should be taken to keep the ends of the wires at least one inch apart.

Another practical method for determining polarity may be used in which the two ends of the charging lines are forced into a raw "spud" or potato; with current flowing the potato will appear to boil or foam at the negative terminal as a result of the evolution of gas at that pole.

If it is desired to charge two or more batteries in the same circuit, all trays must be connected in series with each other; that is, the positive terminal of one tray must be connected to the negative terminal of the adjacent tray, and so on throughout the row of trays.

When facing the front of the tray all batteries used in the naval service are designed with their positive terminals on the right hand end of the tray and the negative terminals on the left hand end, the front of the tray being considered that side which contains the name-plate. The positive and negative terminals are also coated respectively with red and blue enamel paint, and in addition, are stamped "POS" or "+" and "NEG" or "-." Some manufacturers make a practice of also placing these markings on the front side of the tray to serve as an additional precautionary measure in correctly connecting up the battery with the service lines.

In connecting up the battery to the service lines care should always be taken to insure that a proper electrical contact is made between the battery and line terminals in order to guard against damage as a result of a hot terminal.

(4) The electrolyte should be at the proper height above the tops of the plates before beginning a charge.

It is good practice to replenish evaporation just before beginning a charge, for the reason that the water and the acid become thoroughly mixed by the gassing of the cell during the charge, which is conducive to reliable hydrometer readings being obtained during the succeeding discharge; also this procedure is especially desirable in the winter to prevent freezing of the electrolyte. Only pure distilled or other approved battery water should be used for this purpose. Use glass, rubber, or earthenware vessels for handling battery water; never use iron or other metallic vessels.

Never allow the electrolyte to fall below the tops of the wood separators or the plates, as the wood separators will dry out and otherwise deteriorate, thus causing short-circuits between the plates, and those portions of the plates exposed to the air will become injuriously sulphated, with the result that the portions of the plates submerged in the electrolyte will be subjected to correspondingly higher charge and discharge rates, which accordingly tends to shorten their life.

Electrolyte should never be added for the sole purpose of replacing evaporation, as only water is lost in evaporation, and only a small amount of acid is lost through spraying during the gassing period of the cell; therefore, electrolyte should only be added in case of spillage, or for the purpose of bringing up the gravity of a cell after it has been definitely determined by accurate readings taken at the end of a full charge that the specific gravity of the electrolyte is below normal.

In adding water care should be taken to not bring the level of the electrolyte too high above the tops of the plates, as during the charge the expansion of the electrolyte will cause the cell to overflow, thus subjecting the tray and other wood parts to the injurious action of the electrolyte, as well as causing the likelihood of moisture grounds and current leakage between the cell terminals. A large percentage of battery troubles is traceable directly to this feature of adding too much water and the injurious effects incident thereto.

A very convenient method of testing the height of the electrolyte in the cell, either before or after adding water, is to insert a glass tube, having both ends open, into the filling cylinder of the cell cover; by pushing this tube down against the tops of the plates and then closing the top end of the tube with the finger and removing the tube with the top end still closed, as shown in Fig. 101, the height of the column of liquid observed in the bottom of the tube indicates the height of the level of the electrolyte above the tops of the plates. A boiler water-gauge glass will satisfactorily answer this purpose if no other tube is available. After adding water and before beginning a charge, see that all filling plugs are replaced and properly secured in position in order to guard against overflowing of the electrolyte during the charge.

(5) The voltage of the charging lines must always be greater than the sum of the voltages of all batteries or cells connected in series in the circuit.

Obviously, this requirement is necessary in order to overcome the counter-electromotive force of the batteries or cells such that charging current can be passed through them. In regard to this feature it may be said that the voltage of the charging line must be at least 2.65 times the number of cells connected in series in the circuit. Thus, if there are 10 cells connected in series, then there must be at least 26.5 volts available in the charging lines in order to completely charge the cells.

(6) Batteries should be well ventilated while charging.

Before beginning a charge the cell tray covers of all batteries should be removed in order to afford proper ventilation of the cells during the charge.

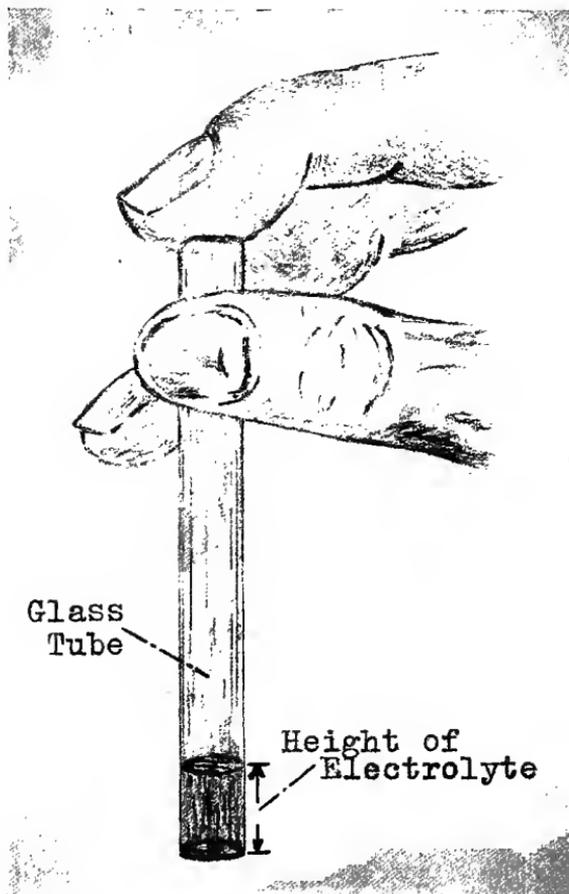


FIG. 101.—Showing Method of Testing the Height of Electrolyte Above Tops of Plates with Glass Tube.

Never bring an open flame or allow a spark near a storage battery, especially during or just after completing a charge, as to do so is to invite disaster from an explosion of the gases given off from the battery. If necessary to use a light in inspecting the batteries, a flashlight or a portable incandescent light should be used. The compartment in which the batteries are located should also be well ventilated periodically in order to prevent an explosive

mixture from being formed in the compartment. The general subject of ventilation is covered more fully in a separate chapter.

(7) The correct *starting* and *finishing* rates should be used in charging.

The name-plates on the front of the cell trays contain data as to the correct *starting* and *finishing* rates for the particular type of battery in question. These name-plates usually specify two rates of charging, the larger one of which constitutes the starting rate and the smaller one the finishing rate. When beginning the charge the starting rate should be used, and the charging current maintained at this rate until the cells begin to gas freely, or until the specified maximum cell voltage has been attained, at which time the charging rate should be reduced or cut to the finishing rate and the remainder of the charge conducted at this rate. Charging should be continued at the finishing rate, provided, of course, that the maximum permissible temperature limit is not exceeded, until the cells again begin to gas freely, and until such time as the cell voltage and specific gravity of the electrolyte have attained a maximum as indicated by four successive readings having the same value, and taken at 15-minute intervals. Charging should never be begun at such a high rate that gassing of the cells occurs immediately after starting the charge.

If the temperature reaches the permissible maximum limit during the charge, the rate should be reduced or charging discontinued entirely until the cells cool down sufficiently to complete the charge without exceeding the temperature limit.

In charging several sets of batteries in the same circuit care should be taken to not connect batteries of different sizes and ratings in series with each other for the purpose of passing the same current through them, as the charging rate will doubtless be too great for the smaller batteries, with the result that they will heat up and gas violently during the charge, and will be seriously injured thereby.

It is good practice to include in the same circuit only batteries of approximately the same degree of discharge, as this is conducive to uniform charging of such batteries.

(8) Watch cell temperatures during a charge.

An especially vital factor in the life of the storage battery is the temperature. It is therefore very essential that the battery be not permitted to become overheated during a charge, as high temperature has a very injurious effect upon the cells in that it tends to soften and disintegrate the active material of the plates, cause the acid to attack the grids, char the wood separators, and warp the rubber jars and covers. As the temperature rises above 100 degrees Fahrenheit, these injurious effects are more pronounced. Never allow the temperature of the cells to exceed 110 degrees Fahrenheit

during a charge. If during a charge it is seen that the temperature of the battery will exceed this limit if the charge at the given rate be continued, either reduce the charging rate or discontinue the charge altogether until the cells have cooled sufficiently to complete the charge without overheating. Best results are obtained if the operating temperature of the battery is maintained between 70 and 90 degrees Fahrenheit.

During a charge the temperatures of the cells should be recorded. Select cells located in the middle of each tray of batteries for taking temperature readings, as such cells will more nearly represent the average temperature values of the battery than will the outside or end cells, which naturally are subjected to more of the cooling influence of the surrounding air.

(9) Take periodic cell readings and record them during charge.

As the charge progresses routine cell readings should be taken and recorded. These readings should include the specific gravity of the electrolyte, voltage, and temperature of the cells. Select at least two pilot cells located in the middle of each tray of batteries for this purpose. The above readings should be taken on each individual cell in the battery at the beginning of the charge, after which readings need only be taken of the pilot cells every 30 minutes, until the last hour of the charge however, when the readings should be taken every 15 minutes. This, of course, provided that no abnormal cells are suspected in the battery, in which case such cells should be watched carefully and cut out should they show signs of overheating with the the charging current. Upon completion of the charge an overall gravity, temperature, and voltage reading should be taken of each individual cell in the battery. Voltage readings should only be taken while charging current is flowing, as open circuit voltage readings are of little or no value.

(10) Thoroughly clean the battery upon completion of the charge.

During the charge, the tops of the cells will gradually collect electrolyte and moisture through spraying of the electrolyte during the gassing period, as well as a certain amount of spillage incident to taking temperature and hydrometer readings. Therefore, the tops of the cells, connectors, terminal posts, and all parts of the tray should be thoroughly cleaned before placing the cells in service. It is good practice to wash off the tops of the cells, connectors, etc., with a rag which has been dipped in warm soda water or ammonia and to then thoroughly dry all parts, and coat the connectors with a thin film of vaseline to prevent them from corroding. The question of cleanliness and the procedure outlined above is a very important one and should be rigidly observed in order to prevent rotting of the cell trays, deterioration of the connectors, and damage to the battery as a result of moisture grounds.

**Alternating Current Rectifiers.**—In locations where the only available current supply for charging storage batteries is alternating, it then becomes necessary to utilize some form of current rectifying apparatus for converting the alternating current into direct current before passing it into the battery. There are in general three types of rectifiers which may be utilized for this purpose, which types are as follows:

1. Motor-generator.
2. Electrolytic.
3. Mercury arc.

With the present stage of the art; it may be pointed out that of the above types the motor-generator is more extensively used in the general practice of charging batteries than either of the other types.

Also, in view of the extensive application of the motor-generator for other purposes in the naval service, it is considered that the knowledge of the principles upon which these sets are based is so generally established as to render unnecessary any description of these sets in this text. However, description of this type as well as the other types of rectifiers may be found in the standard electrical text-books on the subject.

### Discharging.

**The Two Systems of Discharging.**—As in the case of charging batteries, depending upon the manner in which the cells or batteries are connected with each other and with the service lines, and, depending upon the amount of power desired, there are also two systems of discharging storage batteries, which are as follows:

- (a) Series.
- (b) Parallel.

**Discharging in Series.**—When discharging batteries in series, all cells or batteries are connected in series relation with each other, the method of connecting the cells being identical with that as shown in Fig. 94; however, when the batteries are discharging, the direction of the flow of current through the circuits is obviously the reverse of that indicated by the arrows in this drawing.

When batteries are discharging in series, the capacity of the entire battery is that of one cell, but the battery terminal voltage increases in direct proportion to the number of cells or batteries connected in series. In other words, maximum power output is obtainable from a battery when all cells are connected in series.

**Discharging in Parallel.**—When discharging in parallel, all batteries are connected in parallel relation with each other and with the service lines,

and the arrangement of connections of batteries when discharging them in parallel is identical with that as shown in Fig. 95, but the direction of flow of current through the circuits is the reverse of that indicated by the arrows in this drawing.

When the power demand for a given set of batteries is small in proportion to the power capable of being developed by these batteries if all cells are connected in series, then under such conditions the batteries may be

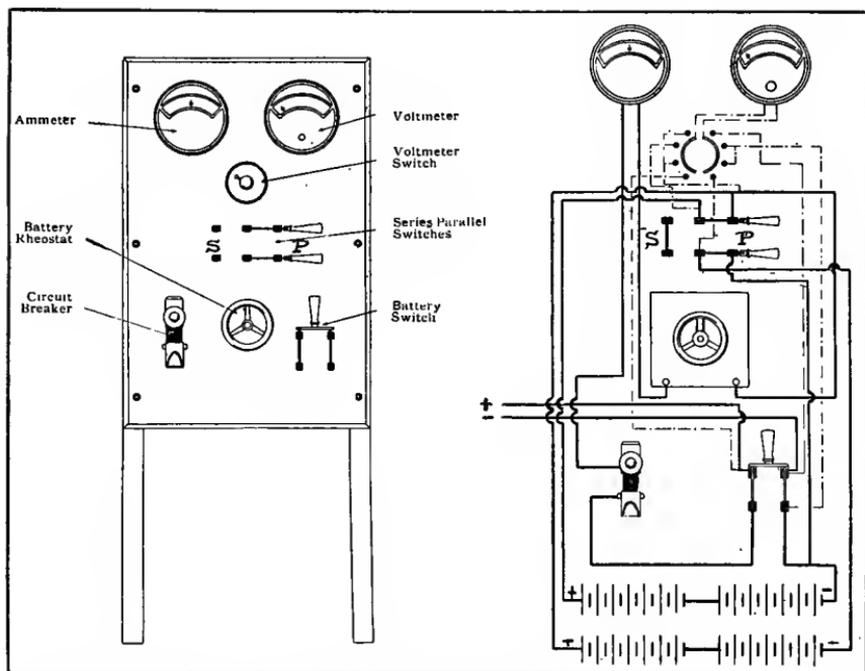


FIG. 102.—Showing Switchboard and Connections for Charging Batteries in Parallel and Discharging in Series.

economically operated by discharging them in parallel. Thus, with two batteries connected, as shown in Fig. 95, for discharging, the voltage on the discharge line is that of a single battery, while the capacity available under such conditions is that of two cells.

**Charging in Parallel, Discharging in Series.**—In some installations the charging equipment is not designed with sufficient capacity to charge the batteries when connected in series relation with each other, but the battery discharge circuits contemplate the arrangement of the batteries in series relation with each other when discharging. In such instances the batteries are accordingly charged in parallel and discharged in series.

Fig. 102 contains an illustration showing the arrangement of switchboard with all instruments, switches, etc., as well as the wiring diagram for such installation. It will be noted in this illustration that the batteries are thrown in either series or parallel relation with each other and with the service lines by means of a series-parallel switch, one side of which connects the batteries in series while the other side of the switch connects them in parallel. Thus, if the switch be closed to the left, as at *S*, the batteries are connected in series with each other and with the service lines, and the switch is thrown in this position when it is desired to discharge the batteries. On the other hand, however, when it is desired to charge the batteries, the switch is closed to the right, as at *P*, in which position the batteries are connected in parallel relation with each other and with the service lines. The polarity of the leads are plainly indicated in the diagram by means of plus and minus signs, and in order to become familiar with the details of the connections for such an installation all leads of the wiring diagram should be traced out in connection with the study of the text.

**Precautions to Observe in Connection with Discharging.**—It is necessary to observe certain precautions in connection with discharging storage batteries in order to protect the cells from damage. The more important of these precautions may be summarized as follows:

(1) Do not discharge the battery below the normal low voltage limit prescribed for the given rate of discharge. To do so will seriously strain the plates through over-expansion of the active material.

(2) Recharge the battery immediately after completing a total discharge. Never allow a battery to stand in a totally discharged condition.

(3) Keep a record of the voltage, specific gravity, and temperature of individual cells during a discharge.

(4) See that all cell connectors are tight before beginning a discharge in order to guard against damage from a hot connector.

(5) Do not let the cells exceed the maximum temperature limit during a discharge; this limit is 110 degrees Fahrenheit for batteries operated outside of tropical climates, while for tropical climates this limit is 125 degrees Fahrenheit.

## CHAPTER XVII.

### THE "TRICKLING CHARGE."

The chemical action which manifests itself in the storage battery cell and the normal cycle of life of this cell may be said to be analogous in many respects to that of the human body; that is, there is a constant wearing away and building up of tissues with a gradual lapse into debility and old age after a more or less definite period of activity. Moreover, just as the human body requires food, water, exercise and a reasonable amount of care and attention to preserve it in a vigorous, healthy condition for performing its characteristic functions of life, so does the storage battery also require, in effect, food, water, exercise and a reasonable amount of attention to enable it to efficiently perform its designated functions.

The application of the storage battery to the art of electrical engineering in our naval service is daily increasing at an unprecedented rate, so much so, in fact, that there is now a storage battery stand-by installation designed for practically every electrical circuit on board ship and, in many instances, the storage battery constitutes the prime source of power for some of those circuits; also, in addition to the application of the storage battery on board ship, it is extensively used for similar purposes on shore stations and in the aviation branch of our service.

Therefore, in order that these storage batteries may receive the proper care and attention which they deserve, thereby insuring that they will efficiently perform the various duties required of them when called upon, it is essential that our personnel charged with the operation, care and maintenance of these batteries duly appreciate the foregoing analogy and bear in mind that there is a certain amount of "human nature" even in a storage battery. This done, it is believed that the sphere of usefulness of the storage battery will be further increased and that it will prove a stepping stone to even greater achievements in the now rapidly developing art of electrical engineering in our naval service.

A very necessary routine practice in the care and maintenance of the storage batteries designed for the various duties of our naval service, and a practice which should be encouraged to the end that these batteries may always be maintained in the prime of condition and ready for instant duty, is known as the *trickling charge*, and it is the purpose of this chapter to explain the salient principles upon which this practice is based, as well as to describe the methods by which it may be applied to the storage batteries

under regular service operating conditions on board ship and in the general naval service.

**"Trickling Charge" Defined.**—It is well at this point to define the term "trickling charge"; it may thus be defined as follows:

*When the storage battery is connected across the electrical supply mains or bus-bars and the conditions obtain wherein the battery is at all times receiving just enough current to counteract local action and thus maintain it in a fully charged condition, the storage battery is said to be receiving a "trickling charge." A fraction of an ampere only, the amount of which depends upon the size of the battery, is required for this "trickling charge," and, aside from the advantages obtained as a result of counteracting local action in the cell, the battery at all times has its entire capacity available for instant use when required.*

In other words, the small amount of charging current passing or "trickling" through the battery is just sufficient to reduce the small layer of lead-sulphate ( $\text{PbSO}_4$ ) normally formed in the plates as a result of the local action incident to the "internal or self-discharge" of the battery, and, furthermore, this small amount of charging current is not sufficient to cause any deleterious effects through heating or undue gassing of the battery. In fact, when the "trickling charge" is properly conducted, practically no rise in temperature is apparent, and there is only a slight amount of gas evolved, if any.

In order that a thorough understanding may be had as to the object of the "trickling charge," it is well in the beginning to again consider the prime constituents of the lead-acid storage battery cell and the fundamental equation of the reactions which take place in this cell during the cycle of charge and discharge.

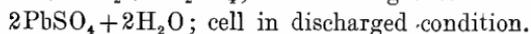
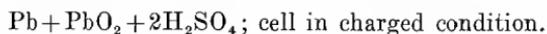
**Fundamental Equation of the Lead-Acid Storage Battery Cell.**—The active constituents of the lead acid storage battery cell are as follows:

(a) Positive plate; lead-peroxide ( $\text{PbO}_2$ ), which is of a velvety "chocolate" brown color.

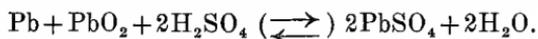
(b) Negative plate; finely divided sponge lead ( $\text{Pb}$ ), which is of a "battleship" gray color.

(c) Electrolyte; dilute sulphuric acid ( $\text{H}_2\text{SO}_4$ ), consisting of chemically pure sulphuric acid diluted with pure distilled water.

The generally accepted fundamental equation for the normal chemical action which takes place in this cell may be thus indicated as follows:



Therefore, in combining the above, the fundamental equation of the complete reaction is written as follows:



In other words, the sign ( $\overset{\leftarrow}{\rightleftharpoons}$ ) indicates that this reaction is completely reversible; that is, reading this equation from left to right ( $\longrightarrow$ ) denotes the action which takes place during discharge of the cell, and reading from right to left ( $\longleftarrow$ ), that which takes place during charge.

It is, therefore, apparent from the above equation that during discharge the acid radical,  $\text{SO}_4$ , of the electrolyte combines with the active materials of the positive and negative plates and converts both of these plates into lead-sulphate ( $\text{PbSO}_4$ ). Moreover, during charge the lead-sulphate is reduced by the charging current and the acid radical returned to the electrolyte, the active materials of both plates being accordingly restored to their original states; that is, to sponge lead and lead-peroxide.

**Self-discharge of an Idle Battery.**—It is an established fact that if a fully charged or a partially charged battery be allowed to stand idle long enough it will eventually become completely discharged of its own accord. This is manifested by a reduction in the cell voltage, drop in the specific gravity of the electrolyte and the formation of lead-sulphate in the positive and negative plates. In other words, although the circuit connecting the terminals of the battery has not been closed during the idle period and, consequently, no current drawn from the battery, the acid radical of the electrolyte has nevertheless combined with the active materials of both sets of plates, converting them into lead-sulphate in the same manner as though the battery had been subjected to a regular useful service discharge.

A fully charged battery will completely discharge itself in approximately 100 days if allowed to remain idle without receiving a freshening charge during this period. However, the degree of acid concentration in the electrolyte and the temperature to which the battery is subjected are governing factors in the time element required for a battery to become discharged through self-discharge, high-acid concentration and high surrounding temperatures tending to lessen the time element necessary for a complete self-discharge as outlined above.

**Factors Which Produce Self-discharge.**—There are several factors which are in various degrees responsible for the internal or self-discharge which takes place in an idle storage battery. These factors, when considered either individually or collectively, are, in battery parlance, usually referred to under the general term *local action*. Chief among these several factors may be stated the following:

- (1) Impurities in the electrolyte.

- (2) Impurities in the materials composing the grids, and defective grid-casting.
- (3) Local couples formed in the manufacture of the positive plates.
- (4) Local couples formed in the manufacture of the negative plates.
- (5) Leakage of current between the cell terminals as a result of moisture grounds, etc.

Each of the above factors may be briefly commented upon as follows:

**Impurities in the Electrolyte.**—As a general rule any metallic impurities present in the electrolyte will cause a loss of charge at the negative plates. During charge such metallic impurities are deposited upon the negative plates where they form innumerable local couples with the active materials of these plates, with the consequent result that in the presence of the electrolyte discharge takes place, thus liberating hydrogen at the negative plates and with a loss of charge at these plates.

Such metallic impurities include antimony, arsenic, copper, iron, platinum and tin. Iron is in general the most active and destructive of the above-mentioned impurities, for, due to the fact that the ions of this metal can exist in two different stages of oxidation, each stage of which is capable of being converted from one to the other, these ions continually oscillate from one group of plates to the other, when the cell is placed on open circuit, thus causing a consequent loss of charge at each group.

It requires only a comparatively small amount of iron in a cell to completely discharge it in a very short while when the cell is left on open circuit. Therefore, great care should be exercised when operating the storage battery that iron is prevented from entering the cell, such as through using electrolyte or water which contains iron, dropping into the cell iron nuts, bolts, washers, nails, tools, etc., or through any other cause. Furthermore, all iron which enters a cell from time to time is cumulative in effect, as none of this metal is lost by electrolytic decomposition or liberated in a gaseous state, as is the case with certain other impurities.

**Impurities in the Materials Composing the Grids and Defective Grid-Casting.**—The alloy used in casting the grids of the storage battery cell consists of lead and antimony. If these metals are not refined to a very high degree the other metallic impurities contained will set up small local couples in the presence of the electrolyte, thus causing a loss of charge of the plates. Also, if the lead-antimony alloy is not a homogeneous mixture, or if there are segregations of pure antimony and pure lead in spots with blow-holes or shrinkage cracks in the casting as a result of improper cooling or insufficient mixing of the alloy before pouring into the moulds, other local couples are formed which accounts for a further loss of charge of the plates.

**Local Couples Formed in the Manufacture of Positive Plates.**—As outlined above, the grids are composed of lead-antimony alloy, whereas the active material of the positive plates consists of lead-peroxide. We thus have a couple formed by the lead-peroxide and the grid in the presence of the electrolyte, which results in a certain amount of discharge of the positive plate, the amount of which depending upon the surface contact area between the positive active material and the grid. However, the discharge from this cause is of comparatively short duration, since a layer of lead-sulphate is eventually formed between the grid and the active material of the positive plate, thus forming an insulating medium which prevents further discharge.

Also, another source of internal or self-discharge of the positive plates, especially in the Planté type, is the failure to remove all of the forming agents which were used in forming the plates. If these plates are not thoroughly cleared of all such forming agents, the loss of charge from this cause is likely to prove quite appreciable in amount.

**Local Couples Formed in the Manufacture of Negative Plates.**—As in the case of the positive plates, we have in the negative plates local couples formed by the lead-antimony alloy grid in contact with the sponge lead active material, and in the presence of the electrolyte a certain amount of discharge takes place in the negative plates from this cause. Also, as was described in the preceding paragraph relating to the positive plates, a thin insulating layer of lead-sulphate is similarly formed between the negative grid and the active material of this plate, thus preventing a further loss of charge from this cause.

Another loss of charge at the negative plate is due to the local action which takes place between the various materials used for obtaining porosity, increasing conductivity and the various expanders used in the manufacture of these plates.

**Leakage of Current Between Cell Terminals.**—Although, properly speaking, loss of discharge from this cause is not due to local action in the strict meaning of the term, it is, nevertheless, included here, since it accounts for quite an appreciable amount of loss of charge in an idle storage battery cell if such a condition is allowed to exist sufficiently long without rectifying it; in fact, the loss of charge through this cause is in some cases equal to, if not greater than, the combined loss of charge due to the other factors outlined above, provided the leakage of current between the terminals is of protracted duration.

**Method of Conducting "Trickling Charge."**—Having considered the effects of the various factors of local action in producing self-discharge of the idle storage battery cell, the object of the "trickling charge" in reducing to a minimum the effects of this local action, as well as maintaining the battery in a fully charged, healthy condition is, therefore, readily apparent.

As was explained in defining the term "trickling charge" in the early part of this chapter, only a fraction of an ampere of current is sufficient to counteract this local action, the amount of the current depending upon the type of the battery in respect to the size and the number of plates installed in the cells.

**Lamp-bank Method.**—A very satisfactory and simple method of conducting the "trickling charge," and one which is very conveniently applied on board ship, is known as the lamp-bank method, and consists in connecting lamp-banks in series with the battery and the charging buses of the ship's main supply lines, the number of lamps used depending upon the following:

- (a) Type of battery; size and number of plates in the cells.
- (b) Number of cells in the battery.
- (c) Voltage of the charging buses.

The function of the lamp-banks is that of a resistance to absorb the excess voltage in the main charging line over that required for the small amount of "trickling charge" current passing through the battery.

Fig. 103 contains an illustration of the equipment and necessary connections required for conducting a "trickling charge" by the lamp-bank method on navy type storage batteries.

The lamp-banks connected in series with the battery and the main charging buses are plainly shown in this illustration, as is also the double-pole snap-switch used for cutting on or off the "trickling charge" current, as desired. The direction of the current in passing through the battery on charge is as indicated by the arrows in the drawing. In this regard, as in all other cases of charging storage batteries, it is essential that only direct current be used for this purpose, and that the positive terminal of the battery be connected to the positive charging bus and the negative terminal of the battery to the negative bus. To do otherwise will result in serious harm to the battery.

In conducting the "trickling charge" by the lamp-bank method, the life of the lamps will be increased if the arrangement of the lamp-banks is such as to reduce the voltage sufficiently to cause the lamps to burn at a low incandescence. Also, as a general rule, on account of their high efficiency and long life, tungsten filament lamps should be used, if obtainable, in preference to carbon filament lamps, as they afford a finer degree of current and voltage regulation than the carbon filament lamps. However, if the conditions are such that it is not practicable to use tungsten filament lamps, carbon filament lamps may be used.

The advantage in using lamp-banks as a resistance, instead of using regular commercial resistance units in conjunction with a low-reading ammeter, rests in the fact that lamp-banks at all times afford a reliable

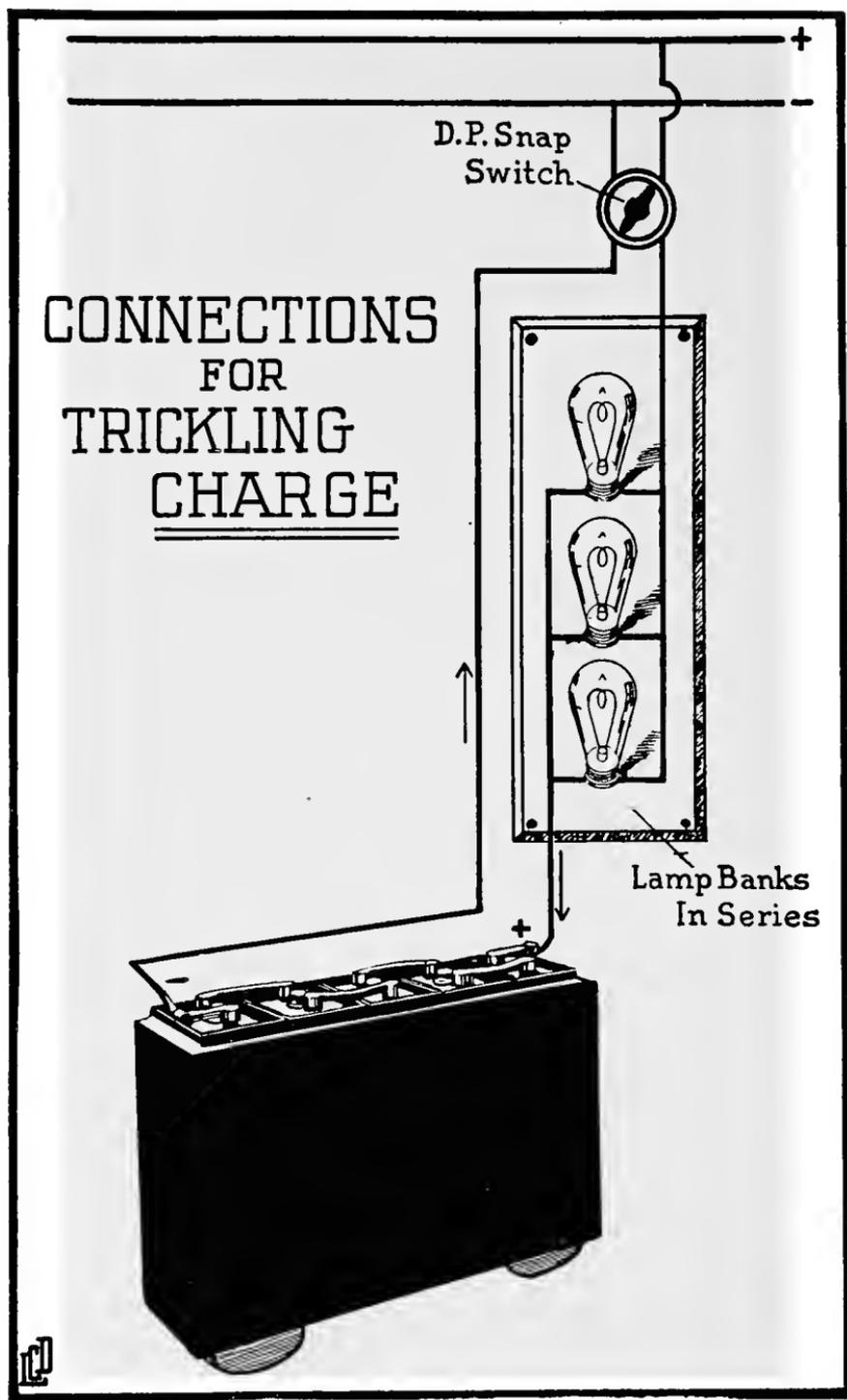


FIG. 103.—Showing Connections for Trickle Charge.

visual indication that current is "trickling" through the battery, whereas, the needle of the ammeter does not present so striking an indication of the charging current; in other words, as long as the lights are burning it is definitely known that current is passing through the battery, and anybody on watch in the vicinity, whether he be a coal-passer or an ordinary seaman, can tell when the charging current is on or off.

At navy yards, shore stations and regular battery service stations, where the organization is such that someone is in constant attendance with the storage batteries on charge, commercial resistance units may well be used in connection with ammeters and voltmeters, as at such places proper facilities are at hand for using at all times accurately calibrated instruments, etc. Standard commercial resistance units of identical rating as standard size lamps may now be obtained; those resistance units are also designed to screw into the standard incandescent lamp sockets.

All storage batteries designed for stand-by circuits on board ship, as well as spare submarine cells kept in the battery service stations on submarine tenders, should be maintained in a charged condition by the "trickling charge" method. Also, spare submarine batteries stored at navy yards for emergency installation can be kept in good serviceable condition and with comparatively little cost of upkeep and maintenance by this method, and its practice should be encouraged.

**Computing the "Trickling Charge" Rate.**—The number of positive plates contained in the cell constitutes the basis for computing the "trickling charge" rate for a given battery installation. For the portable types of storage batteries used in the naval service and having positive plates  $\frac{1}{4}$  inch in thickness, a trickling charging rate of .025 amperes per positive has been found to be sufficient to counteract local action and maintain the plate in a fully charged, healthy condition. Thus, if such a cell contains  $n$  positive plates, the "trickling charge" rate for this cell would be  $n \times .025$  amperes.

For all portable type cells having positive plates less than  $\frac{1}{4}$  inch in thickness .0125 ampere per positive plate, or one-half of  $\frac{1}{4}$  inch plate rating, should be used in absence of any other specific rating designated by the battery manufacturer. In respect to this feature, the navy specifications for portable types of storage batteries require that each storage battery manufacturer submit detailed drawings of every type cell supplied on government contracts; in addition to containing detailed drawings of parts for the information and use of the battery service stations and operating personnel in ordering spare parts, making repairs, etc., these drawings also specify the number and size of the plates installed in the cells. For submarine type cells the battery manufacturers also supply the required "trickling charge" rate for each type.

Therefore, in order to ascertain the "trickling charge" rate for a given cell or battery installation, it is only necessary to consult these detailed drawings supplied by the battery manufacturers. The required "trickling charge" rate should also be found on the metal name-plate attached to the cell tray.

It has also been found that the charge voltage of a cell through which is passing the required amount of "trickling charge" current averages from 2.15 to 2.30 volts. Therefore, when calculating the "trickling charge" rate for a given installation, if 2.15 volts per cell is used the results will be sufficiently accurate for practical application.

*Example.*—The storage battery charging buses on board ship are connected across the 115-volt supply mains, and it is desired to place a set of auxiliary lighting batteries on "trickling charge"; each cell of this battery contains 9 plates, 4 positives and 5 negatives, and the entire battery consists of 12 cells, all of which are connected in series.

Find the "trickling charge" rate for this battery, and the amount of the resistance to be placed in series with the battery in order to conduct the "trickling charge" at the required rate.

*Solution.*—This type of cell conforms to the navy standard for these batteries and contains four  $\frac{1}{4}$ -inch positive plates. Hence, the "trickling charge" rate for this cell is

$$4 \times .025 \text{ ampere} = .1 \text{ ampere.}$$

Also, since there are 12 cells connected in series, the counter-electromotive force produced by this battery when on "trickling charge" at the required rate is

$$12 \times 2.15 \text{ volts} = 25.8 \text{ volts.}$$

Therefore,  $115 - 25.8 \text{ volts} = 89.2 \text{ volts}$ , which must be absorbed by a resistance placed in series with this battery.

Now, by Ohm's law:

$$C = \frac{E}{R}, \text{ or } .1 = \frac{89.2}{R},$$

$R = 892$  ohms, the amount of the resistance to be inserted in series with the battery in order to allow a "trickling charge" of .1 ampere to pass through the battery.

Therefore, in order to translate this resistance in terms of lamp-banks it is only necessary to select lamps of such rating and to so combine them that the value of the resistance offered by the entire lamp-bank will be 892 ohms; various combinations of lamps may be utilized for such a lamp-bank. For the particular problem outlined above, it has been found that a bank consisting of three 25-watt metallic filament lamps placed in series with

each other, and this lamp-bank in turn placed in series with the battery, will allow a "trickling charge" of .1 ampere to pass through the battery.

**Gassing and Ventilation of Batteries During "Trickling Charge" and Care of Compartment in Which They Are Located.**—Although, as has been stated, when the "trickling charge" is properly conducted, the amount of gas evolved from the storage batteries is relatively small, yet, as a precaution during this charge, the trays of these batteries should be left uncovered and the compartment in which they are located should also be well ventilated, periodically, at least, in order that any gas which is evolved will be dissipated before an explosive mixture is formed.

In this regard, tests conducted are conclusive that a 4 per cent mixture of hydrogen in air is dangerous, and it is the established policy in operating storage batteries requiring forced ventilation in our service, such as the submarine types, to design the ventilating apparatus on a basis of sufficient capacity to keep the amount of hydrogen present in the air at any instant below 2 per cent, thus insuring a substantial factor of safety in the operation of these batteries.

The compartment in which the batteries are located should be kept free from sweating and otherwise as dry as possible, in order to reduce the likelihood of moisture grounds occurring around the batteries. The tops of the cells, sides and tops of the trays, stowage racks, etc., should also be kept dry and free from acid spray, as in addition to causing leakage between the cell terminals and other such grounds, the cell trays and other woodwork around the batteries will become acid soaked, and which will eventually result in rotting of the woodwork of the trays and other parts. It is good practice to give the cell trays and other woodwork around the batteries a coating of asphaltum or other acid-resisting paint periodically as necessary. All metal work in the compartment in which the batteries are installed should also be coated with acid-resisting paint to protect it from the corrosive action of the acid fumes, and spray given off from the batteries. It is essential to successful operation of the batteries that the compartment be kept clean and no metals, tools or other materials stored around or on top of the batteries.

**Watering Battery and Routine Overcharge.**—In conducting the "trickling charge," the cells should be watered regularly with pure distilled or other approved battery water to replace that lost in evaporation. Under no conditions should acid be added to replace evaporation.

Also, for the best results, the battery should, as a routine practice, be given an "overcharge" at the prescribed "finishing" rate at least once a month, in order to thoroughly mix the added water with the electrolyte and to prevent the injurious effects of stratification of the acid in the electrolyte. In

this regard, cells which are allowed to remain inactive for protracted periods, that is, not being subjected to regular cycles of charge and discharge, are subject to this acid stratification in the electrolyte, in that the heavier and more concentrated acid tends to settle to the bottom of the cell with the result that effect of local action on the plates is more pronounced in the lower part of the cell. Although, as has been pointed out, the "trickling charge" is designed to reduce the effect of local action to a minimum, the "trickling charge" rate is not sufficient to produce enough gassing in the cell to stir up or agi-

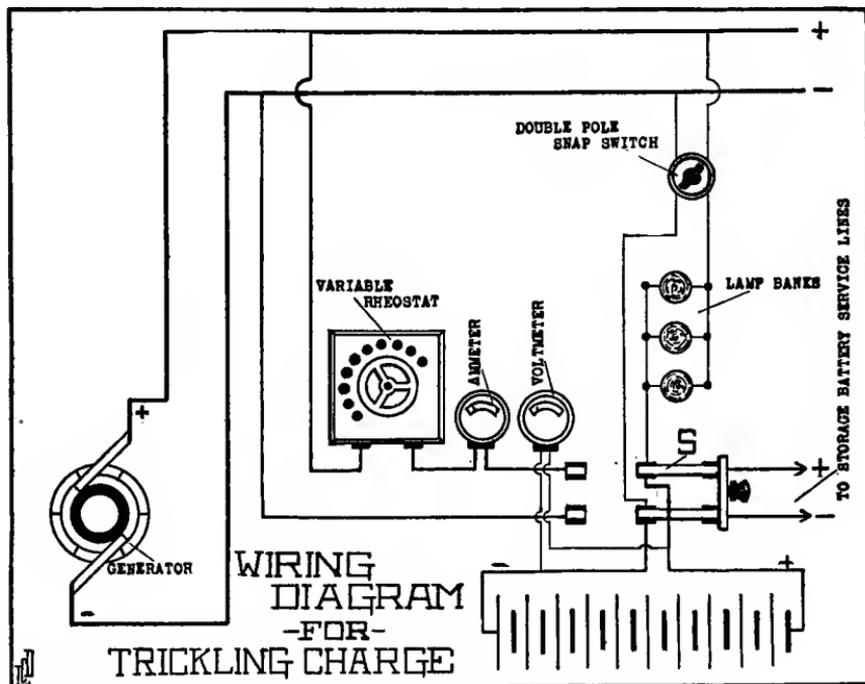


FIG. 104.—Wiring Diagram for Trickle Charge.

tate the electrolyte, and for this reason the periodic overcharge is helpful in dissipating any tendency to stratification of the acid.

The duration of this overcharge should be sufficiently long to insure that a maximum specific gravity reading has been obtained, and as shown by four successive readings taken at equal intervals for a period of one hour. Such a maximum gravity reading insures that practically all acid has been driven out of the plates, if the cells have received the proper attention during previous operation.

There is shown in Fig. 104 a composite wiring diagram of the complete equipment required for charging or discharging a set of storage batteries on

board ship. In addition to the "trickling charge" equipment, which has already been described, this diagram also includes the necessary connections and equipment for giving the storage battery a normal charge, and "over-charge," as well as the connections for discharging the battery through the discharge service lines.

It will be noted in this diagram that the regular charging equipment consists of a variable rheostat, connected in circuit with the main current supply lines, for regulating the charging current to correspond with the prescribed "starting" and "finishing" rates for the particular types of battery used in the installation. Connections to ammeter and voltmeter are also shown in the diagram.

Charging and discharging is effected by means of the double-pole double-throw switch *S*, which may be closed on either side of the circuit, as desired. Manifestly, when discharging the battery, the double-pole snap switch on the "trickling charge" circuit should be in the "open" position; also, when the battery is receiving a "trickling charge" switch *S* should be thrown in the "open" position.

In conclusion it is safe to say that the storage battery has come to stay in our naval service, and the "trickling charge" will accordingly occupy a prominent place in the operation, care and maintenance of these batteries.

## CHAPTER XVIII.

### FLOATING THE STORAGE BATTERY ON THE LINE.

Although the practice of floating the storage battery on the line has been adopted commercially for a number of years and has registered a marked success in the storage battery engineering world, its general adoption for naval use and its application to the submarine electrical plant are of comparatively recent date. However, owing to the rapidly increasing use of the storage battery as a stand-by agent for the various power circuits, as well as other electrical circuits on board ship, floating the storage battery on the line will likewise meet with increased application and will eventually become a regular routine engineering practice in the battery service stations and electrical plants of practically all naval vessels. In fact, this practice has already been adopted as routine on board practically all of our submarines, and this chapter deals mainly with its application to this special branch of our service; but inasmuch as the general principles involved are identical, the subject-matter herein contained is, with a few minor exceptions, equally applicable to the electrical plants of all naval vessels equipped for floating their storage batteries on the line.

Floating the storage battery on the line, or the operation of maintaining the battery in a practically constant degree of charge while directly connected in parallel across the bus-bars of the main power units normally supplying current for the exterior load, is best accomplished in the submarine electrical plant through the application of the principle of electromagnetism, which principle is contained in the action of the reverse-current circuit-breaker. The method of using the reverse-current breaker for this purpose is identical with that employed in running dynamos in parallel and, as is well known, when this practice first came into general use, experience proved it highly essential that some means be provided for protecting the machines against serious damage should either of them fail, through break-down or any other cause, to deliver its designated share of the power required on the line. It being obviously true that when dynamos are working in multiple, the failure of any one of the machines to take its share of the exterior load forces the other machine or machines, as the case may be, to take the additional load, with the possibility of causing the disabled machine to run as a motor. Moreover, depending upon the nature of the break-down and the load on the line in comparison with the ratings of the machines, these may be sufficient to wreck the power units and put the entire plant out of commission.

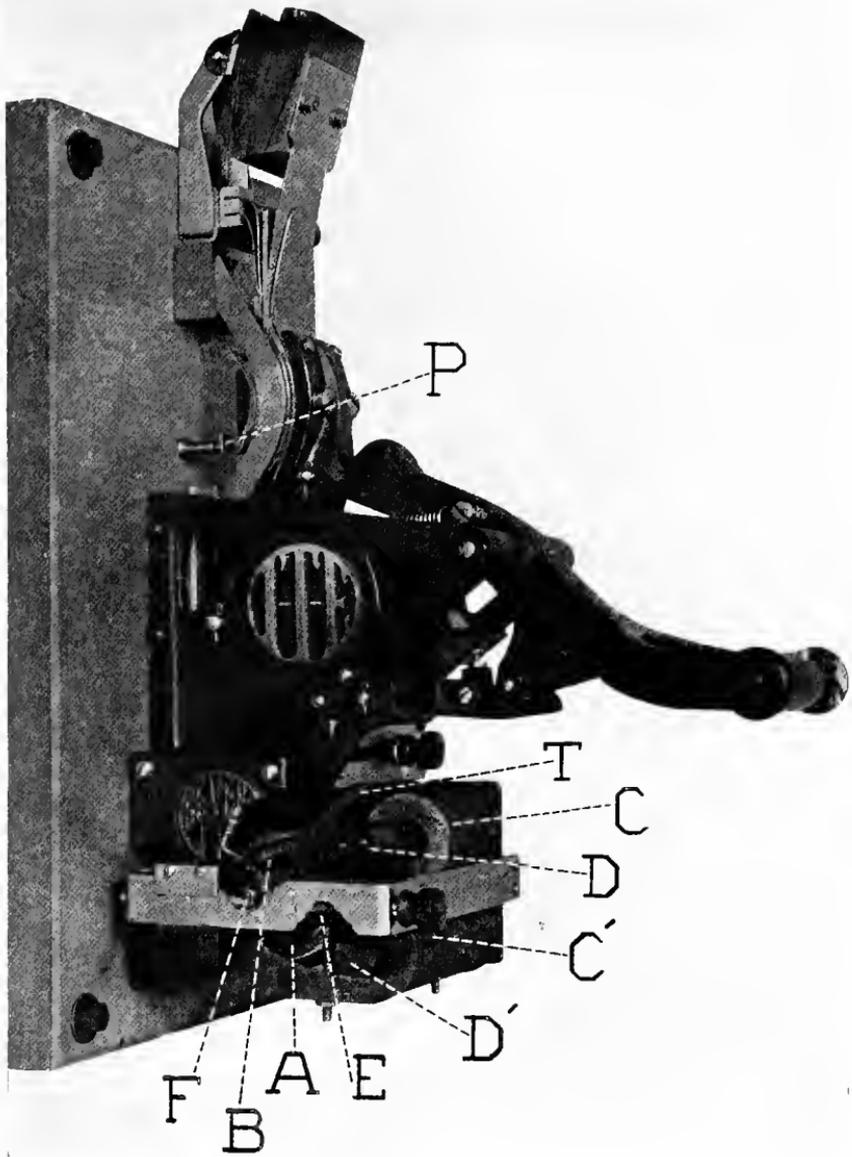


FIG. 105.—Reverse Current Circuit-Breaker.

Hence, the evolution and development of the reverse-current circuit breaker came as a natural result in offering a protective means against damage to the dynamos and other equipment through accidents of this kind, and, as stated, it is the reverse-current circuit-breaker which has been adapted for use and performs a similar function in the operation of floating the storage battery on the line in the submarine electrical plant.

### The Reverse-Current Circuit-Breaker.

The reverse-current circuit-breaker, as its name implies, serves to automatically open the circuit when the direction of current flow in the line is reversed. In Fig. 105 is shown a photographic illustration of one of these circuit-breakers, and in Fig. 106 is shown the corresponding wiring diagram for this breaker and the method of connecting it in circuit with the generator and bus-bars. In the photograph, Fig. 105, the reverse-current circuit-breaker is shown with portions of the frame-work removed in order that the essential parts necessary to the reversal feature may be clearly shown. The reversal feature of this breaker consists of two separate electromagnetic systems as follows:

- (1) A series magnetic system.
- (2) A shunt magnetic system.

The series magnetic system consists of the following parts:

(a) Series magnetic coil *A* in series with the main switch member of the breaker and designed to carry the entire line current.

(b) Series magnetic core *B* surrounded by the series coil *A*, while to each end of this core is attached a pole piece, one of which, marked *E*, may be plainly seen in the photograph. The core *B* is mounted on frictionless bearings which allow a slight angular movement about its axis. One of these bearings, marked *F*, is also shown in the photograph.

The shunt magnetic system consists of the following parts:

(a) Shunt magnetic coils *C* and *C'* shunted across the main bus members of the circuit. These coils, connected in series with each other, are wound with high resistance wire and are adapted to receive the full line voltage. The spring contact *P* automatically closes the shunt coil circuit when the circuit-breaker is closed and likewise opens the shunt coil circuit when the circuit-breaker is opened.

(b) Shunt magnetic cores *D* and *D'* surrounded by the corresponding shunt coils *C* and *C'*. These cores are shown mounted opposite the outer extremities of the series pole pieces and the windings of shunt coils *C* and *C'* are so related to each other that the magnetic poles at corresponding ends of the shunt cores *D* and *D'* are opposite in sign and hence tend to create a strong magnetic flow across the gaps separating the respective poles.

It is the action of the magnetic cores *B*, *D* and *D'* under the influence of their respective coil fields which mechanically operates the tripping mechanism

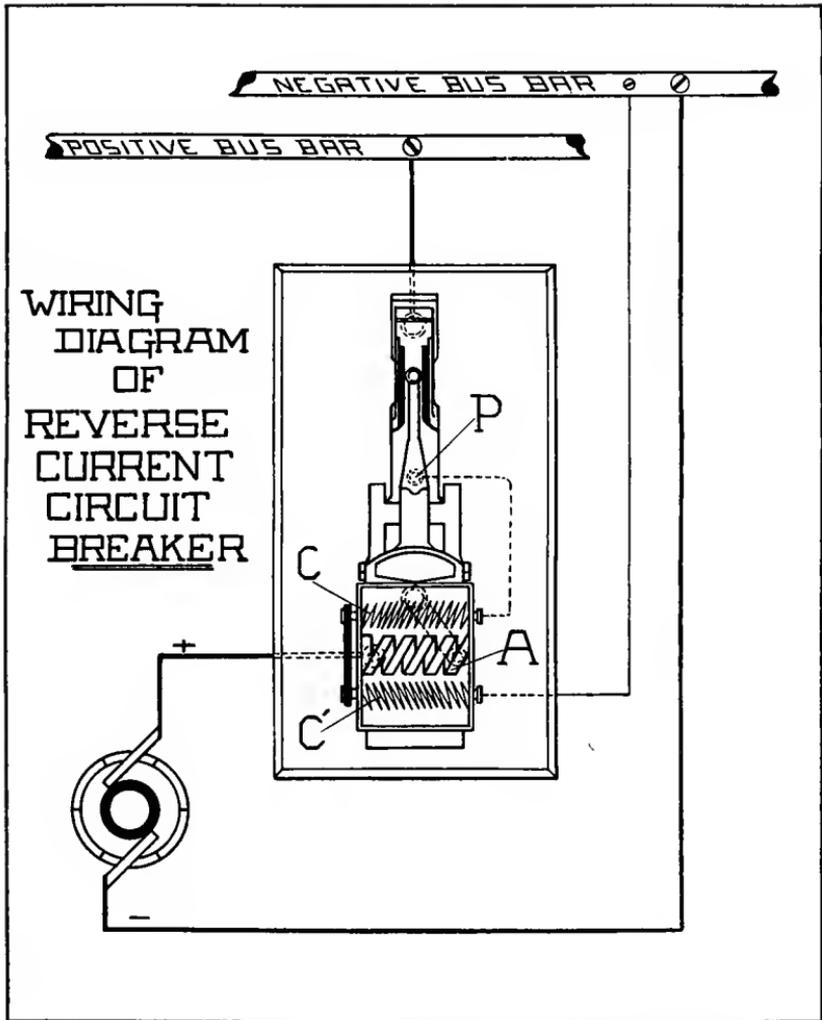


FIG. 106.—Wiring Diagram of Reverse Current Circuit-Breaker.

ism *T* for opening the circuit upon reversal of direction of current flow. These cores are made of Norway iron, an especially high-grade of soft iron containing practically no impurities, and due to its softness, permeability, and low retentivity or capacity for retaining a minimum amount of residual

magnetism when demagnetized upon cessation of a current flowing through its coils, this particular grade of iron is especially adapted for use in the magnetic cores of this type. Relative to the low retentivity feature, when a magnetizing current passing through a coil is reversed, the residual magnetism or remanence in the core must necessarily be neutralized or deadened by a coercive force before the induced magnetism is of sufficient strength to react in the core.

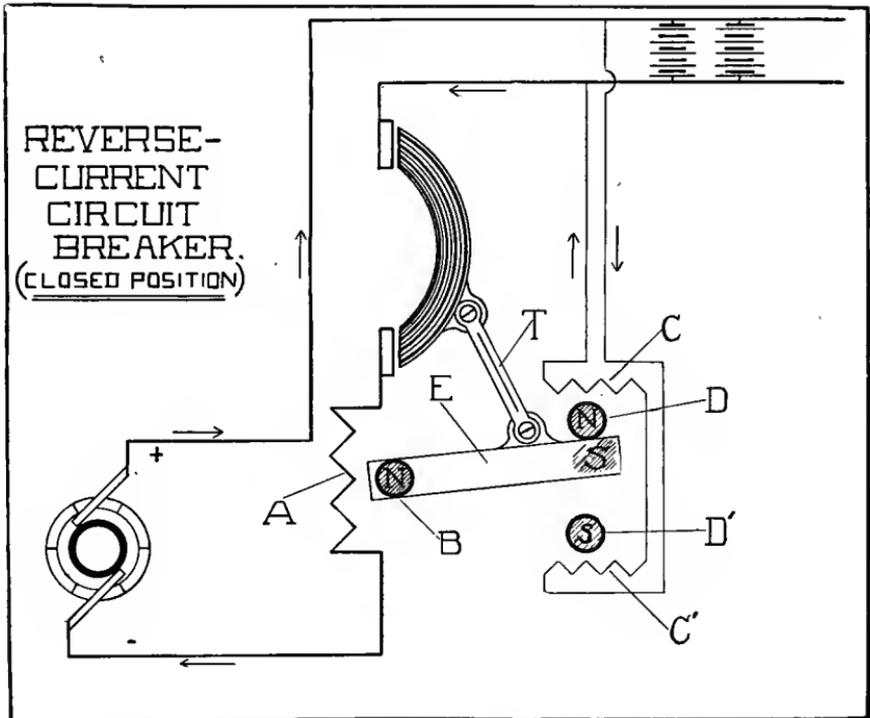


FIG. 107.—Reverse Current Circuit-Breaker (Closed Position).

Hence, it follows that the smaller the amount of residual magnetism present in a core, the smaller the amount of coercive force required to neutralize same and, consequently, the more responsive will be the core reaction in the coil field. This feature explains the advantage gained in using Norway iron for these cores, and is best appreciated when the core reactions of the reverse-current circuit-breaker are considered. In this instance it is essential that the series magnetic core undergo an instantaneous and abrupt change of polarity in order that the tripping mechanism for opening the breaker may be instantly operated upon reversal of current. These core reactions may be

understood by a study of the elementary wiring diagrams shown in Figs. 107 and 108. For clearness in following through the design and operation of the reverse-current circuit-breaker, the descriptive lettering of the various parts in Figs. 107 and 108 are identical with those of Figs. 105 and 106.

In Fig. 107 the reverse-current circuit-breaker is shown closed in the circuit with its series coil *A* connected in series with the main circuit. The shunt coils *C* and *C'*, oppositely wound, are connected in series with each

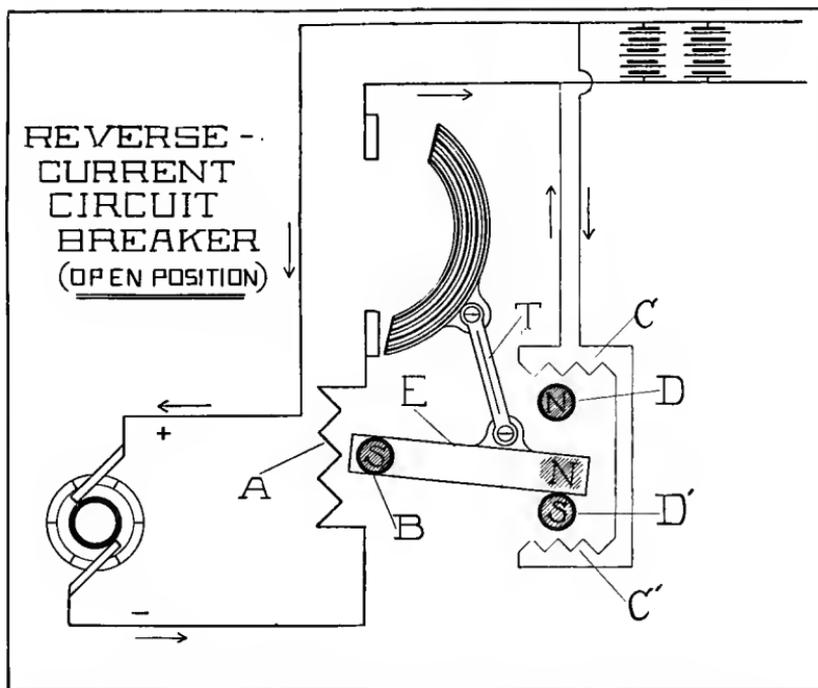


FIG. 108.—Reverse Current Circuit-Breaker (Open Position).

other and in parallel across the main positive and negative buses. The batteries are shown connected in parallel, and in this manner are floated on the line while the generator is supplying current for the load on the line. The direction of the current flowing through the circuit is as indicated by the arrows.

Now with the generator running and the current passing from same through the series coil *A* and the shunt coils *C* and *C'*, their respective magnetic cores *B*, *D* and *D'* are thus inductively magnetized by virtue of the coil fields formed by the generator current; the polarities of these cores are as

indicated and are in accordance with the direction of current flowing through their coils. Thus, in the diagram the induced south pole of pole piece *E*, connected to magnetic core *B*, is shown attracted by the induced north pole of core *D*, while it is repelled by the induced south pole of core *D'*, and in this position the breaker remains closed so long as the direction of current flow is not changed.

Now, as illustrated in Fig. 108, should the engine or generator motive power become disabled or stopped for any reason, the generator current immediately ceases and the battery begins to discharge back into the line; the current in the line then flows in the opposite direction with a consequent reversal of the polarity in the series core *B*, thus occasioned by the change in the field of the series coil *A*. Also, since the shunt coils *C* and *C'* are connected in parallel with the main circuit, it follows that the direction of current flow in these coils remains constant, irrespective of the direction of current flow in the main circuit, and the polarities of the shunt coil cores *D* and *D'* accordingly remain constant.

Furthermore, due to the change of polarity in the series coil core *B*, there occurs a similar change of polarity in the pole piece *E*, and as shown in Fig. 108 the induced north pole of the pole piece *E* is attracted by the south pole of core *D'* and repelled by the north pole of core *D*. This electrical reaction thus resolves itself into mechanically operating the tripping mechanism *T* of the circuit-breaker, which automatically opens the circuit and prevents the current from the battery from running the generator as a motor.

For proper operation of the breaker it is, obviously, of great importance that the shunt coil leads across the main power buses be connected up in circuit with due regard for polarity.

### **Commercial Application of Floating the Storage Battery on the Line.**

Before proceeding further with the subject, as a matter of historical reference and in order to properly develop the subject-matter of this chapter for service application, it is well to consider some of the prominent applications of the principle of floating the battery on the line and the ultimate means to an end which have prompted its adoption commercially in the electrical world. In this connection it may be stated that the practice of floating the battery first came into favor and met with extensive use on a large scale in the field of commercial power and lighting stations, electrically operated railways, and plants of that type.

In the early days, in addition to their regular generating sets for carrying the normal load on the line, these central power stations were equipped with additional auxiliary or stand-by machines which were constantly kept in readiness for immediately connecting in on the line in cases of emergency,

such as break-downs, periodic high-rate power demands or "peaks" on the line, etc. This was found to be highly essential in maintaining a plant of this type, as otherwise the break-down might prove of such a serious nature, or the power demand be of such magnitude as to materially impair the efficiency of the plant, or even put the plant entirely out of commission, with a consequent paralysis of the various other industrial plants, department stores, office buildings, etc., depending upon their sources of power through the feeder lines from this station.

However, as the science of electro-chemical engineering progressed, and when the storage battery had finally been developed to the point of proving a real commercial success, it immediately fell heir to a very important berth in the equipment of these central power and lighting stations. The storage battery in this instance largely replaced the old stand-by machines and performed the function of a stand-by agent, for, owing to its capacity for either giving out or receiving electrical energy, it thus proved a very flexible unit and one which was entirely capable, within certain definite limitations of its inherent capacity, of readily responding to all conditions of load on the line. When operated in this manner it is usual to connect the batteries in parallel with the main generating sets of these stations in order that the batteries may readily be available for emergency discharge or to assist the generating sets in supplying current for the "peaks," thus maintaining constant voltage on the exterior line for any fluctuation of the load; and conversely, when thus connected, the batteries may receive charge when the load on the line is light or below normal, thereby increasing the plant efficiency. Moreover, when the generators are supplying only enough current at the required voltage to meet the demand on the line, the batteries are neither receiving nor giving out electrical energy, and it is thus that the term *floating the battery on the line* is derived. In other words, the operation of floating the storage battery on the line is a function of the change in the line drop in the circuit between the generating set and the battery terminals.

Thus, in the following elementary analytical description, let

$E$  = Generator voltage.

$E_1$  = Battery terminal voltage on open circuit.

$C$  = Current in the circuit.

$R$  = Resistance of circuit between generator and battery terminals.

Then  $(RC)$  represents the drop in the circuit between the generator and the battery terminals.

Hence,  $(E - RC)$  represents the line voltage at the battery terminals. Therefore, it follows that:

(a) When  $E_1 = (E - RC)$ , the battery is neither receiving nor giving out electrical energy and is "floating on the line."

(b) When  $E_1 < (E - RC)$ , the battery is receiving charge from the generator.

(c) When  $E_1 > (E - RC)$ , the battery is discharging and assisting the generator to carry the load.

Stand-by batteries for marine wireless equipment on board merchant ships, and the batteries used in conjunction with the railroad car-lighting sets are other examples of the numerous modern applications of the principle of floating the storage battery on the line; the latter case presents a very ingenious and compact example of this operation. These modern car-lighting sets consist mainly of a generator, a storage battery, and a suitable regulating switchboard containing a voltmeter, ampere-hour meter, automatic cut-outs, etc., and the operating arrangement is such that when the car is in motion the generator is driven from the car axle and thus supplies current for the lighting system, while the battery is floated on the line. Now when the train or car stops, the battery automatically takes up the load and supplies current for the lights until the car is again in motion at sufficient speed to develop the required voltage, when the battery is again automatically floated in the circuit while the generator takes the load.

Another interesting example of the commercial application of floating the battery is found in the case of the batteries connected across the power buses at the ends of long-distance transmission lines and used for maintaining a practically constant voltage on the line under conditions of fluctuating loads, such as at the ends of electrically operated railway systems, etc. These batteries are called "line batteries," and differ from the regular stand-by batteries in the power stations in that they are designed primarily to save the increase in copper, which would otherwise be required to prevent the voltage drop at high current rates over the long-distant transmissions, if these batteries were not installed. These batteries float across the power buses and receive current when the load is light and discharge into the line when the load is heavy, and thus assist the generating sets in the power station.

There is shown in Fig. 109 a typical wiring diagram of one of the commercial power and lighting stations and the stand-by batteries described above. The generators  $G$  and  $G'$  are connected on the three-wire system, and there is a motor generator booster set installed for use in charging and boosting the batteries. The batteries, one set on each side of the neutral, are shown connected in parallel with the main power sets. The end-cells and the end-cell switches  $S$  and  $S'$  are provided for cutting in or out additional cells, as may be necessary, to maintain the normal line voltage when the battery is responding to an emergency discharge and carrying the load on the line. The usual electrical instruments, such as voltmeters  $V$  and  $V'$

ammeter *A*, two-way reading ammeters *A'* and *A''* for reading on charge or discharge, ampere-hour meters, recording voltmeters, etc., are also shown on the diagram. The reverse-current circuit-breakers *R*, *R'*, and *R''*, protecting the generator sets, are also shown in the diagram.

During the operation of floating it is usual to maintain the batteries in these commercial plants at a voltage of from 2.10 to 2.14 volts per cell, for when maintained at practically this potential, the battery is equally capable

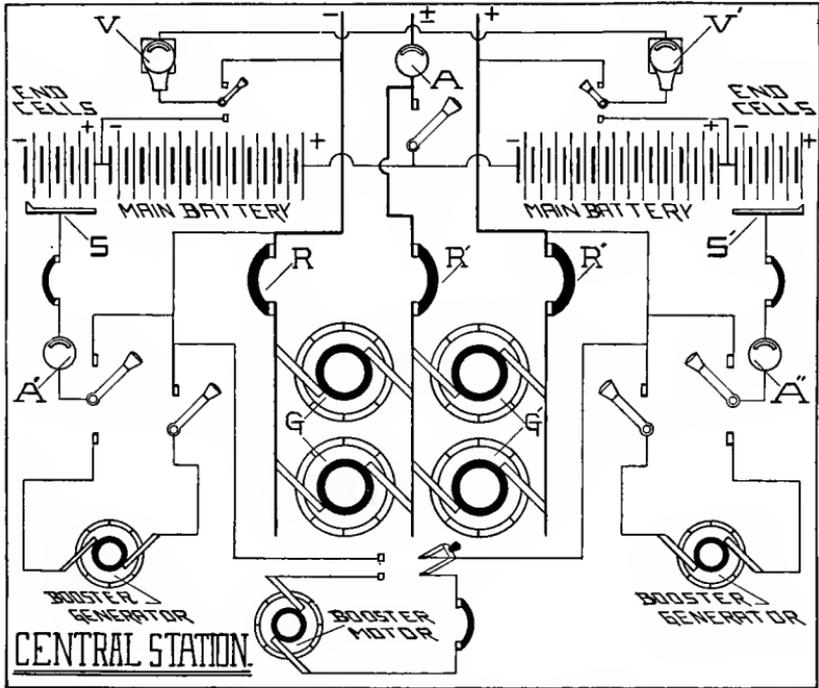


FIG. 109.—Wiring Diagram of Central Station.

of responding for short periods to high-rate discharge as well as receiving and absorbing current during intermittent short hulls or power recesses on the line, and this with practically none of the deleterious effects incident to gassing and constant overcharge, such as would be the case if floating at full charge. However, generally speaking, the particular service required of the battery together with the degree of attention which it receives as to care and maintenance must necessarily govern the potential limit for floating.

As an example of the operation of floating the batteries in one of these stations, assume that the line voltage across the positive and negative legs

of the diagram, Fig. 109 is 220 volts with a corresponding potential of 110 volts across the legs on each side of the neutral. Also assuming that each cell when floating is maintained at 2.12 volts, then the number of cells required in circuit on each leg in order that normal line voltage may at once be available for "peak" duty, or in event of failure of either or both sets of generators, would be

$$\frac{110}{2.12} = 52 \text{ cells.}$$

Also, assuming that the limiting voltage of each cell during discharge is 1.60 volts per cell, then the number of cells required in circuit during a discharge of such duration and magnitude as to reduce the cells to this voltage would be

$$\frac{110}{1.60} = 70 \text{ cells.}$$

Therefore, the number of additional cells required to be cut in on the circuit during such emergency discharge, in order to maintain the normal line voltage, would be  $70 - 52 = 18$  cells. This explains the function of the end-cell switch for cutting in or out cells as may be necessary during a discharge. The end-cell switch of which there are many different types, is usually motor operated and, generally speaking, is automatically controlled by a contact-making voltmeter connected across the battery terminals. This contact-making voltmeter closes, selectively, the exciting circuits of two relays arranged to operate the end-cell switch, one for either direction of travel, so that when the bus voltage is low, cells will be cut in, and when the voltage is high, cells will be cut out until normal line voltage is restored. The end-cell switches may also be used for charging and boosting purposes.

The latest practice, however, in the large commercial power and lighting stations is to use the storage battery primarily as a stand-by agent. This has been brought about as a result of the rapid strides made in the development of the turbo-generator, a machine which in present stage of development affords a very flexible unit and readily adjusts itself to all degrees of load on the line where constant voltage is required, and for this reason, as well as economy, has somewhat relieved the storage battery from "peak" duty. A complete shut-down in one of these plants is now of rare occurrence, for owing to the comparatively short space of time required to raise steam with modern equipment, together with other improvements brought about by modern engineering practices, the storage battery is capable of carrying the load until such time as other machines can be put into service, or until necessary repairs have been made.

Among the conditions requiring an emergency discharge of the stand-by storage batteries in these power stations are the following:

(1) Interruption of the main power supply, such as low steam, boiler or engine troubles, etc.; also any irregularities governing the water supply to hydro-electric generating plants, such as ice floes in the river, etc.

(2) Reduction of the normal generating capacity of the plant through break-down of any portion of the generating machinery.

(3) Unexpected power demands due to sudden increased use of illuminating circuits incident to the darkness brought on by thunder shower, fog, or falling snow.

(4) Accidental opening of transmission lines due to short circuits, lightning, etc.

The storage battery plants in some of the large power and lighting stations are alone capable of delivering from 12,000 to 15,000 amperes continuously for one hour at from 220 to 250 volts, with a corresponding material increase of ampere rating over the above for intermittent short periods of discharge.

There is shown in Fig. 110 a graphic illustration of the load and power distribution curves in one of the central station power plants described above. In this diagram is plotted the total load curve of the power station from 4 a. m. to 9 p. m., and also the curves of the power distribution among the various units of this plant during this interval. The periods during which the storage batteries are receiving charge, floating on the line, and discharging to assist the generating set in carrying the "peaks" of the load on the line are also indicated in the diagram. The curves in this diagram are designed to show the operating cycle of the power units of a central power station under conditions of the daily routine working of this plant, as well as those requiring an emergency discharge of the storage batteries. In following through this cycle of operation, the following conditions will be noted:

From 4 a. m. until about 6.30 a. m. the load on the line is relatively light, and the excess power developed by the generating set during this interval is absorbed in charging the batteries. This is indicated in the diagram by the single line shading of this area of the curve.

At about 6.45 a. m. the load on the line begins to increase rapidly, and the load curve at this point rises above that of the generator output, until at 7 a. m. the load on the line reaches a maximum. From this point the load gradually decreases until 8 a. m., when the generator output is exactly equivalent to that absorbed by the load on the line. During the interval from 6.45 a. m. to 8 a. m. the batteries are discharging on the line and

assisting the generating set to carry the load. This area of the curve is indicated by the double line shading in the diagram.

From 8 a. m. until noon the load on the line undergoes only a slight variation and the generator output is exactly equivalent to the load on the line, and during this interval the batteries are floating on the line. Also during the noon hour the load on the line decreases and the batteries again receive charge.

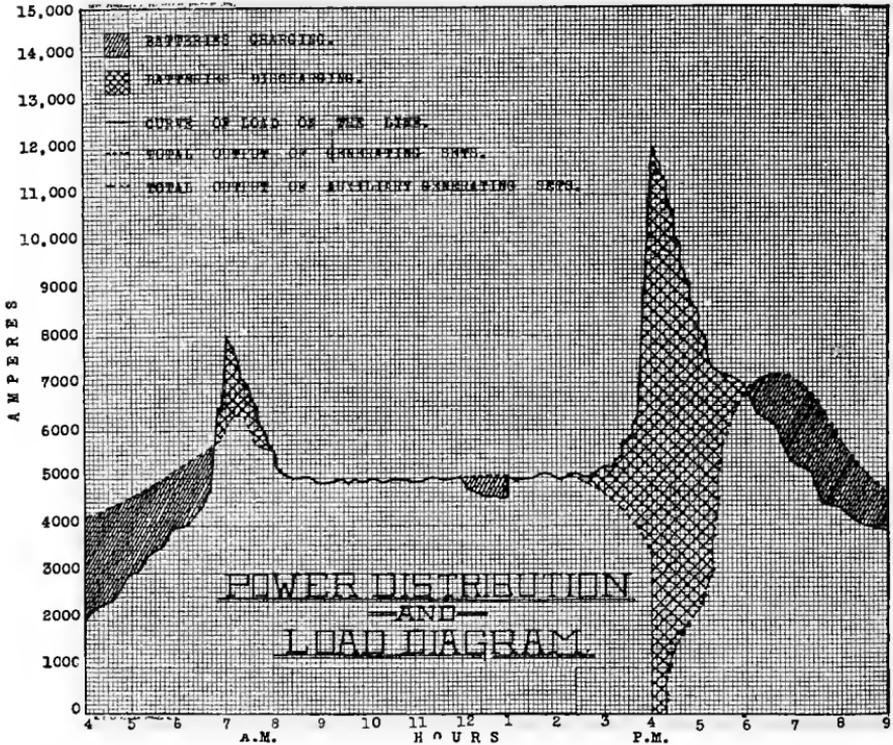


FIG. 110.—Load Diagram.

Now, beginning at about 2 p. m. trouble was encountered in the plant through the generating set developing a hot main bearing. Also, at about the same time the load on the line began to increase as a result of the increased use of illuminating circuits incident to the darkness brought on by a sudden thunder shower. During this emergency, and on account of the hot bearing, it became necessary to shut down the main generating set and to start up the auxiliary generating set of this plant. The double line shading of this area of the curve shows the storage batteries discharging on the line during this interval. It will also be noted that the storage batteries

took the entire load on the line after shutting down the main generating set and until the auxiliary set was put in operation and cut in on the line.

From 6 p. m. until 9 p. m. the load on the line gradually decreases and the storage batteries again receive charge from the auxiliary generating set.

### **Application to the Submarine Electrical Plant.**

In taking up the application of the practice of floating the storage battery on the line in the submarine electrical plant, it is proper to state that, although the principle and methods of floating are practically identical with those of the commercial plants, yet the prime objects in view are necessarily different, in that one is an expedient of commercial efficiency, while the other is military. In other words, in the commercial plants where the storage battery is floated on the line, its use is mainly that of a stand-by agent, and as such constitutes a secondary source of power; whereas, in the submarine plant the battery function is twofold, in that it serves as an auxiliary agent for surface operation, while for submerged work it is immediately resolved into the prime mover or source of motive power.

In order to clearly describe the function and method of floating the storage battery on the line in the submarine electrical plant, a brief outline of the general arrangement of electrical circuits and batteries in this plant is necessary. Thus, for various conveniences in operation, design, economy, etc., the several electrical circuits may, in general, be considered as divided into two separate and distinct power systems, as follows:

(a) Main power system.

(b) Auxiliary power system, which also includes the emergency circuits.

In each of the above systems, the normal operating voltages depend upon the manner in which these systems are connected up to the batteries. Thus, for the main power system the maximum operating voltage is equivalent to the terminal voltage of all cells of the entire battery connected in series, whereas that of the auxiliary power system is represented by the terminal voltage of only one-half of the cells of the battery connected in series. In order to obtain this variation in voltage, it is usual to divide the battery into two equal groups, all cells of which are connected in series, and by interposing suitable series-parallel switches in the line, this arrangement facilitates connecting the main and auxiliary power systems with the battery in such manner as to obtain the desired operating voltages for these systems. Also, the series-parallel switch combination further facilitates connecting the batteries to the dynamo-electric charging sets in such manner as to effectively float the auxiliary load on the line, when cruising under the oil engines.

In Fig. 111 is shown the method of connecting up the reverse-current circuit-breakers  $R$  and  $R'$  with the series-parallel switch  $S$  for floating the storage battery on the line in the submarine electrical plant.

When the submarine is operating on the surface, in normal cruising condition, that is, under the oil engines, the power required for many of the various auxiliaries is supplied by the storage batteries. Hence, in view of the increased size of the modern submarine, together with the corresponding increased size and application of motor-driven auxiliaries and other electrical apparatus in these boats, the auxiliary load on the storage batteries has thus been necessarily increased; so that for a sustained cruise in a modern submarine, the question of the magnitude of the auxiliary load is of paramount importance and constitutes a factor which materially affects the successful operation of the boat and, obviously, counsels the serious consideration and attention of the designers of the boat, her commanding officer and operating personnel.

Therefore, as a means of relieving the storage battery from a large portion of the auxiliary load, thereby reducing the working of the battery to a minimum with the consequent increase in its life, the principle of floating the battery on the line has been adopted and now constitutes one of the routine engineering practices in the modern submarine electrical plant, and in this capacity has proved most advantageous and successful as a military as well as a commercial expedient.

Furthermore, while operating the submarine in normal surface trim, under the oil engines, it is the usual practice to utilize the main generating sets for floating the auxiliary load on the line and since the main generating sets are directly driven from the propeller shafts, the oil engines also supply the power for developing the electrical energy required for operating the various motor-driven auxiliaries. Also, inasmuch as the normal operating voltage of the auxiliary power system is based upon the terminal voltage of one-half of the cells of the battery connected in series, floating the auxiliary load on the line is thus obtained by connecting both groups of the battery in parallel with the main generating sets and so regulating the strength of their magnetic fields and the speeds of rotation as to generate the necessary current at the required voltage for operating the various electrical auxiliaries.

Relative to the feature of voltage regulation while floating the battery on the line, the electromotive force generated by a dynamo-electric machine depends upon three fundamental factors, as follows:

- (1) Strength of the magnetic field (number of lines of force).
- (2) Armature winding (number of cutting conductors).
- (3) Rate of cutting the lines of force (revolutions per minute).

Thus by varying either of the above factors, there is a corresponding variation in the electromotive force generated, and since the armature windings for the main generating sets in the submarine electrical plant are not designed to permit of regulation, this factor may be considered constant. Therefore any regulation of the electromotive force generated in this plant must necessarily depend upon varying either the strength of the magnetic field, the speed of rotation, or both. Also, since the magnetic fields of the

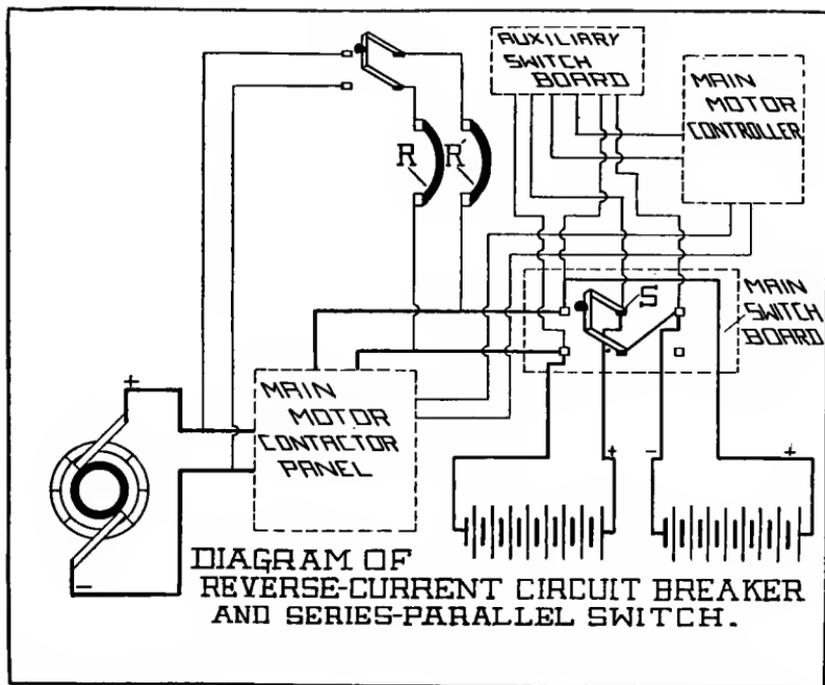


FIG. 111.—Reverse Current Circuit-Breaker and Series-Parallel Switch.

generating sets on board the submarine are separately excited and are capable of adjustment over a wide range, and in view of the wide variations in speed which may be obtained with the oil engines, it is thus seen that the electromotive force generated is also capable of regulation over a comparatively wide range, which under service conditions of operation may range from the voltage required for floating the batteries connected in parallel with each other, and in a practically discharged condition, to that voltage required for putting an overcharge into the batteries when connected in series.

When floating the batteries of the submarine on the line, it is good practice to maintain the cells of same at an average potential of 2.15 volts per cell, or as near that point as practicable, which is from .01 to .02 volt per cell higher than that carried in ordinary commercial practice. This slight increase in the voltage over that usually practiced in ordinary commercial floating, constitutes a strategic expedient resorted to in the interest of military preparedness in maintaining the battery in a state of as nearly full charge as is consistent with its proper care and upkeep under ordinary service conditions of operation. Also, 2.15 volts per cell is sufficiently below the critical gassing point of the cell, as to allow for a slight increase in the floating voltage limit without undue gassing. This is necessary in order to take care of certain irregularities which occur under ordinary cruising conditions. These service irregularities are due to the racing of the propellers, variations in speed incident to maneuvering in formation, etc., as well as to the intermittent use of some of the electrically driven auxiliaries, and, under these conditions, it is impracticable to so regulate the generator fields as to at all times produce the exact floating voltage and amperes actually required for the auxiliary load; hence, as a result there is a small amount of net charge going into the batteries from time to time. Other things being equal, this net charge is cumulative and, manifestly, if allowed to progress far enough would eventually tend to produce a low-rate overcharging of the batteries, and, in fact, this method of overcharging may be resorted to when a very low-rate overcharge is desired, but under other than exceptional circumstances this method of overcharging is not recommended, as due to any existing inequalities in the resistances of the two halves of the battery, the cells of one group of the battery will tend to receive more current than those of the other with a consequent irregularity in the state of charge of the two halves of the battery. Therefore, generally speaking, it may be said that more uniform results with the individual cells will obtain if all regular overcharges, such as the routine bi-weekly overcharges, are carried out under conditions of all cells of the entire battery connected in series.

Moreover, in view of the fact that the arrangement of the auxiliary power system is such that it is capable of receiving power from either of the two groups of batteries, it is further conducive to uniformity, while floating the auxiliary load on the line, to periodically shift the auxiliary load from one group to the other in order to equalize the working of the two groups. It is routine practice on board some submarines to shift the auxiliary load at 8 a. m. each day, and this practice has produced very uniform and satisfactory results.

In regard to the question of liability of the battery to overcharge while floating on the line, it may be said that, since the storage batteries in a sub-

marine receive the constant care and attention of the operating personnel, there is little likelihood of damage to the battery from this cause, for, provided the specific gravities of the pilot cells correspond with those of the other cells of the battery, or if they do not actually correspond with them, if their errors plus or minus in points of gravity are known, it is then only necessary to keep an accurate and regular check on the pilot cell gravity readings in order to at all times know the state of charge of the battery. Thus, by this routine method, when the pilot cell readings indicate that the batteries have reached a state of charge such that satisfactory floating is not obtained without gassing, the generators may be shut down and floating discontinued entirely and the batteries allowed to take the auxiliary load until such time as the state of discharge again permits of satisfactory floating.

Also when cruising in a heavy seaway, and it is desired to float the batteries on the line, it is especially important when so doing that very close attention be paid to the pilot cell readings. These readings should be taken at 30-minute intervals in order to insure against injury to the battery through excessive gassing brought about by the intermittent high rates of charge incident to the racing of the engines when the propellers lift out of the water, and although the racing of the engines is moderated to a certain degree when floating the battery on the line, yet the increase in the number of revolutions per minute when the propellers lift out of the water is such as to cause a much higher rate of charge to pass into the battery than ordinarily occurs during the normal operation of floating the battery when cruising in a smooth sea, and for this reason the special precautions against floating at too high a voltage should be taken to guard against injury to the battery from this cause. Therefore, floating should be intermittent when cruising in a heavy seaway; that is, the battery should be floated until the average voltage per cell is 2.15 volts, when the generators should be shut down and the battery discharged on the auxiliary load until such time as the pilot cell readings indicate that the batteries have reached a state of approximately 25 per cent discharge on the three-hour rated ampere-hour capacity basis.

Another very important point incident to the operation of floating the battery on the line, and one which is worthy of the constant attention and consideration of the commanding officer and the operating personnel, is the question of proper ventilation of the boat while floating. As to this feature, the ventilators should be so operated as to at all times keep the atmosphere of the boat as free as possible from all acid fumes and gases which are evolved from the storage batteries. Also, in so far as is consistent with the demands of the service, floating the battery on the line should be discontinued sufficiently long before sealing the boat for a submerged run as to enable the ventilators to expel all battery gases and fumes before ventilating in-board.

Manifestly, under conditions of wartime operation, a dive may frequently have to be made with very little warning beforehand, yet the training of the crews and development of the organization on board the submarine should be such as to anticipate a dive as far in advance of the actual sealing-up of the boat as is possible. This procedure is entirely essential to the efficient and successful operation of the boat.

Chief among the many advantages obtained as a result of floating the storage batteries on the line in the submarine electrical plant may be included the following:

I. Conservation of man-power. This through no additional duty at watch-standing for charging the batteries upon arrival in port. Only an old submarine man, who has actually experienced the gruelling grind of a strenuous submarine trip at sea and upon arrival in port has had to remain on duty for five or six hours for charging the batteries, can fully appreciate this advantage. Upon arrival in port and when coming alongside, the chief electrician's cheery report, "Full battery, sir!" is a welcome sound to the entire crew, as it betokens a hot bath, clean clothes, fresh food, and "all night in" for all hands.

II. Conservation of battery-power. Over a given period of operation, fewer complete cycles required of the battery; hence increased life of the battery. Also, the battery is kept in a healthy condition, its pores kept open, and effects of sulphation and local action reduced to a minimum.

III. Conservation of engine power. Under ordinary cruising speeds there is a material surplus of engine power available which may well be used for carrying the auxiliary load while the battery is floated on the line. Hence, for a given period of operation, a reduction is effected in the number of hours the engines are actually in operation, with the consequent increased economy in the fuel and oil and lubricating oil consumption.

IV. Battery works at greater efficiency. Over a given period of operation, due to the practically fully charged condition of the battery, the average voltages during discharge are higher; hence, an increase in the number of kilowatt hours developed for this period.

V. Maximum amount of reserve maneuvering power available in event of disability of engines. This is an especially important advantage, since the reserve power gained thereby would be invaluable in effecting an escape should engines become disabled in the presence of the enemy. Likewise, in event of such disability during a heavy storm at sea, it would materially assist in maintaining steerage-way in riding out a gale or even the possibility of reaching port or sheltered waters through the aid of the motors.

Furthermore, if operating in extremely cold weather and disabled at sea, the battery power is available for cooking purposes as well as heating the

boat and preserving the health and comfort of the crew for a considerable length of time.

VI. Acts as a balance for the main engines and thus reduces the wear and tear on parts by assisting in preventing racing of the propellers when cruising in a sea-way.

VII. Under exceptional circumstances it may be used for a long, low-rate overcharging of the batteries.

Finally, in summing up the foregoing advantages, it is, in a word, an increase in the submarine's total plant efficiency, both matériel and personnel.

Therefore, since in light of present day development of the submarine, the storage battery is the accepted source of motive power for submerged maneuvers and operations, it is highly essential from a point of military efficiency that the batteries be maintained in such condition as to enable the submarine to effectively perform its paramount duty—that of submerged approach and attack. Moreover, for a given space and weight, since the high-rate energy output of the storage battery or its capacity for driving the boat through the water at sustained high speed is comparatively limited at best, it is thus necessary, while operating on the surface, that the batteries be kept in a state of practically full charge and in a condition for developing a maximum amount of energy on comparatively short notice, in order that the successful submerged approach and attack may be consummated. This condition obtains, in a measure, through the practice of floating the storage batteries on the line, and, obviously, for successful wartime operations, the desirability of such an expedient is apparent.

## CHAPTER XIX.

### BATTERY VENTILATION.

**The Function of Battery Ventilation.**—In the immediately preceding chapters we have considered those features of storage battery operation relating primarily to watering, charging, and discharging the cells, so we now come to the consideration of another highly important feature of the general subject of operation, and one which is very essential to the safe and satisfactory performance of these batteries. This feature is that of battery ventilation, and it is the prime function of this feature to periodically ventilate the cells in order that the following results may be accomplished :

- (a) Dissipate the heat generated.
- (b) Dissipate the gases evolved.

**Dissipation of the Heat Generated.**—Referring to that feature of ventilation designed to dissipate the heat generated in the storage battery, it may be said that, when considered in its broadest sense, there are four basic factors which are responsible for rise in temperature of the cells, and these factors may be briefly summarized as follows :

*First:* The heat generated as a result of the chemical reactions which take place in the cells, which factor is commonly referred to in chemical parlance as “the heat of chemical reaction.” The density of the acid used in the electrolyte, and the composition of the active materials and other parts of the plates are prime constituents of this factor.

*Second:* The heat generated as a result of electrolysis of the water of the electrolyte, that is, the breaking up or decomposition of the water into its gaseous constituents, hydrogen and oxygen, by the charging current.

This factor occurs at that portion of the charge in which the amount of the charging current is greater than that being absorbed by the battery in the reduction of the lead-sulphate in the plates, and the effects of this factor on the temperature of the cell are greatest during the latter stages of the charge, as it is during this period that the amount of lead-sulphate remaining in the plates is comparatively small, and furthermore, this sulphate being less accessible to the electrochemical action, in consequence it is with greater difficulty that it is reduced by the charging current. Therefore, all charging current which is not utilized in the reduction of lead-sulphate goes to the electrolysis of the water contained in the electrolyte, and since the latter operation is accompanied by an evolution of considerable heat, it is necessary

to reduce the amount of the charging current as the charge progresses in order to protect the cells from injury through violent gassing and the high temperature incident thereto. Also, the necessity for cooling the cells by ventilation manifestly increases during the latter stages of the charge.

*Third:* The resistance offered to the flow of current by the component parts of the cell such as grids, active materials, plate lugs, cross-bars, straps, terminal posts, electrolyte, separators, etc.; this portion of this factor being commonly termed the *internal resistance* of the cell and depends upon the composition of the parts enumerated above and the manner in which they are assembled. This factor also includes the resistance offered to the flow of current by the inter-cell and terminal connectors as well as the other conducting parts on the exterior of the cell, and, although these parts being exterior to the cell cannot properly be included in the internal resistance of the cell, they should nevertheless be taken into account when considering the factors necessitating battery ventilation. In a properly designed battery the amount of heat generated by this factor should be relatively small.

*Fourth:* The remaining factor to be considered is that of the temperature of the surrounding air. Obviously, other things being equal, the effects of all of the factors outlined in the preceding paragraphs are aggravated by high temperature of the surrounding air, and are in general moderated for low surrounding temperature, the amount of ventilation required for controlling the temperature of the cells depending upon the difference between the temperature of the surrounding air and that of the cells; that is, high surrounding temperature manifestly requires more ventilation than that for low surrounding temperature. As an illustration of the application of this feature of ventilation, it may be said that it is standard practice in our service for batteries operated in the Tropics to reduce the specific gravity of the electrolyte and to raise the maximum permissible temperature limit of the battery from 110° to 125° Fahrenheit, since for reasons which will be explained, this expedient is resorted to as a means of increasing the life of the battery when operating in this climate.

High temperatures cause increased activity of all chemical reactions taking place in the cell, with the result that if the cells are subjected to such temperatures the lives of the plates and of the separators, especially those of wood, are materially shortened. It is for this reason, therefore, that a maximum limiting temperature for operating these batteries has been established, and, it is accordingly one of the functions of battery ventilation to maintain the cell temperatures within the specified maximum.

**Dissipation of the Gases Evolved.**—It is characteristic of all types of storage batteries to evolve certain amounts of gases while the cells are either

being charged, discharged, or while they are standing idle, the major portion of these gases, and the ones most intimately associated with the subject of ventilation, consisting of hydrogen and oxygen.

Moreover, although the amounts of these gases evolved are greater while the cells are being charged, especially towards the end of the charge when electrolysis is at a maximum, as already stated, the cells nevertheless evolve certain amounts of these gases during discharge as well as while standing idle, this being due chiefly to the local action which takes place in the cells as a result of the impurities contained therein, as well as to the escape of gases previously formed and entrained in the pores of the plates and separators.

Now, as pointed out above, since the major portion of the gases evolved consists of hydrogen and oxygen, let us next consider their properties and the relation which they bear to the general subject of storage battery ventilation.

Hydrogen is a colorless, odorless, tasteless gas, and is only slightly soluble in water. It is the lightest of all known substances and for this reason its specific gravity is usually taken as unity and is the standard to which the specific gravities of other substances, especially those of gases, are often referred. It is incapable of uniting with oxygen at ordinary temperatures, but like other substances it is necessary that it be heated to the kindling temperature before combustion is effected; however, the heat of an electric spark or that of a lighted match is sufficient to instantaneously raise it to the kindling temperature, thus effecting combustion, or in other words, combination with oxygen.

Oxygen is the most widely distributed and the most abundant element known on earth, and consists of a colorless, odorless, tasteless gas, which is only slightly soluble in water and has a specific gravity of 15.88 as referred to hydrogen as a standard; that is, a given volume of oxygen weighs 15.88 times as much as an equal volume of hydrogen when considered under the same conditions. At ordinary temperatures oxygen does not readily combine with other substances, but at higher temperatures, different temperatures for different substances, it combines with practically all other elements. Its combination with other substances is generally accompanied by an evolution of heat and light, and this process is called combustion, and the temperature to which it is necessary to raise a substance in order for it to combine with oxygen is termed the "kindling temperature" of that substance.

As stated above, the heat of an electric spark or that of a lighted match is sufficient to raise hydrogen to its kindling temperature such that combination with oxygen is instantaneously effected, and, furthermore this combination is accompanied by a violent explosive action. Also, in every case of combination between these two elements it has been proven over and over again and without question that two parts by volume of hydrogen always

combine with one part by volume of oxygen, and that the result of such combination is the formation of water ( $H_2O$ ). Moreover, there is at present no other known ratio in which it is possible to effect combination between these two elements.

It has also been proven over and over again that when an electric current is passed through water such that electrolysis takes place, the decomposition of the water into its gaseous constituents, hydrogen and oxygen, always takes place in the same ratio in which these two elements combine; that is, two volumes of hydrogen are liberated for every volume of oxygen so liberated. It is, therefore, one of the axioms of chemistry that the weight of water decomposed by an electric current is exactly equal to the weight of the hydrogen plus that of the oxygen obtained, and that when hydrogen and oxygen are brought together again under proper conditions as much water is formed as was originally decomposed.

Having thus established that these two elements do combine with each other when brought together in proper proportions and under proper conditions, and that such combination is accompanied by a violent explosion, it may be said that this feature constitutes the vital characteristic of these gases in so far as relates to the subject of storage battery ventilation.

Let us now return to the subject of these gases as evolved from the storage battery. As already pointed out, all charging current entering the cell and which is not utilized in reducing the lead-sulphate of the plates represents a distinct loss of energy in so far as charging the battery is concerned, and this excess current goes to electrolysis or the decomposition of the water of the electrolyte, hydrogen being set free at the negative plates while oxygen is set free at the positive plates.

Moreover, as a result of a series of very accurately conducted experiments it has been established that when, at a temperature of  $80^\circ$  Fahrenheit and a barometric pressure of 760 mm., a continuous current of one ampere is passed through water by means of inert electrodes, such that all of this current is utilized in electrolysis, there are evolved 0.000405 cubic feet of gas per minute; also, as has been shown, since this quantity of gas is divided in the volumetric ratio of two parts of hydrogen to one part of oxygen, it follows that under the given conditions there are evolved:

$\frac{2}{3} \times 0.000405 = 0.000810$  cubic feet of hydrogen per minute, or,  $60 \times 0.000810 = 0.0162$  cubic feet of hydrogen per hour. In other words, for every ampere-hour of current flowing through the inert electrodes there are evolved .0162 cubic feet of hydrogen. Therefore, these figures should be used in calculating the capacity of storage battery ventilating sets, as they represent the maximum amount of gas evolved by each cell while being charged which, as has been stated, is the period of maximum gassing.

It has furthermore been established that when hydrogen to the amount of 5 per cent is present in oxygen, or air, inflammation or free burning is effected, and that under favorable conditions as low as a 3 per cent mixture of hydrogen in oxygen, or air, may result in an explosive action if brought in contact with an electric spark or an open flame. Manifestly, therefore, a 3 per cent mixture of hydrogen in oxygen, or air, should be considered a *dangerous mixture* in storage battery operation, and it is desired to emphasize this point, especially in view of the many disastrous battery explosions which have resulted through insufficient or defective battery ventilation, whether through carelessness on the part of the operating personnel, or through poor design of ventilating equipment.

In this regard, it should be stated that much serious thought and conscientious work has been devoted to this subject by battery engineers in designing and perfecting satisfactory ventilating systems and equipment for storage battery installations, and particularly so in the field of submarine boat construction and design, and it should be further stated that our own naval personnel, both commissioned and enlisted, have contributed in no small degree to the successful designs which have been worked out for ventilating large storage battery installations.

With present stage of the storage battery art it may be said that it is considered good practice to design the ventilating equipment for a given battery installation on a basis of at all times keeping the hydrogen content of the air in and around the cells at or below 2 per cent, thus allowing for a good factor of safety against the formation of an explosive mixture.

The following examples should therefore serve to clearly bring out the salient features of this subject in so far as concerns the design and the operation of the ventilating equipment for a given battery installation:

*Example No. 1.*—A certain battery installation consisting of 60 cells, all of which are connected in series, has a “finishing rate” of 800 amperes. What should be the capacity of the ventilating blowers in order that when an overcharge at the finishing rate is put into the battery the hydrogen content in the cells and the ventilating system at no time exceeds 2 per cent?

*Solution.*—Now, assuming that during this overcharge all of the charging current is utilized in decomposing the water of the electrolyte, then the theoretical maximum amount of hydrogen evolved will be:

$$\frac{800 \times .0162 \times 60}{60} = 12.96 \text{ cubic feet per minute.}$$

Also: Let  $x$  equal the amount of air required to be supplied by the ventilating blowers in order that the percentage of hydrogen present in the system may at no time exceed 2 per cent.

Then :

$$x : 98 :: 12.96 : 2.$$

Or:  $x = 1270.08$  cubic feet of air per minute. Therefore, it is apparent that, under the given conditions, the ventilating blowers should be capable of supplying 1270.08 cubic feet of air per minute in order to keep the percentage of hydrogen at or below 2 per cent.

*Example No. 2.*—Upon completion of the overcharge on the battery outlined in Example No. 1, this battery was then subjected to 6000 ampere-hours of discharge, after which it was again charged, the amount of this charge consisting of 6600 ampere-hours. Assuming that the entire amount of ampere-hours of charge in excess of the discharge was utilized in electrolysis of the water of the electrolyte, how much air was required of the ventilating blowers during this period in order that the hydrogen content in the system at no time exceeded 2 per cent?

*Solution.*—The ampere-hours of charge in excess of the discharge equals 600.

Then:  $600 \times .0162 \times 60 = 583.2$  cubic feet of hydrogen evolved during the overcharge period.

Proceeding as was indicated in the solution of Example No. 1, we find that it was necessary that the ventilating blowers supply a total of 28,576.3 cubic feet of air during this period in order that the amount of hydrogen present in the system should not exceed 2 per cent.

In presenting the foregoing solutions to the above problems, the theoretical maximum of .0162 cubic feet of hydrogen per ampere-hour of charging current has been used and which is based upon an operating temperature of 80° Fahrenheit and a barometric pressure of 760 mm., for both air and hydrogen, since this basis is considered sufficiently accurate for practical application to all conditions of storage battery operation.

Thus it is seen that it is one of the prime functions of battery ventilation to dissipate the gases which are evolved in the cells, and in view of the statements and the general discussion of this subject as contained in the foregoing paragraphs, it is manifest that the importance which attaches to this feature of battery operation cannot be overestimated. Therefore, the subject of proper battery ventilation merits the constant care and attention of the operating personnel in order that these batteries may be safely and satisfactorily operated.

### Two Methods of Battery Ventilation.

There are two methods of ventilation used in storage battery operation, the particular method employed for a given installation depending upon

the type of battery as well as the special operating conditions to which it is subjected. These methods may be classified as follows:

1. Free ventilation.
2. Forced ventilation.

**Free Ventilation.**—In this method the cells are open to the atmosphere of the compartments or rooms in which they are located and in this manner discharge their gases directly into the atmosphere of these compartments without the aid of any other means of air circulation. This method of ventilation is especially characteristic in the portable types of batteries and other small cell installations, since the volume of gas evolved by these cells is in general relatively small in proportion to the volume of fresh air which normally enters the battery compartments. However, the doors, windows, or other openings in these compartments should be opened periodically as necessary to effect proper circulation for renewing that air around the batteries. In those unit assembly type cells designed for ventilating by this method each cell cover is equipped with a vent plug containing small vent holes for permitting the free egress of the gases from the cells.

Also, if the cells are assembled in trays equipped with covers, it is especially important that all trays be uncovered while charging in order to allow the gases to escape from the cells before an explosive mixture is formed, as well as to provide sufficient ventilation for controlling temperature. The designs for all tray covers should provide for appropriate vent holes for permitting the escape of gases when the covers are secured in position, as is often the case when the batteries are being discharged or while standing idle.

Some of the larger types of cells such as are used for stand-by and other purposes in the large central power stations, etc., also discharge their gases directly from the cells into the rooms or compartments in which they are located, and, although such installations may be properly included under this general classification of free ventilation, it may be said that these battery compartments are usually specially designed for affording free circulation of the air, such as by means of ventilator cowls which automatically trim with the wind, etc.; indeed, in some instances of these battery installations special supply and exhaust blowers are installed in the compartments for increasing the circulation of the air.

Owing to the fact that each bubble of gas which is liberated from the cells into the atmosphere of these battery compartments contains a thin film of sulphuric acid sprayed up from the electrolyte, it is especially advisable that all wood and metal parts in the immediate vicinity of the batteries be coated with an acid resisting paint in order to preserve these parts against the corrosive action of any acid deposited upon them from this spray.

The never too often repeated caution of not allowing an electric spark or an open flame of any kind around the batteries should be especially rigidly observed in these installations.

**Forced Ventilation.**—This method of battery ventilation derives its name from the fact that the circulation of the air through the cells is effected by artificial means, or in other words, this circulation is “forced.” This method is extensively used for ventilating the larger types of cells, such as are used in central power station work, as well as those used in the submarine service. In some of these installations all of the cells are open to a common trunk or duct and the required cell ventilation obtained by forcing the air through this trunk or duct; in other installations in which the unit assembly type of cell is used, each cell is individually connected directly to a common exhaust duct or to one of several such ducts comprising the ventilation system, each cell being thus individually ventilated by forcing the air circulation through these ducts.

Depending upon the special means employed in circulating the air through or about the cells, this method may be further divided into two distinct types or systems of ventilation, as follows:

- (a) Pressure system.
- (b) Suction system.

**Pressure System.**—It is characteristic of this system of circulation that the air is forced by pressure through the ventilating ducts, thus collecting the gases evolved from the cells and discharging them into the atmosphere on the outside of the battery compartment. As a general rule, it may be said that the application of this system of forced ventilation is confined chiefly to commercial practices, such as for the various types of stand-by services and other plants of this nature, since for battery installations of this type there are certain advantages to be obtained by using this system as against the suction system. One of the outstanding advantages of the pressure system rests in the fact that the acid fumes and gases do not pass through the ventilation blowers, and consequently the fan-blades and interior of the blower casings, which are usually composed of metal, are unattacked by the acid of the electrolyte. Obviously, it is essential that the ducts be composed of a material which is unattacked by the acid, such as hard rubber, paraffined impregnated wood, or wood coated with an acid resisting paint, etc. Also, it is especially important that the discharge ends of the exhaust ducts be led well clear of any parts liable to be damaged by the acid contained in the exhaust, nor should the ends of these exhaust ducts be placed where the exhaust gases are liable to come in contact with sparks, or an open flame, since if these gases should become ignited there is danger of a battery explosion as a result of a back-flare through the exhaust ducts.

**Suction System.**—As its name implies, this system consists in circulating the air through the ventilation ducts by means of suction blowers, and is the system which meets with extensive application in submarine storage battery installations, since as will later be explained this system is especially adapted to such installations. From the nature of submarine operations, it is very necessary to the comfort, health and safety of the crew that the interior of the boat be at all times kept as free as possible, especially while charging, from all battery fumes and gases, and with present stage of the art it

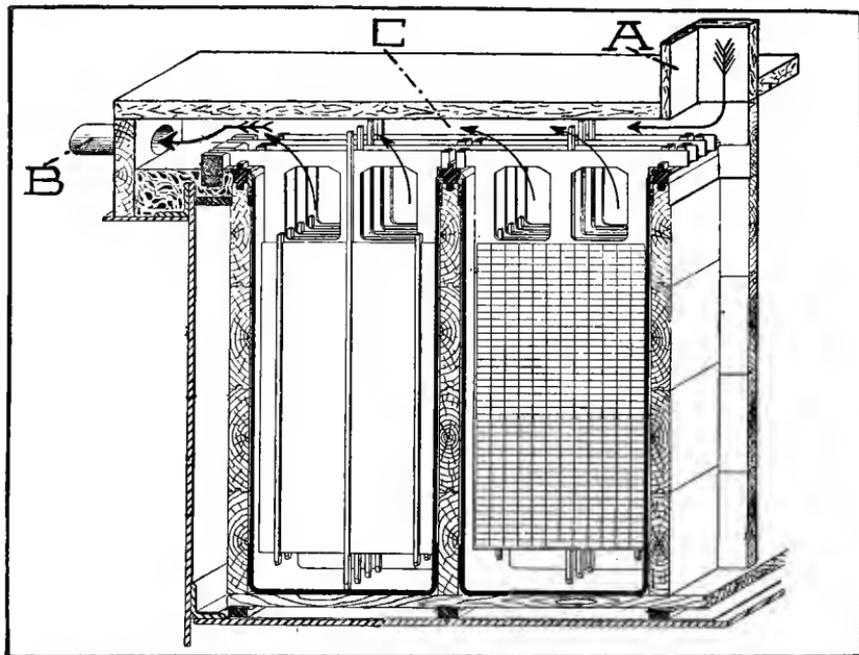


FIG. 112.—Suction System of Ventilation as Applied to Open Type Cell Installation.

may be said that the suction system of ventilation is superior to the pressure system for this service, inasmuch as when using the suction system the pressure in the cells is less than that of the interior of the boat, hence, the battery gases are accordingly prevented from escaping into the boat. When operating submerged, however, the air is usually exhausted from the ventilation system directly into the interior of the boat, but at such time the batteries are either discharging or are standing idle, and as has been previously pointed out, there is relatively little gas evolved from the cells during these periods, and in consequence there is little objection to exhausting the air of the ventilation system into the interior of the boat.

In using the suction system of ventilation it is apparent that it is necessary that special measures, such as lead plating or acid resisting coatings, be taken to preserve the suction blower casings and fan-blades against the corrosive action of the acid of the electrolyte, since all of the acid fumes and spray picked up from the cells pass through these blowers with the ventilating air before being discharged from the exhaust ducts.

As a feature of design the volumetric ratio of the various sections of the ventilation system should be so proportioned as to produce as uniform ventilation of all cells connected to the system as is possible, that is, the design of ducts should be such that the cells remote from the blowers will receive the same degree of ventilation as those cells located near the blowers.

Fig. 112 contains an illustration showing the suction system of ventilation as applied to an open type cell battery installation. It will be noted from this drawing that all cells discharge their gases into a common duct or trunk, shown at *C*, and that to one end of this duct is attached the air intake, shown at *A*, while at the other end is located the exhaust opening, shown at *B*, which connects to the suction side of the ventilation blower. As indicated by the arrows it will be seen that the fresh air is drawn down through the intake *A*, passes through duct *C* over the tops of the cells, thus collecting the gases evolved and cooling the cells, and passes out through exhaust duct *B*, into the suction blowers and from thence the air and gases are discharged from the system. The intake *A* should be located as high as possible in the battery compartment and as near as practicable to a fresh supply in order to increase the efficiency of ventilation. This intake should also be screened with wire gauze at its upper end in order to prevent foreign matter from entering the ventilation system.

#### Special Notes on Forced Ventilation.

Due to the variation in operating conditions no set rules for operating the ventilation equipment can be laid down, but the following broad procedure is outlined as a guide in operating the forced ventilation equipment of a given battery installation; this procedure is based upon the assumption that the ventilation system is designed with sufficient capacity for properly ventilating the cells when charging equipment is being used at maximum efficiency, as should manifestly be the case for a well balanced installation.

Now, considering that the battery is to be recharged following a complete discharge, ample ventilation will in general be afforded if the ventilation equipment be run at from 25 to 35 per cent of its rated capacity during the early stages of the charge and until the battery is approximately 50 per cent charged, at which time the cells will generally show signs of gassing and rise

in temperature; the ventilation should then be increased to from 50 to 75 per cent of its rated capacity and continued at this rate until the battery attains a stage of not more than 75 per cent charged, when the entire ventilation equipment should be put into operation at full capacity. In any event, full capacity of ventilation equipment should be in operation when the cells attain an average of 2.35 volts per cell, which is approximately the *critical gassing point* of the cell.

Moreover, the ventilation equipment should be operated at full capacity for at least 30 minutes after completing the charge.

It will also usually prove satisfactory during the idle periods of the battery if the ventilation system be run for one hour every day at 50 per cent rated capacity.

It is especially important that the various units of the system be kept in good condition and no leaks or other defects which would impair the efficiency of ventilation be allowed to exist. This applies particularly to the goose-necks or other parts used in connecting the cells to the system, as well as to the connections made between the other parts of the system and the ventilation blowers. Should a cell appear to have a higher temperature than the other cells of the battery it may be an indication that this cell is not getting a proper amount of ventilation.

Due to the fact that the amount of active material contained in the plates decreases, and also to the fact that the impurities entering the cell increase with the age of the cell, it may be said that for a given rate of charge the amount of gas evolved by a cell increases with the age of the cell.

## CHAPTER XX.

### SHIPPING STORAGE BATTERIES.

**Methods of Shipping Storage Batteries.**—There are two general methods of preparing storage batteries and storage battery parts for shipment from the works of the battery manufacturers, for use in the naval service, which methods are as follows:

1. Unassembled or “knocked-down” condition.
2. Assembled condition.

**Unassembled or “Knocked-Down” Condition.**—In this method the plates, separators, straps, connectors, jars, electrolyte, etc., are shipped separate or in an unassembled condition. In general, in so far as the naval service is concerned, this method is now used only in shipping spare parts for use in making repairs at battery service stations, etc. In the early days, before the development and adoption of the unit assembly type cell as standard for submarine boat installations, the *tandem type* installations were used exclusively in submarines, and in this method of shipping the component parts of the battery in a “knocked-down” condition was necessarily used for those installations. For replacements, however, this method of shipping these parts is also now used. The tandem couples are thus boxed in seaproof cases, which consist of wooden boxes encased in a hermetically sealed tin or zinc container, this container being in turn encased in another one of wood. This method insures the plates against damage or contamination, should seawater or other impurities come in contact with these cases. In packing these couples or plates, each plate is wrapped in paraffined paper and should be packed positive to positive and negative to negative. These cases in which are packed the tandem groups also contain a partition which separates the positive plates from the negative plates, there being a suitable recess in this partition for accommodating the top bar of these groups. The treated wood separators for tandem installations should also be packed in hermetically sealed cases to prevent the separators from drying out, as on account of cracking, checking and warping these separators become unserviceable if allowed to dry out.

Also, in some instances, in shipping parts for unit assembly type cells, the plates are burned up in groups and the groups are in turn separately boxed for shipment, there being spacing blocks or boards placed between the plates in the groups to preserve the proper plate separation and thus prevent

vibration and injury to the plate lugs where they are burned to the cross-bars. With the present facilities now available in the battery service stations, on board ship and at naval stations, it may be said that best results will obtain in having the plates shipped separately and burned up in groups, as required at those stations, and in order to develop our own battery engineers and operating personnel and thus assist our service to become self-sustaining in respect to all necessary battery repairs, this practice should be encouraged.

**Assembled Condition of Shipment.**—There are in general six different methods of assembling and preparing storage batteries for shipment from the works of the battery manufacturers, and these six methods may be further subdivided into two main conditions, namely, “Charged” and “Uncharged,” as follows:

- |                    |   |   |
|--------------------|---|---|
| I. Charged . . . . | { | 1. Filled.<br>2. Dumped.<br>3. Dumped and washed. |
| II. Uncharged . .  | { | 4. Unfilled.<br>5. Dry.<br>6. Bone dry.           |

In the above two conditions, it will be understood that in the “Charged” condition the batteries have received their *initial* charge and have thus been developed before shipment, whereas, in the “Uncharged” condition the batteries have never received their *initial* charge, and, therefore, must be developed after receipt at destination before they can be placed in commission. A general description of each method included in the two subdivisions outlined above will be given.

**Filled Method.**—In this method, which is sometimes referred to as the “wet” method, the element is completely assembled and installed in the jar, after which the electrolyte is poured and the cell made ready for receiving the “initial charge” and conducting the test discharge. After the cell has shown up satisfactorily on the test discharges, it is then recharged, thoroughly cleaned and carefully packed in the shipping case preparatory to shipment. Thus, it is seen that in this method the cells are shipped assembled, sealed, charged and filled with electrolyte, and from whence the term *filled* or *wet* method is derived.

In preparing batteries for shipment by this method, great care should be taken in conducting the re-charge, or *shipping charge* to see that the cell has been charged to a maximum gravity reading and thus insure that all acid has been driven out of the plates. This is necessary in view of the fact that batteries shipped by this method are liable to be left standing idle without charge for some little time, and if all acid has not been driven out of the

plates on the "shipping charge," the effects of local action will be much more pronounced. In general, such batteries should not be left standing idle longer than three months without receiving a "freshening charge," or within three months from the date of the "shipping charge"; or in any case, they should be given a "freshening charge" before the specific gravity of the electrolyte has dropped one hundred points (.100 expressed in specific gravity), as referred to the maximum gravity reading obtained on the "shipping charge." Thus, if the specific gravity of the electrolyte was 1.250 at the time of the "shipping charge," the cell should in every case be given a "freshening charge" before the specific gravity has dropped to 1.150. Best results will obtain, however, if all batteries shipped by this method and required to be stored are placed on "trickling charge" at the service stations, store-houses, etc.; the method of conducting the "trickling charge" is fully described in another chapter. With present stage of the art it may be said that this method of preparing storage batteries for shipment and for use in the naval service is preferable to any of the other methods.

**Dumped Method.**—In the *dumped* method, the cells are completely assembled, electrolyte poured, cells sealed and given their initial charge and test discharges, after which they are completely charged, filling plugs removed, the cells then turned upside down and the electrolyte *dumped* out; it is from this operation that this method derives its name. After the cells have thus been "dumped" and all free electrolyte allowed to drain out, they are then thoroughly cleaned up and packed in the shipping cases.

Ordinarily, cells assembled and prepared for shipment by this method should not remain in this condition longer than three months before filling with electrolyte and giving a complete "freshening charge," for due to the fact that it is practically impossible to remove all of the electrolyte by this method from the pores of the plates and the wood separators, and also to the fact that the water in this contained electrolyte evaporates, leaving behind the strong acid, the deteriorating effect of this acid on the plates and the separators will become quite pronounced after three months standing in this condition, the degree of deterioration after this period increasing in proportion to the increase in time that the cells are allowed to remain in the *dumped* condition.

This deteriorating effect is manifested by excessive sulphation of the plates, the sulphate crystals becoming of the hard type which are difficult to reduce, and also to the burning or "charring" of the wood separators. In fact, it may be said that this method has been given a thorough trial in the commercial storage battery field in making export shipments, and has been practically abandoned by all of the leading storage battery manufacturers, on account of the generally unsatisfactory results obtained.

Therefore, with present stage of the art, it is considered that there is little advantage to be gained in preparing storage batteries for shipment by this method, with one exception, however, in cases where it is necessary to make shipments of charged batteries under conditions which do not permit of handling and storing electrolyte.

The *dumped* method is considered entirely unsuitable for use in preparing for shipment storage batteries intended for the naval service.

**Dumped and Washed Method.**—This method is an improvement upon the “dumped” method previously described and is used principally in making shipments in which no electrolyte in the cells is permissible, but where it is desired that the cells be given their initial charge prior to shipment and such that the plates may be shipped in a fully charged condition, but without electrolyte.

In carrying out this method of shipment, assemble the cells in the usual way, give the plates the initial charge, take capacity discharges, and after the final charge adjust the gravity of the electrolyte to its normal full charge value. Place the cells in their service crates, make necessary cell connections, put the covers and vents in place and seal the cells with compound in the usual way.

When the assembly is complete remove the vents, invert the battery, allow the acid to drain from the cells, giving a time limit of about 5 minutes to insure thorough drainage, after which place the battery in an upright position and fill the cells with distilled or other approved battery water. Allow the water to remain in the cells from two to three minutes, then again invert battery and allow all water to drain from the cells. Repeat this washing process until five washings are given, permitting at least 5 minutes for the last draining in order to insure that all water not absorbed by the plates and separators is thoroughly drained from the cells. Give this washing process as much detailed attention as possible as the above instructions must be carefully carried out in order to insure a minimum amount of trouble with acid densities when the cells are later filled with acid and placed in commission. After the last draining, as outlined above, secure the vent plugs in position, the vents previously having been treated by immersing them several times in hot paraffine allowing the paraffine to harden between each immersion, thus insuring the vent holes to be securely closed. Seal tightly with paraffine all other openings where it is possible for air to enter the cell, such as around the terminal posts, filling cylinders, etc.

When the sealing process is completed the battery is ready for packing and shipment. With large batteries where the assemblies are too bulky and too heavy to be handled easily, the above process may be carried out on single cells and connections made after the sealing process is finished.

A short time previous to placing the battery in commission remove the vent plugs and fill each cell with sulphuric acid of 1.300 specific gravity, to the required height above the tops of the plates and separators. After cells are filled with acid connect all cells in series and place the battery on charge at the charging rates as specified for the particular type of battery in question. Continue this charge until the voltage and specific gravity have ceased to rise. Under ordinary conditions this charge will require about 3 hours, but if the battery has been in transit for several months, 10 to 12 hours charging may be necessary. Carefully take the temperature of the electrolyte in a cell near the center of the battery. If during the charge the temperature rises to 110° F., reduce the charging current or stop charging if necessary, until the electrolyte in the cells reaches a temperature such that charging can be continued without exceeding 110° F. At the end of the charge the specific gravity of the electrolyte should be 1.215 at 80° Fahrenheit. If not, adjust to this specific gravity by the addition of 1.300 acid, or pure water, as the case may require. After this charge is completed the vent plugs are secured in position, they previously having been put in hot water to release the paraffine; the battery is now ready for placing in commission.

On all such shipments a tag should be attached to each battery; these tags give necessary instructions for placing the battery in commission.

In general, it may be said that this method has few advantages, if any, for batteries intended for the naval service.

**Unfilled Method.**—In the *unfilled* method the cells are completely assembled with treated wood and rubber separators, and covers sealed in position on the jars, but no electrolyte is poured in the cells and the cells are thus shipped without having received their initial charge. This method may be advantageously used when it is known that the cells will be put into service within a definite period after the date of assembly.

In preparing cells for shipment by this method, it is essential that all openings in their covers, such as filling plugs, hydrometer plugs, air intake vents, exhaust vents, etc., be hermetically sealed to prevent drying out of the treated wood separators; these openings may thus be effectively sealed by using tight fitting corks, or by pouring molten paraffine around the filling plugs, hydrometer plugs, etc., after they have been screwed home. Although the cells are hermetically sealed, experiments conducted on cells assembled by this method have proven that the treated wood separators will not remain sufficiently moist indefinitely, and that, for the best results, the cells should be filled with electrolyte and given their initial charge within not more than ten months from the date of their assembly. If the elements of cells assembled by this method are examined at the expiration of from eight to ten months after assembly, it will be noted that small globules of basic lead-

carbonate have been deposited on the top edges of the plates, cross-bars and post straps. This deposit is caused by drops of moisture collecting on these lead parts. No concern should be had over this deposit, if noted, as in pouring the electrolyte in the cells most of this deposit will be carried to the bottom of the cell where it is converted into sulphate, and any which should remain on the plates and straps will ultimately be converted into active material.

Generally speaking, cells which have been assembled by the *unfilled* method will require from 50 to 75 per cent more ampere-hours on their initial charge than cells charged practically immediately after assembly. The advantages in assembling and shipping cells by this method are as follows:

- (a) No freshening charges, watering or other care and attention required during the ten months' period of storage.
- (b) Cells are at all times in immediate condition for pouring electrolyte and receiving initial charge when required.
- (c) On account of containing no acid, storage facilities increased.

**Dry Method.**—In this method the plates are burned up in groups and the two groups installed in the jar in practically the same manner as when making the usual battery assembly, with the exception that no treated wood separators are placed between the plates, there being dry, untreated boards installed instead of the regular treated wood separators in order to preserve the proper plate spacing and separation and to prevent motion of the plates in the jar. In some instances also with this method no rubber separators are installed, the thickness of the wood spacing boards thus being the combined thickness of the wood and the rubber separators.

After placing the groups in the jar as outlined above the cell cover is placed in position, but not sealed in position with sealing compound, since the groups have to be removed from the jar and the wood spacing boards removed from between the plates in order that the regular treated wood and rubber separators may be installed in their stead. After re-installing the element in the jar, the cover is properly sealed in position, the cell filled with electrolyte, after which time it is ready for receiving its initial charge.

It should be stated that when this method of assembly and shipment is used, the treated wood separators should be packed in hermetically sealed cases in order to prevent their drying out before installation in the cells. Also, these hermetically sealed cases should not be opened until ready to use the separators contained therein, and when once opened the separators should be moistened with pure water, periodically, by pouring the water into the cases, in order to prevent damage to the separators through drying out.

This method is often used for preparing the spare cells of a submarine battery for shipment and for such services it is considered satisfactory, but, for general use with a large number of cells, it is considered of doubtful value, on account of the damage which is done to the plates when they are removed from the jars to have their regular separators installed, as when removing the spacing boards, due to the dry condition of the paste in the plates, it is practically impossible to prevent loss of active material, and, obviously this represents a reduction in capacity of the cell. So, all things being equal, this method is not recommended for general use.

Some manufacturers at times use this method for assembling some of the smaller types of cells, but the wood spacing boards in such cases are of identical design as a regular separator, and in fact, they are used as such, and when it is desired to place the cell in commission, the acid is poured and cell given its initial charge without removing the untreated wood separators and installing treated ones. As stated, however, for reliability as to proper operation of the battery, with present stage of the art this method is considered of doubtful value, and is not recommended for use with batteries intended for the naval service.

**Bone Dry Method.**—At the present writing, (1920), the *bone dry* method of assembling and shipping storage batteries is practiced by only one company, The Willard Storage Battery Company, who make use of their special type separator, and which they have called the “Threaded Rubber Separator.” This separator consists of a ribbed reinforced and corrugated sheet of vulcanized rubber through which are threaded hundreds of strands of cotton wicking which permit the required circulation of the acid of the electrolyte in the cell for diffusion into the plates. No wood separators are used in conjunction with these threaded rubber separators, and it is from this fact that this company maintains that batteries assembled and shipped by this method can remain practically indefinitely without pouring of the electrolyte and conducting the initial charge, since it is their contention that there is no deterioration of these separators when assembled in an uncharged element and sealed in the jar. To date, the experience with these separators in our naval service and also with this method of assembly is comparatively limited, as sufficient time has not elapsed since their installation in navy batteries to reach a definite decision as to the merits of this method of assembly in respect to the life of the threaded rubber separators. However, it is understood that the results obtained with this method of assembly in the commercial trade, principally in the automobile industry, have been very satisfactory. Cells assembled and shipped by this method require filling with electrolyte and conducting the initial charge before placing in commission. During the World War, which has just passed,

many batteries assembled by this method were shipped overseas to France, England and other points for use in the aviation service, such as for ignition, lighting, radio, etc., and this method proved especially adapted for this service, since they contained no electrolyte and thus required no special facilities for handling and caring for them during shipment, such as would have been necessary if filled with electrolyte. Upon arrival at destination they were filled with electrolyte and given the initial charge, after which they were ready for placing in service.

### **Packing Storage Batteries for Shipment.**

Owing to the fragile nature of the parts composing storage batteries, special precautions should be observed in packing them for shipment in order to guard against breakage and other damage in transit. As a result of long experience in packing and shipping these batteries certain well founded principles have been established and suitable packing cases have been developed, and should be at all times used when necessary to pack and ship such batteries. The most important of these general principles and methods of packing will be outlined in the following paragraphs. It should also be stated that the subjects of packing and shipping storage batteries resolves itself into two main classes as follows:

1. Portable types of storage batteries.
2. Submarine types of storage batteries.

Each of the above classes of shipments may be further divided into "Domestic Shipments" and "Foreign or Overseas Shipments."

### **Packing Portable Types for Shipment.**

In packing the portable types of batteries, the packing cases should be built of strong lumber of from 1" to 1½" in thickness, and should be securely nailed; the inside dimensions of the case should be such as to allow from two to three inches all around the bottom, sides and ends of the battery, this space to be utilized for packing excelsior, coarse straw, sawdust, shavings, etc., around the battery.

**"Dog-house" Packing Case.**—A very satisfactory type of packing case extensively used for shipping portable storage batteries is known as the "Dog-house" type packing case and derives its name from the gable shaped "dog-house" construction of its roof. There is shown in Fig. 113 an illustration of this type of packing case, including the complete details of its construction. There is so much merit attached to this design that special mention should be made of some of the especially desirable features incorporated therein.

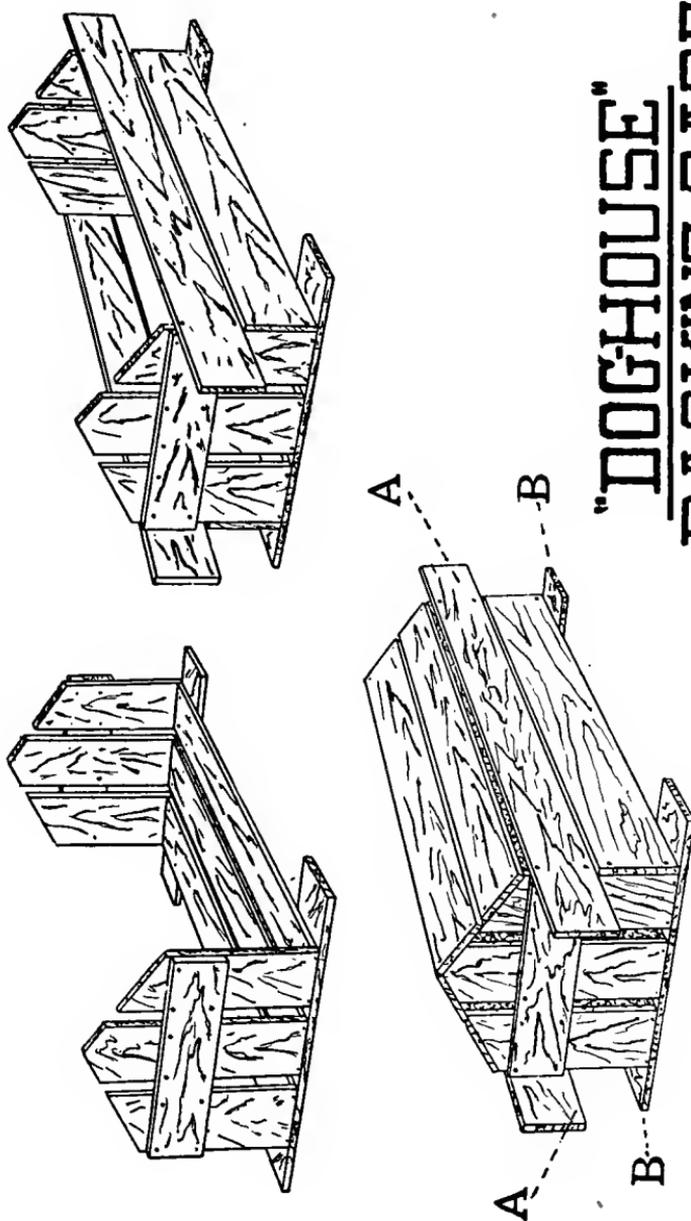


FIG. 113.—“Dog-House” Type Packing Case.

In the first place, it will be noted that the sideboards on each side, shown at *A*, are extended beyond the ends of the case to serve as handles for carrying the case in an upright position. It will also be noted that two of the athwartship bottom-boards, one installed at each end of the tray and shown at *B*, project beyond the sides of the case in order to prevent the packing case from being easily tilted over on its side and spilling the electrolyte. The gable shaped or "dog-house" roof is conducive to stowing the packing case right side up. The boards forming this roof should be secured in position with wood-screws and not with nails in order to promote care, through using a screw-driver instead of a hammer or other such tool, in packing and unpacking the battery. In respect to this feature the navy specifications require that the covers for all packing cases for portable types of batteries shall be secured in position with screws and not with nails.

When ready for packing the batteries for shipment a layer of heavy corrugated card-board, excelsior, coarse straw, shavings, etc., should be placed on the inside bottom of the packing case to act as a cushion or shock-absorber. The battery should be thoroughly cleaned, electrolyte adjusted to the proper level, filling vents secured in position and all acid and spray removed from the tops of the cell covers, connectors, etc., after which the tray covers should be securely placed in position. The battery should then be carefully wrapped in heavy paraffined paper and then placed centrally, top side up, in the packing case. The space around the sides and ends of the battery should then be filled with excelsior, straw, coarse shavings, etc., care being taken to ram this packing material tightly in place in order to prevent the battery from shifting position in the case during transit.

The packing case should contain appropriate shipping markings, preferably on the top, such as "Handle with Care," "Fragile," "This Side Up," "This Case Contains Acid," etc.

Fig. 114 shows the detailed method of packing a glass jar battery assembly for shipment in the "dog-house" type packing case.

**"Shanty Roof" Type Packing Case.**—Another design of packing case which has been found very satisfactory for shipping portable types of storage batteries is known as the "Shanty Roof" type cases, and takes its name from the sloping construction of its roof. This type of case contains many of the essential features of design as were described in the preceding paragraphs for the "dog-house" type case. Fig. 115 contains a detailed illustration of this type of case, and may be used as a guide if desired to construct a case of this type. The end boards, shown at *E*, project beyond the sides of the case and thereby prevent the case from being easily tilted over on its side; the side boards, shown at *S*, also project beyond the ends of the case and serve as handles for carrying the case; the roof boards, shown at *R*, are secured to

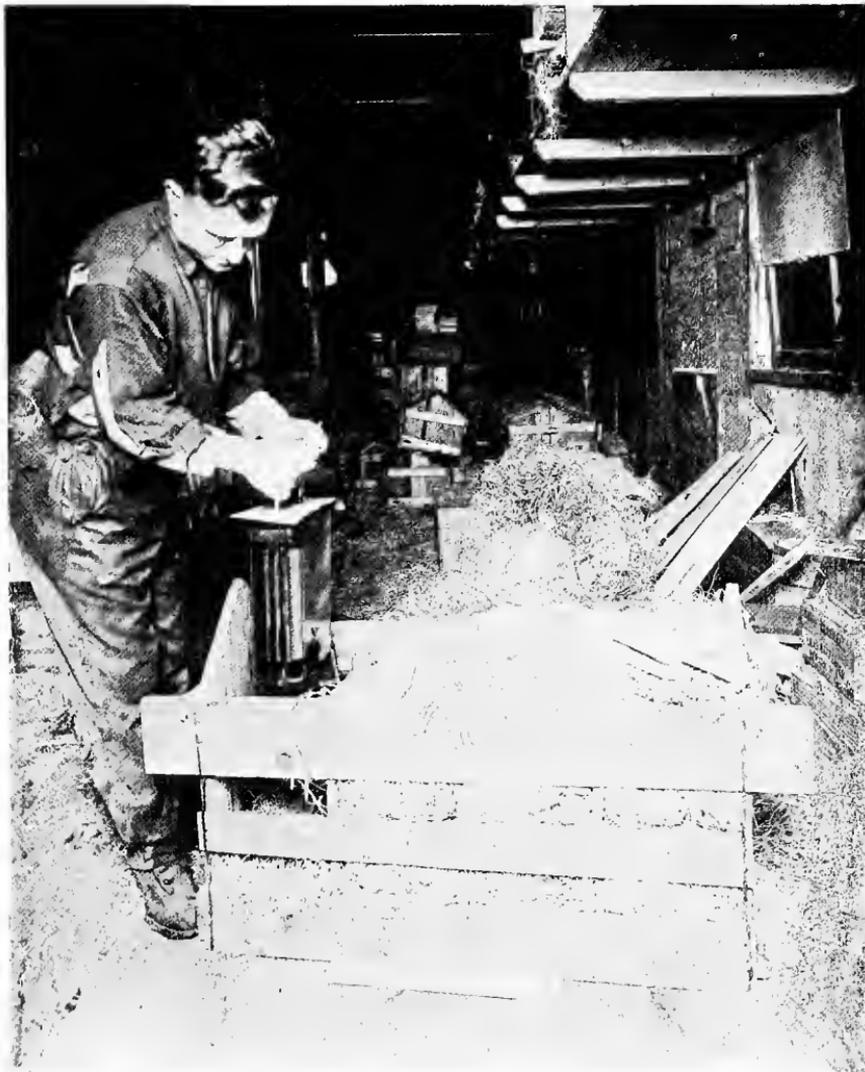


FIG. 114.—Detailed Method of Packing a Glass Jar Assembly Battery in "Dog-House" Packing Case.

the case with wood screws in accordance with the specifications for packing portable types of storage batteries. The sloping construction of the roof is designed to promote care in handling and to serve as a guide for transporting and stowing in an upright position. The usual shipping markings, such as,

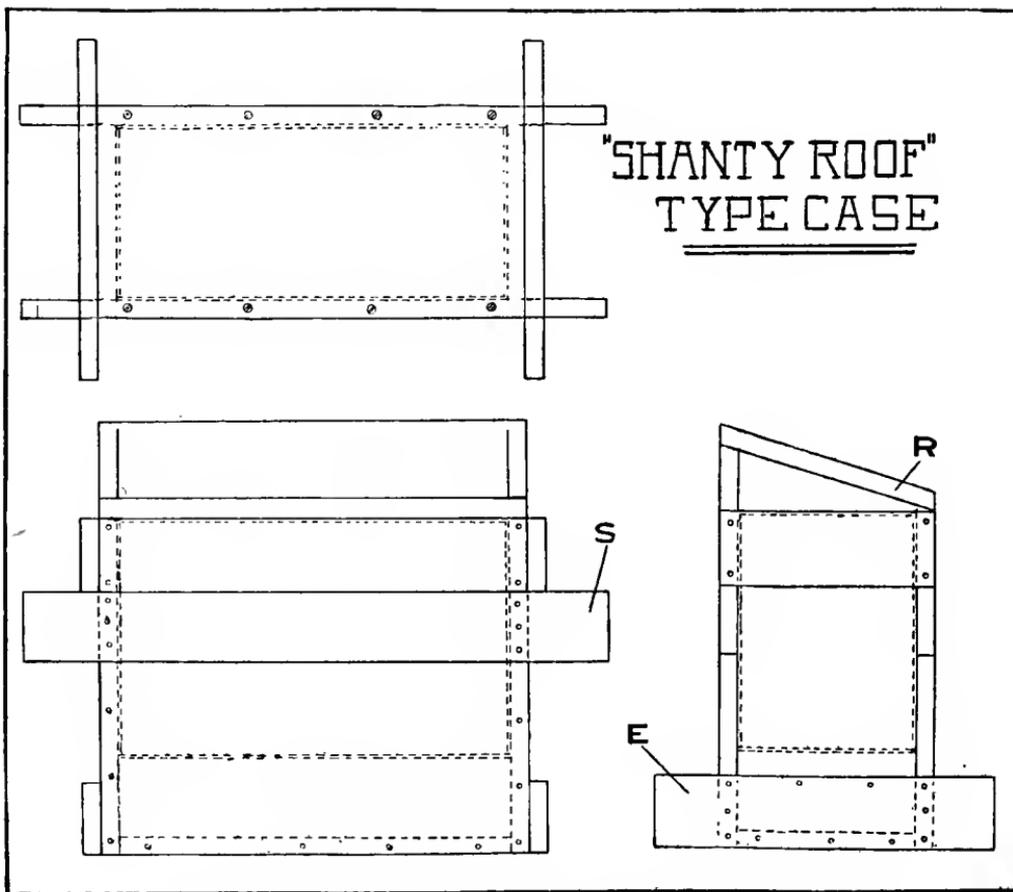


FIG. 115.—"Shanty Roof" Type Packing Case.

"Handle with Care," "This Side Up," etc., should be placed on the outside of the case. The method of preparing the batteries for packing in the case is identical with that explained in the preceding paragraphs.

#### **Packing Portable Type Storage Batteries for Foreign or Overseas Shipment.**

In packing the portable types of storage batteries for foreign shipment, if they are shipped assembled but not filled with electrolyte, they should be

packed in double or *sea-proof* cases. This method of packing consists of an inner and an outer case constructed of a good grade of lumber. The construction of the inner case is substantially the same as that described in this chapter for "domestic" shipments, with the exception, however, that the roof of this case should be flat. Also, in order to prevent damage through the weight of the element being carried by the hard rubber cover, should the battery be turned upside down, jolted, etc., there should be installed a system of blocking or filler pieces between the tops of the terminal posts, inter-cell connectors and the top of the inside packing case; care should be taken to secure a neat fit with this system of blocking, in order that there will be no shifting of position of the battery in the case. The battery should also be similarly packed in position with shavings, excelsior, coarse straw, etc., as was described for domestic shipments.

The inside dimensions of the outer case should be of sufficient size to allow from  $3\frac{1}{2}$  to 4 inches of space between the top, bottom, sides and ends of the inside packing case for packing with excelsior, saw-dust, coarse straw, etc. This packing material should be rammed securely in position around the inner case. The lumber used in the outer case should be of at least 1 inch stock and secured together with nails and additionally reinforced all around with banding iron of at least  $\frac{1}{2}$  inch in width. Fig. 115a shows illustrations of the cases used for making foreign shipments.

The electrolyte should be shipped in glass or lead carboys or jugs, these containers being packed with sawdust in a well constructed wooden packing case.

#### **Packing Cases for Submarine Cells (Domestic Shipment).**

Owing to their large size and weight as well as the comparatively fragile nature of the parts, it is necessary that each cell of the submarine type be individually packed in a separate shipping case; also, in view of their size and weight, it is necessary that the packing cases used for this purpose incorporate such features of design as to accommodate the special equipment which must be provided in properly handling these cells in transit, etc.

Fig. 116 contains a detailed illustration of a type of submarine cell packing case which has been developed through considerable experience in shipping a large number of these cells and which is now extensively used in our service for shipping cells of this type; the credit for the original design of this case belongs to the engineering department of the Electric Storage Battery Company. The drawing in Fig. 116 shows in detail both the assembled and the knocked-down views of this packing case. It will be noted that this packing case is of the adjustable, collapsible type and is so constructed as to permit of readily assembling around the cell for shipment and can be as readily dis-assembled when it is desired to unpack the cell for installation.



FIG. 115A.—Showing Method of Packing for Foreign Shipments. The Center and Right Hand Rows Show the Inside Packing Case, while the Left Hand Row Shows the Outer Case.



This case as at present developed consists of four uprights or corner posts, shown at 1 and 2, which form the supports for the sides of the case, and by which the side boards are drawn up against the walls of the jar by means of the adjustable tie-rods, 7 and 8; these tie-rods also permit of adjusting the sides of the case against the jar in order to compensate for the contraction or expansion incident to the drying out or checking of the lumber, as well as the heating of the cell during the initial charge and test discharges. It is therefore possible by this means to maintain the sides of the packing case firmly against the walls of the jar, thus preventing relative motion between the cell and the packing case, which is desirable in preventing damage in transit and subsequent handling; it is also possible by this means to prevent bulging or other distortion of the jar when conducting the development charges and discharges.

After the cell has received its development charges and discharges and given the necessary re-charge, it is usual practice to go over all of the tie-rods of the packing case and to take-up on them as necessary, but care should be taken in this operation to not set-up on them too tightly, as to do so puts an unnecessary and unequal compression on the jar, which might prove conducive to fracturing the jar in transit. In other words, the tie-rods should be set-up on just sufficiently to prevent relative motion between the cell and the packing case.

Some battery manufacturers make a practice of nailing the sides of these packing cases to the uprights after setting-up on the tie-rods, and then removing the tie-rods before shipping the cases; other manufacturers leave the tie rods in position after setting-up on them for the last time before shipment, and accordingly do not nail the sides of the case to the uprights. It now appears that either of these methods is equally satisfactory. However, in shipping spare cells in the *dry* condition, these tie-rods should not be removed, nor should the sides of the cases be nailed to the uprights, as it is necessary to give these spare *dry* cells their development charges and discharges on board submarine tenders, at naval stations, etc., before placing these cells in commission, and the packing case should therefore permit of the same adjustment during this period for these spare cells as was explained in the case of the development of the other cells prior to shipment from the works of the manufacturers.

It will be further noted that the cover of this packing case is secured to the uprights by means of screws, which feature is conducive to the exercise of care when removing the packing case cover incident to unpacking the cell, as at such times it is very important that special care be taken to prevent damage to the intake vents, filling cylinder, and other fragile parts of the



FIG. 117.—Showing Damage to Cells as a Result of Improperly Loading in Car.

cell cover. The filler pieces, shown at *A*, are placed on the under side of the cover and are designed to seat on top of the cell terminal posts when the packing case cover is secured in position, thus preventing vertical motion of the cell in the case while in transit.

The skids, shown at *6*, on the bottom of the packing case, are intended to permit of using a small automatic jacking truck or conveyor, of standard commercial design, for transporting these cells in an upright position around the dock, shipping platforms, or other places as desired. The notches, shown at *B*, on the bottom of the packing case are designed for passing a cargo strap around the case when it is desired to sling it for hoisting on board ship, etc., these notches are also conveniently used for accommodating the special lifting rods or irons used in placing these packing cases in the foreign shipment crates, which crates will later be described.

The usual shipping markings, such as "Handle with Care," "Fragile," "This Side Up," etc., should be stenciled in plain lettering on the outside of this packing case, as should also the particular cell number in the given battery installation, type of cell, name of vessel or station for which intended, and in short all information which will promote careful and expeditious handling to its ultimate destination.

In preparing the spare cells, which are assembled in a "dry" condition, for shipment, it is standard practice to paint the packing case covers of these cells a "battleship gray" in order to easily identify them as spare cells; the instructions for placing these spare cells in commission are contained in a heavy envelope attached to one of the terminal posts of the cell. These spare cells should not be filled with electrolyte until proper examination of the element has been made and the other preliminary instructions relative to placing these cells in commission have been carried out.

### **Shipping Submarine Batteries by Rail.**

Special precautions should be taken in loading the packing cases containing submarine cells in the railroad cars. Care should also be taken to not load the car beyond its rated full load capacity, and when practicable a steel frame car, which is in good condition, should be selected for the battery shipment.

Each cell should be so stowed in the car and in such relative position with respect to the adjacent cells as will prevent as much as possible any motion of the cells in the car. It has been found that best results are obtained by stowing the cells in an "egg-crate" fashion, that is, each cell is held in position by a series of athwartship and longitudinal braces composed of lumber of approximately 3" x 3" stock, these braces thus forming a skeleton cribbing in the car for holding the cells rigidly in position.

This method of loading usually resolves itself into stowing the cells in two groups, one group of cells and the corresponding cribbing being located on each side of the car doors; the success of this method depends largely upon the manner of loading the first row of cells in each end of the car, which cells should be stowed firmly or jam-up against the end of the walls of the car, so that each succeeding row of cells can be just as firmly secured in position, thus preventing lost motion in the whole group. The space in the car in wake of the side doors and between the two groups of cells outlined above should be utilized for the stowage of other battery parts, such as connectors, bolts, nuts, ventilation ducts and fittings, separators, sealing compound, or any other parts; this space between the two groups of cells should also be utilized in bracing the two groups of cells against each other by means of athwartship filler pieces consisting of lumber on the order of 4" x 6" stock, this to prevent fore and aft movement of the two groups of cells.

It is also a good plan to chart the location of each individual cell in the car such that should the car be damaged in a wreck or other accident, a record of the cells contained in the car will be on file at the factory, and steps can therefore be immediately taken to assemble replacement cells, should the urgency of the occasion demand it. Moreover, it is highly desirable that, when practicable, arrangements be made with the carrier company to bill the shipment through to destination, thus obviating as much as possible the necessity of transferring the cells from one car to another in transit, as a transfer of this kind is usually accompanied by damage unless special care is taken in handling, reloading and securing the cells in the car. Fig. 117 contains a photographic illustration of a condition such as might be expected when the cells are not properly stowed and secured in the car. This particular photograph was taken of a carload of batteries upon their receipt at destination after having been transferred from the original car en route. Obviously, therefore, when the value of the parts, as reckoned in labor, material, and strategic importance, is considered, it is apparent that every effort should be put forth to insure safe and sound delivery at destination, and the subject of properly packing these batteries should be accordingly looked after in great detail.

Before loading submarine cells in the cars they should be given a freshening charge at least within two weeks of the date of loading, and they should be watered as late as practicable before securing the packing case covers in position for shipment.

It is also a good plan to ship inter-cell connectors, bolts, nuts, washers, cell lifting-devices, etc., with the first carload of cells shipped in order to facilitate expeditious handling at destination, and also to have these parts

at hand in case it is desired to connect the cells up for giving them a freshening charge upon receipt at destination. It will usually be found advantageous to ship the cells in the consecutive order in which they are numbered in the battery installation, as in such cases the work of installation can be begun prior to receipt of all of the cells. There are numerous details of shipment, such as have been outlined above, which if studied and considered for each individual shipment will result in efficient and satisfactory service for all hands concerned.

### **Packing Submarine Cells for Foreign Shipment.**

In making foreign shipments of submarine cells a system of double packing cases is used. The inside case is of the same design as is used for domestic shipments which has previously been described and as shown in Fig. 116. This case is placed in another case of much heavier general design and of sufficient dimensions as to allow at least six inches of tightly packed sawdust between the top, bottom, and all four sides of the inside case and the walls of the outer case; in other words, the inner case containing the cell "floats" in a tightly packed bed of sawdust.

In order to prevent the sawdust from entering the cell, the inner packing case should have a sufficient amount of oil-cloth or other such heavy material tacked around it in such manner as to prevent the sawdust from sifting through the cracks and other openings in the inner case.

The outer case is equipped with skids to facilitate moving the cell around in an upright position. This case also contains an iron strap or sling securely fastened to the sides and in such manner as to prevent slinging the cell in the cargo falls for hoisting on board ship, etc., in any other but an upright position.

The usual conventional shipping markings, such as "This Side Up," "Handle with Care," "This Case Contains Acid," etc., should be plainly stenciled on the outside of this packing case; other identification markings such as the type of the battery, individual number of the cell in the installation, gross and net weights of the case, name of boat or station for which intended, and such other information as will assist in carefully and expeditiously handling the cell to its ultimate destination.

## CHAPTER XXI.

### RECEIVING STORAGE BATTERIES. PLACING IN COMMISSION. PLACING OUT OF COMMISSION.

#### Receiving Storage Batteries.

**Unpack with Care.**—The very first step in unpacking a battery upon arrival at destination is to exercise due care in order to not damage the fragile parts of which it is composed. The specifications for batteries supplied to the naval service require that the covers for the packing cases shall be secured in position with screws, and not with nails, in order that these covers may be removed by means of a screw-driver, thus facilitating the unpacking of the battery with a minimum amount of rough handling.

After removing the packing case cover carefully lift the tray or cell out of the case, care being taken to maintain the tray or cell in an upright position, in order to prevent the weight of the element from being carried by the cell cover, and also to prevent spilling the electrolyte, should the cells be shipped in a *filled* condition. In case the battery is too large and heavy for lifting out of the case, it will usually be found convenient to remove one side of the packing case and slide the battery out of the case. For unpacking submarine cells a special lifting-device is provided for attaching to the jar and the cell terminal posts, such that the cell may easily be lifted out of the case by means of a chain fall or other suitable lifting gear. However, on account of their large size and weight submarine cells should not be removed from their packing cases until ready for installation, or if they are temporarily removed from the packing cases for purpose of inspection they should be returned to the packing cases as soon as the inspection has been completed in order that the case may form a support for the cell and prevent distortion of the jar walls.

Having removed the battery from the packing case clear the tray and cells of all saw-dust, excelsior and other packing material and clean the tops of the tray and cell of all dust and foreign matter preparatory to making a thorough inspection of the battery. Should the packing case, excelsior, or other parts show signs of being acid-soaked it is likely that the battery contains one or more leaky jars, in which case it is necessary that they be renewed before placing the battery in commission.

**Inspection.**—After unpacking the battery the next step is to make a thorough inspection of all parts for breakage or other damage which may have occurred in transit. In making this inspection the filling plugs of all

cells should be removed for the purpose of ascertaining the height of the electrolyte above the tops of the plates and separators; pure distilled or other approved battery water should accordingly be added to the cells as may be found necessary to bring the level of the electrolyte to the proper height.

Should a cracked or broken jar be found, the cell containing such jar should be disconnected from the other cells and removed from the tray in order to renew the broken jar; in renewing the jar the cell connectors should be removed, and the sealing compound lifted with a hot putty-knife in order to unseal and remove the cell cover for lifting out the element. After removing the element it should be thoroughly inspected for ascertaining the condition of the plates and separators, and renewals of these parts made as may be found necessary. In case it is found that the element is dried out, or that the plates are in a badly sulphated condition, it will usually be found necessary to give the cell a special *treating* charge in order to restore its capacity. This treating charge is usually conducted at the prescribed *finishing* rate of the particular type cell in question.

Before watering, hydrometer readings should be taken of all cells in order to determine their states of charge.

After watering, the cells should be connected up and given a *freshening charge* at the earliest practicable opportunity. It is especially important in maintaining the plates in good condition that the freshening charge be given within 100 days from the date on which the battery was last charged.

**Storage.**—In case it is not desired to place the cells in service immediately upon their receipt, after having made the detailed inspection as outlined above, they should be stored in a dry place, preferably in a building in which the temperature is moderate and where ample ventilation is afforded. During the storage period the cells should be watered regularly as necessary to keep the level of the electrolyte at the proper height, and also a freshening charge should be given to the cells within every 100 days that they remain in storage. The tops of the cells, including the connectors, terminal posts, etc., should also be cleaned periodically during the storage period in order to keep them in a neat serviceable condition.

### Placing in Commission.

**Procedure Depends Upon Method of Shipping.**—The procedure to be followed in placing storage batteries in commission depends upon the special method employed in assembling the cells and preparing them for shipment, that is, whether they were shipped *filled*, *unfilled*, *dumped*, *dumped and washed*, *dry* or *bone-dry*. Also, in each case the detailed instructions issued by the battery manufacturers should be studied and carefully followed in placing the batteries in commission.

**Batteries Which Have Received Their Initial Charge Prior to Shipment.**—

As a matter of policy batteries which have received their initial charge prior to shipment should in general be given a *freshening* charge at the earliest practicable opportunity after their arrival at destination, whether they were shipped with or without electrolyte, the latter case obviously requiring that the cells be filled with electrolyte before conducting the freshening charge. In this regard great care should be taken to insure that only chemically pure sulphuric acid and distilled or other approved battery water are used in mixing the electrolyte for the cells, as this feature constitutes one of the most important ones looking to the satisfactory operation of the battery. The subject of preparation of electrolyte as well as that of watering battery have been covered in detail in other chapters.

**Batteries Which Have Not Received Their Initial Charge Prior to Shipment.**—Before attempting to place in commission batteries which have not received their initial charge, the necessary facilities for conducting the initial charge through to completion should first be made available. This includes proper charging equipment, facilities for mixing and pouring the electrolyte, accurately calibrated instruments such as ammeters and voltmeters, the usual acid testing sets such as hydrometers and thermometers, and an ample supply of appropriate forms for recording the various data as the initial charge progresses. It should here be stated that much of the future success in operating the battery depends upon the manner in which the initial charge is conducted, and special attention should therefore be devoted to this subject. The details in connection with conducting the initial charge are outlined elsewhere in this volume and should be studied carefully in conjunction with the special instructions issued for placing the particular type of battery in commission.

**Spare Cells—Submarine Type.**—With present stage of the art it is the accepted policy in the submarine service to supply for these batteries the spare cells assembled in a *dry* condition; that is, no wood or rubber separators are installed between the plates at the time of assembly, but these separators are shipped in separate containers and are to be installed later when placing the cell in commission.

Wooden spacing boards of the combined thickness of the regular wood and rubber separators are installed between the plates when assembling the plate groups in order to preserve the proper plate separation and to thus prevent relative motion of the plates and the probable damage incident thereto in handling the cell prior to installation of the regular separators.

In some instances, however, the rubber separators are installed with the dry wood spacing boards at the time of assembling the plate groups, in which case the thickness of these wood spacing boards is the same as that of the

treated wood separators, thus preserving the proper amount of spacing between the plates as well as maintaining the proper compactness in the groups until ready to install the regular treated wood separators.

The treated wood separators are packed in hermetically sealed cases in order to prevent them from drying out and these cases should therefore be not unsealed until ready to install the separators. If the treated wood separators be allowed to dry out they are thus rendered unfit for installation in the cells.

When it is desired to place in commission a spare cell which has been assembled in the manner described above, it is necessary that special prepar-

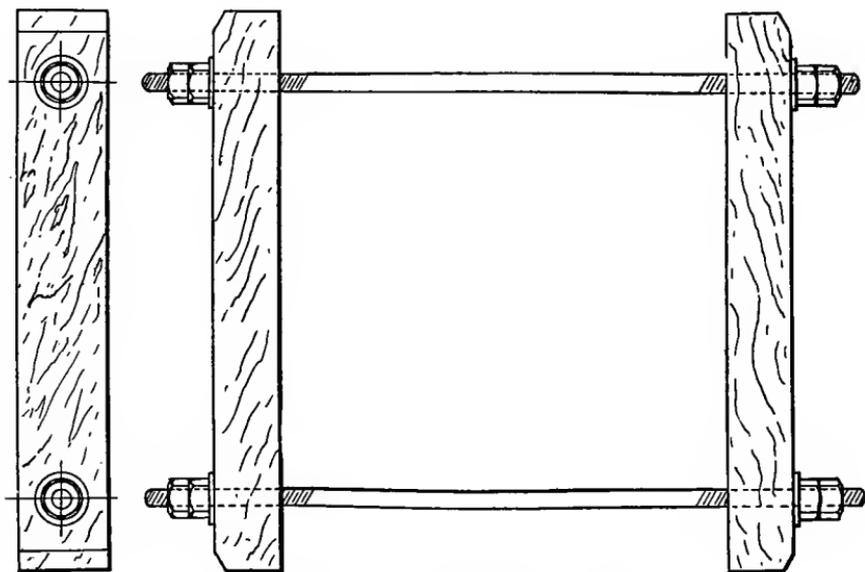


FIG. 118.—A Set of Element Clamps.

ations be made and certain equipment be provided in order to obtain best results in this operation. The following equipment and method of procedure when used in conjunction with any special instructions or equipment issued with a given type of battery will in general prove satisfactory for placing in commission these spare cells.

**Equipment Required.**—(a) Element and cell lifting device.

(b) Differential chain hoist or other tackle capable of supporting the completely assembled cell when filled with electrolyte.

(c) At least two, and preferably three, sets of element clamps for preventing the “fanning” or spreading motion of the plates when the element is removed from the jar. These clamps can easily be made on board ship or

other place as necessary, each set consisting of two hard wood boards, two tie-rods of  $\frac{1}{2}$ " or  $\frac{3}{8}$ " in diameter threaded at both ends, and a corresponding set of four washers and nuts. The boards should be approximately 2 inches thick, 3 or 4 inches wide, and about 12 inches longer than the width of the element, such that the boards extend about 6 inches beyond the vertical edges of the element when the clamps are secured in their proper positions. A hole of sufficient diameter to freely accommodate the tie-rods should be bored at about 2 inches from each end of the boards. The tie-rods should be at least 8 inches longer than the combined thickness of the boards and the element, and threaded sufficiently on each end to permit of ample spreading of the plates when removing the spacing boards and installing the regular wood and rubber separators, as well as to afford the proper amount of draw or compression of the plates and separators when it is desired to re-install the element in the jar. Fig. 118 contains an illustration of a set of these clamps from which a clear idea of their construction and use may be obtained.

(d) Two sets of sheet brass or copper element guides for use in re-installing the element in the jar. Each set of guides consists of two pieces of sheet copper or brass, one set being used for guiding the edges of the plates, while the other set is for guiding the flat faces of the element into the jar. The set for guiding the edges of the plates should be at least  $\frac{1}{8}$ " less than the inside length of the jar, while the other set should be at least  $\frac{1}{8}$ " less than the inside width of the jar. Thus it will be seen that these guides serve the purpose of "shoe-horning" the element into the jar.

(e) The required number of treated wood separators. As a rule from 10 to 15 per cent in excess of the number actually required should be provided to make up for breakage in handling, etc., as the wood separators are comparatively frail.

(f) The required number of rubber separators.

(g) The required number of hard rubber plate support and separator support pins or rods.

(h) Terminal sealing nut wrench.

(i) Lead-lined, rubber, or earthenware tank for containing the electrolyte.

(j) Rubber buckets, gloves, and aprons for handling the acid.

(k) Necessary amount of sealing compound.

(l) Appropriate vessels for melting and pouring the sealing compound.

(m) Necessary amount of oakum and soft rubber tape for use with the sealing compound in sealing the cell cover in position.

**Method of Procedure.**—The spare cells assembled as described above have not been sealed with sealing compound, and it is therefore only necessary to remove the oakum from the channel-way formed between the walls of the jar and the dome of the cover. After removing the oakum, next remove the

terminal sealing nuts by means of the terminal sealing nut wrench, and, after attaching the cell lifting device to the cell terminal posts, lift the element from the jar by means of the chain fall or other suitable lifting gear. Fig. 119 contains an illustration of a type of terminal sealing nut wrench used with these batteries.

Now, remove the separator support pins from the bottom of the element, and then remove the dry wood spacing boards from between the plates, being careful to not "fan" or spread the plates far enough apart as to place an undue strain upon the plate lugs. Care should also be taken when removing

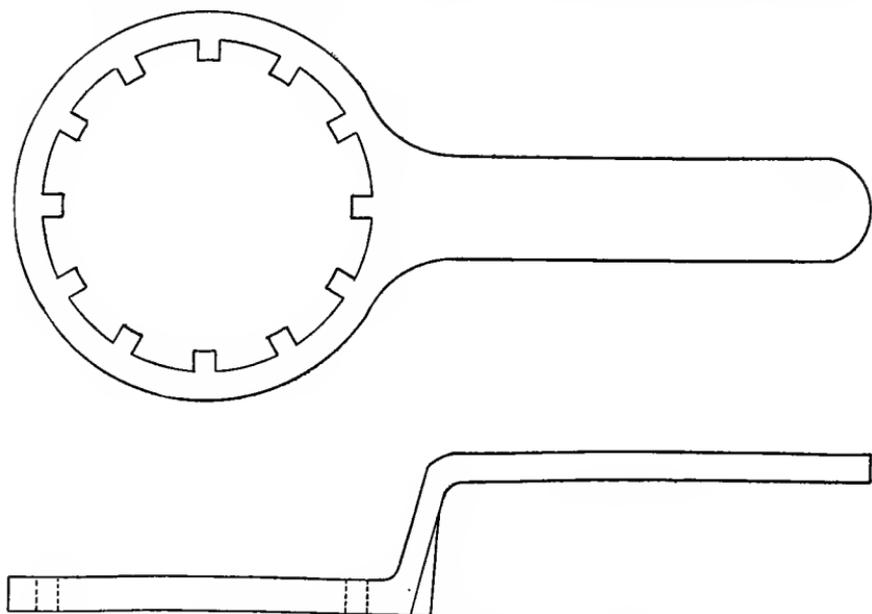


FIG. 119.—Terminal Sealing Nut Wrench.

the spacing boards to prevent as much as possible the dislodgment of the active material from the plates, as due to the dry condition of the plates some of the pellets of active material may become loose in the grid, and special care should therefore be taken to guard against loss of active material during this operation. In general, such pellets as may become loose through drying out, as mentioned above, usually expand and again tighten themselves in the grids when the acid is poured in the cell and during the development charges and discharges an subsequent cycles.

Having removed the wood spacing boards, next begin the installation of the regular separators by taking a treated wood separator and a rubber separator and placing them together in their proper relative positions as installed

in the cell, that is, the ribbed side of the wood separator is placed against the rubber separator; by thus handling each pair of these separators as a single unit the next step is to place them in position between the plates. Starting at one end of the element, with a diagonal motion slip the separator unit up between the first two plates, the rubber separator being habitually placed in contact with the positive plates, while the wood is placed in contact with the negative plates during the entire course of the separator installation. Continue this diagonal sliding motion until the separators are placed in their proper positions, the bottom and side edges of the separators being lightly tapped with a mallet and block of wood as necessary to exactly line them up with the edges of the plates as well as the separator support pins. It is especially important that no separators be allowed to project beyond their positions in respect to the edges of the plates, as on account of the small clearance allowed between the edges of the plates and the walls of the jars, such separators will be injured when installing the element in the jar.

Upon completion of the installation of separators, next install the hard rubber separator support pins and secure the element clamps in position preparatory to lowering the element into the jar. In order that no unequal strains will be put upon any portion of the plates during this operation, all clamps should be set up on uniformly in succession, that is, by setting up a little on one set and then a little on the other set, and so on until the element is sufficiently compressed for lowering away into the jar.

Before installing the element, a thorough inspection should be made of the jar in order to detect any defects, and especially to insure that the interior of the jar is clean and free of all bolts, nuts, washers, nails, tools, or any other objectional foreign matter.

Now, slip these two sets of element guide sheets into position around the top edges of the jar, the upper edges of these sheets being turned over in such manner as to permit of hanging or supporting them in position from the top edges of the jar. This done we are now ready for installing the element in the jar. Begin this installation by slacking off on the chain falls and thus gently lowering away the element, having care to guide the bottom edges and feet of the plates into position as they enter the jar. When the bottom of the element has entered the jar sufficiently then remove the element guide sheets and continue lowering away the element until the bottom set of element clamps is about level with the top of the jar. If the element is easily entering the jar, the bottom set of element clamps may be removed entirely, but in case there is a tendency for the element to "stick" or jam against the walls of the jar, it will usually be found better to progressively shift up the position of the clamps as necessary to effect proper installation of the element. In regard to this feature it should be stated that if properly designed with

respect to plate clearances, thickness of separators, etc., each element should be capable of installation in the jar without the application of any force other than the weight of the element itself, in other words, the weight of the element should be sufficient to force it home into the jar. However, should the element be found to bind slightly against the jar walls, it will usually be found that it will slide home by gently rocking the jar or by raising and lowering the element a little at the time, by taking up on and slacking off on the chain falls, thus gently working the element down into the jar.

The main objection to using force other than the weight of the element itself when installing it in the jar rests in the fact that such installation places an unnecessary bursting strain on the inside of the jar which may prove conducive to cracking the jar when the cell is placed in commission and installed in the boat, and since the question of a broken jar may, under certain conditions of operation, prove a very serious one, it is therefore very important that every possible precaution be taken to guard against the occurrence of a broken jar. With properly designed element it may be found that the binding or jamming of the element is caused by some or all of the separators running a little full in thickness, in which case a suitable set of separators of the proper thickness should be selected and installed before proceeding with the installation of the element.

The element having been installed such that it rests firmly and squarely upon the supporting ledges of the jar, the next step is that of installing and sealing the cell cover in position. Place the cell cover in position such that it rests squarely upon the soft rubber terminal post gaskets which are seated on top of the shoulders cast on the post straps, care being taken when doing this to insure that the edges of the cover do not bind at any point against the walls of the jar. Having thus shipped the cover, screw on the terminal sealing nuts and set up on them gradually and uniformly in succession in order to not strain the cover at any point. These nuts should be set up on sufficiently to seat the cover firmly in position against the soft rubber gaskets and such that an acid tight joint is effected between the cover and the post-straps.

Now, lay the soft rubber tape around the channel-way formed between the cover and the jar walls, after which pack a layer of oakum on top of this soft rubber tape. The cover is now ready for sealing by pouring the sealing compound.

Although, when it is properly done, pouring the sealing compound is a comparatively simple operation, it nevertheless requires a certain amount of care and technique in order to effect a neat and satisfactory seal around the jar, which is very important from an operating point of view, since after all it is the sealing compound that makes the cell both acid and water tight.

When pouring the compound it should be just hot enough to run freely into all crevices around the channel-way of the cover, thus filling all openings through which acid and water could pass. If the compound be too hot while pouring it will be found that it contracts considerably in cooling, forming hollow spots or honey-combs in the body of the compound which impairs its sealing properties. Also, pouring an excessive amount of compound should be guarded against, since the surplus compound must be trimmed off, leaving a ragged surface which must be smoothed off with a hot putty-knife or flame. A clever workman thus has his sealing compound at the proper temperature and only pours sufficient compound to properly seal the cell, leaving a smooth finished surface to the compound upon completion of the sealing operation. The surface of the compound should be finished off flush with the flat top of the cell cover in order to eliminate any pockets in which moisture, acid, or dirt could collect.

Having sealed the cell as outlined above, next pour the electrolyte into the cell, this electrolyte being of the required density to produce the desired full charge specific gravity upon completion of the initial charge. In general, due to the water contained in the treated wood separators, it will be found that the specific gravity of the electrolyte poured into the cell will have to be from 20 to 30 points (.020 to .030) higher than the required full charge value of the electrolyte.

After pouring the electrolyte the cell should be allowed to stand until the electrolyte has cooled sufficiently for beginning the initial charge; the temperature of the electrolyte should not be above 100 degrees Fahrenheit, and preferably lower, when beginning the initial charge.

The method of conducting the initial charge is covered in detail in another chapter.

#### Placing Out of Commission.

**Method of Placing Out of Commission.**—Should it be desired or found necessary to lay-up or store away a battery for an indefinite period, or for a period which exceeds 10 or 12 months, it will in general be found both convenient and economical to place the battery out of commission, since when out of commission the usual upkeep routine such as freshening charges, periodic watering, cleaning, etc., is not required.

A satisfactory method of placing out of commission batteries of the unit assembly type may be outlined as follows:

*First.*—The battery should be given a thorough equalizing charge in order that all acid contained in the plates may be driven out preparatory to removing the elements from the jars.

*Second.*—Disconnect each cell by removing all inter-cell and terminal connectors. Also remove all terminal post nuts, gaskets, etc.

*Third.*—Unseal the cell by passing a hot putty-knife through the sealing compound, and, after clearing away all sealing compound from around the cover, remove the cell cover.

*Fourth.*—Lift all cells out of the trays.

*Fifth.*—Lift the elements out of the jars, after which gently separate the positive and the negative groups, being careful to not injure the active material.

*Sixth.*—Remove the separators from between the plates. It will usually be found to not prove worth while to attempt to save the wood separators, and consequently they should be discarded. However, the rubber separators will usually be found to be in good condition, and in most cases can be saved for re-installation.

*Seventh.*—Remove the acid from the positive and negative groups by rinsing them sufficiently in fresh water. Then rectify any defects in these groups, such as straightening out the grids, pressing the active material back in position, etc. These features will be taken up in detail later.

*Eighth.*—Remove all acid from the jars by dumping out the old electrolyte and rinsing them out thoroughly with fresh water. Place the jars bottom side upward in order to allow all acid and water to drain out preparatory to re-installing the groups for storage.

*Ninth.*—Soak the trays in a strong caustic soda solution contained in a tub, barrel or other vessel in order to neutralize all acid contained in and around the trays; then thoroughly clean and dry them preparatory to storing them away in a clean, dry place.

*Tenth.*—After thoroughly cleaning all parts as outlined above, assemble or enmesh the positive groups in pairs in the jars, and likewise the negative groups preparatory to storing them away. In some instances it may prove desirable to place the jars containing the groups in the trays and thus storing them away together.

**Preparation of the Various Parts for Storage.**—In the preceding paragraphs we have considered in a general way the successive steps which are necessary in placing a battery out of commission, so we will now take up in detail the preparation of the various parts for storage. As previously explained, the plates should be fully charged before disassembling the battery for placing out of commission, and the detailed account of the treatment of the various parts will be begun with the plates.

**Negative Plates.**—Due to the fact that charged negative plates heat up as a result of the oxidization of the surface active material when exposed to the air, the negative groups should therefore be taken care of first after separating them from the positive groups.

The negative groups should first be rinsed off in clean fresh water and then placed on a clean bench or table to allow the acid and water to drain from them. For reasons which have been stated above, it will generally be found that the negative plates will show signs of heating and will steam when first placed on the bench, in which case they should be sprayed or sprinkled with fresh water to cool them off, continuing this spraying at intervals as necessary until the plates cease to show signs of heating. The negative groups should then be examined to determine the condition of the plates and other parts.

If it is found that the pellets of active material have expanded or bulged out beyond the surfaces of the grids, this active material should be pressed back into position while soft and before it becomes dry. A very convenient method of pressing this active material back into position is by placing clean, smooth wooden boards, of the proper size and thickness, between the plates and pressing them together in a plate press, or if a special plate press be not available, an ordinary bench vise will very well answer the purpose. It is especially important that this over-expanded or bulged active material be pressed back into position in order that proper contact with the grid may be restored, since if proper contact with the grid is not made, the plate will not give its required capacity.

It is also important that the spacing boards be of sufficient size to entirely fill the space between the plates in order to prevent fracturing the plates when they are pressed together.

Should any of the edges or corners of the plates be buckled, they should be straightened, a pair of flat nose pliers being very convenient for this work.

After straightening and pressing the plates as described above, the groups should then be immersed in sulphuric acid of about 1.250 specific gravity, or the old electrolyte removed from the battery may be conveniently used for this purpose. The groups should be allowed to remain in this acid for from 3 to 5 hours, after which they should be removed from the acid and allowed to dry without further washing. Then, placing the groups together in pairs, place them in jars preparatory to storing away. This process produces the required amount of sulphating action in the plates to maintain them in good condition while stored away.

In some cases it will prove very convenient after straightening and pressing the plates to place a pair of negative groups in each jar, and then to pour the acid over them and thus allow them to stand for from 3 to 5 hours, after which pour off the acid and store the jars and groups away without removing the groups from the jars.

**Positive Plates.**—The positive groups should be rinsed off by gently dipping them in clean fresh water, in order to remove the acid, sediment, and

any foreign matter from them, having care in this operation to dislodge as little of the active material as possible. This active material is usually soft and of relatively frail structure when first removed from the jar, and for this reason under no circumstances should a hose or any other method be used in rinsing the groups which will tend to wash this soft "muddy" active material out of the plates.

Should it be found that any of the pellets of active material are bulging out beyond the surfaces of the grids, they should be pressed back into position by either using a wooden paddle or by placing them in a plate press or vise in the same manner as was described for the negative plates.

After removing the groups from the press set them on end on the bench and allow them to dry. Then place the positive groups together in pairs and place a pair of groups thus assembled in each jar for storing away.

If any of the positive plates show signs of excessive wear they should be cut away from the cross-bars and scrapped, and new plates burned into the groups. As a general rule it will be found that more plate renewals are required in the positive than in the negative groups.

For best results all plates should be stored away in a dark place where they will not come in contact with the light.

**Wood Separators.**—Only in rare instances will it be found practicable to attempt to save the treated wood separators; however, in instances where it appears to prove worth while to save them, the separators should be thoroughly rinsed off in fresh water, after which they should be packed away in hermetically sealed cases to prevent them from drying out.

**Rubber Separators.**—After scraping off all of the sediment, active material, parts of the wood separators, and any other matter which may have lodged on the rubber separators, they should be thoroughly washed off in fresh water or by turning a hose on them. They should then be made up in bundles, by stacking them between wooden boards of approximately the same dimensions as the separators. Another satisfactory method of storing them away is to pack them in appropriate size wooden boxes or cases.

**Hard Rubber Covers.**—Thoroughly rinse the covers off in fresh water or wash them off by turning a hose on them. Should they be found to be warped when removed from the cells they may be straightened by first soaking them in hot water. For storing them away either pack them in suitable cases or place them in their normal position on the jars.

**Connectors.**—Wash the connectors in a bicarbonate of soda solution to neutralize all acid contained on them; then rinse them off in fresh water. After thoroughly cleaning them in this manner make them up in bundles or pack them away in suitable cases.

**Jars.**—After removing the elements and emptying the electrolyte from the jars, the jars should be thoroughly washed out with fresh water, being careful to remove all sediment which may have been deposited on the bottom and sides of the jar. This done, the jars are now ready to receive the groups, as has already been described.

**Electrolyte.**—If the electrolyte is sufficiently pure it should be emptied from the cells into carboys, earthenware crocks, or other suitable containers for storage. This electrolyte may also be utilized in preparing the negative groups for storage, as outlined above. If the electrolyte be not pure enough to be used again, it should be thrown away.

## CHAPTER XXII.

### FAULTS. METHODS OF DETECTING AND RECTIFYING.

**Faults Classified.**—The faults which develop in storage batteries may be said to resolve themselves into three general classes, or a combination of them, as follows:

- (a) Mechanical.
- (b) Electrical.
- (c) Chemical.

Thus by having the above classes in mind, and by pursuing a systematic course of inspection and reasoning, the cause for troubles which develop with the battery should be comparatively easily determined. Moreover, after having determined the cause, appropriate steps for rectifying or remedying these faults can then be taken.

The following table contains a list of the faults which are commonly encountered in operating the storage battery. The methods of detecting and remedying these faults are also appropriately placed in the columns of this table to serve as a guide in determining and rectifying these faults:

Faults.	How detected.	How rectified.
1. Broken jar.....	Habitually low electrolyte in the cell. Trays and other parts show signs of being acid soaked.	Renew jar.
2. Poor contact between terminal posts and connectors.	Low cell voltage. Heating of terminals or connectors. Poor lead-burning apparent. Corroded terminals and connectors.	Clean terminals and connectors. Renew joint between terminal posts and connectors. Keep battery clean.
3. Insufficient ventilation.	Battery overheats. Hydrogen content in surrounding air increases.	Improve the ventilation.
4. Too much electrolyte in the cells.	Visual inspection. Flooding of electrolyte over tops of cells with the consequent grounds and corroded terminal posts and connectors. Cell shows tendency to heat up owing to restricted ventilation.	Add only a sufficient amount of water to bring level of electrolyte to proper height above the tops of the plates and separators.
5. Leaky or improperly sealed cover.	Visual inspection. Signs of corrosion around cell terminals, connectors, etc. Top of cover acid soaked as a result of "creeping" of the electrolyte. Moisture grounds; cell loses charge on standing idle.	Seal cover properly.

Faults.	How detected.	How rectified.
6. Insufficient amount of electrolyte.	Visual inspection. Cell heats on charge. Tops of wood separators in charred condition. Tops of plates in sulphated condition. Unable to obtain hydrometer readings.	Add a sufficient amount of water.
7. Plates short-circuited.	Battery heats on charge. Battery will not hold charge. Gradual reduction in capacity. Presence of defective separator. Presence of lead-drops or other conducting material between plates. Buckled plates.	Lift the element from the jar and eliminate the short circuit.
8. Excessive sulphation of the plates.	High cell voltage during charge. Low cell voltage during discharge. Loss in capacity. Drop in the specific gravity of the electrolyte. Plates not of normal color; positive plates become a reddish brown while negative plates become a dead whitish gray. Both plates contain white spots of sulphate.	Special "treating" charge required.
9. Charging at too high a rate.	Abnormal heating of cell. Abnormal evaporation of electrolyte. Excessive gassing as shown by the "boiling" of the electrolyte. Abnormal shedding of active material from the plates.	Reduce the charging rate.
10. Internal or self-discharge.	Battery will not hold charge on standing idle. Impurities in electrolyte. Gradually loses capacity. Gradual drop in specific gravity of electrolyte. Abnormal sulphated condition of plates. Gradual drop in cell voltage. Gassing while standing idle.	Renew the electrolyte. Renew separators if defective. Eliminate any short-circuits. Keep battery clean, especially the top of the cell around terminal posts and connectors.
11. Buckled plates.....	Visual inspection. Plates short-circuited through cutting of separators when the buckling takes place. May be caused by habitually discharging battery below low voltage limit. Also it may be caused by charging battery at too high a rate, thus causing the cell to heat abnormally.	Remove element from jar and straighten plates by pressing them between clean flat boards. If too badly buckled cut plates out and renew. Do not discharge below low voltage limit. Use correct charging rate.
12. Lean plates.....	Visual inspection. Abnormal amount of sediment in bottom of the jar. Marked reduction in capacity.	Cut out lean plates and renew provided remainder of plates in group are in satisfactory condition.
13. Excessive overcharging.	Reduction in capacity through excessive shedding of the active material from the plates. Wood separators damaged through the high temperatures incident to overcharging. Frequent watering.	Reduce amount of overcharging.
14. Repeatedly under-charged.	Gradual reduction in capacity. Gradual drop in specific gravity of electrolyte. Plates abnormally sulphated. Reduction in cell voltage. Cadmium readings.	Give the battery an equalizing charge every two weeks.

Faults.	How detected.	How rectified.
15. Specific gravity will not come up on charge.	By hydrometer readings. Electrolyte density too low. Excessive sediment in jars. Loose or dirty connectors. Plates abnormally sulphated.	Give battery a "treating" charge, then add acid as necessary to bring specific gravity to required value.
16. Acid added instead of water.	High specific gravity of the electrolyte. Increased local action in cell. Marked increase in operating temperature of cell.	Reduce the specific gravity of the electrolyte.
17. Salt water in the cell..	Unmistakable signs of chlorine gas.	Dump out the electrolyte and give the cell special treatment.
18. Impurities in electrolyte.	Reduction in capacity. Battery will not hold charge. Abnormal heating of cell.	Renew electrolyte. Give cell special treatment as required.
19. Battery frozen.....	Frozen "slush" formed on the surface of electrolyte. Due to allowing battery to stand in discharged condition in freezing weather.	Keep battery charged. Have electrolyte of proper density.
20. Battery tray and other wood parts rotted.	Visual inspection. Caused by allowing acid to slop on the wood parts.	Keep battery clean. Keep wooden parts coated with an acid resisting paint.

### Series of Photographs Representing Battery Faults.

The following series of photographs will give a clear idea of some of the faults which may be expected with storage batteries if they are not given the proper care and attention.

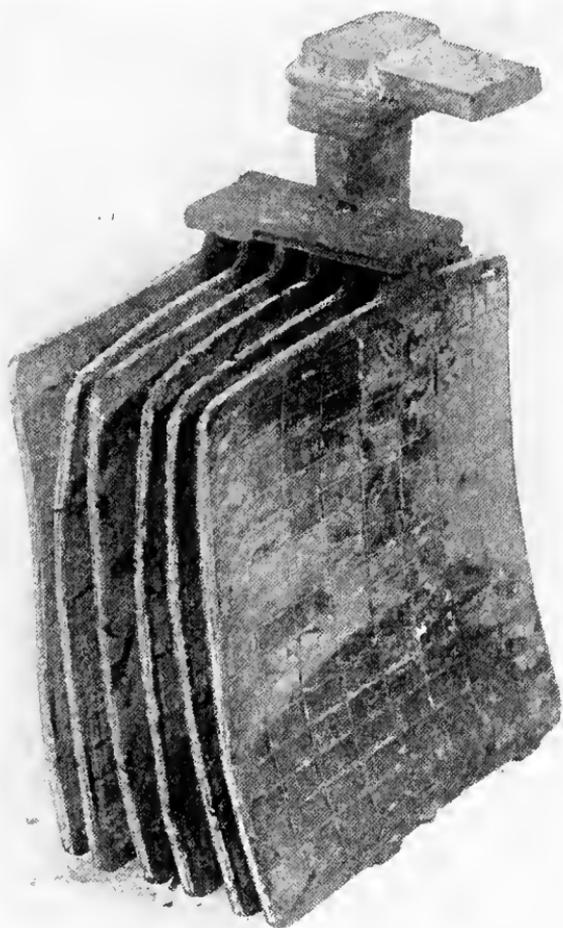


FIG. 119A.—Showing "Buckled" Plates Which Require Straightening and Pressing.

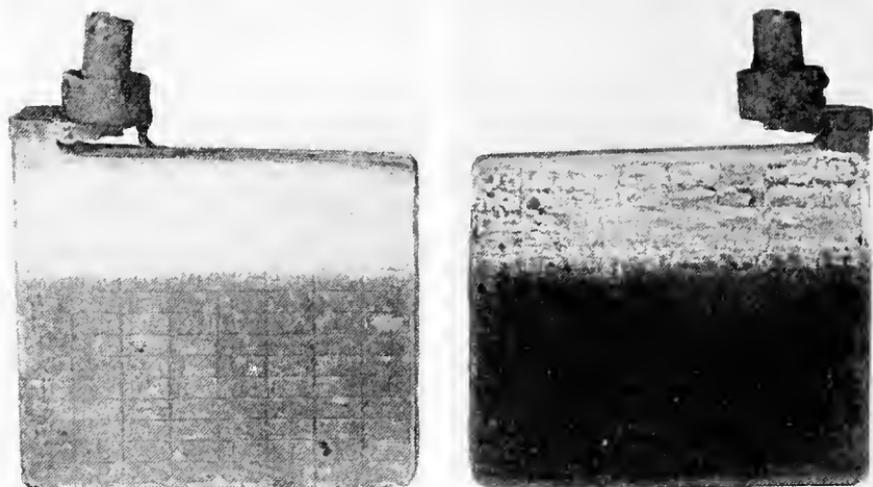


FIG. 119B.—Showing the Effects of Low Electrolyte in the Cell. Note the White Line of Sulphate on Upper Portion of the Plates.

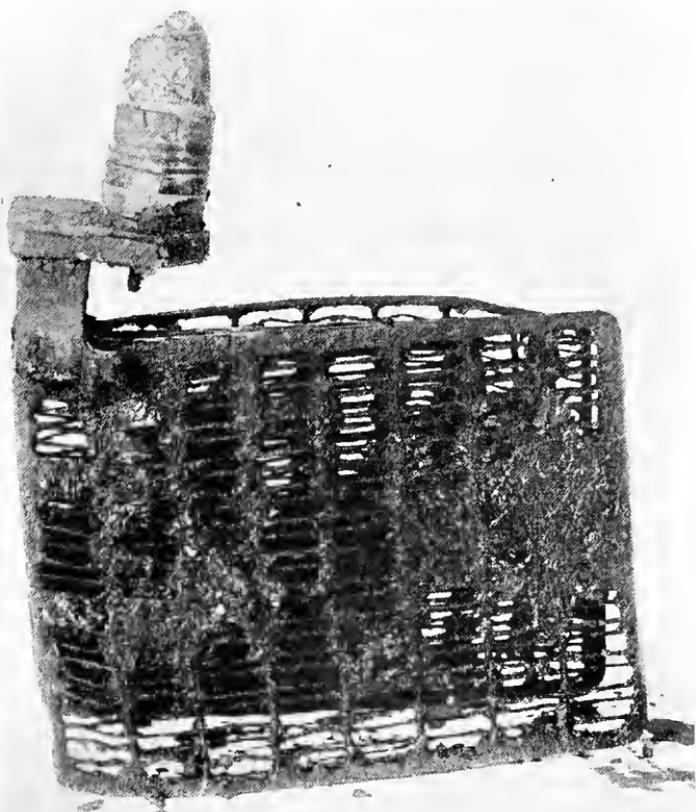


FIG. 119C.—Showing the Effects of Freezing on a Group.



FIG. 119a.—Showing the Effects of High Gravity Electrolyte and General Neglect. Note How the Grids Have Been Eaten Away by the Acid.

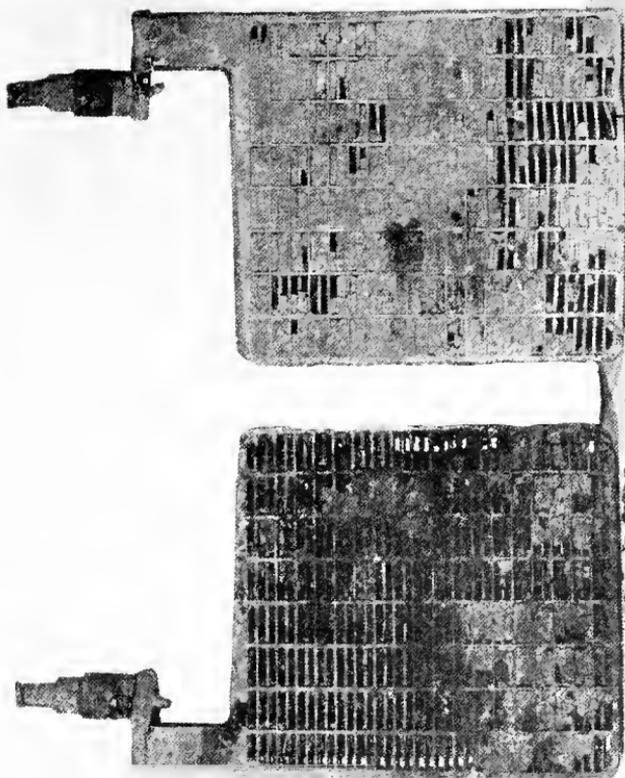
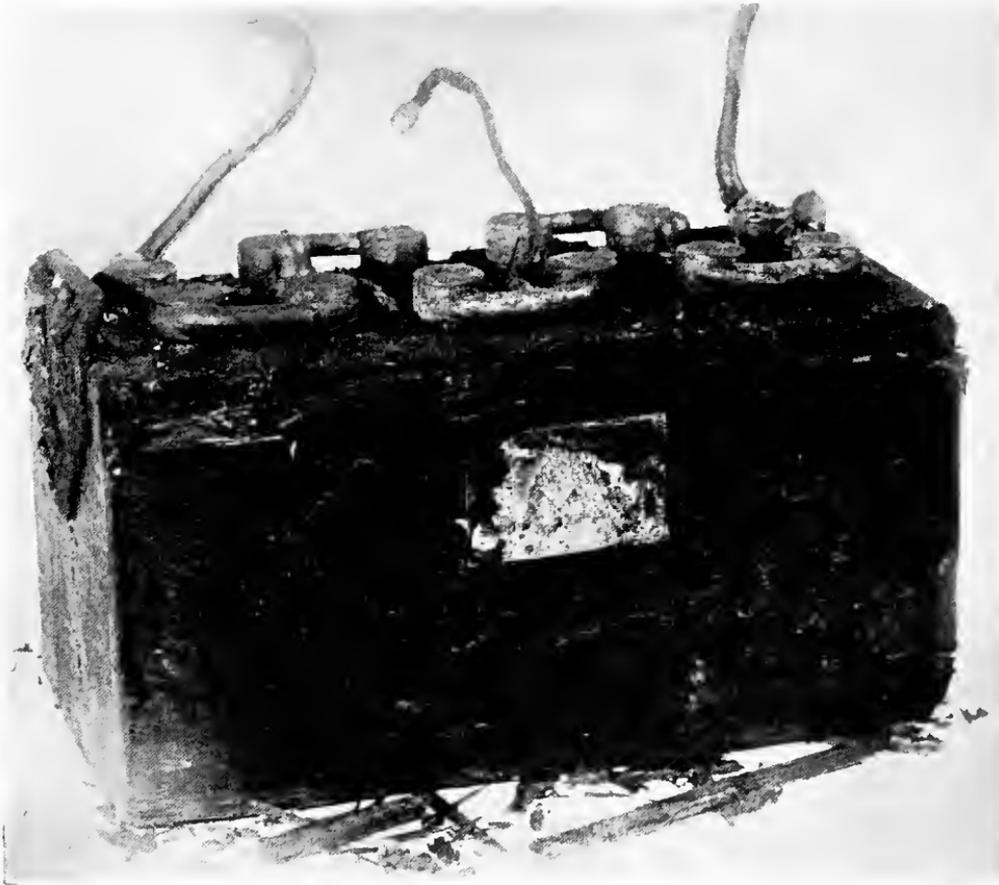


FIG. 119b.—Showing the Effects of High Charging Rates and Overheating.



**FIG. 119F.—Showing the Effects of Allowing Electrolyte to Slop-over on the Tray, and General Neglect in Keeping Battery Clean. Note the Corrosion of Connectors and How Tray is Rotted Away.**

## CHAPTER XXIII.

### REPAIRS AND GENERAL OVERHAUL.

**General Remarks on Repairs.**—As is the case with all other types of machinery and electrical apparatus the storage battery from time to time during its useful life requires a certain amount of repairs in order to enable it to efficiently perform its allotted duties, and, although these repairs are in general of a minor nature, providing that the battery is operated intelligently and given the proper attention, it is nevertheless necessary that certain technique and principles be employed in order that the repairs may be satisfactorily made. It is therefore the purpose of this chapter to point out the methods and principles involved in performing certain work incident to effecting satisfactory repairs, and since these methods and principles have resulted from a long period of practical experience in operating and repairing storage batteries, they represent the best methods and ways of effecting the various repairs, and they should be closely followed in order to obtain best all around results

**Provide Necessary Tools and Equipment.**—Before proceeding further with the subject of repairs and general overhaul, a list of the tools and equipment required for this work will be given, for in order for the battery repair gang to turn out first class work it is necessary that suitable tools and equipment be provided for them. Of course, the amount of such tools and equipment to be provided will depend largely upon the size of the battery service station, the amount of work to be done, and the extent to which it is desired to equip a given station.

The following list, however, represents the tools and other equipment which will in general be found satisfactory for practically all classes of battery repairs, and every well regulated battery repair and service station should be provided with them:

- 1 Source of direct current with suitable rheostats, charging panels, including instruments, etc., for charging the batteries.
- 1 Acid testing set, including hydrometers and thermometers.
- 1 Portable voltmeter, low reading type.
- 1 Cadmium stick and prod for taking cadmium readings of the plates.
- 1 Discharge panel with suitable rheostats for conducting test discharges on batteries before and after repairing.
- 1 Source of distilled or other approved battery water.
- 1 Large lead-lined tank for storing battery water.
- 1 Set of chemical reagents for testing electrolyte (see Chapter IX).

- 1 Soft rubber bulb syringe for adjusting the height of the electrolyte in cells.
- 1 Set of carboys for storing electrolyte.
- 1 Supply of battery acid (1.400 specific gravity).
- 1 Rubber apron to protect the clothes from the acid.
- 1 Pair rubber gloves to protect the hands when handling acid.
- 1 Pair rubber boots.
- 1 Pair goggles for wear when mixing and handling electrolyte.
- 1 Set of rubber buckets for handling electrolyte.
- 1 Glass or earthenware crock for use in mixing electrolyte.
- 10 Pounds of bicarbonate of soda for making up neutralizing solution, for washing the hands and other parts of the body while and after handling electrolyte. Fine sawdust saturated with this soda solution has been found very convenient and effective for this purpose.
- 1 Supply of sealing compound.
- 1 Metal pot for melting sealing compound.
- 1 Metal ladle for pouring sealing compound.
- 1 Putty-knife for working the sealing compound when sealing or unsealing the cell cover.
- 1 Ball peen hammer for general work.
- 1 Set of Stillson wrenches, assorted sizes.
- 1 Set of monkey wrenches, assorted sizes.
- 1 Set of open end wrenches, assorted sizes.
- 1 Ratchet brace and assortment of twist drills for drilling the connectors loose from their terminal posts, etc.
- 1 Center punch for use with ratchet and drills.
- 2 Sets of square nose pliers for pulling the elements from the jars, removing separators, straightening plates, etc.
- 1 Set of screw drivers of various sizes for general work around the trays and other parts of the battery.
- 1 Adjustable hacksaw frame and set of saw blades for general work.
- 1 Differential chain hoist for handling submarine and other large type cells.
- 1 Element lifting device for lifting submarine and other large type cells.
- 3 Sets of element clamps for use with submarine and other large type cells.
- 1 Lead-lined drip pan for catching the acid drained from the element after removal from the jar.
- 1 Sink with running water for washing jars, separators, connectors, and other parts.
- 1 Assortment of wood chisels for cutting out plates, trimming up the cross-bars and other parts after burning-in plates, etc.
- 1 Wood mallet for use with wood chisels, adjusting separators, etc.
- 1 Set of end cutting nippers for cutting plate lugs, terminal posts, straps, cross-bars, connectors, etc.

- 1 Lead-burning outfit complete.
- 1 Pair colored glasses for use when lead-burning.
- 1 Triangular scraper for scraping plate lugs, cross-bars, and other lead parts preparatory to lead-burning.
- 1 Assortment of coarse files or rasps, including handles, for dressing-up plate lugs, cross-bars, and other lead parts.
- 1 Steel file brush for cleaning files.
- 1 Wire brush for brightening up lead parts preparatory to lead-burning.
- 1 Supply of lead-antimony and lead-solder sticks for use in lead-burning.
- 1 Adjustable plate burning rack for lead-burning plates to their cross-bars, straps, and terminal posts.
- 1 Hand bellows for clearing the element and other parts of lead filings, etc.
- 1 Bench vise or other type of press for use in pressing the plates after removal from the jars.
- 1 Supply of clean flat boards of appropriate sizes for pressing and straightening out certain plates as necessary.
- 1 Lead lined case for holding a supply of treated wood separators.
- 1 Assortment of positive and negative plates of various types and sizes.
- 1 Assortment of rubber separators for the various types and sizes of batteries.
- 1 Assortment of treated wood separators of various sizes.
- 1 Assortment of cell covers and sundry parts such as soft rubber gaskets, filling plugs, terminal nuts, intake vents, etc., to fit the various types and sizes of cells.
- 1 Assortment of cell connectors to fit the various types and sizes of cells.
- 1 Assortment of cross-bar, strap and terminal post castings of various types and sizes.
- 1 Assortment of rubber jars.
- 1 Assortment of porcelain insulator skids for cell trays.
- 1 Supply of acid-resisting paint for painting cell trays and other wood parts.
- 1 Complete set of blue-prints of all types of cells, showing all part numbers for use in ordering spare parts, assembling batteries, etc.
- 1 Set of characteristic curves for all types of batteries for use in conducting test discharges, charging batteries, etc.
- 1 Set of steel numeral stencils for stamping the numbers on cells, etc.
- 1 Set of steel stencils marked "Pos" and "Neg" for marking the battery terminal posts.
- 1 Set of battery record blanks for keeping a record of charges and discharges on the various cells.

**First Make Preliminary Surface Inspection of Battery.**—Before attempting to dismantle a battery preparatory to doing any repair work, the battery should first be given a thorough surface inspection, as it is often the case that satisfactory repairs can be made or proper treatment administered without even breaking the connections between the cells. Also, when taken in conjunction with this surface inspection it is often possible that by considering the reports or repair letters forwarded to the repair station with the battery, or in questioning the operating personnel, the exact nature of the battery trouble is readily apparent and schedule of the necessary repairs or treatment can then be arranged accordingly. Attention is here invited to the table of faults and methods of detecting and rectifying them as outlined in the preceding chapter.

Furthermore, in making this preliminary surface inspection it is very essential that the exterior of the battery be in all respects thoroughly clean, especially on the tops of the cells, around the terminal posts, connectors, etc., and, if the battery is not clean in this respect when received at the repair station, then the very first step in the preliminary inspection is that of cleaning the battery. This cleaning can be very satisfactorily done by wiping off these parts with a rag dipped in a boiling solution of bicarbonate of soda and water, as this solution not only cleanses the parts, but it neutralizes any acid contained on the exterior of the battery.

It is also well in making this preliminary inspection to consider the data contained on the name-plate secured to the battery, as this name-plate should contain the date on which the battery was shipped from the works of the manufacturers, and also the terms of the guarantee. Batteries for the naval service are purchased on a guarantee basis of developing not less than 80 per cent of the rated capacity for a given period (in years) from the date of shipment from the works of the manufacturers. In this regard it may be stated that provided the surface inspection does not indicate any abnormal condition or defects, and if test discharges conducted on the battery show it to be as low as 70 per cent of rated capacity, the chances are that the plates are worn out, in which case the battery should either be replaced or, if practicable, such parts as are in satisfactory condition salvaged and battery rebuilt. The successive steps in making the preliminary inspection and arranging a schedule of any repairs or treatment found necessary and as outlined above may be summarized as follows:

*First.*—See that the exterior of the battery is thoroughly clean.

*Second.*—Make inspection for loose or defective connectors and terminal posts, poor lead-burning, defective sealing of the cell cover, height of the electrolyte in the cell and note how much water is required to bring it to the proper level over the tops of the plates and separators, specific gravity of the electrolyte, and cracked jar, cover or other broken parts.

*Third.*—Consult any letters, records or reports submitted with the battery, or, if possible, question the operating personnel.

*Fourth.*—Also consult the data contained on the battery name-plate. If no defects are apparent from the surface inspection, see battery charged and conduct test discharges for available capacity for comparison with normal rated capacity.

*Fifth.*—If the inspection of the battery shows that the cause of the trouble is external or that the faults can be rectified without unsealing the cell, then

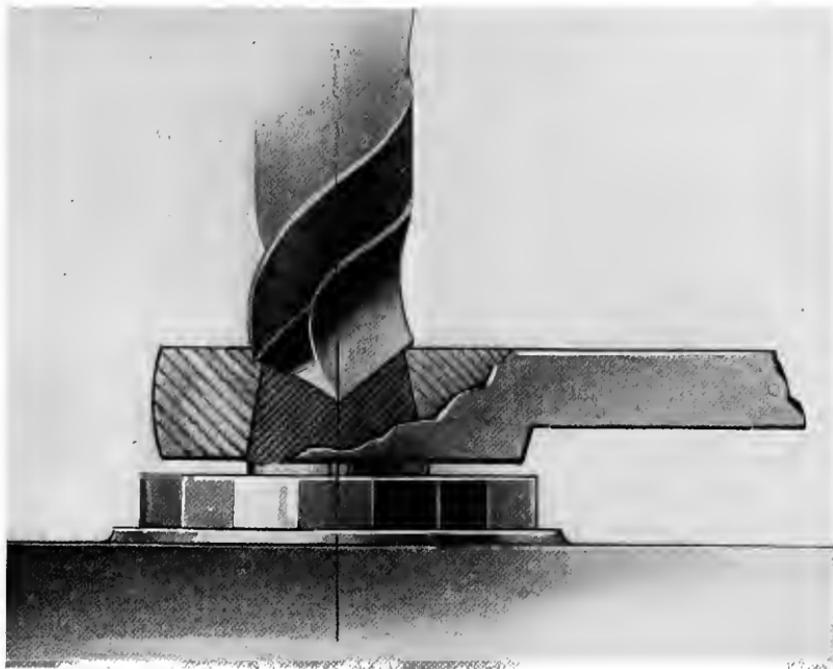


FIG. 120.—Drilling Connector Loose from Terminal Post.

take necessary steps to rectify them by effecting repairs or administering proper treatment.

*Sixth.*—If trouble lies within the cell and cannot be rectified by treatment, unseal the cell and proceed with necessary repairs.

**Drilling Connectors Loose from Terminal Posts.**—In order to disconnect cells having their connectors lead-burned to the terminal posts it has in general been found that the best method consists in using a ratchet brace and twist drill, the drill to be slightly larger in diameter than that portion of the terminal post which passes through and is lead-burned to the connector. The hole should be carefully centered with the terminal post and should be

drilled to a depth which is slightly in excess of the thickness of the lead-burned portion of the connector in order to allow the connector to be lifted or pried off of the terminal post. In order to reduce the amount of labor required when building-up and re-burning the connector to the terminal post, the hole should be drilled no deeper than is necessary for freely removing the connector. Fig. 120 contains an illustration of this operation. After removing the connectors clean off the top of the cell and remove all lead shavings or drillings deposited while drilling the connectors loose, having care to prevent any of these lead particles from entering the cell.

**Unsealing Cell and Removing Cover.**—After removing the connectors as described in the preceding paragraph the next step in opening up the cell for inspection and repairs is that of unsealing the cell and removing the cover.

Take a hot putty-knife, such as shown in Fig. 121, and by passing it with a gouging or scooping motion remove all sealing compound from the channel-way formed between the dome of the cover and the inside walls of the jar.



FIG. 121.—Putty-Knife Used in Removing Sealing Compound.

In performing this operation it is very essential that the inside walls of the jar be thoroughly scraped clear of all compound in order to prevent the edges of the cover from binding when removing from the jar. In case soft rubber tape and oakum are used in sealing the cell, these materials should also be removed from around the cover before attempting to remove the cover.

In some instances it will be found convenient to heat the compound with a flame, such as that from a lead-burning tip or from a blow-torch, but in such instances, and in order to prevent an explosion, care should be taken to insure that the interior of the cells are cleared of all gases before bringing the flame near the battery; an air hose or a hand bellows will be found satisfactory for this purpose.

Care should also be taken in using this flame not to injure the cover, jar, or any other parts of the cell.

Now, take two pairs of flat nose pliers and by gripping the top of a terminal post of each group of plates, lift the element and cover vertically until they are clear of the jar. In this regard provided the cover, terminal posts, gaskets, etc., are found in good condition, it will generally be found best to

remove the cover and element intact from the jar, since if the trouble is found to be with separators or of any other nature which can be remedied without detaching the cover from the element, much unnecessary labor and probable breakage will manifestly be saved.

The above description applies to the portable types of cells, as the method of procedure for unsealing submarine and other large type cells is contained elsewhere in the text.

**Dis-assembly and Inspection of Element.**—Having removed the element from the jar and after allowing all electrolyte to drain from the plates and separators, in preparing the element for inspection place it on a clean flat top table or work-bench, the element thus resting on the normal vertical edges of the plates. This done, it will usually be found that the plates are best inspected after removing the separators.

To remove the separators, gently spread or “fan” the plates apart, having care to not spread them any further apart than is actually necessary for removing the separators; the separators can be very conveniently removed by pushing them out with a putty-knife, or by pulling them out from the bottom of the element by means of a pair of flat nose pliers.

The rubber separators will usually be found in satisfactory condition for re-installation after thoroughly washing them, but in most cases it will prove more satisfactory in the end to not attempt to re-install the old treated wood separators, and a fresh supply of these separators should therefore be kept on hand for repair purposes.

If upon inspection it is found that some of the plates will have to be renewed, then remove the terminal sealing nuts and lift the cover from the element, after which gently separate the groups. We are now ready to proceed with cutting out the defective plates and burning in new ones. It should here be stated that the negative plates will generally show signs of heating when they are removed from the jar and exposed to the air, in which case they should be kept cool by dipping or spraying them as necessary with pure fresh water. If only the positive group requires plate renewals, then the plates of the negative group should be immersed in fresh water or electrolyte until ready to re-assemble the element.

**Cutting Out Plates.**—As a guide in the inspection of the groups to ascertain if any plate renewals are necessary, a few of the principal points in connection with this work will be given. In this regard it may be said that during the normal operation of the battery there is in general more wear on the positive plates than on the negatives, and for this reason it will usually be found that more plate renewals are required in the positive than in the negative groups.

Let us begin by first considering the visual characteristics of plates which are in normal healthy condition, and from which a comparison can be made with plates which are not up to standard.

Positive plates which are in a fully charged, healthy condition and which have just been removed from the electrolyte, are of a dark brown chocolate "fudge" color, and the active material is of a firm consistency and is in good contact with the grid. When in a discharged condition these plates are of a rusty, reddish color.

Negative plates which are in a fully charged, healthy condition, and when just removed from the electrolyte, are of a "battleship-gray" color, and the active material is in good contact with the grid. If when scratched with the finger nail or with a knife the scratched surface of the plate presents a lustre or a shiny appearance such as that from a mark made by a soft lead pencil, it is an indication that the negative active material is in good healthy condition. When in a discharged condition these plates are of a lighter color than when fully charged.

Both the positive and negative plates, when dried out but in good condition, are of a lighter color than described above.

However, it does not necessarily follow that all plates, which do not have the appearance of the normal, healthy plates described above, will have to be cut out and renewed, for many plates which are in poor condition as regards capacity and which do not present a good appearance can sometimes be restored to satisfactory condition by administering proper treatment. Each case of a battery overhaul involving plate renewals will have to be decided upon its own merits when taking into consideration the nature of the duty to be performed by the battery, the facilities for making repairs, and the spare plates and other parts which are available.

As a general rule, however, it may be said that plates which answer to the following description should be cut out and renewed:

(a) Plates in which the active material is worn away to the extent that the bases of the grid-bars are exposed; in other words *lean plates*, as very little capacity is obtainable from such plates.

(b) Plates which are so badly buckled that they cannot be satisfactorily straightened.

(c) Plates having cracked grids.

(d) Plates which are so badly sulphated that their capacity cannot be restored with the usual "treating cycles" which are described elsewhere in the text.

(e) Positive plates having abnormally soft "muddy" active material.

(f) Negative plates in which the active material is bulged or expanded to such an extent that it has lost its conductivity through improper contact

with the grid, and which cannot be satisfactorily restored by pressing the plates.

(g) Negative plates the active material of which has shrunk or contracted to the extent that conductivity is lost through improper contact with the grid.

(h) Plates in which the pores of the active material have become clogged or congested through the deposit of metallic or other impurities contained in the cell.

The work of cutting out defective plates from portable types of batteries can be very conveniently done by sawing the plate lug loose from the cross-bar by means of a hack-saw, or sometimes a pair of end cutting nippers such as are shown in Fig. 122 will be found very handy for this operating. For cutting plates out of submarine and other large type cells a wood-chisel and mallet will usually prove satisfactory.

**Straightening and Pressing the Plates.**—As has been stated, sometimes it will be found that plates which are buckled or which have their active



FIG. 122.—End Cutting Nippers for Cutting Plate Lugs, Cross-Bars, Etc.

material loose in the grid can be placed in satisfactory condition by straightening them or by suitably pressing them.

Plates which are buckled should be straightened by means of a pair of flat nose pliers, care being taken to prevent cracking the grid in this operation.

Plates in which the pellets of active material have expanded or bulged out beyond the surface of the grid-bars should be pressed back into position while soft and before it becomes dry. The plates should be gently rinsed off before pressing them, and in view of the relatively frail structure of the positive active material when soft, these plates should be rinsed off by gently dipping them in clean fresh water, and under no circumstances should a hose or any other method be used in rinsing the positive plates which will tend to wash this soft "muddy" active material out of the plates. The structure of the negative active material being of a more durable nature, these plates can be rinsed by spraying them with a hose, but care should be observed to not dislodge any of the active material in this process. As stated elsewhere in the text, the negative plates will usually show signs of heating, when exposed to the air and appropriate steps such as spraying or dipping them in fresh water should be taken to keep them cool.

A very convenient method of pressing the active material back into position and of restoring proper contact with the grid consists in placing clean smooth wooden boards, of the proper size and thickness, between the plates and pressing them together in a plate press, or if a special plate press be not available, an ordinary bench vise will very well answer the purpose. The spacing boards should be of sufficient size to entirely fill the space between the plates of the groups in order to prevent fracturing the plates when they are pressed together.

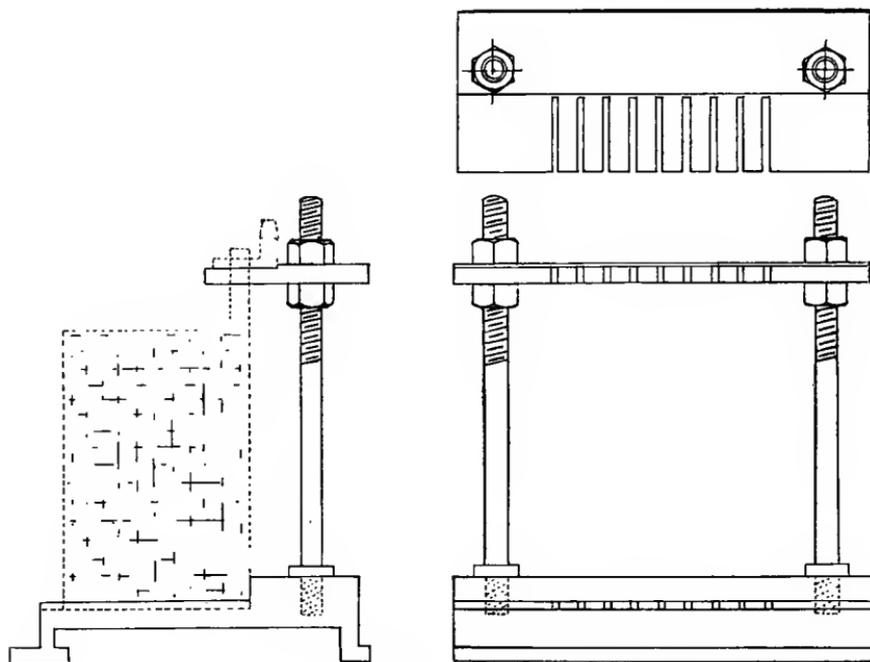


FIG. 123.—Plate Burning Rack.

In the case of submarine or other large type cells, it is a good plan to place the plate on a table or bench, and after placing a piece of card-board or canvas on the plate, press the active material back into position by passing a roller of sufficient size and weight back and forth over the plate, then turn the plate over and repeat the operation.

**Burning-in the Plates.**—After cutting out any defective plates which may have been found and as outlined in the preceding paragraph, the next operation in order is that of replacing the defective plates by lead-burning them to the cross-bars. A special form of rack, called a *plate-burning rack*, is used for this purpose, an illustration of one of these racks being shown in

Fig. 123. It will be noted from this drawing that this rack consists of a grooved or notched stand upon which the plates are placed, these grooves being used for properly spacing the plates apart. The comb-shaped burning bar at the top of this rack is also slotted for receiving the plate lugs, the slots being so placed that they line up with the grooves in the base of the rack.

It will also be noted that the cross-bar, strap and terminal post casting is placed on top of the burning bar such that the plate lugs line up with corresponding slots or notches in the cross-bar, and in this manner the plates are lead-burned to the cross-bar. The method of placing the plates in the rack and also that of the cross-bar casting are indicated by dotted outlines in the drawing. These burning racks are usually designed such that they easily permit of adjustment for height and plate separation to accommodate the various sizes of plates and batteries.

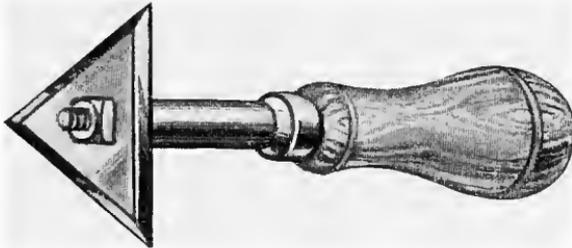


FIG. 124.—Triangular Lead Scraper Used for Scraping Plate Lugs, Etc.

From an operating point of view it should be stated that the work of lead-burning the plate lugs to the cross-bar is one of the most important features entering into the construction of the battery, and great care should therefore be observed to insure that a good job of lead-burning is obtained in this operation, since all current delivered or received by the plate must pass through the plate lug and also through the lead-burned joint between the lug and the cross-bar.

The plate lugs and the inside of the slots and other burning portions of the cross-bar casting should be scraped bright and clean with a triangular lead scraper before beginning the lead-burning operation. A triangular scraper such as is conveniently used in this work is shown in Fig. 124. The sticks of lead or lead-antimony should also be scraped clean before using them in order to permit only clean lead to enter the fused or lead-burned joint.

In the case of submarine or other large type cells in which the cross-bar is built up in successive stages while lead-burning the plates into groups it is necessary to scrape the surfaces of each successive layer of the fused lead

as it is built up in order that a clean bright surface of metal is always available for fusing or lead-burning to the next layer of metal. Although the triangular lead scraper is also used in this operation, it will be found that in cleaning and brightening up large surfaces of metal for lead-burning, such as in the present case, a wire brush will prove very satisfactory and convenient; a type of wire brush extensively used in this work is shown in Fig. 125.

The subject of lead-burning, however, is covered more fully in a separate chapter.

**Re-assembling Groups, Installing Separators, and Replacing Element in Jar.**—After repairing or renewing any plates as found necessary, we are now ready to reassemble the groups and to install the separators.

To assemble the groups set a positive group and the corresponding negative group on the work-bench, terminal posts out-board and pointing up, and with the groups facing each other in the normal positions for assembly. Then gently bring the groups together and enmesh the plates in their proper relative positions, being careful to prevent as much as possible the plates from



FIG. 125.—Wire Brush Used for Cleaning Lead Parts for Lead-Burning.

scraping or chafing against each other in order to not injure or dislodge the active material. The negative group contains one more plate than does the corresponding positive group, and when properly assembled the outside plates of the groups are therefore negatives.

Having thus assembled the groups and lined up the edges of the plates with each other, place the groups on edge on a block of wood; terminal posts pointing away from you and bottoms of the plates facing you. The groups are now in position for installing the separators.

To install the separators, take a rubber separator and the corresponding treated wood separator, and after placing them together, ribbed side of the wood in contact with the rubber, gently spread the plates apart and slide the pair of separators into position between the plates, the wood separator being habitually placed next to the negative plate for the reason that the positive active material rots or disintegrates the wood, whereas the treated wood has a healthful effect upon the negative active material. It will usually be found that the best results will be obtained by installing the first pair of separators between the plates in the middle of the element, and then work alternately and outward on each side of the first pair of separators installed until the

installation of all separators is completed. All separators should then be accurately positioned and lined up with the edges of the plates by tapping them with a block of wood or a wood mallet. This done, the element is now ready for installation in the jar.

After having thoroughly cleaned the jar and inspected it for any defects, set the jar on the work-bench preparatory to receiving the element. Now, take the element in the hand and set it squarely in the jar such that the plates rest firmly upon the bridges or supporting ledges in the jar. We are now ready for installing the cover and sealing the cell. In case it is desired to run test discharges or to give the plates special treatment after installation in the jar, it may prove desirable to pour the electrolyte into the cell and to conduct the test discharges or the treating cycles before installing the cover.

**Lifting and Inspecting Element, Renewing Separators, Etc.—Submarine Type.**—Whenever it is desired to lift the element of a submarine or other large type cell for inspection or repairs, such as for renewing plates or separators, etc., the same equipment should be provided as was described for placing a spare cell in commission, Chapter XXI, with the addition of a large drip pan for catching any electrolyte or sediment drained from the element. The connectors, cover fittings, etc., should be removed and cover unsealed as has already been described. Provision should also be made for spraying or otherwise cooling the element while out of the jar, and all necessary preparations should be made in advance of lifting the element as will serve to expedite the work of inspection and repair, in order that the element may be returned to the jar as early as possible.

If a plate is to be renewed, tap the separator support pins and the plate support pins out far enough with the aid of another set of such pins as to permit the removal of the plate and the separators on each side of it, these pins thus holding and supporting the other plates and separators of the element in position during the repair work. Cut the plate out by means of a wood chisel or other appropriate tools. Then install the new plate and lead-burn it into position, care being taken to not damage the other plates and separators with the flame, and also to prevent any lead-drops or run-downs from lodging between the plates or separators. Next, drive the plate support pins home and lower the element into the jar.

In case it is desired to renew any separators the method of procedure in handling the element is in general the same as described above.

Whenever an element is removed from a jar, it is a good plan to make an inspection of it and to enter all notes in the battery record book for future reference. Soundings should be taken to ascertain the amount of sediment deposited on the bottom of the jar. This data will in general prove useful in estimating the condition of the other cells of the battery.

After installing the element and sealing the cell, all connectors should be thoroughly cleaned before reinstalling and all cover fittings should also be cleaned and put in good condition as necessary. It is especially a good time to clean the baffle discs of the ventilation fittings and to overhaul the connections to the ventilation system.

**Installing the Cover and Pouring the Sealing Compound.**—The element having been installed such that it rests firmly and squarely upon the supporting ledges or the bridges in the bottom of the jar, the next step is that of installing the cover and pouring the sealing compound.

Place the cell cover in position such that it rests squarely upon the soft rubber terminal post gaskets which are seated on top of the shoulders cast on the post straps, care being taken when doing this to insure that the edges of the cover do not bind at any point against the walls of the jar; if there should be any tendency for the cover to bind, it should be removed and the edges dressed down as necessary with a mill file. Having thus shipped the cover, screw on the terminal sealing nuts and set up on them gradually and uniformly in succession in order to not strain the cover at any point. These nuts should be set up on sufficiently to seat the cover firmly in position against the soft rubber gaskets and such that an acid-tight joint is effected between the cover and the terminal post straps. Always use the special wrench provided with these nuts in order to not injure or score them when screwing them home. The top of the thread on the post strap should be upset with a center-punch or a nail after setting up on the nuts in order to prevent the nuts from backing off.

In installing covers on those types of batteries which contain lead-antimony bushings vulcanized in the cover for lead-burning directly to the terminal posts and connectors, it is necessary that these covers be squarely and firmly placed in position such that an acid-tight joint is effected between the bushing and the post strap before attempting to lead-burn these parts together.

The cover having been firmly secured in position as outlined above, we are now ready to seat the cell by pouring the sealing compound.

Although, when properly done, pouring the sealing compound is a comparatively simple operation, it nevertheless requires a certain amount of care and skill in order to effect a neat and satisfactory seal around the jar, which is very important from an operating point of view, since after all it is the sealing compound that assists in making the cell both acid and water tight.

When pouring the sealing compound it should be just hot enough to run freely into all crevices around the channel-way of the cover, thus filling all openings through which acid and water could pass. If the compound be too hot while pouring, it will be found that it contracts considerably in cooling, thereby forming hollow spots or honey-combs in the body of the compound,

which impairs its effective sealing properties. Also, pouring an excessive amount of compound should be guarded against, since the surplus compound must be trimmed off, leaving a ragged surface which must be smoothed off with a hot putty-knife or flame. Therefore, a clever workingman will have his sealing compound at the proper temperature and will be careful to pour

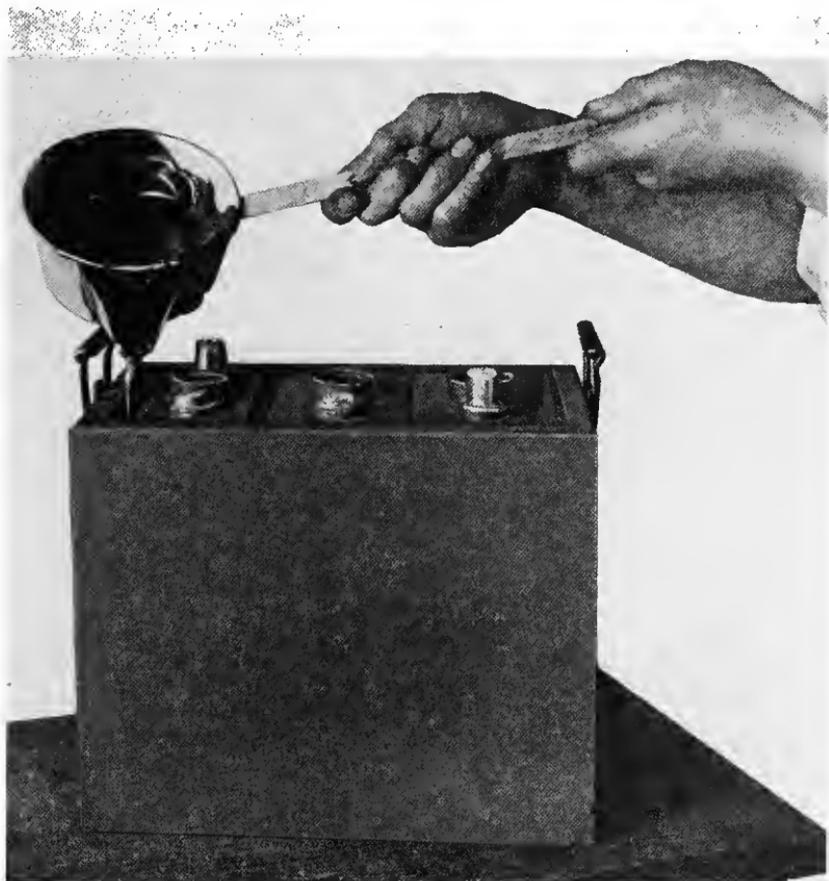


FIG. 125A.—Pouring the Sealing Compound Around the Cell Cover.

only the required amount of compound to properly seal the cell, thus leaving a smooth, finished surface to the compound upon completion of the sealing operation. In this regard it should be stated that the surface of the compound should be finished off flush with the flat top of the cell cover in order to eliminate any pockets or recesses in which moisture, acid, or dirt could collect. Fig. 125A contains an illustration of pouring the sealing compound around the cell cover.

**Mixing and Renewing Electrolyte.**—When overhauling storage batteries it is a good plan to renew the electrolyte of all cells, since it is one of the prime requisites of satisfactory battery operation that the electrolyte be kept pure. A supply of sulphuric acid of 1.400 specific gravity, commonly known as “battery acid,” should therefore be kept on hand for this purpose.

Complete details of the equipment required and the method of mixing the acid with the water in order to obtain electrolyte of any desired density will be found in Chapter IX; it is especially important that no acid which does not conform with the purity specifications, as contained in this chapter, be used.

**Removing a Single Cell from Tray.**—In case it is desired to remove for repairs only one cell from the tray of batteries it will be found necessary in most cases to drill the inter-cell connectors loose from the terminal posts of the adjacent cells as well as from the cell to be removed, especially if rigid type connectors are used. If flexible type connectors are used it will sometimes be found that it is only necessary to drill the connectors loose



FIG. 126.—Alligator Pincers Used for Removing Jars from Trays, Etc.

from the terminal posts of the cell to be removed, and then to bend the connectors back over the tops of the adjacent cells in order to permit removal of the one cell.

Should a jar show a tendency to stick or bind in the tray it will usually prove advisable to first remove the element, and then after drawing off the electrolyte, fill the jar with boiling water, which will usually soften the rubber and the sealing compound such as to allow the jar to be withdrawn by means of gripping the top edges with two pairs of pliers or alligator pincers and lifting vertically on the jar. A pair of alligator pincers such as are conveniently used for this purpose are shown in Fig. 126.

**Jars to be Washed Out.**—After removing the element and drawing off or dumping the electrolyte, the jars should be washed out thoroughly with fresh water, being careful to remove all sediment deposited in the bottom of the jar and on the inside walls. If jars have been removed from the tray thoroughly examine them for cracks or other defects. In order to test them for leaks fill them with fresh water and after insuring that they are thoroughly dry on the outside, set them on a piece of dry paper in a warm room and allow them to thus stand for a period of about 5 hours, at the expiration

of which time any "leakers," will be detected by moisture spots on the paper.

A good rule to follow is to never re-install a jar if it is not in the very best of condition, or if there is the least suspicion that it is not up to standard, as it is best in the end to scrap a good jar rather than run the risk of battery trouble later on as a result of a defective jar.

**Overhauling Trays.**—After removing the cells the trays should be gone over and given a thorough overhaul before re-installing the cells. This overhaul should consist mainly in soaking the trays in a warm bicarbonate of soda solution to neutralize any acid contained in the wood and on the tray fittings, after which thoroughly rinse the trays off in clean fresh water and allow them to dry. Then go over all of the tray fittings such as porcelain insulator skids, tie-rods, handles, hold-down attachments, and repair or renew these parts as found necessary. All rotten or damaged wood work about the trays should also be repaired and all wood-screws tightened up. All repairs having been made as outlined above, the trays should then be given a couple of coats, both inside and outside, of asphaltum or other acid-resisting paint, and when this paint has thoroughly set the trays are then ready for re-installation of the cells.

**"Treating Cycles."**—In order to restore the capacity of badly sulphated plates or of plates in which the active material has lost contact with the grid and has had to be pressed back into position, a special cycle of charge and discharge, called a *treating cycle*, or a series of such cycles, is used. This treatment consists in charging the cells for a long time at a very low rate, this rate to be low enough to produce a maximum gravity reading of the electrolyte with a minimum amount of gassing and rise in temperature of the cells. After completing this charge, then discharge the cells at approximately the 10-hour rate and to a final voltage of not less than 1.80 volts per cell, then re-charge as described above; this treatment thus allows the minute particles of active materials to re-adjust themselves in the plates and to assume their normal healthy condition.

By taking cadmium readings of the plates, and also by noting the increase in the capacity developed and in comparing this with the normal rated capacity of the plates, the time for discontinuing the *treating cycles* can be determined.

In administering such treatment to badly sulphated plates the specific gravity of the electrolyte should not be higher than 1.200 during the early stages of the treatment or for the first few cycles, as the lead-sulphate contained in the plates is more easily reduced in low gravity electrolyte than that of high specific gravity.

However, after the plates begin to show signs of satisfactorily responding to treatment, such as by increase of capacity, the specific gravity of the

electrolyte can then be brought up to the normal full charge value for conducting the test discharges for capacity.

If the plates are abnormally sulphated to the degree that they respond very slowly to this treatment, they should be scrapped.

**Working Drawings and Characteristic Curves.**—In order to have at hand a ready reference of the details of construction of the various types of batteries used in the naval service, each battery repair station should be equipped with a complete set of detailed drawings of these batteries. Each manufacturer supplying batteries for the naval service is therefore required to furnish with these batteries complete sets of working drawings; these drawings in addition to showing the various details of construction and assembly of the batteries also give a stock list of the individual parts, the materials of which they are composed, the number of such parts required per battery, as well as the manufacturer's individual part number for use in easily identifying the various parts when it is desired to order spares. Thus, with each drawing numbered, and also with each individual part on the drawing carrying an individual number, it is comparatively easy to identify any part as desired.

Characteristic curves are also supplied by the manufacturers with all batteries issued to the naval service. These curves are for the guidance of the operating personnel and show the ampere-hour and the kilowatt-hour capacities for the various rates of discharge; capacity correction curves for temperature coefficient; initial, average, and final voltages for the various discharge rates; charging curves and various data relating to the different conditions of operation. A typical set of these characteristic curves is shown in Fig. 97.

These characteristic curves are especially useful for conducting capacity tests in the battery repair stations in order to ascertain the available capacity of a battery and for comparison with the normal rated capacity, or that as shown by the characteristic curves. Proper charging rates are also obtained from these curves.

**General Overhaul—Submarine Battery.**—With the present practically exclusive application of the unit assembly type cell for submarine battery installations, the subject of the general overhaul of the battery does not require as much time and labor, in so far as the crew of the boat are concerned, as was formerly the case when the old tandem type installations were used. In fact, in so far as the boat is concerned what was originally termed a battery general overhaul period now resolves itself into a battery renewal or replacement period, since when the battery is so far gone as to require a general overhaul, this battery should be removed from the boat and a new one installed. The old battery should then be sent to the battery repair and

service station to be put in proper condition for reinstallation in the boat at another time or for replacing a battery in another boat as the case may be.

In the case of trouble developing with certain individual cells of a submarine battery, such cells should be removed from the boat and replaced by cells which are kept on *trickling charge* on board the submarine tender and ready for immediate installation in a boat when required. The defective cells or *hospital cells* thus removed from the boat should be placed on board the tender and overhauled by the battery repair gang in the battery service station on board. When these cells are again in normal healthy condition they should be placed on *trickling charge* and thereafter kept in condition for immediate installation as replacement cells on board a submarine when required. In this way cells are always kept in readiness on board the tender for installation in the submarine and the submarine battery is accordingly kept in full commission.

In case of an accident in which so many cells and other materials are damaged that the tender cannot supply the replacement cells and material, an immediate summary of the extent of the damage and the amount of replacement material required should be dispatched to the navy yard or station which the submarine is to visit in order that this material or replacement cells may be made available upon arrival of the boat and such that repairs may be effected at the earliest moment. It should be borne in mind that when her battery is out of commission a submarine is of little or no military value, and the necessity for perfecting organization to the end that submarine batteries be at all times kept in commission and in good condition is therefore very apparent. Moreover, it is the duty of everyone having any connection with the operation of the storage batteries on board a submarine to familiarize himself with all details of the construction of the battery, and also with all rules and instructions which are issued for the proper care and maintenance of these batteries.

**Method of Locally Lead-Plating Copper Connectors, Terminal Posts, Etc.—**By using the process and equipment described below it will often be found convenient and comparatively easy to locally lead-plate or touch-up exposed copper spots on lead-plated copper terminal posts, connectors, etc., which may have become worn or damaged, without disconnecting or removing the cells from the battery.

**Preparation of the Plating Solution.—**The plating solution for this operation is made up by taking some clean sand and thoroughly saturating it with hydrofluoric acid, after which neutralize this mixture with lead carbonate, litmus paper being conveniently used as an indicator in this process. Then to this mixture add about 20 per cent, by volume, of hydrofluoric acid and

1 per cent, by volume, of a good grade of glue or gelatine. This solution should then consist of approximately 20 per cent free hydrofluoric acid, 4 per cent lead, and 1 per cent glue or gelatin, the glue or gelatin being put into the solution to prevent the lead from being deposited or plated in the form of "lead trees" on the copper parts. The ingredients for making up this solution can usually be obtained from any navy yard chemist or from any commercial chemist.

In preparing this solution be very careful to prevent the mixture from coming in contact with the hands and body.

**The Plating Process.**—A six volt battery or direct current from any other source and of any voltage may be satisfactorily used in this process, but in order to obtain best results the current rate should be relatively low. It should also be stated that the success of the operation depends as much upon the density of the current and the concentration of the plating solution as it does upon the skill of the operator.

In conducting this process connect the positive terminal of the source of current to a piece of pure lead bar or wire around the plating end of which is secured a piece of muslin or other cloth wrapped in bag-like form and containing some of the plating solution; this cloth should also be kept thoroughly saturated with the solution during the plating process.

Connect the negative terminal of the source of current with the object to be plated and apply the saturated cloth of the positive terminal to the spot to be plated.

Now, with the current flowing, and by firmly rubbing the saturated cloth bag of plating solution back and forth over these bare spots the lead-plating will take place on them. This operation should be continued until the desired thickness of the plating is attained.

If current from a 125 volt line is used it will be necessary to have quite a heavy wrapping of cloth around the pure lead plating wire or stock in order to provide the required amount of resistance for reducing the current to a value small enough for properly conducting the process.

Also, if current density and the concentration of the solution be not correct, the plating will take place in the form of a granular structure, and not in the smooth sheet form which is desired and such as will be the case when all details of the process are correct.

Fig. 127 contains an illustration from which a clear idea of the details of this process may be obtained.

**Protective Coating for Steel Decks of Battery Repair and Service Stations.**—A very effective method of preparing and coating the steel decks of battery repair and service stations, on board submarine tenders and other ships, in

order to protect the steel from the corrosive action of the acid contained in the electrolyte of storage batteries, consists of the following:

*First.*—Sufficient concrete should be laid upon the steel plates of the deck as to present a perfectly smooth and level surface over the whole deck, a trowel or other suitable tool being used in effecting this even surface. It is

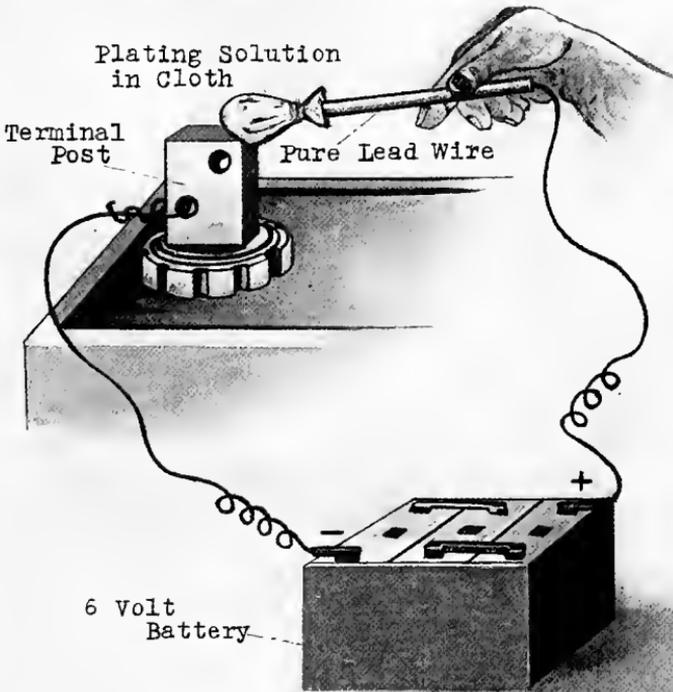


FIG. 127.—Showing Method of Locally Lead-Plating Copper Terminal Posts, Connectors, Etc.

especially important that this layer of concrete be thick enough to entirely cover all rivet heads, butt and lap-joints, and other irregular places in the deck in order to form a smooth even base upon which to lay the sheet lead covering.

*Second.*—On top of this concrete base lay a covering of 6 pound sheet lead, care being taken to cut the lead such that it contains as few seams as possible. After placing this sheet lead covering in position lead-burn all of the seams,

special pains being taken to make a good job of the lead-burning of these seams, as the effectiveness of this method of preserving the steel deck depends largely upon the acid-proof qualities of the sheet lead covering.

The outer edges of this lead covering should be turned up for at least from 1 to 2 feet in order to form a protection for the steel bulkheads of the compartment.

*Third.*—On top of the sheet lead are to be laid two layers of an acid-resisting felt, all joints between the two layers to be lapped. The bottom layer of felt is to be laid on the sheet lead after thoroughly and heavily coating the surface of the lead and the under side of the first layer of felt with an acid-resisting asphaltum compound, this compound to be very hot when applied to the felt and the lead, and the felt should be laid while the compound is hot, weights being used on top of the felt until the compound cools and sets in order to effect a good seal or union between the felt and the lead. Next, lay the second layer of felt on top of the first layer, lapping all joints between the two layers as pointed out above.

*Fourth.*—After laying the second layer of felt apply to it a heavy coating of the hot asphaltum compound, then while hot pave the top of this compound with vitrified paving bricks, care being taken to press or embed them firmly into the hot compound. These bricks should be spaced from  $\frac{3}{8}$ " to  $\frac{1}{2}$ " apart on all sides, then place wooden filler pieces in the spaces between the bricks to prevent them from shifting positions, these filler pieces to be of the exact width of the spaces between the bricks in order to effect compactness in the flooring.

The height of the wooden filler pieces should be about 1 inch less than the height of the bricks in order to leave a space for a hot layer of the compound to be poured between the bricks and on top of the wooden filler pieces. In filling the joints between the bricks with the hot compound, it is necessary to use great care in all the details of the process in order to obtain a perfectly acid-tight job. The bricks must be absolutely dry, otherwise the compound will not adhere to them.

Also, after the joints are poured it is necessary to go over each one of them with a blow torch in order to thoroughly heat the bricks and to bring the compound to the running point such that it will flow into all of the minute crevices all around the bricks and wooden filler pieces. The compound will generally be found to settle considerably during this heating process, in which case a sufficient amount of hot compound will have to be added to bring it on a level with the top surfaces of the brick paving as it is especially important that all of these compound joints be brought up on a level with the pav-

ing in order to eliminate all low spots or pockets which would collect dirt, water, acid, etc.

The above method if carefully carried out in all details of its construction will be found to constitute a very satisfactory one for preserving the steel deck, and at the same time will produce a very practical and serviceable flooring for the battery repair and service station.

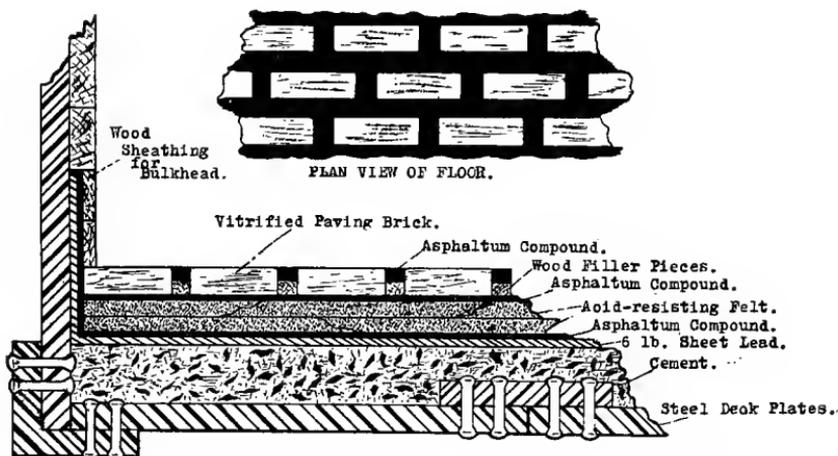


FIG. 128.—Method of Preparing Steel Deck of Battery Service Station to Protect the Steel from Acid.

Fig. 128 contains an illustration of the details of construction of this flooring.

Lead drain boxes may be conveniently installed in this flooring as found necessary. All drain pipes and aprons of such drain boxes should be securely lead-burned to the 6 pound sheet lead covering in order to form a perfectly acid-proof joint. Hot compound should also be freely applied between these drain boxes and the brick paving in order to produce an acid-proof joint around the drains.

## CHAPTER XXIV.

### LEAD-BURNING.

**Lead-Burning Defined.** The art of fusing or melting together the component lead parts of the storage battery, as by means of a flame, electric arc, or any other method of applied heat, is technically termed *lead-burning*.

#### Various Methods in Use.

Depending upon the source and the type of the applied heat, the various methods of lead-burning may be stated as follows:

- (a) Hydrogen gas and compressed air.
- (b) Compressed hydrogen and oxygen.
- (c) Oxygen and illuminating gas.
- (d) Electric arc.
- (e) Soldering iron.
- (f) The compound ladle.

A description of the equipment used in each of the above methods, including special notes on each of them, will now be given.

**Hydrogen Gas and Compressed Air.**—This method consists in using an hydrogen flame for fusing or lead-burning the parts together and is considered a very satisfactory method, and is one which is in extensive use both in the naval service and in the commercial world. It is especially convenient to use this method when the hydrogen can be obtained in suitable tanks. Also, special portable lead-burning outfits, including a hydrogen generator, are designed for use with this method and these outfits may be obtained from the regular trade and are very convenient for use where tanks of hydrogen are not obtainable.

The principle upon which the hydrogen generator supplied with these outfits operates is that when sulphuric acid is brought in contact with zinc, the acid radical,  $\text{SO}_4$ , combines with the zinc thus liberating hydrogen. The primary reaction involved in this instance being chemically expressed as follows:

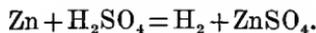
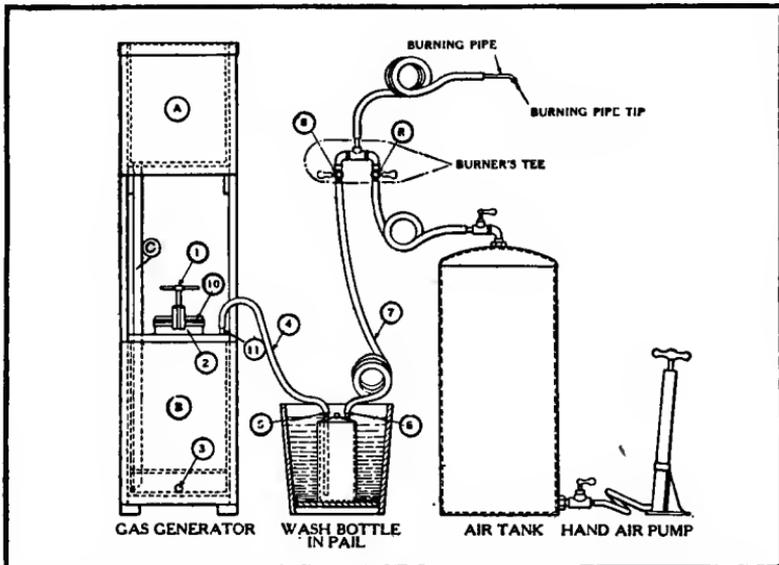


Fig. 129 contains an illustration of one of these portable lead-burning outfits, and from which a clear idea of its construction and method of operation may be obtained. Referring to this illustration it will be noted that the acid reservoir, shown at *A*, consists of a lead-lined tank and located such that the sulphuric acid which it contains is fed by gravity through the acid downtake *C*, and into the lead-lined gas generating compartment *B*, where

it comes into contact with the small particles of zinc contained in this compartment, whereupon the hydrogen gas is liberated in accordance with the equation outlined above. The charge of zinc is placed in the gas generating compartment through the hand-hole 2, after which this hand-hole should be closed air-tight by means of the hand-hole plate 10, and the hand-hole plate dog 1.

The hydrogen gas being generated as explained above, in tracing its path through the system it will be noted that it passes out of the generating compartment at 11, then through the rubber hose 4, and into the bottom of the



- |   |   |
|---|---|
| A. Sulphuric Acid Reservoir.            | 5. Wash Bottle Hose Connection (supply).    |
| B. Hydrogen Generating Compartment.     | 6. Wash Bottle Hose Connection (exhaust).   |
| C. Acid Down-take.                      | 7. Gas Hose.                                |
| 1. Dog for Hand-hole Plate.             | 8. Gas Regulating Valve.                    |
| 2. Hand-hole to Generating Compartment. | 9. Air Regulating Valve.                    |
| 3. Generating Compartment Drain.        | 10. Hand-hole Plate.                        |
| 4. Gas Hose.                            | 11. Generating Compartment Hose Connection. |

FIG. 129.—Hydrogen Generator and Lead-Burning Outfit.

wash bottle where it is cooled and purified by passing through the water contained in the wash bottle; it then passes out of the wash bottle at 6, into the rubber hose 7, through the regulating valve 8, where it mixes with the air from the compressed air tank, and then passes on to the burning tip where it is ignited, thus supporting the hydrogen flame for the lead-burning process. It will also be noted that the wash bottle is immersed in a pail of water for cooling purposes, and this water should be renewed from time to time as it becomes warm. The wash bottle should be about three-fourths filled with fresh water.

In preparing the flame for lead-burning have the air regulating valve 9 closed, and the gas regulating valve 8 wide open, then apply a match or a lighted candle to the end of the burning tip until the hydrogen is ignited. after which crack open the air regulating valve 8, and adjust both the gas regulating and the air regulating valves until the correct mixture of air and gas are obtained for the desired type of flame. A little experience will enable one to correctly regulate the valves for the desired flame. It is a good plan to have a standing light, as from a torch or a gas jet, for use in igniting the burning tip from time to time during the lead-burning process, as this eliminates the necessity of igniting the tip with a match each time; a lighted candle will serve the same purpose.

The amount of zinc, sulphuric acid, and water required depends upon the size or capacity of the gas generator; the instructions accompanying a given set should state the required proportions of these materials to use. Old electrolyte from storage batteries may be very well used in these hydrogen generating outfits. The density of the acid should be not above 1.225 nor below 1.160; any density between these limits will in general be found satisfactory. If the acid used is oil of vitriol, then it should be diluted by mixing with the proper proportion of water. In mixing the acid with the water follow the rules and precautions as laid down in Chapter IX.

The charge of zinc should be replenished from time to time as necessary to maintain the required amount in the gas generating compartment. Should zinc be not obtainable, iron filings may be used instead in this type of gas generator, although in general it may be said that the gas derived from iron is not as pure as that from zinc.

When the gas generator is to be laid up overnight the old solution should be allowed to drain from the generating compartment at the drain hole 3, after which the entire set should be thoroughly cleansed by pouring fresh water into the acid reservoir and allowing it to drain from the bottom of the gas generating compartment. A new charge of materials should then be placed in the generator when it is to be used again.

If compressed air from another source is available, the hand pump and air tank need not be used with these sets, though in such case it will probably be necessary to interpose a reducing valve between the source of supply and the air regulating valve of the set.

**Compressed Hydrogen and Oxygen.**—The gases used in supporting the lead-burning flame in this method consist of hydrogen and oxygen supplied from separate tanks. After passing by means of a hose through the regulating valves these gases are mixed in proper proportions and pass on to the burning tip where they are ignited and support the flame in a very similar manner as was described in the preceding method. A very hot flame is produced by these gases and is characteristic of this method.

**Oxygen and Illuminating Gas.**—This method consists in using illuminating gas and oxygen for supporting the flame at the burning tip, and may be said to constitute a very satisfactory method, as both gases can usually

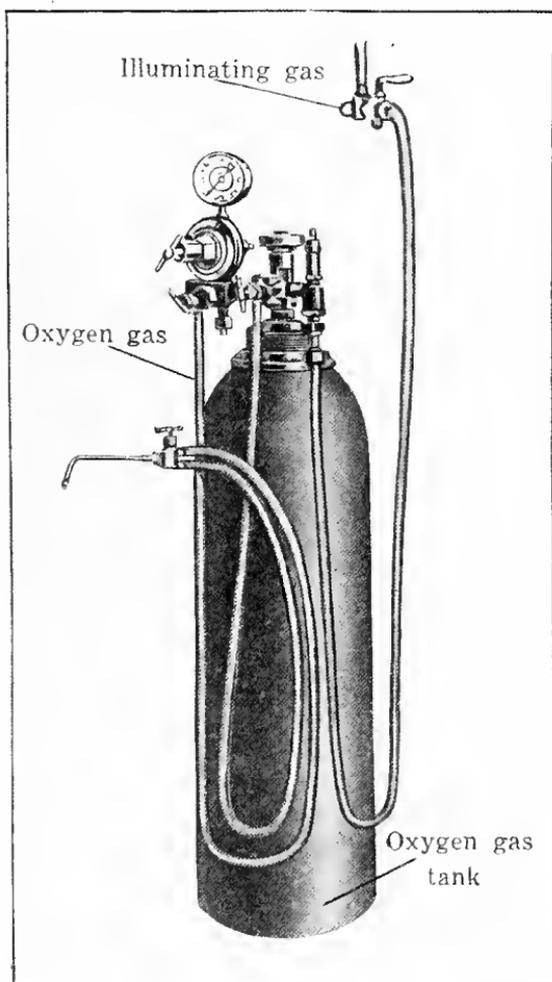


FIG. 130.—Oxygen and Illuminating Gas Lead-Burning Outfit.

be obtained in all localities. The illuminating gas is obtained from the regular gas jets or lines, while the oxygen is commercially supplied in tanks. Fig. 130 contains an illustration showing the equipment and the arrangement of this equipment as used in this method.

**Electric Arc.**—This method consists in using a carbon, heated by means of an electric current, to fuse the metal and thus lead-burn the parts together. In some instances this method may prove very convenient since, if desired, the battery to be repaired can be used as the source of current for heating the carbon, provided, of course, that the battery is in a charged condition, thus requiring no additional equipment for the lead-burning operation. However, it may be said that this method is in general satisfactory only for light jobs of lead-burning, such as for burning connectors to terminal posts of portable types of batteries, and is not suitable for heavier work, such as that of burning plates into groups, etc.

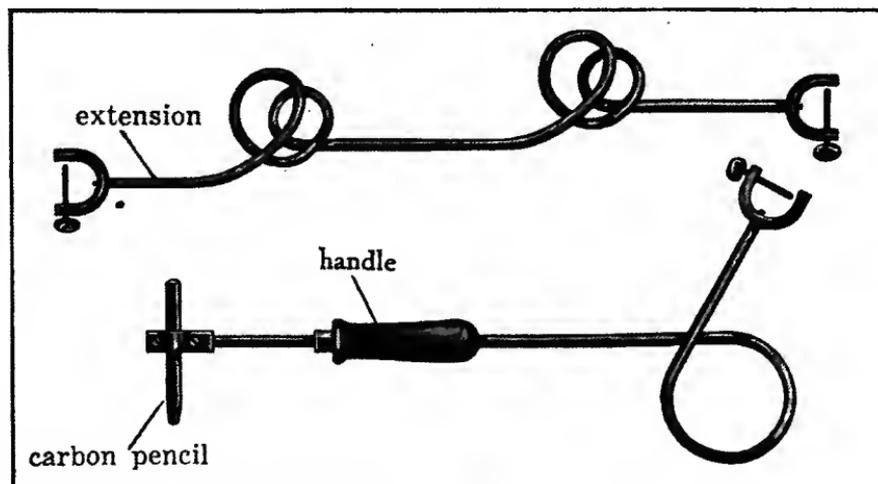


FIG. 131.—Electric Arc Lead-Burning Outfit.

The apparatus used in this method consists of a carbon point, a combination carbon holder and handle, the necessary lengths of flexible cable, and the corresponding contact clamps for conveying the current from the source to the carbon and to the parts to be lead-burned.

Fig. 131 contains an illustration which will give a clear idea of the special equipment employed in this method of lead-burning. The carbon, the carbon holder and the handle, as well as the flexible cable and corresponding clamps, are plainly shown in this drawing.

For best results in using this method the carbon should be at a bright cherry red heat when used and the source of current or the number of cells connected across the carbon and the parts to be lead-burned should accordingly be sufficient to produce this degree of heat.

The arrangement of the parts in the circuit should be such that when the carbon point is placed in contact with the parts to be lead-burned, these parts

as well as the carbon point and the source of current are connected in series with each other. That is, the clamp on the end of the flexible cable attached to the handle of the carbon holder is connected to one terminal of the battery or source of current, while the other terminal of the battery or source of current is connected with one end of the extra length of flexible cable, the other end of this cable being connected to the parts to be lead-burned, thus when the carbon is placed in contact with these parts the circuit is completed and the carbon heated thereby. A six volt battery will usually prove sufficient for any job of lead-burning to be done by this method, and for some work four volts will be found ample.

The carbon should be sharpened to a pencil point and should be secured such that it projects from  $2\frac{1}{2}$  to 3 inches from the holder. It is especially important that good electrical contact be made between all parts and the clamps of the flexible cable, these parts to be scraped bright and clean as necessary to accomplish this.

Due to the film of scale which will form on the surface of the carbon, it will be found that when used for a time the pencil will cease to heat properly, in which case it will therefore be necessary to scrape this scale off with a knife, triangular lead scraper, file, or other such tool. It will also be necessary to dip the carbon and the holder in a bucket of water from time to time to cool them off.

The carbon should be kept in motion during the whole lead-burning process and over the whole surface of the parts to be burned together in order to prevent stratification of the metal and to obtain an homogeneous joint.

**Soldering Iron.**—Although a soldering iron is not suited for general lead-burning work or where an extensive amount of lead-burning is required, it may be said that for emergency work and in instances in which no other lead-burning apparatus is available, a satisfactory job can be obtained by this method if due care is exercised. In fact, a very creditable job of lead-burning can be accomplished with a soldering iron, provided that the required amount of pains and technique are put into the work.

An ordinary soldering iron may be used for this purpose but the shape of the point should be long and narrow in order to get into small places, such as for lead-burning connectors to terminal posts, etc.

In order to obtain best results two soldering irons should be used in this work for it is necessary that the iron in use be very hot when working the molten metal. The iron should be at a cherry red heat when used, and on account of its low melting point lead solder wire or bar should be used instead of lead-antimony burning stock.

The irons should also be well tinned and thoroughly cleaned in soldering acid before attempting to use them. A tallow candle is used for the solder-

ing flux and should be rubbed on the parts to be lead-burned before applying the soldering iron. The parts to be lead-burned must also be scraped bright and clean by means of a triangular lead scraper or a wire brush before attempting to do any lead-burning. The lead-burning stock or soldering wire is fused by rubbing against the sides of the hot soldering iron while at the same time fusing the parts to be burned together with the point of the iron; by thus carefully working the iron and the burning stock a satisfactory job can be obtained, but it should be borne in mind that the iron must be at a cherry red heat.

**The Compound Ladle.**—This method is used where the work to be done is of a very delicate nature and where a flame cannot be conveniently used, such as in repairing small sections of grids, plates, etc. In using this method a special form of ladle, called a compound ladle, is employed, this ladle being fitted with a burning tip with necessary flexible hose connection to the gas lines for supporting the flame which heats the metal contained in the ladle.

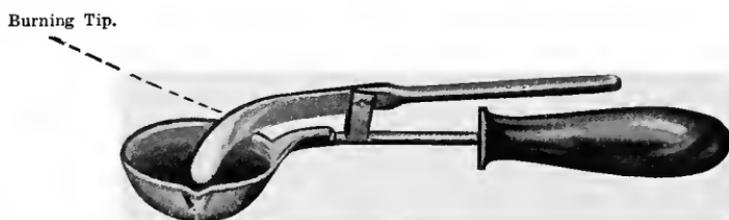


FIG. 132.—Compound Ladle for Use in Delicate Jobs of Lead-Burning.

The lead in the ladle is brought to a red heat and then poured on or around the parts to be lead-burned together, the heat of the molten metal thus being sufficient to fuse the parts to be lead-burned together, the molten metal combines with them and effects the required lead-burned joint. A suitable form or mould is usually employed in conjunction with the ladle, this form being placed around the parts to be lead-burned in order to retain the molten metal when poured from the ladle, thus producing the desired shape or form of the lead-burned joint. Fig. 132 contains an illustration of a type of compound ladle such as has been described above.

**Special Notes on Lead-Burning.**—In discussing the special notes on lead-burning it should first be stated that no matter which of the methods of lead-burning is used, it is essential to first-class workmanship that all parts to be burned together be scraped bright and clean before attempting the burning process. The tools used in cleaning these parts, such as triangular scrapers, wire-brushes, files, etc., have been described in the preceding chapter. Also, for best results, not only should the lead-burning sticks be clean and bright

but they should as far as practicable be composed of the same grade of alloy as the parts to be burned together.

In order to prevent damage to covers, jars, trays and other parts it is a good plan to place strips of asbestos around these parts when burning connectors to terminal posts, etc.



FIG. 132A.—Building-Up a Terminal Post by Lead-Burning Process.

Before attempting to do any lead-burning work around a battery be sure that all cells have been well ventilated and cleared of all gases in order to prevent an explosion when using the flame. Fig. 132A contains an illustration of a method of building-up a battery terminal post by means of the lead-burning process. The burning tip, flame, lead alloy burning stock, and iron forms around the terminal posts are plainly shown in this illustration. Attention is especially invited to the method of holding the burning tip in relation to the alloy burning stock.

## CHAPTER XXV.

### MANUAL OF INSPECTION.

(Storage Batteries and Parts.)

**Manual Divided into Two Parts.**—The subject of inspection of storage batteries and parts for the naval service may be properly divided into two main parts, as follows:

- I. Storage Batteries—Submarine Type.
- II. Storage Batteries—Portable Type.

The subject matter of this manual of inspection will, therefore, be taken up in the order outlined above.

#### PART I. STORAGE BATTERIES—SUBMARINE TYPE.

**General Outline of Assembly and Inspection of Submarine Cells.**—In order that a clear understanding may be had of the various important details which should be observed in conducting an inspection of storage batteries and parts designed for the submarine service, a general outline of the successive stages which the cell passes through during process of manufacture is given as a guide in studying the various important features of inspection required for this type of cell and other parts making up the submarine battery. The following outline, therefore, includes the various successive stages passed through in the manufacture of the unit assembly type cell:

**I Casting Room—(Paste Plates).**—(a) Grids cast in specially constructed moulds; moulds kept hot with gas flame or electrical heating units during moulding process. Soap-stone or talcum powder used on the moulds to obtain a smooth casting. Moulds clamped together tightly before molten metal is poured and then opened up and grid removed from the mould when metal has cooled and set sufficiently. Molten metal maintained at an even temperature in the melting pots in order to obtain uniform grade of castings. Fig. 132B contains a typical illustration of a scene in a grid casting room.

(b) Grids trimmed, straightened and made ready for burning on the plate lugs. Grids inspected for broken gridbars, blow-holes and other imperfections in castings. Grids which cannot be reclaimed are melted up and recast. All blow-holes in grids should be removed by flame-puddling process before going to pasting room. This is necessary in order to prevent the paste from entering the blow-holes and the consequent *forming* which will take place in the blow-holes during the formation charge. It is practically impossible to obtain a satisfactory plate if the grids are pasted and formed before removing the blow-holes with the flame-puddling process.

(c) Plate lugs burned on. Some manufacturers design their moulds such that the plate lugs are cast integral with the grids.

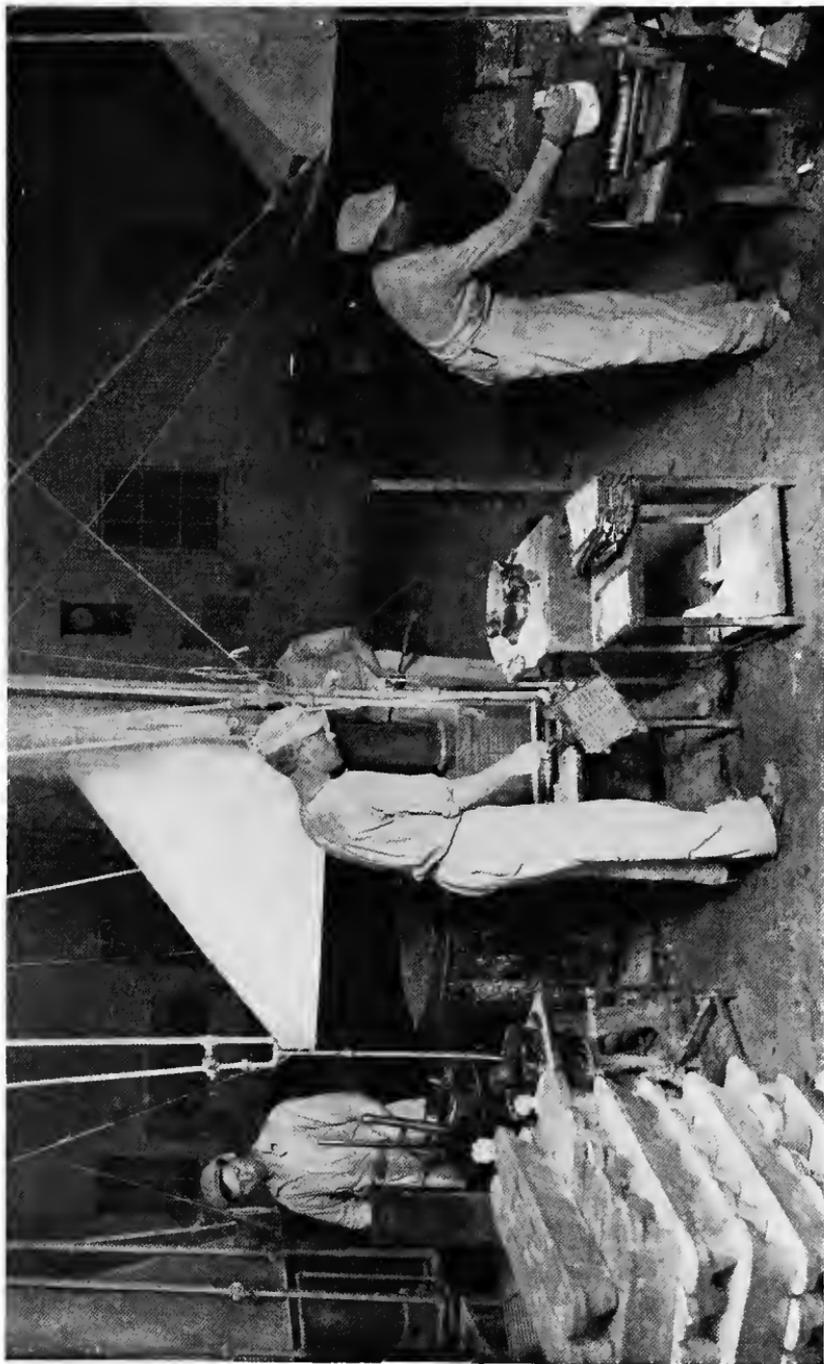


FIG. 132B.—Typical Scene in Grid Casting Room.

**II. Spinning Room—(Planté Plates).—**(a) Lead blanks stamped out from the sheets of rolled lead.

(b) Blanks then carefully weighed and inspected for proper thickness.

(c) Blanks placed in the spinning machines where the grooves are spun in the plate.



FIG. 132c.—Typical Scene in Grid Pasting Room.

(d) Spun plates removed from the spinning machine and inspected for imperfections in the spinning process. Plates which cannot be reclaimed are melted up and re-spun.

(e) Plates removed to cleaning machines where all oil used in the spinning process is removed and plates thoroughly washed and cleaned. This is a very important step, as any oil or other foreign matter remaining on the

plates will seriously interfere with the forming process during the formation charge.

**III. Pasting Room—(Paste Plates).—**(a) Paste mixed in the mixing machines.

Positive paste consists of red-lead and dilute sulphuric acid.

Negative paste consists of litharge, dilute sulphuric acid and the various materials commonly used for an expander.



FIG. 132D.—Placing Plates in Drying Rooms after Pasting.

(b) Grids pasted. Fig. 132C shows a typical scene in grid pasting room.

(c) After pasting the grids, they are dipped in dilute sulphuric acid in order to increase the degree of sulphation in the active material, which is commonly referred to as the *cementing process*.

(d) Plates are then sent to the drying ovens to be thoroughly dried before placing in the forming tanks. Fig. 132D shows a method of placing the plates in the drying ovens after pasting.

**IV. Forming Room.—**(a) Plates placed in the forming tanks which consist of lead-lined wood tanks or glazed earthenware jars containing dilute

sulphuric acid or any other *forming agents* used by various manufacturers. Fig. 132E illustrates a method of placing the plates in the forming tanks.

(b) The plates are connected up in groups of required polarity for receiving their "forming charge." Some manufacturers form positive and negative plates in the same tank, whereas, other manufacturers have a constant



FIG. 132E.—Placing Plates in the Forming Tanks.

set of electrodes installed in the tanks and only form one set of plates of like polarity at the time. In the formation of Planté plates, it is usual to form all plates as positives, after which the required number of negatives are formed from these positives. Fig. 132F shows a typical scene in "forming" room.

(c) After plates have received their forming charge they are then removed from the tanks, washed and dried and sent to the store-room where they remain until ready to be assembled in groups.

**V. Assembly Room.**—(a) Plate lugs scraped, cleaned and drilled preparatory to assembling and lead-burning in groups.

(b) All plates inspected for cracks, loss of active material, defective lugs, improper formation, blow-holes in grids and other imperfections.

(c) All wood separators inspected for cracks, knots, thin spots and other imperfections in manufacture. Fig. 132G shows method of inspecting wood separators.



FIG. 132F.—Taking Voltage, Specific Gravity, and Temperature Readings During "Forming" Charge.

(d) All rubber separators inspected for imperfect perforations, slots, broken separators and other imperfections in manufacture.

(e) Cross-bar, strap and terminal post castings inspected for imperfections in casting and lead plating.

(f) Plates and separators assembled in the jig and clamped for burning the plate lugs to cross-bars, straps and terminal posts.

(g) Jig containing the plates and separators placed on the burning platform and plate lugs burned to the cross-bar, strap and terminal post castings.

(h) Element removed from the assembly jig and swung vertically in a chain hoist where the hard rubber separator and plate support pins are inserted. The element is then given a minute inspection for the following:

1. Improper lead-burning.
2. Lead drops and run-downs.
3. Plates and separators examined for purpose of ascertaining whether or not they have been injured during process of assembly and renewals made where necessary.
4. If this inspection proves that the element is satisfactorily assembled, the element is then ready for installing in the jar.



FIG. 132c.—Inspecting Wood Separators for Imperfections. Note the Illuminating Box with Ground Glass Cover as Used in this Work.

(i) Jars washed out, inspected and crated in packing cases. Fig. 132H illustrates how the hard rubber jars are tested dielectrically before the element is installed.

(j) Element installed in the jar. Care should be taken that no nails, bolts, nuts, washers, tools, dirt or any other foreign matter are present in the jar when the element is installed.

(k) Cell covers inspected for cracks, imperfections in moulding, such as defective threads, etc.

(l) Cell cover placed on the jars and terminal post gaskets, washers and hold-down nuts secured in position. Cover sealed to the jar by means of pouring sealing compound around the edges.



FIG. 132H.—Testing Hard Rubber Jars Dielectrically Before Installing the Element.

(m) Cell given proper number in accordance with the approved layout prints of cell ventilation system.

(n) Cell carried to the charging and testing room

**VI. Charging and Testing Room.**—(a) Cell placed in position and connecting up in circuit for receiving the *initial charge*.

(b) Electrolyte poured and cell allowed to stand until temperature has dropped sufficiently for conducting the *initial charge*.

(c) Placed on initial charge at the required charging rates corresponding to the special type of cell. Routine readings of cell voltage, temperature, gravity and charging current recorded as the initial charge progresses. If temperature becomes excessive during the initial charge artificial ventilation is resorted to.

(d) Equalize specific gravity readings of the electrolyte as necessary preparatory to conducting the official test discharges.

(e) When initial charge is completed and cell temperatures are at 80 degrees Fahrenheit (unless tests are to be conducted in accordance with approved temperature correction curves for capacity) the cells are ready for running the 3-hour official test discharge. Take voltage, gravity and temperature readings as per routine. Select pilot cells and record routine readings of same during discharge. The pilot cells should be selected after the discharge has begun in order that cells representing high, intermediate and low voltages may be obtained for these readings. No terminal cells should be selected as pilot cells. Essential that proper current rate be maintained throughout the discharge.

(f) Check average and final voltages with the approved characteristic curves to see if rated capacity has been obtained.

(g) Select the two cells of each circuit having the lowest final voltage at end of the 3-hour discharge for the 1-hour official discharge.

(h) During 1-hour official test discharge record voltage, gravity and temperature readings as per routine.

(i) Check average and final voltages with approved characteristic curve to see if rated capacity has been obtained.

(j) Recharge all cells preparatory to shipment. This charge is known as the "Shipping Charge" and should be conducted sufficiently long to insure that all acid has been driven out of the plates as these cells may be required to stand idle without receiving a "freshening charge" for some little time. Cells watered as necessary before shipping.

(k) Electrolyte of each individual cell subjected to chemical analysis to insure that iron content and other impurities are not above the permissible amount.

(l) If chemical analysis of electrolyte shows O. K., cells are then disconnected and taken out of circuit preparatory to cleaning up for final inspection before crating for shipment.

**VII. Final Inspection.**—(a) Cell covers and terminals thoroughly cleaned. Covers inspected for cracks, warping and other defects which have developed since assembly. All intake and exhaust vents and baffle discs inspected and renewed as necessary. Terminal posts inspected for poor lead-plating and damage to terminals through connecting up and disconnecting in the charging and testing room.

(b) Cell numeral discs installed on top of cell covers.

(c) Cell terminals coated with vaseline.

(d) After cell has thus been given a thorough inspection, the crate cover is placed in position, care being taken to not damage the cell cover and parts in this operation. The crate cover should not be secured in position until the cell crate tie-rods have been set up on to take any lost motion out of the crate such that it takes-up firmly against all four sides of the jar.

(e) Stencil cell number, battery identification markings, "Handle with Care," and other such markings on the top and sides of the packing case.

(f) If for foreign shipment the cells are then crated in another packing case and packed in sawdust. In such instances the cover of the inside packing crate should be securely covered with oil-cloth to prevent the sawdust from entering the cell.

(g) Cells then loaded in the railroad cars. They should be securely packed in the cars and well braced with timbers to prevent motion and damage en route.

The foreign shipment packing crates contain an iron strap for slinging the crates in cargo falls for loading on board ship. These iron straps are so placed on the crates that it is impossible to sling the cells upside down.

## **PART II. STORAGE BATTERIES—PORTABLE TYPE.**

### **Test for Capacity.**

When portable storage batteries are submitted for inspection at the works of the manufacturer it is customary to select at random one complete battery of each type and to conduct capacity tests on it. The procedure for conducting such tests is in general as follows:

1. The following readings taken while battery is on charge and just prior to discharging:

(a) Voltage of each cell.

(b) Specific gravity of each cell.

(c) Temperature of each cell.

2. Cut the battery in on discharge, regulate the current to the proper value as quickly as possible.

3. After discharge has run for from five to fifteen minutes take voltage reading of each cell. Select cells having lowest voltage for use as pilot cells.

4. Take individual cell voltage, specific gravity, and temperature readings every 30 minutes. .

5. During the last hour of the discharge take overall readings as above every 15 minutes.

6. Upon completion of the test take overall readings as above.

7. If the battery fails to deliver the required capacity all other batteries of the type on the order are held up pending a satisfactory test for capacity.



FIG. 132I.—Assembling the Elements.—Portable Type Batteries.

If the batteries are properly rated, and contain no defects, the capacity should be obtained within the first three cycles of charge and discharge.

**Check Dimensions, Construction and Weight.**—The dimensions, construction and weight of the batteries should be checked up to see that they conform to the specifications. An approved drawing or blueprint is usually provided for this purpose by the battery manufacturer. Fig. 132I shows operation of assembling the elements of portable types of batteries by placing the groups of plates together.

**Surface Inspection of Batteries.**—If the capacity tests are satisfactory and the batteries conform to specifications, they are then ready for the surface inspection.

In making the surface inspection of the batteries it is well to place together in line all trays belonging to a set of batteries, as in this way the record of the inspection is easily kept track of.



FIG. 132J.—Showing Celluloid Instruction Sheet Secured to Inside of Battery Tray Cover

Now, in order to insure that all cells in each tray are in good condition and that they are connected up properly with regard to polarity the terminal voltage of each tray should be checked. If a cell should happen to be reversed, short-circuited, or contain any other serious defect, the voltage reading will usually serve as a means of detecting the defective cell. In portable batteries manufactured for the naval service the positive terminal should be

to the right hand when facing the front of the tray, the front being the side on which is secured the battery name-plate.

Specific gravity readings of the electrolyte should be taken to see that the acid is of the prescribed full charge density. Also see that the height of the electrolyte above tops of plates is correct.

The covers and tops of all cells should be inspected for breakage.

The cells should be inspected to see that they are installed in the trays correctly. It sometimes happens that the proper spacing boards have not been used, and that the cells are loose in the trays. Such defects should be rectified before the batteries are accepted.

All connectors and terminal posts should be inspected for poor lead-burning. The terminal connectors should be inspected to see that they are of the correct type and size, and that they line up properly with the cable holes in the trays.

All parts of the battery should be thoroughly clean and the trays and other wood parts neatly covered with acid-resisting paint.

All trays should contain suitable instructions for care and operation. It is customary to secure the celluloid sheet containing these instructions to the inside of the tray cover. Fig. 132J contains a photograph illustrating this feature.

Porcelain insulator skids should be inspected for breakage.

Be sure that the polarity of the terminals is plainly marked on each tray.

Having inspected the batteries as outlined above, they are now ready for packing for shipment. Special notes on the various methods of preparing the batteries for shipment have been given in another chapter.

## CHAPTER XXVI.

### TESTING STORAGE BATTERIES.

**Object of Testing.**—In general it may be said that the testing of storage batteries has as its primary object that of ascertaining the following:

- (1) Voltage characteristic.
- (2) Ampere-hour capacity.
- (3) Watt-hour capacity.

Other factors such as the various efficiencies, weight and size per unit of capacity, temperature characteristics, etc., may be obtained in conjunction with the three fundamental test factors enumerated above. Also, the testing of storage batteries serves the purpose of bringing out any defects in design, or of other local defects, such as short-circuits, bad plates or separators, impurities in the electrolyte, poor lead-burning, etc. The method of conducting the tests will now be described.

**Method of Conducting Tests.**—In order to obtain uniform and accurate results in conducting tests on storage batteries it is necessary that considerable attention be devoted to certain of the minute details which are characteristic of storage battery operation, and which will later be described. The method outlined below is therefore given to serve as a guide in conducting such tests, and if carefully followed, the three fundamental test factors as enumerated in the preceding paragraph, as well as any other pertinent factors, may be comparatively easily and accurately obtained.

The rate at which it is customary to test a battery naturally depends largely upon the type of the battery and the purpose for which it is used. For example, automobile starting batteries and batteries of similar types designed for high discharge rates of short duration are frequently tested at as high as the 20-second discharge rate and sometimes at even higher rates than this, whereas, other types such as are designed for very low-rate discharges are tested at as low as the 20-hour discharge rate. However, with proper facilities, a test may be conducted on a battery at any rate of discharge of which it is capable of producing and it is customary for the manufacturers to prepare and supply to the naval service characteristic curves which include all rates of discharge within the scope that the particular type of battery will likely be called upon to perform. The characteristic curves of submarine batteries include all discharge rates from zero to 20 hours, while the curves for the smaller types of batteries include rates from zero to 10 hours. Thus, it is only necessary to consult these curves to ascertain the discharge characteristics for any desired discharge rate and to check the performance of the

battery on a given test discharge against the characteristics as contained on these curves. Curves such as are here described are shown in Fig. 97.

For purpose of illustrating the method of conducting a test, a three-hour test will here be used, that is, the test will be conducted at the three-hour discharge rate of the given battery. However, the principle involved in the method is the same for tests at all other rates of discharge.

Before beginning the test consult the approved drawings and characteristic curves of the battery in order to obtain necessary data as well as to establish uniform conditions for conducting the test. The following outline represents in general what should be done in this respect before beginning the test:

- (a) Ascertain from the curves the three-hour discharge rate.
- (b) Ascertain from the curves the average cell voltage during discharge at the three-hour rate.
- (c) Ascertain from the curves the minimum final cell voltage for the three-hour rate of discharge.
- (d) Ascertain from the curves the temperature correction for capacity if initial temperature of cell is above or below 80 degrees Fahrenheit, the standard temperature upon which all battery data of batteries for the naval service is based. If temperature is above 80 degrees, the discharge should run for a certain period of time, as shown by the temperature correction curve, more than three hours to the prescribed minimum final voltage; if below 80 degrees the discharge should run less than three hours to the same final voltage.
- (e) See that the level of the electrolyte is at the proper height above the tops of plates and separators, as shown by the approved battery drawings.
- (f) See that the specific gravity of the electrolyte of all cells is within the permissible limits of the full charge value. It is customary to allow a tolerance of 10 points in specific gravity, 5 points below to 5 points above the normal full charge value. Thus if the normal full charge value of the specific gravity is 1.250, then the permissible specific gravity range at the beginning of the test is from 1.245 to 1.255. If the battery is conservatively rated the variation in capacity between the above limits of specific gravity may be said to be negligible for all practical purposes.
- (g) Be sure that battery is fully charged before beginning the test.
- (h) See that all voltmeters, ammeters, ampere-hour meters, hydrometers, thermometers, and all other instruments used in connection with the test are accurately calibrated.
- (i) If an ampere-hour meter is to be used in connection with the test see that it is either set at zero, or that a record is made of the reading which it registers at the beginning of the test.

Having obtained the data and satisfied the conditions outlined above, next place the battery on charge at the *finishing rate* for about 5 minutes, and while thus on charge take a voltage reading of all cells, after which close the switch between the battery and the discharge lines and regulate the discharge current to the proper value, 3-hour rate, as quickly as possible. This discharge rate should be maintained as constantly as possible throughout the test, as this constitutes one of the most important details in connection with a satisfactory test.

After the test has been running for five minutes take another set of overall voltage readings and from which select the pilot cells to be used during the test. At least two each of the high, the intermediate, and the low cells, as shown by this set of overall voltage readings, should be selected for pilot cells, as the readings taken on such cells will give a clear indication of the condition of all cells of the battery in respect to their states of discharge as the test progresses. In this regard it should be stated that care should be taken to not select a cell located at the end of a row for use as a pilot cell, as due to better ventilation on account of its location, or due to any heat from terminal connectors the temperature of an end cell may vary somewhat from the other cells of the battery, which in turn will cause a variation in the cell voltage reading, and for this reason such a cell is not suitable for a pilot cell.

Having thus selected the cells to be used as pilot cells, the routine readings for the test, consisting of voltage, specific gravity, and temperature, should be begun on these cells; the first set of such readings should be taken and recorded after the test has been running for 15 minutes, and thereafter at 15 minute intervals. The ampere-hour meter on the discharge circuit should also be read and recorded at these intervals.

In addition to the above pilot cell readings an overall set of voltage, specific gravity, and temperature readings should be taken and recorded every hour during the test, as this serves as an additional check on the performance of each cell in the battery.

After the test has been in progress for 2 hours and 30 minutes, the low pilot cells should in general indicate the condition of the low cells in the circuit, and if the low cells at this time are within .025 to .030 volts of the limiting final voltage, an overall set of voltage readings should be taken at intervals of 5 minutes during the remainder of the test in order to determine at what period of the test the low cells, if any, go below the specified limiting final voltage. This is important from a point of view of standardization of cells, as it is usual practice to include a fixed standard in the specifications for the various types of batteries, and a certain tolerance is often allowed in the number of cells which pass below the specified limiting final voltage on the test. This tolerance is generally limited to 10 per cent of the cells of the battery, and the final voltage of such cells must not be more than .10 volt

below the specified limiting final voltage at the end of the test. Especially is this true in the case of testing new cells, as during the first few cycles of a cell's life, there is a certain amount of irregularity in its performance, and this tolerance on the tests is designed to take care of such irregularities and at the same time to insure that only normal cells are permitted to remain in the battery. If cells do not come within the tolerance allowed in the approved specifications, they should be replaced by cells which conform to the standard, and the cells which are below standard should be examined and necessary steps taken to rectify any defects which may be found.

At the expiration of 3 hours take and record an overall reading of voltage, specific gravity, and temperature, whereupon the test is completed, and the discharge may be stopped. This, of course, providing that the initial temperature of the cells was at 80 degrees Fahrenheit; if above or below this value, the duration of the test should be changed accordingly.

**Temperature Coefficient Curves.**—Fig. 133 contains an illustration of a typical set of Temperature Coefficient Curves such as are used in conducting capacity tests. This set of curves includes the temperature coefficients for the one, three, and ten hour rates of discharge. It will be noted that the 100 per cent of capacity for each of the above discharge rates is based on a temperature of 80° Fahrenheit, and that these curves include all temperatures from 40° to 120° Fahrenheit. Thus, should the initial temperature of the battery be 54°, then in referring to the three-hour rate curve it will be noted that the test will only be required to run for 2 hours and 30 minutes, to the specified final voltage.

It will further be noted that as the rate of the discharge in amperes decreases, the variation in capacity due to temperature increases; this feature is plainly shown by the relative pitch of the three curves contained in the drawing. Moreover, it will be noted that the element of time for a test increases or decreases, respectively, with an increase or decrease in initial temperature from 80° Fahrenheit. It is customary to include the temperature coefficient curves on the same sheet with the other characteristic curves of a battery.

#### Recording the Test Data.

All readings and other data obtained during the test should be systematically recorded. This data is essential in computing the ampere-hour and the watt-hour capacities, as well as other factors. When prepared in the proper form such data constitutes an important portion of the history of the battery and should therefore be preserved with the other battery records for further use, should they be required.

Figs. 134 and 135 contain typical examples of a method of preparing and recording test data which has been found very satisfactory and which can be

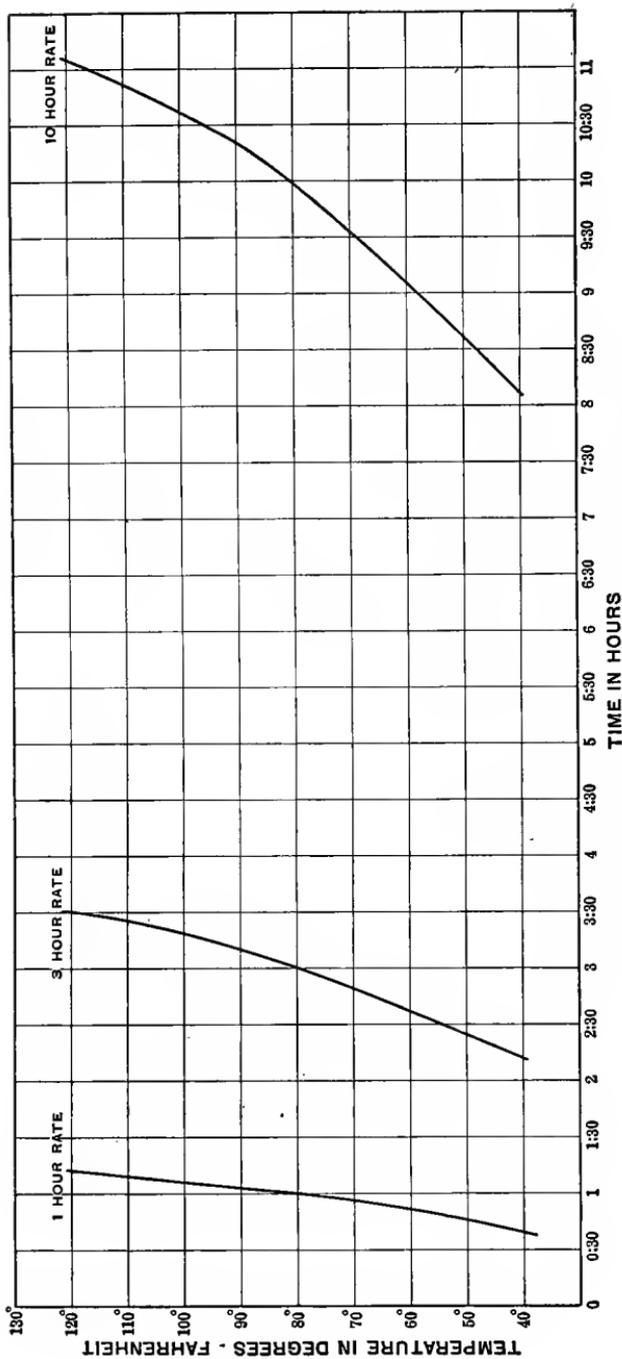


FIG. 133.—Typical Set of Temperature Coefficient Curves.

**RECORD OF 3 HOUR INITIAL DISCHARGE**  
OF BATTERY FOR U. S. NAVY

June 28, 1918

TEMPERATURE OF ROOM {Before Discharge 71  
After Discharge 73

3 Hour Rated Capacity 8850 A.H.

3 Hour Actual Capacity 8850 A.H.

TYPE OF BATTERY PASTE-PASTE ASSEMBLY

Average Discharge Rate 98

This Test 2950 Amperes

CELL No.	INITIAL CHARGE			3 HOUR INITIAL DISCHARGE				Recharge Following Hr. Discharge			REMARKS
	Gravity	Temperature	Voltage	Volts Start	Volts Final	Gravity Final	Temperature Final	Gravity	Temperature	Volts	
1	1.279	81	2.61	1.935	1.73	1.192	97	1.284	75	2.59	
2	1.280	80	2.62	1.93	1.735	1.184	100	1.284	74	2.62	Pilot
3	1.278	80	2.63	1.92	1.73	1.184	97	1.280	75	2.60	
4	1.280	80	2.60	1.92	1.70	1.187	95	1.281	75	2.61	
5	1.280	81	2.61	1.925	1.73	1.183	96	1.284	74	2.63	
6	1.279	80	2.59	1.91	1.705	1.178	98	1.279	78	2.58	
7	1.280	81	2.62	1.94	1.725	1.183	100	1.278	79	2.61	Pilot
8	1.280	81	2.60	1.92	1.725	1.180	98	1.281	78	2.60	
9	1.279	80	2.61	1.92	1.71	1.180	102	1.283	77	2.60	
10	1.280	81	2.62	1.905	1.70	1.182	98	1.283	75	2.59	
11	1.279	80	2.58	1.92	1.725	1.179	97	1.280	77	2.60	
12	1.279	80	2.61	1.935	1.715	1.191	99	1.280	76	2.61	
13	1.278	80	2.63	1.92	1.705	1.180	99	1.284	75	2.63	
14	1.279	79	2.60	1.91	1.69	1.187	101	1.284	74	2.60	
15	1.278	80	2.61	1.90	1.675	1.183	97	1.274	95	2.62	#
16	1.280	80	2.59	1.94	1.72	1.180	100	1.283	75	2.59	Pilot
17	1.278	81	2.62	1.915	1.70	1.179	99	1.279	76	2.61	
18	1.279	80	2.60	1.935	1.745	1.185	102	1.281	75	2.62	
19	1.279	80	2.61	1.915	1.71	1.191	99	1.282	74	2.63	
20	1.283	79	2.59	1.91	1.70	1.178	97	1.280	84	2.54	
21	1.280	78	2.60	1.91	1.69	1.183	98	1.281	75	2.58	
22	1.279	78	2.61	1.92	1.705	1.194	98	1.283	75	2.63	
23	1.278	80	2.62	1.915	1.695	1.178	98	1.280	77	2.58	
24	1.278	80	2.59	1.89	1.73	1.183	103	1.279	79	2.62	Pilot
25	1.279	81	2.58	1.93	1.72	1.180	96	1.280	78	2.60	
26	1.277	80	2.60	1.915	1.72	1.189	98	1.278	79	2.61	
27	1.279	80	2.61	1.90	1.68	1.185	99	1.278	79	2.59	
28	1.278	81	2.62	1.925	1.735	1.193	97	1.278	79	2.62	
29	1.276	81	2.60	1.905	1.705	1.184	98	1.277	80	2.60	
30	1.279	80	2.61	1.93	1.74	1.186	101	1.278	80	2.60	Pilot
31	1.280	80	2.59	1.92	1.72	1.195	96	1.278	80	2.61	
32	1.278	81	2.62	1.905	1.71	1.189	99	1.278	80	2.63	
33	1.278	81	2.60	1.93	1.74	1.182	98	1.277	84	2.58	
34	1.277	81	2.61	1.915	1.72	1.186	97	1.280	84	2.60	
35	1.278	81	2.59	1.93	1.74	1.194	97	1.280	80	2.61	
36	1.278	80	2.58	1.92	1.685	1.202	101	1.279	79	2.47	#
37	1.279	81	2.62	1.915	1.70	1.186	101	1.280	79	2.62	
38	1.279	80	2.61	1.925	1.725	1.190	97	1.280	79	2.59	
39	1.282	80	2.59	1.93	1.74	1.193	98	1.283	78	2.58	
40	1.278	80	2.58	1.925	1.715	1.185	101	1.278	79	2.57	
Av.	1.278	80.20	2.602	1.919	1.714	1.185	98.55	1.280	77.85	2.601	

# Denotes 1 hour pilots  
Second cycle.  
Cell #36 was replaced.  
This cell was so low in capacity that  
it was not used.  
Cell #36 was run as a one and three  
hour pilot; records of these tests  
are not shown since cell was discarded

FIG. 134.—Battery Test Record Sheet.

**Record of Pilot Cell Readings Taken**  
**During 3 Hour Official Discharge**  
**OF BATTERY FOR U. S. N A V Y**

Discharge Rate 2950 Amperes

DATE June 28, 1918 TYPE OF BATTERY PASTE-PASTE ASSEMBLY

TIME	PILOT CELL No. <u>2</u>			PILOT CELL No. <u>7</u>			PILOT CELL No. <u>16</u>			REMARKS
	Voltage	Gravity	Temperature	Voltage	Gravity	Temperature	Voltage	Gravity	Temperature	
Chg.	2.62	1.280	80	2.62	1.280	81	2.59	1.280	80	
5	1.95			1.94			1.94			
15	1.925	1.274	82	1.935	1.274	82	1.93	1.275	82	
30	1.91	1.270	84	1.92	1.268	84	1.91	1.269	84	
45	1.895	1.264	86	1.905	1.260	86	1.895	1.266	86	
60	1.88	1.258	88	1.89	1.253	88	1.88	1.253	88	
75	1.865	1.250	90	1.875	1.248	90	1.865	1.249	90	
90	1.85	1.240	92	1.86	1.239	92	1.85	1.230	92	
105	1.835	1.233	94	1.84	1.232	93	1.83	1.231	94	
120	1.815	1.223	95	1.82	1.223	95	1.805	1.221	96	
135	1.795	1.214	96	1.80	1.218	96	1.79	1.213	98	
150	1.78	1.203	97	1.78	1.207	97	1.77	1.203	98	
165	1.76	1.193	96	1.76	1.197	98	1.77	1.203	98	
180	1.735	1.184	100	1.725	1.183	100	1.72	1.180	100	
AV.	1.8458			1.8514			1.8420			

TIME	PILOT CELL No. <u>24</u>			PILOT CELL No. <u>30</u>			PILOT CELL No. <u>40</u>			REMARKS
	Voltage	Gravity	Temperature	Voltage	Gravity	Temperature	Voltage	Gravity	Temperature	
Chg.	2.59	1.278	80	2.61	1.279	80	2.59	1.280	79	
5	1.89			1.93			1.905			
15	1.885	1.275	82	1.925	1.276	82	1.895	1.276	81	
30	1.875	1.268	84	1.91	1.270	84	1.885	1.271	82	
45	1.86	1.263	86	1.90	1.264	86	1.87	1.264	85	
60	1.845	1.258	88	1.885	1.258	88	1.855	1.259	86	
75	1.83	1.249	90	1.87	1.251	90	1.835	1.251	88	
90	1.82	1.239	92	1.855	1.241	92	1.825	1.243	90	
105	1.80	1.230	94	1.84	1.233	94	1.805	1.238	90	
120	1.78	1.223	96	1.825	1.226	96	1.79	1.228	91	
135	1.765	1.213	98	1.805	1.218	98	1.775	1.222	92	
150	1.77	1.203	100	1.785	1.208	99	1.755	1.210	93	
165	1.77	1.203	100	1.765	1.195	101	1.735	1.203	93	
180	1.73	1.183	103	1.74	1.186	101	1.71	1.188	96	
AV.	1.8158			1.8500			1.8195			

Fig. 135.—Pilot Cell Record Sheet.

used to advantage as a guide in the preparation of battery test data in record form.

It will be noted that Fig. 134 contains a record of the final readings taken on the initial charge of a battery consisting of 40 cells, also the final readings taken during a 3-hour test discharge, as well as the record of the final readings of the re-charge following this 3-hour test discharge.

Fig. 135 contains the discharge records of the pilot cells which were used for this 3-hour test. It will be noted that the first set of readings of the pilot cells was taken while the battery was being charged at the *finishing rate*, and just prior to beginning the test; the second set of readings was

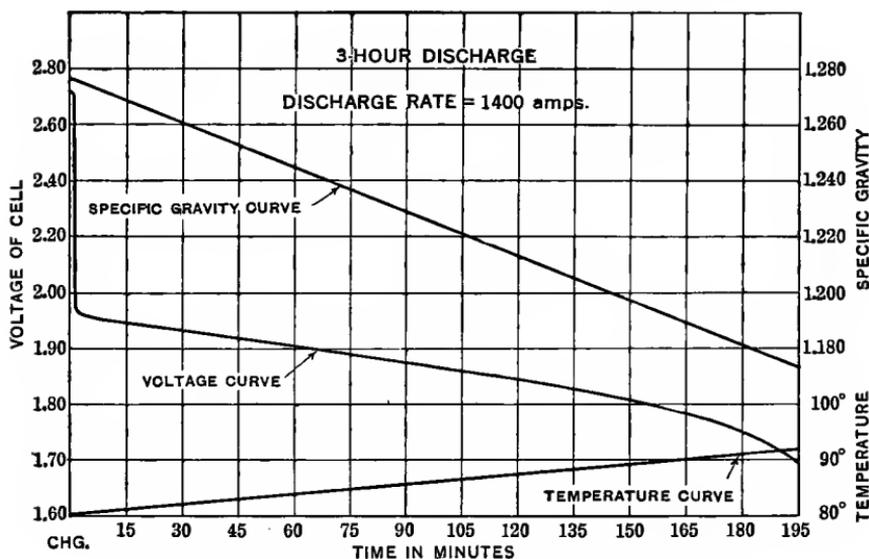


FIG. 136.—Typical Set of Battery Characteristic Curves.

taken after the test had been running for 5 minutes, while the other readings were taken at 15-minute intervals and as has already been explained in the early part of this chapter.

Fig. 136 contains an illustration of a typical set of curves which have been plotted from the records of the readings taken during a 3-hour test discharge. The relative characteristics of voltage, specific gravity, and temperature of battery during the test are plainly indicated by these curves.

Other forms for the preparation of battery data are shown in Figs. 98, 99, and 100. Fig. 136A shows a scene in the testing room during the preliminary test on cells before assembling them in trays and before the final acceptance tests are conducted.

### Computing Ampere-Hour and Watt-Hour Capacities.

As has been stated, it is one of the primary objects of testing storage batteries to obtain the ampere-hour and the watt-hour capacity developed on such a test. Inasmuch as the pilot cells selected for the test comprise those which are representative of the high, the intermediate, and the low cells of the battery, it is customary to use the readings taken on such pilot cells for



FIG. 136A.—Taking Voltage Readings on Cells During Preliminary Tests Before Assembling Them in Trays. Note the Voltmeter and Prods in the Hands of the Testers.

computing these capacities, as this method is sufficiently accurate for all practical purposes. However, should a battery consist of comparatively few cells, readings can be taken on all cells of the battery during the entire test and the capacity of each cell computed individually, but, for large battery installations, such as for the submarine service, etc., it is more practical to select pilot cells and to compute the capacity of the entire battery from the pilot cells readings.

**“Ampere-Hour Capacity.”**—The ampere-hour capacity developed by a battery is represented by the product obtained by multiplying the average value of the discharge current during the test by the time of the discharge expressed in hours, and is expressed as follows:

$$AH = C \times t.$$

Where:

$AH$  = Ampere-hour capacity.

$C$  = Average value of the discharge current during the test.

$t$  = Duration of the discharge test expressed in hours.

Thus, as a function of design, having determined the limiting final voltage for the given rate of discharge, the ampere-hour capacity developed by a particular type of battery during a test is represented by the product of the discharge rate and the length of time the discharge runs before the given limiting final cell voltage is reached.

Referring to Fig. 134 it will be noted that the average value of the discharge current during the test was 2950 amperes, and that the duration of the test was 3 hours; hence the ampere-hour capacity developed by the battery on this test was  $3 \times 2950 = 8850$  ampere-hours.

**“Watt-Hour Capacity.”**—The watt-hour capacity developed by a battery is represented by the product obtained by multiplying the ampere-hour capacity by the average value of the battery voltage and the number of cells in the battery, and is represented by the following expression:

$$WH = AH \times V_a \times N.$$

Where:

$WH$  = Watt-hour capacity.

$AH$  = Ampere-hour capacity.

$V_a$  = Average cell voltage during the discharge.

$N$  = Number of cells in the battery.

Thus, in referring to Figs. 134 and 135, the ampere-hour capacity during this test is 8850 ampere-hours, the average value of the cell voltage as obtained by averaging the average voltage readings of the pilot cells is 1.8372 volts, and the number of cells in the battery is 40. Hence, the watt-hour capacity developed on this test is:

$$8850 \times 1.8372 \times 40 = 650368.8 \text{ watt-hours.}$$

Now, for convenience it is customary to express large numerals like this in terms of kilowatts, and since a kilowatt is a unit 1000 times as great as a watt, it follows that the value of the above capacity expressed in kilowatts is 650.36 kilowatt-hours.

### The Water Rheostat.

For making test discharges on storage batteries it is usually necessary to provide a special resistance for current regulation purposes. A form of resistance extensively used for this purpose and one which can be very conveniently constructed is known as the *water rheostat*. The principle upon which this form of rheostat is constructed is that of utilizing water as a resistance, there being two metal plates immersed in a tank of water and to which plates are connected the wires of the discharge circuit. Thus, by varying the distance between the two plates the resistance offered by the water to the flow of current is also varied and the discharge current is

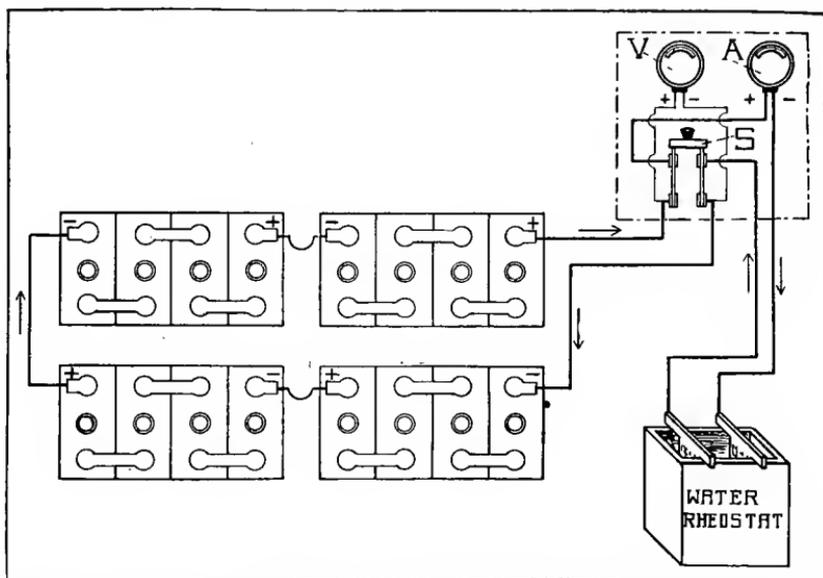


FIG. 137.—Showing Connections for Discharging Through Water Rheostat.

accordingly regulated by this means; that is, the closer the plates are together the smaller the resistance offered to the flow of current, and vice versa. The conductivity of the water is increased by making it slightly acidulated through the addition of a small amount of salt or of sulphuric acid.

Fig. 137 contains an illustration of a type of water rheostat described above, and the proper connections necessary for conducting a test discharge by this method of current regulation. Referring to this illustration it will be noted that the wires of the discharge circuit are each connected to one of the plates in the tank containing the acidulated water. The plates in this

instance consist of unpasted grids, but plain sheets of lead or of iron will well answer the purpose. The tank may be of wood, earthenware, glass, iron or any such material, but, in general, a water tight tank constructed of wood will be found very satisfactory. It is especially important that care be exercised to prevent plates from coming in contact with each other while current is flowing through the circuit; in this regard it is a good plan to place a thin wooden board or a perforated rubber separator between the plates to prevent them from coming in contact with each other during the discharge.

In conducting a test discharge with the apparatus shown in this illustration it will be noted that it is only necessary to place the plates, which are suspended from the top of the tank, at the proper distance apart and to then close the single-throw double-pole switch *S*; the current is then regulated during discharge by varying the distance between the plates as may be found necessary. After the current has once been regulated to the proper value it is a good plan to keep a small stream of fresh water running into the tank by means of a hose in order to keep the water in the tank at as near a constant temperature as possible, as the water will show a tendency to heat during the discharge. The connections to voltmeter and ammeter are also plainly shown in the diagram of the switchboard in this illustration, as are also the connections from the trays of batteries to the single-throw double-pole switch *S*.

Another type of water rheostat used for conducting test discharges on the larger types of cells consists of circulating water through a series of coils of brass pipes, the proper degree of current regulation being effected by making connections with the discharge circuit at various points as necessary along the length of the pipe coils, thus varying the resistance to the flow of current through the coils.

## CHAPTER XXVII.

### THE CADMIUM TEST.

**Object of the Cadmium Test.**—Although it has been stated that the readings taken of the voltage and specific gravity give an indication of the state of charge or discharge of a cell, it should also be said that these readings are only valuable in this respect for cells whose plates are in a normal condition as regards delivering the full capacity of which they are capable. That is to say, a battery may show normal values for the voltage and specific gravity readings at the end of a charge, yet if one or both groups of plates are not in a state of full charge the capacity of the battery is limited by the poorest group of plates.

It is therefore the object of the cadmium test to ascertain the relative states of charge of the two groups of plates in the cell, and to thus detect the plates which are not in normal condition as regards capacity in order that they may be given appropriate treatment and placed in such condition that they will deliver the full capacity of which they are capable.

**Description of the Cadmium Stick.**—In order to detect the relative states of charge of the two groups of plates in the storage battery cell, a neutral or inert electrode is generally used, cadmium being extensively used for this purpose.

Cadmium is an element which occupies a position between lead-peroxide and sponge lead in the electro-chemical series, hence, it is possible to measure the potential difference between cadmium, and the lead-peroxide (positive) plates, as well as that between cadmium and the sponge lead (negative) plates, and in this way the plates which are below normal as regards capacity may be detected. That is to say, with the fully charged cell, cadmium is electro-negative to the positive plates, whereas, it is electro-positive to the negative plates; on the other hand, however, when the cell is in a discharged condition, the cadmium electrode becomes electro-negative to the negative plates, but the positive plates remain electro-positive to cadmium.

By a very carefully conducted series of tests the values for the potential difference between cadmium and the two sets of perfectly normal and healthy plates of the lead-acid storage battery cell have been accurately established under conditions of both charge and discharge. Therefore, by comparing the readings obtained on a cadmium test with these established normal values, the condition of the plates as regards capacity may be determined.

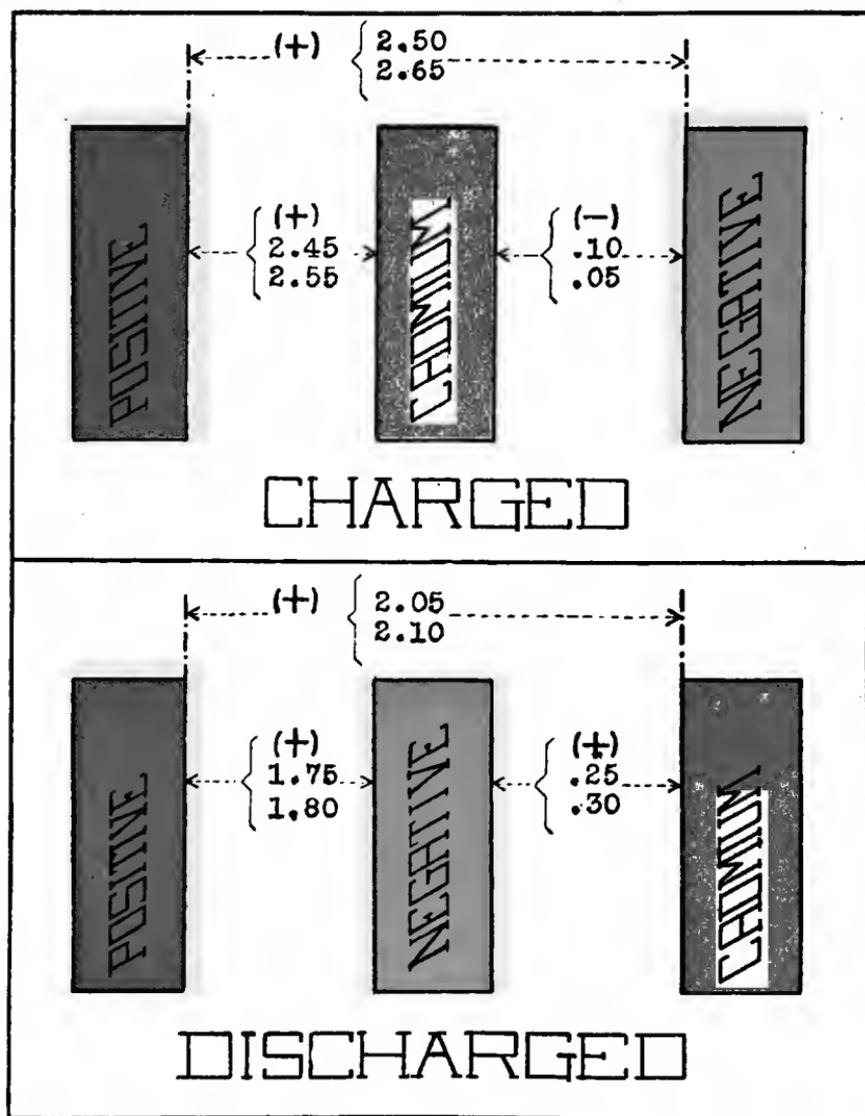


FIG. 138.—Chart Showing Normal Cadmium Readings.

The following table represents the normal values of the differences of potential between cadmium and the positive and the negative plates:

TABLE OF NORMAL CADMIUM READINGS.

Condition of plates.	Potential difference between Cadmium		Cell voltage
	Positive plate ( $\text{PbO}_2$ ).	Negative plate (Pb).	
Charged . . . . .	(+) 2.45 to (+) 2.55 volts.	(-) .05 to (-) .10 volts.	(+) 2.50 to (+) 2.65 volts.
Discharged . . . . .	(+) 2.05 to (+) 2.10 volts.	(+) .25 to (+) .30 volts.	(+) 1.75 to (+) 1.80 volts.

It will be noted in the above table that the cell voltage at any time is represented by the algebraic sum of the differences of potential between

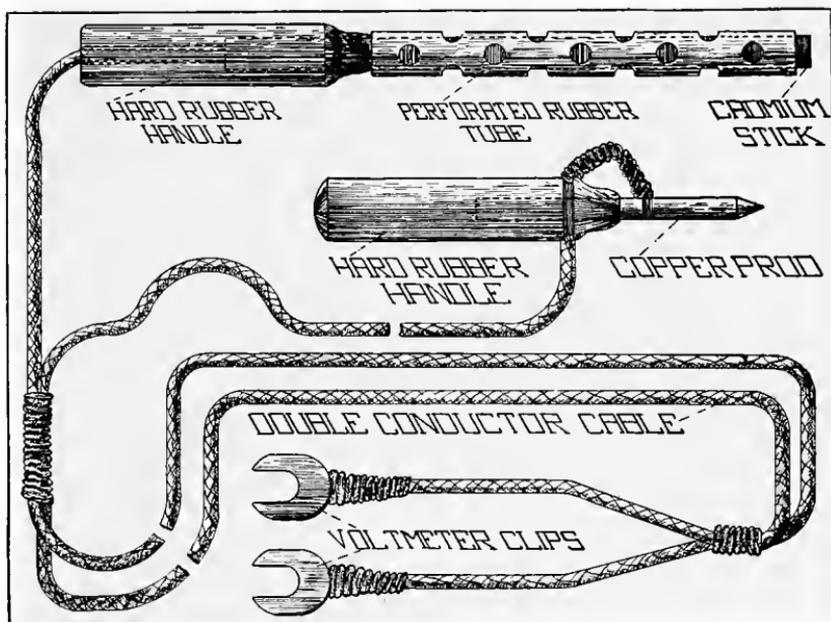


FIG. 139.—Apparatus for Taking Cadmium Readings.

cadmium and the positive and negative plates respectively. The values given in this table may also be graphically illustrated by the chart in Fig. 138 which clearly shows the normal cadmium readings for both charge and discharge.

Fig. 139 contains an illustration of the equipment required for making a cadmium test. This equipment consists of a stick of cadmium of approxi-

mately  $\frac{1}{2}$  inch in diameter enclosed in a perforated rubber tube, the cadmium being secured to a hard rubber handle and connected with one end of the flexible cable which forms one of the voltmeter leads. The other voltmeter lead is connected with a regular copper pointed prod which is also secured to a hard rubber handle. The clips for connecting the flexible leads to the binding posts of the voltmeter are also plainly shown in the illustration.

**Method of Making the Cadmium Test.**—For conducting the cadmium test, either during charge or discharge, current of the desired rate should be flowing through the circuit to or from the battery. It is also important in obtaining uniform readings that the cadmium stick be free from impurities, and that the surface of the cadmium be kept in a corroded condition and never scraped or polished.

In measuring the voltage between the set of plates, the cadmium stick should be placed in the electrolyte between the plates to be tested, having care to prevent the cadmium from coming in contact with either plate. Each time that a reading is taken it is necessary that the cadmium occupy the same relative position in the cell in order that uniform and accurate readings may be obtained.

In making the cadmium test the method of making the connections between the leads of the cadmium stick, the copper pointed prod, and the binding posts of the voltmeter depends upon the type of the voltmeter used.

If the voltmeter is of the type which has its zero point in the center of the arc of the scale, commonly known as the two-way reading type, it is not necessary to shift the leads to the binding posts when taking the respective readings between cadmium and the positive and negative plates.

However, if the voltmeter is of the type which has its zero mark located at the left hand end of the arc of the scale, it then becomes necessary at times to shift the binding post leads in order to measure the difference of potential between cadmium and one set of the plates. Thus, if the leads are properly connected for measuring the difference of potential between cadmium and the positive plate, it would then be necessary to shift the binding post leads in order to measure the difference of potential between cadmium and a completely charged negative plate, for the reason that the negative plate when in this condition is electro-negative to cadmium; this of course, providing that the negative plate is in a perfectly normal condition. A little practice with taking cadmium readings will assist in determining when it is necessary to shift the binding post leads if the one-way reading type voltmeter is used.

Let us now proceed to take a set of cadmium readings on a cell. The cell is being charged at the normal rate, and it is near the completion of the

charge. The two-way reading type voltmeter is to be used. We will begin by taking a reading between cadmium and the positive plates.

First, connect the clip, which is attached to the end of the flexible cable of the copper pointed prod, with the positive binding post of the voltmeter, and then connect the clip, attached to the end of the cadmium stick cable, with the negative binding post of the voltmeter. We are now ready to take cadmium readings.

Next, insert the cadmium stick in the electrolyte and close to the positive plate to be tested, but exercise great care to prevent the cadmium from coming in contact with any of the plates in the cell. Now, press the copper pointed prod against the lug of the positive plate to be tested, and at which time it will be noted that the needle of the voltmeter will be deflected and will register on the positive side of the scale the difference of potential between cadmium and the positive plate.

Now, in order to test the negative plate proceed in the same manner as described for the positive plate, with the exception, however, that the copper pointed prod is placed in contact with the lug of the negative plate to be tested. It will then be noted that the needle will register on the negative side of the scale the difference of potential between cadmium and the negative plate, since the negative plate is electro-negative to cadmium when nearing a condition of full charge.

Thus, as has been pointed out, having at hand the normal values which have been established for the differences of potential between the plates under certain given conditions, if these values are not obtained on the cadmium test when taken under the given conditions, then the plates or group of plates which do not show normal values for the difference of potential are faulty and should be given appropriate treatment in order to restore them to a normal condition.

For example, suppose that at the end of a charge it is found by test that the potential difference between cadmium and the negative plates of a cell show that the negative plates are electro-positive to cadmium; this would indicate that a large portion of lead-sulphate in the negative plates had not been reduced to sponge lead during the charge, and this group of plates would therefore become completely discharged very quickly after being placed on discharge, which would accordingly reduce the capacity of the cell; in this regard it should be stated that like the chain which is no stronger than its weakest link, the capacity of the storage battery cell is no better than the poorest group of plates which it contains. Thus it is that the cadmium test is designed to indicate the relative states of charge of the individual plates or group of plates in the cell, in order that the plates which limit the capacity of the cell may be detected and any defects which may exist rectified.

Fig. 140 contains a photographic illustration of two groups of plates taken from cells, and such as would prove below normal on a cadmium test. It will be noted that both groups of plates are in a very badly sulphated condition, and there is also very poor conductivity between the grids and the pellets of active material on account of the poor contact between the grids and the active material.

A cadmium test on these groups at the end of a charge would show that the readings between the positive group and cadmium would be abnormally low, and that the negative group would be electro-positive to cadmium. Very little capacity would be obtainable from these plates in their present condition.



FIG. 140.—Badly Sulphated Groups Which Would Show Below Normal on Cadmium Test.

The treatment required to restore the capacity of such plates is a series of charges and discharges (*treating cycles*) at a very low rate and in electrolyte of comparatively low specific gravity (1.200).

**The "Standard Negative" Electrode Test.**—For laboratory work in connection with ascertaining the relative states of charge of storage battery plates some battery engineers prefer to use a *standard negative* electrode instead of the cadmium stick described in the preceding paragraphs. This electrode consists of an ordinary negative plate which at all times is kept in a perfectly healthy and fully charged condition. The method of using such an electrode for this purpose is practically identical with that which has already been described for making the cadmium test, with the exception, however, that the values of the differences of potential are obviously not the same as in the cadmium test.

CHAPTER XXVIII.  
MISCELLANEOUS NOTES.

**Health Hints.**

When working around storage batteries or in the manufacture of various parts composing the cells, certain precautions for preserving the health should be observed. These health hints may be divided into two classes, as follows:

- (1) Protection against the injurious effects of sulphuric acid.
- (2) Protection against lead poisoning.

**Protection Against Injurious Effects of Sulphuric Acid.**—Sulphuric acid produces very painful burns when it comes in contact with the skin, and the following precautions should be observed when handling this acid:

- (a) Wear rubber gloves, apron, boots or shoes.
- (b) Wear goggles to protect the eyes.
- (c) Woolen clothes should be worn in preference to cotton clothes for the reason that cotton is easily attacked and eaten away by the acid. If cotton clothes are worn, it will be found that it is a good plan to soak them in a strong solution of bicarbonate of soda and then allowed to dry, as this process will tend to neutralize the effect of any acid which may come in contact with the clothes. It will also prove a good plan to have at hand a bottle of strong ammonia solution for applying to the clothes to neutralize any acid spilled on them.
- (d) In order to protect the hands from acid have at hand a bucket or other vessel filled with a solution of bicarbonate of soda for rinsing off the hands or other parts of the body from time to time while handling the acid.
- (e) In case acid should be splashed in the eyes they should be immediately washed out thoroughly with warm, fresh water, after which apply warm vaseline, Albany grease, olive oil, or ordinary lubricating oil to and around the eyes.
- (f) Additional precautions for handling and mixing acid will be found in Chapter IX.

**Protection Against Lead Poisoning.**—In working around storage batteries or handling storage battery parts always bear in mind that the major portions of such parts are composed of lead in some form, and that if lead be allowed to enter the human system serious injury from lead poisoning may result. The following precautions are therefore given as a guide in preventing injury to the health from this cause:

- (a) In order to prevent as much as possible any lead from entering the system through the mouth, do not eat and do not chew tobacco while handling such parts.

(b) Keep hands out of the mouth while handling such parts.

(c) When knocking-off work, the face and hands should be thoroughly washed clean with soap, being careful to also clear out the nostrils and clean the finger nails. Clothes should also be changed before leaving the workshop. Bathe frequently.

(d) Use a mild purgative if necessary to prevent constipation.

(e) Good fresh milk is especially effective in preventing lead poisoning. Drink plenty of it.

(f) The characteristic symptoms of lead poisoning are loss of appetite, constipation, indigestion, muscular pains developing into weakness, and in advanced cases, paralysis. In some cases the gums become abnormally dark or blue.

#### Notes on Lead Oxides for Storage Battery Plates.

The quality and characteristics of storage battery plates of the paste type depend largely upon the quality and grade of the lead oxides of which the



FIG. 141.—Microphotograph of Lead Oxide of Rugged Molecular Structure. Produces High Capacity, Long Life Plates.

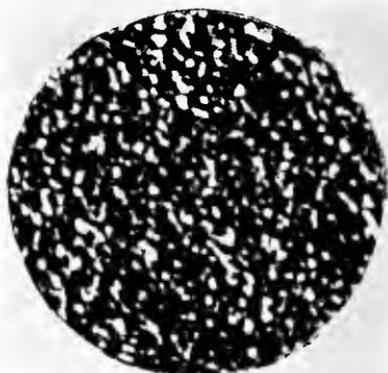


FIG. 142.—Microphotograph of Lead Oxide of Light, Smooth Molecular Structure. Produces Low Capacity, Short Life Plates.

paste is composed. A considerable amount of research work has been done in the past, and is still going on, in improving the quality and characteristics of the plates through improving the quality of the lead oxides used for this purpose.

From present research data available it would seem that a definite relation exists between the capacity of a plate and the molecular structure of the oxides used in the paste composing the active material. Moreover, it appears to be an established principle that the grade and quality of the oxide produced and its suitability for storage battery use depend upon the special nature of the process of converting the virgin lead into the oxides.

As illustrating that feature of the relation existing between capacity and the molecular structure of the oxide of which the active material of the plate is composed, attention is invited to the microphotographs shown in Figs. 141 and 142. These photographs represent specimens of lead oxides which are magnified by approximately 400 diameters.

The specimen shown in Fig. 141 is of large, rugged molecular structure and it may be said that it is characteristic of this grade of oxide to produce a relatively heavy and rugged crystalline formation when mixed in the paste and subjected to the electro-chemical action which takes place in the storage battery cell. Furthermore, it may be said that on account of these properties, this grade of oxide will in general produce a plate of high capacity, and one



FIG. 143.—Testing Lead Oxide to Determine Ratio of Volume to the Weight of the Sample. Known as the "Volumeter Test."

which is possessed of a high factor of cohesion between the particles of active material, and, since this factor is a function of the life of a plate, it follows that the plates composed of this grade of oxide should be of comparatively long life.

The photograph shown in Fig. 142 represents a specimen of oxide the particles of which are of light, smooth molecular structure and have a relatively low factor of cohesion. Plates composed of this grade of oxide may in general be said to be of low capacity and short life.

Rigid specifications covering the grade and quality of storage battery oxides have therefore been developed as a result of the extensive amount of research work which has been performed by electro-chemists and battery engineers. All leading storage battery manufacturers accordingly subject the oxides going into the fabrication of their plates to a rigid series of specification tests before using such oxides. Fig. 143 contains an illustra-

tion of one of the tests being conducted on a lot of oxides intended for storage battery use; this particular test is known as the *volumeter test*, and is designed to determine the ratio of volume to the weight of the sample, and constitutes one of the most important tests in this line of work.

### **Gun-Firing Battery.**

The gun-firing battery is given special mention in the text of this volume by reason of the unique position which it occupies in being the pioneer in the field of general application of storage batteries to the naval service, and in view of the fact that many people in the service received their first experience in the care and operation of storage batteries with this type of cell. It is therefore considered eminently fitting that this type of battery should receive special mention in this volume.

Fig. 144 contains an assembled view of a type of battery used for this purpose, while Fig. 145 contains a disassembled view of the same battery and from which a clear idea of the details of its construction may be obtained.

### **Paraffin Impregnation of Wood Parts Used in Storage Battery Installations.**

Where it is necessary to use wood parts around storage battery installations, it has been found that the life of the wood is materially increased through impregnating it with paraffin. This operation is designed to thoroughly saturate the wood with the paraffin, thereby preserving it against the corrosive action of the sulphuric acid of the electrolyte, and also adding to its insulating qualities. This method of treating the wood has also proved more effective for this purpose than the use of acid-resisting paints and other like coatings. For wood parts such as cell-wedges, battery tank liners, etc., as used in submarine battery installations, this method of treating the wood has proven very effective in preserving these parts.

Due to its capacity for absorbing a relatively large amount of molten paraffin, maple-wood has been found especially adapted for such parts used around storage battery installations. The process of impregnating wood by this method will be described in detail.

**Paraffin Impregnation Process on Wood.**—This process is based upon the principle of immersing wood in a bath of boiling paraffin, the temperature of which is sufficient to drive out the moisture and other free organic matter contained in the wood, and to replace this matter with molten paraffin. The length of time required to complete this process depends upon the temperature of the molten paraffin bath, which is a function of its power of penetration, the higher the temperature the shorter the time required.

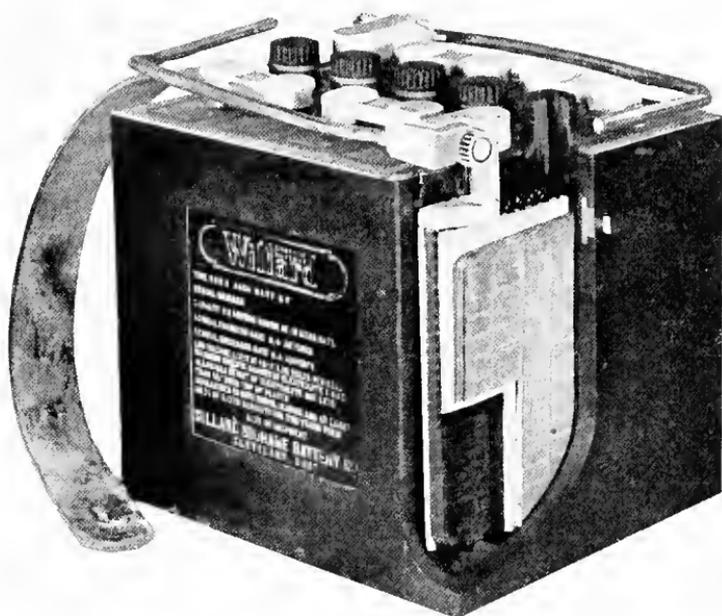


FIG. 144.—Assembled View of Gun Firing Battery.

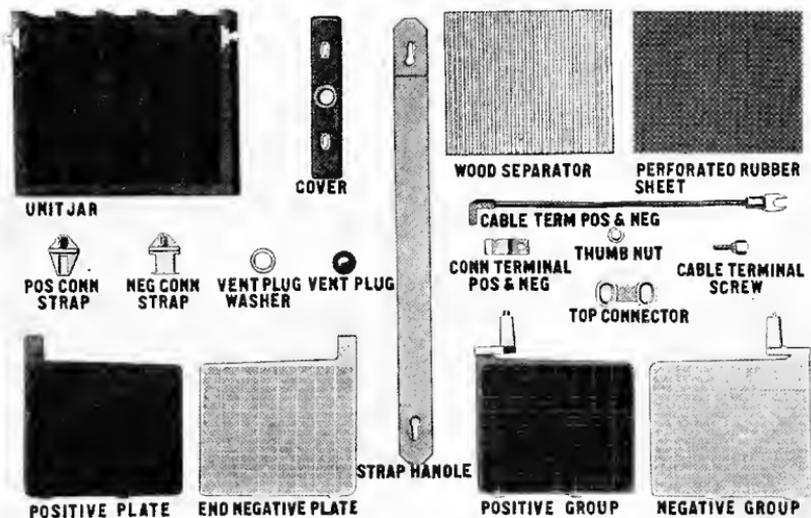


FIG. 145.—Disassembled View of Gun Firing Battery.

Fig. 146 contains a diagram indicating the apparatus required to impregnate wood with paraffin by this process. Referring to this diagram, tanks T-1 and T-2 are approximately two-thirds to three-fourths filled with paraffin,

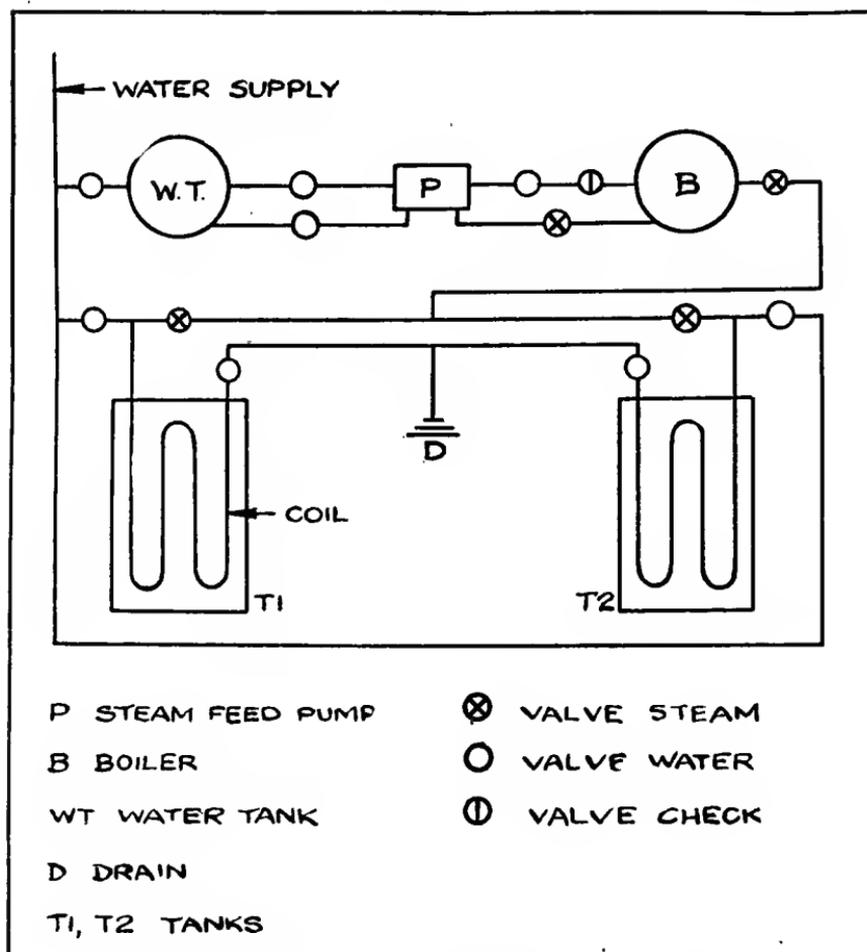


FIG. 146.—Equipment Used for Impregnating Wood with Paraffin.

which may be obtained commercially in 10-pound cakes. Steam is then passed through the coils in these tanks until the paraffin is brought up to the melting point, which occurs at around 175° to 200° F. The wooden parts to be impregnated are then dropped into the molten paraffin and as the wood parts become saturated with the paraffin, they sink to the bottom of the

tank, which requires about two hours when the paraffin bath is maintained around 212° F. If the bath is maintained around 380° F., it requires from 8 to 12 minutes for the wood to become thoroughly saturated with the paraffin.

After all of the wood parts have become thoroughly saturated as outlined above, steam is turned off and cold water passed through the coils in the tanks to facilitate cooling off the paraffin, which operation should be continued until the paraffin solidifies. In order to insure that the wood parts have become thoroughly saturated or impregnated with the paraffin, it is especially important that they be not removed from the tanks until the paraffin has reached a state of solidification. After the paraffin has solidified, the cold water is shut off and steam again passed through the coils and temperature of the paraffin again brought up until it is sufficiently liquid in consistency as to permit of removing the wood parts; as these parts are thus removed, the excess paraffin should be allowed to drain back into the tanks.

Should it be desired to rig up an apparatus, such as has been described, on the dock or any other place, a steam launch boiler may well be used for this purpose. It will also be observed in the drawing that the arrangement of piping and valves is such that both tanks may be heated or cooled at the same time, or one may be heated and the other cooled as desired. This arrangement is conducive to speed in carrying out this process.

#### Storage Battery Testing Outfits.

The testing outfits for storage batteries of the naval service should each consist of the following parts:

- (1) Two hydrometers.
- (2) One hydrometer syringe.
- (3) Two thermometers.
- (4) One packing case.

**Hydrometers.**—The hydrometers shall be of the best quality transparent glass of sufficient thickness to withstand ordinary use, and so proportioned that they will float perpendicularly in solutions of all densities within their range.

The hydrometers shall indicate both specific gravity direct and degrees Baumé.

The Baumé scale shall be that adopted by the Bureau of Standards.

The specific gravity scale of one of the hydrometers shall be from 1.000 to 1.250 and the other from 1.150 to 1.400.

The scale shall not be less than 3 inches long and neatly engraved on a high-grade paper firmly fixed in position inside the hydrometer, and shall be divided into divisions of 0.005 specific gravity and shall be accurate to 0.01

specific gravity. Each hydrometer shall have a serial number on the paper scale.

Means shall be provided either in the hydrometer syringe tube or on the hydrometer to insure free flotation of the hydrometer when testing liquids.

**Hydrometer Syringe.**—The hydrometer syringe shall be composed of the following parts:

(a) **Syringe Bulb.**—The syringe bulb shall be made of the best grade of soft vulcanized rubber, free from defects, fitting the glass tube in a perfectly air-tight manner and suitable for the purpose intended. It shall be of such design as will allow sufficient liquid to obtain all specific gravity readings to be drawn into the tube but shall not allow flooding of the bulb itself.

(b) **Syringe Tube.**—The syringe tube shall be made of high-grade, transparent glass, free from blisters, spots, or defects of any nature, and of uniform thickness. The glass shall be of sufficient thickness to withstand ordinary jars, shocks, or vibrations encountered on shipboard. The tube shall be of such diameter and form as to insure the free flotation of the hydrometer. The tube shall be fitted at the bottom with a rubber stopper of sufficient thickness to act as a buffer for the hydrometer, and with flange projection under glass tube of a diameter greater than tube, sufficient to act as a buffer when laying assembled hydrometer on a flat surface. The stopper shall be so fitted in the tube that it will not fall out of place when it has deteriorated from use, and shall be provided with a hole or holes of sufficient size to allow the liquid to enter the tube.

(c) **Rubber Tube.**—The hydrometer syringe shall be fitted with a soft vulcanized rubber tube at least 12 inches long.

**Thermometers.**—The thermometers shall conform to the following specifications:

(a) **Type.**—The thermometers shall be of the paper-scale, inclosed-stem type, shall be especially adapted for storage battery use, and shall float in a vertical position in all solutions having densities between unity and 1.900.

(b) **Dimensions.**—Thermometers shall have an over-all length of about 9 inches, and an effective scale length not less than  $4\frac{1}{4}$  inches. The outside diameter of inclosing tube shall be  $\frac{1}{2}$  inch, and for a distance of about  $2\frac{1}{2}$  inches from end of bulb the diameter of inclosing tube shall not exceed  $\frac{1}{4}$  inch. The bulb shall be cylindrical and not more than  $\frac{1}{4}$  inch diameter. The top of tube shall be drawn out into a ring for suspension.

(c) **Material.**—The stem shall be of high-grade, enamel back, magnifying lens tubing. The inclosing tube shall be of perfectly clear and transparent high-grade glass, free from blemishes of any kind. The bulb shall be of especially blown Jena-glass. The paper scale shall be fixed inside the tube in such a manner that no relative motion with respect to the thermometer stem shall be possible.

(d) **Range, Calibration, and Accuracy.**—The temperature range shall be from 0 to 150° F. The scale graduated every degree and figured every 5 degrees. All lines and figures shall be distinctly, neatly, and uniformly engraved on the paper. The thermometers shall be calibrated for 2 inches immersion and correct within 1° F. A temperature correction scale for correcting specific gravity readings of sulphuric acid solutions based on 80° F. shall be included on thermometer scale.

**Packing Case.**—A varnished, hinged-cover hardwood box, designed to hold the parts securely in position shall be furnished. The box shall be of sufficient size and strength and provided with suitable partitions, clips, and fittings so as to securely hold free from breakage all the parts comprising the outfit.

The box shall be provided with a suitable catch; hinges and catch to be of brass.

### Melting Points of Metals or Elements.

The following table contains the melting points of metals or elements in degrees Centigrade and Fahrenheit, as supplied by the Bureau of Standards, Washington, D. C.

TABLE OF MELTING POINTS OF METALS OR ELEMENTS.

Element.	Degrees Cent.	Degrees Fahr.	Element.	Degrees Cent.	Degrees Fahr.
Hydrogen .....	—259	— 434	Barium .....	850	1562
Oxygen.....	—218	— 360	Silver .....	960	1761
Nitrogen .....	—210	— 346	Gold .....	1063	1945
Chlorine.....	—102	— 151	Copper .....	1083	1981
Mercury.....	— 39	— 38	Manganese .....	1260	2300
Phosphorus.....	+ 44	+ 111	Silicon .....	1420	2588
Potassium.....	62	144	Nickel .....	1452	2646
Sodium.....	97	207	Cobalt .....	1480	2696
Sulphur S.....	113	236	Chromium.....	1520	2768
Iodine.....	113	236	Iron.....	1530	2786
Lithium.....	186	367	Palladium.....	1549	2820
Selenium.....	218	424	Zirconium.....	1700?	3090?
Tin.....	232	450	Thorium.....	1700?	3090?
Bismuth.....	271	520	Vanadium.....	1720?	3128?
Thallium.....	302	576	Platinum.....	1755	3191
Cadmium.....	321	610	Titanium.....	1800?	3272?
Lead.....	327	621	Rhodium.....	1950?	3542?
Zinc.....	419	787	Boron.....	2200?	3992?
Tellurium.....	452	846	Iridium.....	2350?	4262?
Antimony.....	630	1166	Ruthenium.....	2450?	4442?
Cerium.....	640	1184	Molybdenum.....	2500?	4532?
Magnesium.....	651	1204	Osmium.....	2700?	4892?
Aluminum.....	659	1218	Tantalum.....	2850?	5160?
Calcium.....	810	1490	Tungsten.....	3000?	5430?
Arsenic.....	850?	1562?	Carbon.....	3600?	6510?













