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A Study of the Inhibiting Value of Various Separators on the Plating of Lead

Lawrence E. Ehrnst

A STUDY

OF

THE INHIBITING VALUE OF VARIOUS SEPARATORS

ON THE PLATING OF LEAD

By

LAWRENCE E. EHRNST

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SUMMARY

P R E F A C E

This thesis was suggested by the work of Mr. B. J. Pozorski and Mr. W. Adashek. Mr. Pozorski investigated the inhibiting qualities of various separators when placed between two platinum electrodes in a copper sulfate solution. Mr. Adashek worked on the efficiency of various lead plating solutions using lead electrodes and electrlytes containing soluble lead salts. Combining the work of these men, the author is investigating the prohibitive plating properties of various separators using a lead plating solution. By so doing, the investigation has a closer relationship to the actual performance of the storage battery.

The author wishes to acknowledge with sincere thanks the co-operation and help given by Dr. John Koch, thesis director, and Dr. H. Heinrich, professor of chemistry. The Globe Manufacturing Company has been most generous in supplying separators for this work.

PART 1

HISTORY

Introduction:

A storage battery is simply constructed and yet the mechanics of the reactions are difficult to understand. Although much progress has been made[1] with the storage battery, little is really known of the detailed chemical reactions that takes place within it. This lack of knowledge is usually given as the reason for not having the storage battery developed to the perfection today that it might be if these reactions were known. The storage battery is relatively an old device, but it has not become widely developed until the last fifteen years or so. This development took place with the inventions of the automobiles. The total sales have increased in value from about twelve million dollars per annum, to one hundred million dollars, while the plate material used per annum has increased from forty million to over two hundred million pounds within one decade. (1914-1924).[2]

In treating this subject it is essential that certain distinctions be made. Unfortunately, the type of battery that is to be discussed has been called "storage battery" or "accumulator." Although these names are somewhat suitable to this battery, they have often created a false impression of it. This false impress-

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2. M. Arendt, Storage Batteries, p.1 1928.
1. A. Treadwell, Jr. - The Storage Battery-p.109, 1898

ion is that quantities of electrical energy are stored up within the cell. That this is a misconception will be easily seen in the course of this treatise. Then also, considering the fact that they are called "secondary batteries" we must remember that they are secondary only in respect to the fact that another source of electric current is necessary in the making of them.

The theory of a storage battery does not differ much from that of a primary battery. They both must follow the same laws, but there is a distinction in the chemical reactions that take place in them. The reactions in the primary cell are not reversible, and when used up must be disposed of with no further utility. The reactions in the storage battery are reversible and the unit may be charged by an electric current passing through the battery in the opposite direction of discharge. The charging current practically replaces the battery to its original form. The theory of a storage battery can best be explained by exemplification of a simple one. When two plates of lead are immersed[3] in the solution of sulfuric acid, no current flows when the two poles are connected. If a charging current is sent through this cell and then the two poles connected when the charging current is off, it is found that a reverse current flows. When the charging is taking place, the positive pole turns a brownish color. This brown color is due to the formation of lead peroxide. The negative pole becomes gray due to the formation of pure lead. During discharge both electrodes[4] are con-

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3. Wood and Jansky, "Elements of Storage Battery" p.3
4. Treadwell, A. Jr. "The Storage Battery" p.110 1898.

verted into lead sulfate. During this process, the sulphion is extracted which reduces the density of the solution. The peroxide on the positive plate first reduces to monoxide and then the monoxide is converted to the sulfate. Charging a battery is just the reverse process of forming the original plates by passing a current through the opposite way. In this action the SO_3 ions are given up to the liquid which gains weight and the density again increases. As to what forms on the positive plate there are different opinions. We must remember that this is merely using the lead-acid battery as an example for there are several types of storage batteries. The equations for the reaction taking place in a lead-acid battery are as follows:[5]

On the positive pole the action is

$$Pbo_2 + H_2SO_4 \longrightarrow PbSO_4 + H_2O + O$$

On the negative pole

$$Pb + H_2SO_4 \longrightarrow PbSO_4 + H_2$$

And combining these equations the combined result is

$$Pb + PbO_2 + 2H_2SO \longrightarrow 2PbSO_4 + 2H_2O$$

Although there has been a difference in the opinions of many scientists in regard to the reactions and products formed in the lead-acid storage cell, the above reactions are usually accepted as being correct.

The first noteworthy discovery of the storage battery[6]

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5. Lyndon, "Storage Battery Engineering" p.14 - 1903
6. Arendt, M. "Storage Batteries" p.2-1928

was in 1800 by Volta with the invention of his electric pile, but it was not developed until 1859 by Planté when he was doing research work on "Secondary Currents and Polarization Voltages." The apparatus[7] which Volta used consisted of discs of zinc and silver placed alternately over one another, the silver disc of one pair being separated from the zinc disc of the next by a piece of blotting paper moistened in brine. Such a pile, if composed of a sufficient number of pairs of discs, will produce electricity enough to give a shock, if the top and bottom discs or wires connected with them, are touched with the moist fingers. This experiment of Volta's lead to the study of electrolysis of saline solutions. In these studies it was noticed that gases were liberated at the poles, that films were formed on them, and that if the poles were connected together after the charging current was disconnected, the current given by the battery would flow in an opposite direction. These discoveries were due to the studies of Gautherot, Richter, Grave, and Davy. These men called the process polarization, and it was Planté who then saw the possibility of increasing the polarization so as to make battery plates. He formed the active material on the plates by charging. This process of making plates wasted much time and was difficult because, during this time, the primary batteries were the only means of obtaining a charging current.

In 1881 Faure[8] improved upon Planté's process of making

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7. Getman and Daniels, "Outlines of Theoretical Chemistry"p.360
   1931 - Ed.5
8. Vinal, G. "Storage Batteries" p.8, 1928

plates. In order to increase the cell capacity, the electrodes should be given as large an amount of surface as possible. This, Faure discovered, could be done by pasting the surface of the lead plates with a compound of lead. He made a paste of lead oxide and red lead and held it together by means of a lead grid. Two of these pasted plates were placed into sulphuric acid and subjected to the action of a charging current. The current was passed until spongy lead formed at the cathode and lead peroxide formed at the anode. It was also noted that, under these conditions, the plates changed more easily into the active material, which was an improvement over Planté's discovery. Brush about the same time obtained patents on the covering of the plates mechanically with compounds, and ever since this time further improvements have been made on the plates.

An electrolyte may be defined as any non-metallic liquid which will decompose, and has electrical conductivity, or more clearly, it is a non-metallic liquid whose component elements are disassociated when an electrical current is passed through.[9] In the lead acid batteries, sulfuric acid has been found to be the most satisfactory, but due to the adoption of the batteries for starting and lighting service, an increase in demand for storage batteries by non-technical users[10] arose, and special electrolytes came on the market which were sold with extravaga nt claims. The use of these electrolytes can not be recommended.

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9. Dunn, L. D. "Storage Battery Manual" p.88-1920
10. Vinal, G. "Storage Batteries" p.72-1928

For a storage battery to opera te best, a proper amount of sulfuric acid and water must be used. In order to get this correct amount of sulfuric acid and water, the solution is usually tested for specific gravity with a hydrometer at a definite temperature. In order to get an electrolyte of the correct specific gravity, pure sulfuric acid is diluted with distilled water; but care must always be taken to paur the acid into the water. The electrolyte contains concentrations of hydrogen ions (cations) SO_4 ions (anions).[11] 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. Any foreign metal is likely to cause difficulty in a lead acid storage battery. Those metals which are below lead in the electromotive series are transferred to the negative pole and local action takes place. Hydrogen is evolved at the foreign metal, and the efficiency of the battery is lowered. Iron, which is most commonly present in water, has salts which are easily oxidized. When ferrous sulfate comes in contact with the PbO_2 of the positive plate it readily oxidizes to ferric sulfate, and this coming in contact with sponge lead is reduced to ferrous sulfate again. These actions cause a loss of charge on the plates, and lead sulfate is formed on both plates. Foreign acids also hinder the good working of a battery since they cause a corrosion of the plates.

Capacity and efficiency are important factors to be con-

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11. Dunn, L. D. "Storage Battery Manual" p.88-1920

sidered in the development of the storage battery. Capacity when considered in this sense[12] may be defined as the amount of electrical energy delivered by a cell from the beginning of discharge until the potential becomes too low for the battery to be of service. The unit of capacity is the ampere hour. The most important factors influencing the capacity of a battery are as follows:[13]

1. Amount of plate active material
2. Arrangement of active material
3. Quality of active material
4. Amount of specific gravity of electrolyte.
5. Distribution of Electrolyte
6. Purity of the electrolyte
7. Rate of Discharge
8. Temperature of cell
9. Past performance
10. Health of cell
11. Age of cell

Since the electrical energy comes from the action of electrolyte on the active material, we know that there must be a sufficient amount of the electrolyte to accomodate the change in composition at the plates. The contact of the electrolyte and the active substances causes the electrical energy, and it follows that the capacity of the battery will be greater when the active material is designed so as to expose more surface

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12. Dunn, L. D. "Storage Batteries Manual" p.74-1920
13. Arendt, M. "Storage Batteries" p.68-1928

to the electrolyte. Likewise, each of the above factors influencing the capacity of the battery must be according to set regulations determined by experiment. The efficiency of a storage battery is usually stated as the ratio of the output to the input. This efficiency is dependent upon the amount of local action taking place in a battery.

Formerly, the most extensive use of a storage battery was as a reserve power supply in connection with central electric station service. They were used extensively in railway power stations, and the first usage of them for this purpose was in the power plant of Zurich-Hirslanden Railway, in Switzerland. Storage batteries have also been of use in Elevator work in office buildings in cases when the central station would not allow its usage. One of the most notable developments in storage batteries[14] has been the application of them to starting and lighting service on automobiles and trucks. Starter systems for internal-combustion engines were first suggested about 1902 but the development of the electric systems began about 1911. Between 1912 and 1915 a number of different systems were devised, and electric starters for automobiles became almost universal. Before the electrical systems were developed a number of devices of ther kinds were tried. These included various compressed air, acetylene, and mechanical starting devices. Aside from the fact that many of these

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14. Vinal, M. "Storage Batteries" p.326

earlier starting devices were not entirely satisfactory, the demand for electric lights on automobiles was an important factor in establishing the supremacy of the electric starting systems. These batteries are compact and usually consist of 6, 12, or 24 volts. These batteries are charged with a generator driven by the engine of the automobile. Other uses not mentioned are the use of the batteries for voltage regulation, train-lighting, farm lighting, driving submarine motors, and auxiliary power equipment on yachts.

PART 11

P R O B L E M

In the early history of the storage battery, glass rods, hard rubber sheets or perforated and corrugated hard rubber sheets were inserted between the plates to prevent short circuits through buckling the plates.[15] With the development of more modern machines it was necessary for the storage battery to meet further requirements. A compact portable battery was very desirable. In order to obtain maximum capacity in current per unit space, it was necessary to install a larger number of plates. This number is limited by the strength, life, and durability of the battery.[16] The thickness of the plate was reduced, and the plates were placed closer together. Placing the plates closer together, immediately brought the problem of internal short circuits, and it was necessary to construct separators between the plates. The function of the separator is primarily to keep the negative and positive poles apart so that trees do not form between them and cause a short circuit, and at the same time having the internal resistance of the cells at the lowest point because obviously current used to overcome internal resistance can not be used in the external circuit.

Separators may be of wood, rubber, glass or celluloid and

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15. Vinal, G. "Storage Batteries," p.36 1928
16. Dunn, L. D. "Storage Battery Manual," p.1920

also of fibrous or vitreous materials. The earliest type of separators generally consisted of glass rods placed between the plates. This type was especially used in large central stations. Later untreated cherry wood separators, placed between two thin sheets of asbestos and having auger holes, replaced the glass rods as separators in the central stations. Hard rubber or perforated and corrugated hard rubber sheets were also extensively used. The first wood used for separators was cherry wood. Other woods were tried, but where acetic acid existed in appreciable amounts it was found harmful to the battery. Cherry wood contained very little of acetic acid, and it was claimed by Skinner[17] that a small quantity of acetic acid is beneficial rather than harmful to the negative plate. The reasons why it is beneficial are not fully understood as yet. At the present time those woods that before contained too much acetic acid, may be used due to a chemical treatment of them with caustic soda. This neutralizes the acid and removes soluble and easily hydrolized matter. This treatment also causes an expansion of the pores making a porous, fibrous separator.

Many other attempts have been made to discover a separator to take the place of wood. In these attempts, experiments have been made with different designs of rubber separators, volcanic ash, powder glass, and powdered silicates with or without binders. Celluloid separators were also used with holes punched in them. The electrolyte will not pass through celluloid as

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17. Vinal, G. "Storage Batteries" p.40-1928

also the author found in his experimental work.

There are various types of rubber and wood separators used. In the rubber type we find rubber sheet (ribbed or unribbed), slotted rubber sheet (ribbed or unribbed), "Ironclad" slotted rubber tube, and threaded rubber separators. The woods used are basswood, poplar, douglas fir, California redwood, white cedar, and cypress.[18] Of these basswood has the shortest life as a separator, and cypress the longest. The others are listed in order of serviceability but, as will be discussed later, the life of the separator is not the only thing to consider. Cypress has a high factor of internal resistance and therefore has less conductivity.

From the preceding statement we see that a separator must be selected in accordance with life and conductivity. Besides serving as an insulator, Dunn outlines further requirements of a separator in his Storage Battery Manual. These requirements are as follows:

(a) They must be impervious to the action of the acid 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.

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18. Dunn, L. D. "Storage Battery Manual" p.109-1920

(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, this reducing the effects of polarization to a minimum.

As has been stated, the separator must be of low resistance. Tests of resistance,[19] are commonly made at high rates of discharge to determine the voltage characteristics of the battery, since this in turn depends on the internal resistance of the battery and so upon the separator resistance. The porosity of the separator not only affects the internal resistance, but it also affects the equalization of the acid concentration during charge and discharge. In wood separators the resistance is dependent upon the grain of the wood, kind of wood, and the length and cross section of the pores. Then, also, the efficiency of separators is determined by the effect of the acid on the separator. The separator must be resistant to the strength and temperature of the acid used.

In this thesis, the author has chosen the problem of determining the efficiency of different separators from the standpoint of the separators plating prohibitive properties. The amount of current through the different separators is to be measured by an apparatus described later.

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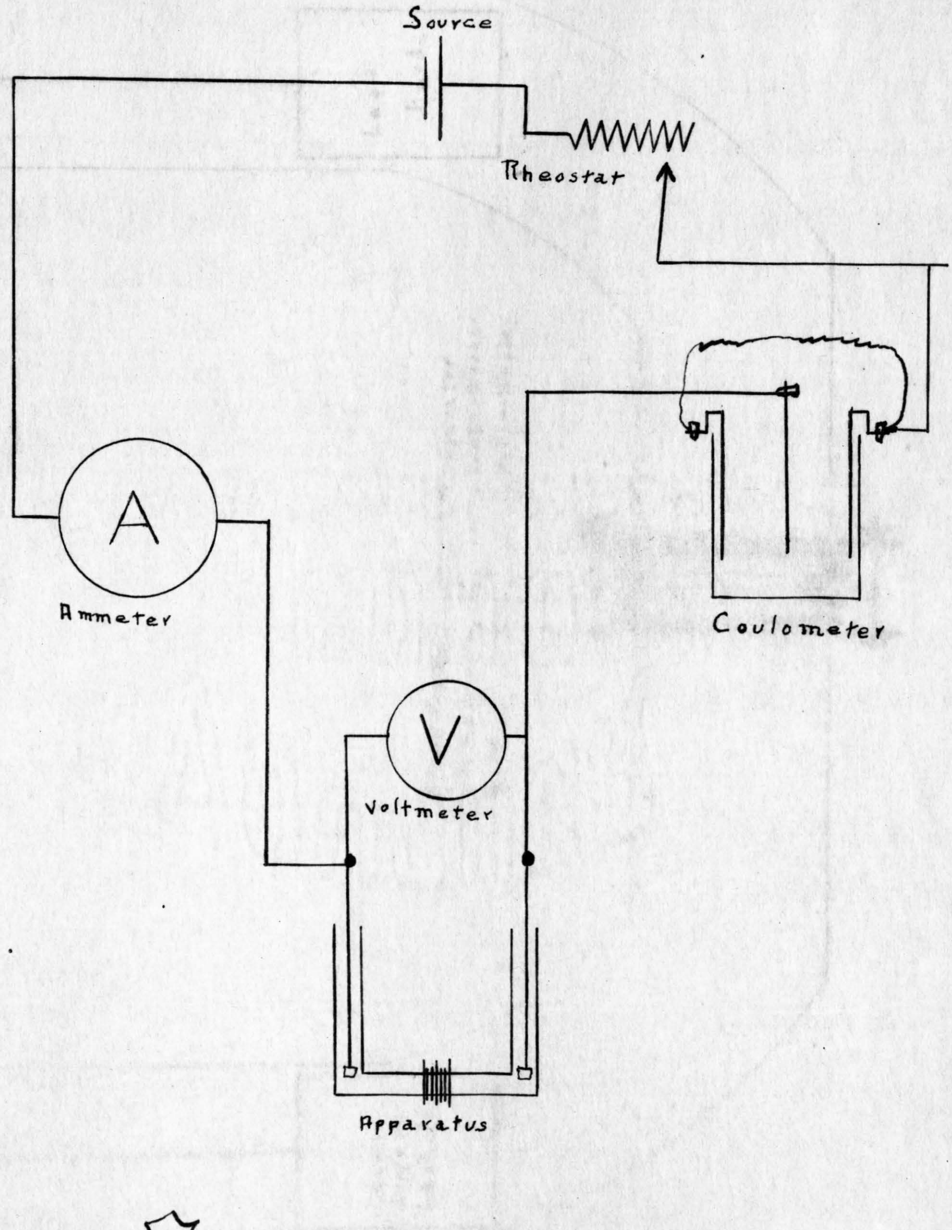
19. Vinal, G. "Storage Batteries" p.45-1928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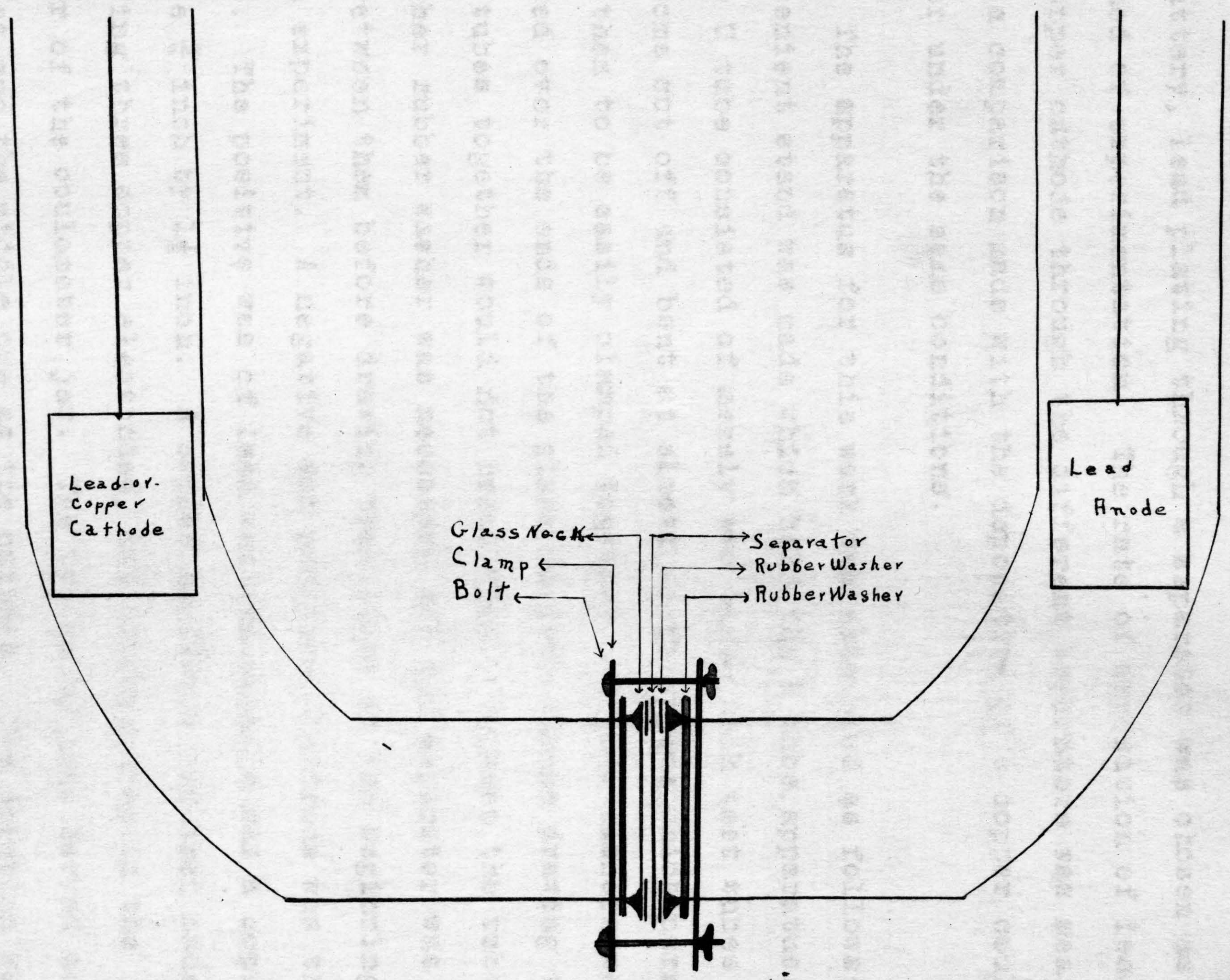

Diagram of U Tube

PART 111

In order to be somewhat in accordance with the reactions of a battery, lead plating through a separator was chosen as the method of experimentation. The rate of deposition of lead on a copper cathode through the different separators was measured, and a comparison made with the deposition of a copper coulometer under the same conditions.

The apparatus for this work was assembled as follows: a convenient stand was made which held the U tube apparatus. This U tube consisted of merely two eight inch test tubes with bottoms cut off and bent at almost right angles which permitted them to be easily clamped together. Rubber washers were placed over the ends of the glass so iron clamps drawing the two tubes together would not break them. Between the tubes another rubber washer was necessary and the separator was placed between them before drawing them tight at the beginning of each experiment. A negative and positive electrode was then made. The positive was of lead and the cathode was a copper plate $\frac{3}{4}$ inch by $1\frac{1}{2}$ inch. A copper coulometer was then made by cutting three copper electrodes, and placing them in the cover of the coulometer jar. The two outer ones served as anodes and the middle one as the cathode. The solution was made up by using a mixture of -

1000 grams of water
150 grams of crystallized copper sulfate
50 grams of concentrated sulfuric acid
50 grams of alcohol

Considerable time was spent in making up a lead solution that would plate lead favorably so that the plates could be weighed without error. It was also found that at high amperages "trees" of lead would form on the plates. Finally, the lead solution that operated without "Treeing" was a perchlorate solution of -

85 grams of lead acetate
$42\frac{1}{2}$ grams of perchloric acid (60%)
1703 cc. of water

Dry peptone was added to this solution which is the agent to prevent treeing. The author added this in different amounts and experimented for "trees." After about 6 grams was added and well mixed the solution was filtered. This solution and an amperage of .03 amperes was found to work very favorably. An ammeter, voltmeter, and a rheostat was also in the circuit. A 20 volt line, direct current, was used chiefly for the source of current.

EXPERIMENT 1 - Wood Separators

Of all the separators, wood is most extensively used and occurs in the most numerous kinds and designs of batteries. The most common wood separators are made of bass, poplar, pine, douglas fir, cedar, cypress, and red wood. These are cut into narrow sheets of the required width with slots on one side. The separators are placed in a battery with the slots adjacent to the positive plate.

The most detrimental defects in wood separators are knots, checks, and shakes. Checks are radial splits in the log caused by stresses occuring during the seasoning process, and shakes are separations between two annual rings. Any of the a bove defects render the separator inefficient.

Porosity is an important factor in wood used for separators. The resinous and fatty substances must be removed to obtain the greatest degree of porosity. The woods, listed in their order of porosity, are poplar, cherry, basswood, redwood, fir, cedar, and cypress; cypress being the least porous. It hasbeen shown that the less porous the wood, the longer the life of the separator. There are several methods of sawing the wood for separators. Quarter sawed separators are obtained by quartering the logs and then cutting radially to the annual growth rings of the timber, while the plain sawed separators are cut tangentially to these rings. The quarter sawed is probably the best because the path of the diffusing electrolyte is directly through the more porous portions of the wood.

Treatment of the wood to remove practically all its component parts, except cellulose, is very essential. The methods of treating most commonly encountered are the alkaline and steam baths respectively. The alkaline bath, as previously explained, removes the acetic acid and all soluble and easily hydrolized matter. In the steam bath, the separators are placed in steam under a pressure of thirty pounds, and are left in this condition for fifteen to twenty hours. This bath is used more for wood separators made from pine, fir, and cedar.

Cedar wood is extensively used for separators in storage batteries today, and this wood the author has taken for the initial experiment. A cedar separator already subjected to the alkaline treatment, which made it porous and fibrous, was cut to the proper size. The ridges were shaved evenly with the rest of the wood and the separator was inserted between the two sections of the U tube. After the clamps were tightened, the tube was placed on the apparatus holder, and 40 cc's of the plating solution poured into each side of the U tube in order to get an even distribution of the solution.

The copper sulfate was placed in the coulometer. The copper electrode of the apparatus is weighed before and after each experiment to determine the amount of deposit in the apparatus. Likewise, the cathode of the coulometer was weighed before and after each run. In order to get a good comparison of separators, a constant current of .03 amps was maintained. In all cases the electrodes were one and one-half inches by three fourths inches. Under these conditions of amperage and size of plate "treeing" did not occur. Each experiment was run for exactly one-half hour. Fortunately, the electrochemical equivalent of lead is high, and hence it is possible to deposit a coating of lead sufficient for a good comparison in this length of time. Having lead deposited in the apparatus, and copper in the coulometer, it is necessary to change both deposits to gram equivalents to obtain a comparison.

This was done by dividing the grams of each by their respective equivalent weights ($\frac{\text{atomic W't}}{\text{valence}}$). With this wood separator being used, a deposit of .0004438 gram equivalents in the apparatus, and.0005082 gram equivalents in the coulometer were found after one-half hour.

PERFORATED RUBBER SEPARATORS

Due to the relatively short life of the wood separators in the electrolyte, much has been done to improve this life. Perforated rubber separators have been used in some batteries in an attempt to lengthen the life of the separator. These are thin sheets of rubber containing small round holes. It is claimed that these separators prevent particles of the active material of the positive plate from falling out without increasing the internal resistance of the battery. The amount of perforation in rubber separators is of considerable importance. If the perforation is too great the separator may be weak and easily broken, and if it is not sufficiently perforated the internal resistance of the cell is increased.

As in the previous experiment, 80 cc's of the plating solution were used, and a constant amperage of .03 amperes was allowed to pass through the apparatus with a perforated rubber separator replacing the wooden one. After one-half hour, it was discovered that .0005482 gram equivalents deposited in the apparatus, and .0005990 gram equivalents deposited in the coulometer. Here we see that under the same conditions as the wood separator experiment, a greater amount is deposited in the apparatus and coulometer. These results indicate that wood has higher plating prohibitive properties than perforated rubber. This resistant power to plating of lead justifies the wide usage of wood separators.

RUBBER COMPOSITION

In this experiment the separator under investigation, the author believes, is of a rubber composition. This separator was received through the courtesy of the Globe Manufacturing Company. It has a yellow appearance, and was found to be very brittle. This composition was placed between the tubes of the apparatus, and the experiment was continued as before. After one-half hour, .0005116 gram equivalents were plated on the cathode of the apparatus, and .0005726 gram equivalents were plated in the coulometer. Considering resistance power to plating as the only criterion for judging separators, this composition would be more efficient than the perforated rubber and less efficient than the cedar wood. But, we must remember that the power to prohibit plating is not the only basis of judging the efficiency of separators.

CELLOPHANE

Cellophane is not used as a separator in stora ge batteries, but being a permeable membrane, there is, nevertheless, the possibility of its use. It is a cellulose product and has found extensive usage as a wrapping for cigarette packages, etc. In this experiment a deposit of .0004802 in the apparatus, and .0005344 in the coulometer was found after one-half hour. Cellophane is attacked by dilute sulfuric acid and would therefore have a very short life as a separator.

THREADED RUBBER SEPARATOR

This separator was received through the courtesy of the Willard Storage Battery Company. It consists of thin sheets of rubber containing several hundred thousand threads passing through the thin sheet of rubber from one side to the other. With these separators the manufacturers are able to send out the batteries in the so-called bone-dry condition. The batteries are, therefore, not subject to discharge and sulphation before being put into use. The experiment was performed under similar conditions to previous experiments, but with a threaded rubber separator in the apparatus. During the same length of time it was found that .0005946 gram equivalents deposited in the apparatus and .0006104 gram equivalents in the coulometer. A table of comparison of these saparators with the others will be found later.

WOOD SEPARATOR NOT TREATED

The plating inhibitive power of a wood separator treated by the alkaline bath method, was previously tested. By testing a separator not having this treatment, the effect may be seen that the treatment has upon a separator. An untreated wood separator of cedar was placed in the apparatus. In order to get a current to pass through the 120 volt line was necessary. A current of only .015 amperes passed and this deposited 0002638 gram equivalents in the coulometer. These results indicate the high resistance of untreated wood necessitating the use of a higher voltage. The wood must be treated to increase the porosity, and to remove organic materials which are injurious to the other parts of the battery.

CELLULOID, LINOLEUM, LEATHER

Celluloid is a transparent, pla stic material. It may be prepared from cellulose nitrate. Celluloid possesses good mechanical properties and can be machined or molded. This substance is not attacked by dilute acids, and is therefore used for storage battery jars. Glacial acetic acid or a solution of celluloid in amyl acetate is used to cement the seams together. It has been used for separators, but it was necessary to have a series of V-shaped passages in the celluloid sheets to allow the passage of the electrolyte. This V-shaped type of separator was patented by Luthy[20]. The author found, when subjecting celluloid, linoleum, and leather without perforation to the method of experimentation, that the plating in all cases was negligible in that the high resistance did not allow the passage of an appreciable amount of current. This was true even in the case where 120 volts were used across the apparatus.

WITHOUT SEPARATOR

As a blank experiment prior to the study of the separators as a preventive means to plating, an experiment was run without a separator. .0006216 gram equivalents plated in the apparatus and . 0006544 gram equivalents plated in the coulometer. It will be noted that there is more plating in the coulometer than in the apparatus even without a separator being present.

All experiments were repeated under the same conditions, but using both lead electrodes instead of one copper and the other lead. The results were very closely related to the results obtained with the copper cathode. A comparison of results will be found in the table following.

WITH COPPER CATHODE

SEPARATOR	LEAD IN APPARATUS	GRAM EQUIVALENT	COPPER IN COULOMETER	GRAM EQUIVALENT	RATIO cu. in coulometer / Pb. in apparatus
Without Separator	.0644	.0006216	.0104	.0006544	1.029
Threaded Rubber	.0616	.0005946	.0195	.0006104	1.033
Wood Sep- Not Treated	.0288	.0002638	.0084	.0002682	1.042
Perforated Rubber	.0568	.0005482	.0184	.0005990	1.0926
Cellophane	.0496	.0004802	.0168	.0005344	1.113
Rubber Composition	.0530	.0005116	.0182	.0005726	1.1194
Wood Treated	.0458	.0004438	.0162	.0005082	1.145
Celluloid Linoleum Leather	Resistance does not allow passage of Current				

WITH LEAD CATHODE

SEPARATOR	LEAD IN APPARATUS	GRAM EQUIVALENT	COPPER IN COULOMETER	GRAM EQUIVALENT	RATIO
Without Separator	.0612	.0005908	.0208	.0006542	1.1075
Threaded Rubber	.0564	.0005440	.0192	.0006042	1.1106
Perforated Rubber	.0528	.0005096	.0192	.0006042	1.186
Cellophane	.0484	.0004674	.0183	.0005746	1.230
Rubber Composition	.0496	.0004788	.0190	.0005985	1.250
Wood Treated (dried)	.0300	.0002896	.0124	.0003902	1.347
Brown Composition	.0596	.0005754	.0207	.0006501	1.130

S U M M A R Y.

1. A comparison of the efficiency of separators was obtained by comparing the amount of deposit in the apparatus with the deposit in the coulometer. This data was then compared with that of the next separator. A good separator from the standpoint of preventing plating was one which had a high ratio of

$$\frac{\text{copper equivalent in coulometer}}{\text{lead equivalent in apparatus}}$$

2. The apparatus used for obtaining these results consisted of a U tube between the halves of which a separator could be inserted. A lead anode and copper or lead cathode was used. The rest of the apparatus consisted of a copper coulometer, an ammeter, or volt meter, and a rheostat.

3. A lead solution containing 85 grams of lead acetate, 42½ grams of perchloric acid (60%), 1703 cc. of water, and 6 grams of peptone was found most favorable. A copper sulfate solution containing 1000 grams of water, 150 grams of crystallized copper sulfate, 50 grams of concentrated sulfuric acid, and 50 grams of alcohol, was used in the coulometer.

4. From the experimental results the treated wood separator should be noted, for it has the highest ratio. Its ratio was 1.145, showing that wood prevented plating more than did the other separators.

5. From the standpoint of plating inhibitive properties, the rubber composition is next in order with a ratio of 1.1194. Even though this ratio is fair, the composition is very brittle and therefore it would not be as satisfactory as wood as a separating material.

6. Cellophane has a ratio of 1.113 which does not differ far from that of the rubber composition. However, celophane has other disadvantages as a separator. It is destroyed in a short time by dilute sulfuric acid, and therefore its life is short.

7. Perforated rubber has not as high a ratio as wood, rubber composition, and cellophane, but its life is longer. The rubber has a greater resisting power to dilute sulfuric acid and mechanical strain. The ratio for perforated rubber is 1.0962.

8. The wood separator that was not treated gave a ratio of 1.042. This separator can not be compared with the others very favorably due to the necessity of using a 120 volt line. The standard current of .03 amperes could not be obtained.

9. The threaded rubber separator follows the perforated rubber in effectiveness to prevent plating. It has a ratio of 1.0265. The threaded rubber is made from thin sheets of rubber containing thousands of threads which makes it more durable than some of the previous separators.

10. While working with both lead electrodes another composi-

tion was experimented with. The ratio obtained was 1.0825. This separator is very porous and brittle.

11. Celluloid, linoleum, and felt would be very good separators if the plating prohibitive properties were the only basis of judgment; but, porosity is also an important quantity which they lack. The resistance of these separators did not allow the passage of the current.

12. Similar results were obtained when two lead electrodes were used in the lead solution.

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Approved:

John R Koch

W. J. Grace, Jr.

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