Test of a New Type of Storage Cell

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1906

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"TEST OF A NEW TYPE OF STORAGE CELL."

A THESIS

PRESENTED BY

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

JUNE, 1906.

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THESIS.

THE LEAD ACCUMULATOR.

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HISTORICAL OUTLINE.

It seems necessary, in writing on a subject of this kind, that a short sketch of the history and development of the storage battery, or lead accumulator, as it is sometimes called, be given in order to give the reader a better understanding of the ultimate conditions of operation of the test, and to gain a better understanding of the action of the cell.

The first battery of any sort to be invented was the voltaic pile. This was composed of a pile of metallic sheets, between which were interposed pieces of blotting paper saturated in the electrolyte. This had hardly been discovered than it was also noticed that there was some resisting force developed in it, which tended to choke or hinder the flow of the current. It was further noticed that, if the pile was connected to some metallic electrodes dipping in some salty or saline conducting fluid, these electrodes became electrified, so to speak, or obtained the power of giving a momentary current after the pile had been disconnected. This was the phenomenon of the secondary battery, and was first discovered by Gautherot in 1801. This same thing was also noticed smoe two years later by another man, Ritter, and he forthwith constructed what he termed his secondary pile. This was built in the same manner as the voltaic pile, with a change in the electrolyte. This pile was capable of giving out currents of considerable strength, for a short time, when charged by a

primary pile composed of a larger number of elements than itself.

Following this investigation, there were numerous inventors at work along these lines, and it was at this period that the famous Daniell, Grove, and Bunsen cells were invented. The first man, however, to investigate polarisation with a view to finding a use to which they could be put, was Caston Plante, and in 1859 he commenced his series of investigations that have made him famous. It was not, however, until 1881 that the lead accumulator became a commercial proposition, and it was not well defined at that time. Therefore we will study the history of the cell from that time on. This study practically means a study of the different forms of electrodes and plates that were used from this time.

There have, of course, been many types of electrodes used, some of them too expensive to be of any commercial importance, but the one that is in common use today is the lead plate type.

The first cells were constructed of pure unalloyed lead, but in one of his 1881 patents, Mr. J.S. Sellon claims the use of electrodes constructed of alloys of lead and antimony. This claim however, does not appear to have been upheld as the construction material of the electrodes has been alloys of lead ever since, and in now used in general practise. Many other materials have been tried, and some of them with more successthan the lead materials, but these have been mostly too costly. Gold and silver alloys, platinum, and even carbon have all been tried, but have been found wanting in some particular. This brings us to the subject of active materials. In the case of a lead cell, the active materials are always the same, although the way or the material from which they are prepared may differ through a wide range.

In designing an electrodes, it was first found that if plates of solid lead were subjected to a forming charge, the negative plates were turned to spongy lead, while the positive plates were acted upon in such a way as to produce a granular structure which was not self supporting, and would fall to the bottom of the cell. The theory of this action will be taken up later. This condition of things of course brought up the problem of the support of the active material, and to this end there were various types of supporting plates constructed. There were about as many ways also tried of producing the active material. The first of these ways was to subject plates of alloyed lead to a forming charge, thereby producing the active material in the cell. This, however was found to be an expensive process, and interfered with the cost of production of the cell, so there were other ways devised. In 1881 Plante proposed to heat the electrodes during formation, and in 1887 , Brush put forward the same idea. In 1892, a patent taken out by H.C.Tudor shows that the formation of the plates may be accelerated by carrying it out in an electrolyte containing a small percentage of sulphuric acid. This process, however, presupposes the preliminary treatment of the electrodes in such a way that they may be rapidly oxidised, or else their formation in some special oxidising electrolyte.

In 1882 Plante patented a preliminary treatment of the electrodes in nitric acid. In 1896, P.J.R.Dujardin proposed a forming solution consisting of dilute sulphuric acid, with potassium or sodium nitrate added to it, and in 1900 Epstein took out a patent for a preliminary boiling in a 1 per cent solution of nitric acid, followed by a forming charge in a sulphuric acid electrolyte. All of these schemes are based on the formation of the

active material from the electrodes themselves. The first to introduce the idea of the preparation of the active material not prepared from the plates was Faure. He proposed to employ any lead salt that could be utilized, such as lead sulphate or lead oxides. This he proposed to mix to a paste and use with some suitable form of support as the active material of both positive and negative electrodes. The liquid used in the mixing of this paste was dilute sulphuric acid. All these forms of active materrial tend toward the use of sulphuric acid as an electrolyte, but chlorides have also been used.

In the use of these pasted electrodes, it was found that a considerable saving of the current necessary for the formation of the plate could by the substitution of litharge in the place of the sulphates and oxides for the negative plates. Faure appears to have tried all kinds of substances and salts in the construction of his battery.

There is also another class of raw active materials, and those are those salts of lead which are readily fusible. The only one of these which has received any practical attention is the chloride. In 1888, F.Maxwell Lyte for the use of lead chloride, using it either cast in pieces of a suitable size, and a lead frame cast round these afterward, or using it direct without any frame at all. There have been many attempts to prepare active materials of sufficient mechanical rigidity to be self supporting, but it has been found that the action of the cell destroys this quality, and hence, supports of some character are used in every type of cell in present use.

In the first pasted plates used by Faure, the supports were nothing more nor less than plain sheets of lead with the active

material pasted on their surfaces. This method was, however, found to be inefficient, and hence some other type had to be devised. There were two classes of the so-called grid plates devised at almost the same time. These are the cellular and the grooved types. The first or cellular type consisted of a plate of lead with hexagonal openings straight through from one side to the other, and their walls at right angles to the sides of the plate. These were found to be faulty owing to the fact that the active materials would shrink away from the cell walls, and then their use was destroyed, as the material would fall out. This was especially found to be true of the positive plates. In view of this fact, Sellon, in 1881, devised a grid that had cellular construction, but the opening of the cells was smaller in the center of the grid than at the outside. He thought that this construction would grip the material and hold it in place. These first ones had flat sides, coming to an edge in the center. He also devised some convex grids. The cells in this case had convex surfaces, making a smaller opening in the center that would prevent the falling out of the material. These grids were very successful at first, but it was observed that the double taper of the cells made the cross section of the material at the center point so small that there was continual trouble with the cracking of the material at that point, and its subsequent falling out. It was at this point that Sellon brought his concave grid. This was of the reverse construction of the convex grid, having the cell surfaces concave. This made the opening in the center of the grid larger than the opening in the surface of the plate. Various other forms of grid were devised at this time, such as the Menges grid in 1887. This grid had V-shaped bars, and partook more

of the chemical t[illegible] cell [illegible] action. [illegible] first appearance of the barrel grid which is [illegible] popular [illegible] at the present time. In 19[illegible] [illegible] section bars, [illegible] pointing toward the [illegible], in effect, amounted to the same [illegible] the [illegible] with the tapered sides. [illegible] the fact that more active material could be [illegible] without increasing its size. [illegible] all of the various [illegible] of grid [illegible] would fill much more space [illegible] will conclude that these types [illegible] be [illegible] practical.

We have [illegible] from the first pasted lead [illegible] grid construction.

THEORY.

The theory [illegible] lead [illegible] is [illegible] present time one that is open to discussion at all points. The one that is among the more [illegible] by a Russian, DOLAZELEK. This seems [illegible] the most probable of those we have investigated, so it will be used as the general theory of the action of the cells [illegible] by a [illegible] of this paper.

There have been many theories advanced [illegible] origin of the electric current, and among them is the chemical theory. It is a well known fact that [illegible] electric current may be produced by the chemical action of certain elements. This reaction was also found, with certain other elements, to be a reversible one. The principal credit for the reactions in a storage cell [illegible]

to Planté. During the charge of a cell there are two reactions present. The essential action consists of the oxidation and the reduction of the lead plates, and the other action is the decomposition of the water in the electrolyte into its components. The liberation of the oxygen in the water oxidizes the lead of the positive plate to lead peroxide, while the negative is changed to spongy lead. The process is somewhat similar in the case of the discharge, the lead peroxide being changed into a state of ~~xx~~ still lower oxidation while the spongy lead is now changed to lead oxide. This is the theory as expressed by Planté, but it was opposed by J. H. Gladstone, and A. Tribe. The theory of these men was that during the charge the sulphuric acid was decomposed into H_2 and SO_4, the first being set free at the positive pole and the latter at the negative pole. These radicals then act upon the plates according to the following:

Neg. Pole $PbSO_4 + H_2 = Pb + H_2SO_4$

Pos. Pole. $PbSO_4 + SO_4 + 2H_2O = PbO_2 + 2H_2SO_4$

During the discharge the current flows in the opposite direction so that the radicals are set free at the opposite poles. Then

Neg. Pole. $Pb + SO_4 = PbSO_4$

Pos. Pole $PbO_2 + H_2 + H_2SO_4 = PbSO_4 + 2H_2O$

This, it will be noted is the reverse action of that which took place before, so that we have the surfaces of both of the plates covered with sulphate, and the current [illegible] production of [illegible]. From these equations we can then combine them and form the equation of the lead accumulator as given by [illegible]:

$$PbO_2 + Pb + 2H_2SO_4 \rightleftarrows 2PbSO_4 + 2H_2O$$

This gives the change during charge reading from left to right, and that for discharge from right to left.

In order to understand the above equation, and to appreciate the physical and chemical significance of the working of the reactions in the production of current, it is necessary to consider these actions separately, and their relation to the production of the current. To do this we must show that these actions really take place in the cell during charge and discharge, and that the formation of these substances is an essential part in the formation of the current. Since we have seen that the process is reversible, we must consider both the formation and the decomposition of the substances appearing in the equation. The first quantity that appears in the equation is lead peroxide, hence we will consider it first. It was first shown by Planté in 1859 that during the electrolysis of sulphuric acid between lead electrodes, lead peroxide and spongy lead are formed. It is an evident fact that the spongy lead is formed, since it is distinctly apparent on the plates after the action. This has, therefore, never been questioned. From samples of the active material that have been taken from the positive plate at different stages of charge and discharge, it has been brought out that the quantity of the lead peroxide present is very nearly proportional to the current through the plate. It may be also shown that the density of the acid in the cell varies almost directly with the current. This change in the density of the acid is evidently due to the presence or absence of water. From this we deduce that water is formed during one stage of the action, and decomposed at another. It would appear that the formation of the water takes place during the discharge, and that its decomposition takes place during the charge, since the density of the acid rises on charge, and falls on discharge. There is one other quantity that it is necessary to show

takes a part in the action of the cell. This change is lead sulphate. [illegible] by taking [illegible] mass of active material and determining the [illegible] of the sulphate in it by analysis. This [illegible] by Gladstone and Tribe. They also found that the [illegible] of the sulphuric acid [illegible], not only [illegible] water, but that the acid [illegible] active [illegible] lead sulphate. This [illegible]. It was also found that the [illegible] was proportional to the current [illegible] are determined by actual [illegible].

Having now established [illegible] fact that it is open to [illegible] proceed [illegible] consideration of the variation of [illegible] cell [illegible] E.M.F. Plante noticed that [illegible] cell, depending on the state of charge of the cell, [illegible] as the density of the acid, [illegible] carry out any extended [illegible] showed that the [illegible] proportion to the [illegible]. In fact, if we [illegible] it is [illegible], [illegible] accounted for theoretically. This [illegible] Helmholtz [illegible] of the thermodynamic cycle, [illegible] cells [illegible] with sulphuric acid of different [illegible], [illegible] the heat energy [illegible] of one cell into the other, and [illegible] dilution of sulphuric acid, [illegible] equating this to the [illegible] by the [illegible] of the sulphuric in the cell of [illegible] density. [illegible] voltage of the cells, he finds that the statement of the rise and

fall of the E.M.F. with the density of the acid in the cell is, theoretically speaking, true. This was also found to be true, by the actual experiment.

Another line of research was opened when the question of the effect of temperature on the E.M.F. of the cell was brought into question. It was shown by several different investigators that the E.M.F. of the cell is independent of the temperature. The question of temperature effects also brought up the pressure question. This has also been shown to have no effect on the E.M.F. of the cell.

We will now consider the behaviour of the cell during charge and discharge. It has been found that the E.M.F. of the cell is several tenths volts lower during discharge than during charge. From this fact we infer that there is a constant loss of energy accompanying the operation of a cell, and that, therefore, the efficiency can not rise above a certain point. This loss in potential is explainable along the line of a change in the resistance of the cell. This is, however not the case, as the resistance would have to change about 70 times the amount to produce the change in the voltage that does occur. The only other explanation is then, by assuming polarization of the plates. Several views have been put forward to explain this matter, but the one that seems plausible is the idea of the change being due to the change in the concentration or the density of the acid. As we have established the fact that the E.M.F. of the cell changes with the density of the acid, it seems probable that this would be the cause of the difference between the charging and the discharging potentials.

The behaviour of a cell in operation, may be expressed in somewhat the following manner.

When the charging current is sent through a cell, the voltage is seen to rise rather abruptly, and then to fall slightly to the point at which it continues until the end of the charge is neared, at which point it begins to rise rapidly again. The sudden rise at the first is probably due to the rapid concentration of the acid contained in the active material. This would be the apparent result, since we now know that the E.M.F. varies with the density of the acid, and we also know that the active material is a porous mass, and that the acid formed in it can only get out by diffusion, and that slowly, so that it would seem that the sudden concentration of the acid contained in the active material would be responsible for the abrupt rise in the voltage at the beginning of the charge. It has also been noticed that during rest, there is a slight film of sulphate formed over the surfaces of the plates, and that this will offer a resistance to the passage of the current. Then we may assume that the slight drop in the voltage, shortly after the charge has been started, is due to the destruction of this film of sulphate by the charging current. The discharge of the cell works in just the reverse order. The discharge voltage dropping abruptly at first, then rising higher, at which value it remains until nearing the end of the discharge when it drops rapidly. The first drop of the curve is probably due to the formation of the sulphate in the immediate proximity of the plate, and a consequent decrease in the density of the acid. This diminution in the density causes a decrease in the voltage, which is proportional to it. The final falling off of the voltage of the cell is due in a like manner to the decrease in the density of the cell's acid.

After considering the [illegible] of the cell under the conditions of charge and discharge, we must also take into account the changes that take place in the cell when it is inactive. There are several changes that take place in the cell under inactive conditions. The first of these is the recovery of the cell. When a cell has been subjected to a discharge, and the cell is allowed to stand, it will be found that the E.M.F. of the cell will rise. This rise is called the recovery of the cell. This rise will be found to be rather rapid at first, but as the length of the time of inactivity increases the rise of the E.M.F. becomes more gradual, [illegible] [illegible] [illegible] [illegible] [illegible] be [illegible]. If a recovery curve [illegible] with time as abscissas and volts recovery as ordinates. Since we have seen before that the E.M.F. of the cell varies approximately directly with the density of the acid in the cell, it is at once evident that the recovery of the E.M.F. reaches its maximum value when the E.M.F. has reached a value corresponding with the density of the acid that is present in the cell at that point. This recovery effect is probably due to the fact that the acid density in the active mass of material is much lower than that of the acid in the cell surrounding the plates. This is due to the rapid absorption of the acid by the active material during discharge, which takes place faster than the acid from the outside of the active mass can circulate through it. Then when the charge is stopped, the acid in the mass is at a lower density than that outside, and as the outside acid gets into the mass, the E.M.F. rises in proportion to the density in the mass.

Another effect in the open cell is the effect of self discharge. It has been observed that, if a cell be allowed to remain idle,

the density of the acid will gradually decrease. There will, therefore, be a consequent drop in the E.M.F. of the cell, since we have seen that it varies with the acid density. This discharge will vary under different conditions existing in the cell. If the acid in the cell be pure, the discharge will range from one to two per cent of the quantity of electricity in the cell. This rate is per day. If the acid contains impurities, the rate of self discharge will reach as high as fifty per cent, running higher in some cases. This will, of course, vary with the amount of impurities in the acid. Probably the discharge of the negative, or spongy lead electrode is of the greater importance, since it has been observed that the effect in that case is the more pronounced. If the acid be impure, due to the presence of some strong negative metal, this metal will be precipitated by and on the spongy lead. This precipitation forms a local battery in itself, and this element is short-circuited on itself, thereby causing the change of the spongy lead into lead sulphate. This action is accompanied by a strong effervescence of hydrogen. There has been advanced by Nernst that the potential difference of a metal against its solution depends not only on the nature of the metal, but upon the amount of the metal ions in the electrolyte surrounding the metal. Lead can, according to this theory, precipitate other metals in sulphuric acid, but can not do so in the presence of soluble lead salts. Now since the evolution of hydrogen is accompanied by the presence of a voltage, it remains to be seen the voltage present when this action takes place with the various metals, thereby determining the metals which can cause the self-discharge of a lead electrode. The voltages of evolution of hydrogen have been measured by Nernst, and it has been

found that metals having a voltage of less than .77 accompanying the evolution of hydrogen can cause the self-discharge of a lead plate. The metals that have been determined as producing this effect are:

Platinum --	.05 volts.
Gold--	.0[illegible] "
Iron--	.0[illegible] "
Silver	.15 "
Nickel	.07 "
Copper	.0[illegible] "

From the above, it will be seen that the effect is the most rapid in the case of platinum, and the slowest in the case of copper. This has also been observed in the practical operation of batteries. This condition, in the case of platinum, should be especially noted, as some sulphuric acid is concentrated in platinum retorts, and it is more than likely, in a case of this kind, that there will be platinum present in the acid. This quality, in purchasing acid for storage battery use, should be carefully guarded against.

We must consider at this point, the self-discharge of the positive plate. This effect is not so marked as that of the negative, as it takes place much more slowly, and consequently will not given as much attention, as it is of much less importance in the practical operation of the battery. Since metallic substances that might be present in the acid are not precipitated by lead peroxide, they are not of importance at this point, having no action on the discharge of the plate. The self-discharge of a positive plate is due to the fact that the lead peroxide is electro-positive to the lead composing the supporting frame or

grid that lies underneath the active material. This fact shows the formation of a local battery in the plate itself, the lead forming one pole and the peroxide the other. Then the oxidizing action of the peroxide on the lead forms a short-circuited cell, and the electrolytic action of this cell is to turn both the lead and the peroxide into lead sulphate. From this action it will be seen that the lead grid is gradually destroyed. This action is, however, not of much practical importance, since it takes place so slowly that it is scarcely perceptible. In cells of the best modern construction, this feature is practically eliminated, on account of the heavy covering of the lead peroxide. In this case the acid cannot circulate with any degree of freedom around the lead grid, hence the action of the peroxide on the lead is hindered. From this we may infer that this self-destruction of the plates, as it might be called, is not of practical importance in plates of heavy construction.

Another effect that is noticeable in the cell as it stands on open circuit, is the sulphating action of the acid on the plates. If an attempt is made to recharge a cell that has stood on open circuit for some time in a discharged condition, it will be found that the internal resistance of the cell has materially increased. This effect is noticeable for some time after the charging current has been turned on. This effect is due to the sulphating of the cell. This fact will be noticed if the plates are discharged and allowed to stand for some time in that condition. The principal fact that will be noted in this connection is the fact that the plates become of a lighter color as they are allowed to stand. This change in color is due to the formation of a thin layer of lead sulphate on the surface of the plates.

Further, [illegible] will [illegible] ially [illegible] of [illegible] tion. [illegible] From [illegible] it is [illegible]

Another [illegible] in the [illegible] wall. E[illegible] from the wall [illegible] that will influence [illegible] general [illegible] discharge [illegible] varies inversely [illegible] capacity [illegible] but [illegible] result [illegible] will [illegible] possible to obtain [illegible] be [illegible] capacity [illegible] of Fick. This relation [illegible] ly for ~~xxx~~ small [illegible]. From Fick's law it will be [illegible] that the quantity [illegible] ial per second is approximately proportional [illegible] difference

in concentration b[illegible] [illegible] is [illegible] the [illegible] part of the mass. From [illegible] it will be [illegible] capacity is also proportional to the diffusion coefficient. [illegible] also inversely proportional to the length of the pore, and [illegible] to the cross-section [illegible] the pore, [illegible] in this connection, that the [illegible] is proportional to [illegible] the current [illegible] is [illegible] active material, and upon the [illegible] current. [illegible] effect [illegible] into the [illegible] material. The distance to which [illegible] is [illegible] proportional to the amount of current [illegible] is considered [illegible] proportional to [illegible] of the current; in other [illegible] is to be considered. Therefore for [illegible] is equal to [illegible] since the current [illegible] cells, since lead sulphate occurs [illegible], on the lead, [illegible] considerably during [illegible] charge, the [illegible] of the cell [illegible] and the concentration of the acid [illegible] which is taken to be the same for all [illegible] facts we may derive the [illegible] that

I [illegible]

in which K is the capacity of the cell, I is the [illegible] n [illegible] and t is the time of the [illegible] is [illegible] found to agree very closely [illegible] experiments, and hence [illegible] been [illegible].

Another effect that influences the capacity of the cell is the thickness of the plate.

From the previous discussion it is then evident that if the active material be distributed in a thin layer over the surface of the plate, thus giving great surface exposed to the action of the acid, the acid can more easily penetrate it, than if it were spread out in a thickness of smaller surface, and so it is seen that thin plates are more preferable from the standpoint of the capacity of the cell. There is, however, another consideration that must be borne in mind, and that is the life of the plate. It has been previously seen that the penetration of the acid into the active material has a tendency to soften the lead of the supporting grids. Thus, in the case of thin plates, there is the question of the life of the plate strongly in evidence. It has been found that plates constructed with thin grids are very short lived, and to get around this difficulty the thicker plate is used in the best cell construction.

The density of the acid in the cell is another influence that influences the capacity. This was first investigated by Heim, using a Tudor cell. He found that the capacities of the cell are increased by an increase in the density of the acid up to a certain point, after which it falls off rapidly. This point he determined to be at a specific gravity of about 1100. This effect must now be explained theoretically. It would seem, at first glance that the capacity of the cell would rise continuously with the increase of the density. This, as shown by Heim's experiment is untrue. At the start of the discharge, the current, following the path of least resistance, follows the outer layers of the active material, but as the discharge continues, the current penetrates deeper and deeper into the mass. This is due to the polarization of the outer layers of the mass, and is performed

that the loss of potential in the pores [illegible] in the density of the acid is proportional to the polarization prevailing in the outer layers of the active material. It is evident that this condition is present since the mass of active material is a very good conductor, and therefore has the same potential in the pores as on the outside.

Another influence on the capacity is that of temperature. This effect is due to the change in the conductivity of the acid with a change of temperature. Since the conductivity of the acid increases with a rise of temperature, it is at once evident that the capacity of the cell rises greatly with an increase of the temperature. This is due also to the fact that the temperature has an effect on the diffusion of the acid in the pores of the active material, increasing with the temperature.

Now since we have considered some of the changes that take place in the cell during its action, we are in a position to consider the changes that take place during the formation of the plates. This consideration, properly, comes first, since the formation of the plates precedes the working action of the cell, but it was necessary to consider the other action first in order to obtain a knowledge of these actions so that we may apply them to the changes that take place during the formation action. We saw at the beginning of the discussion that there are two kinds of plates used; one in which the active material is formed by the forming current from the lead plates themselves, and another in which the active material is formed from lead compounds placed on lead supporting grids. We will first consider the action of the first type of cell, thereby leading up to the second class which is of a later development. The fis

The first method of formation is due to Plante. [illegible] before, this method consists of subjecting lead [illegible] [illegible] elec-trolytic action of the forming current in dilute sulphuric acid. Plante formed his elements by charging the cell [illegible] [illegible] times during the first day, [illegible] [illegible] [illegible] the [illegible] time of charging [illegible] [illegible] [illegible] [illegible] hour. [illegible] [illegible] discharge [illegible] cell. [illegible] continuing this method of [illegible] until the cell [illegible] [illegible] maximum condition of capacity [illegible] [illegible] visually [illegible], [illegible] specific [illegible] each consecutive [illegible], [illegible] in an oppo-site direction. [illegible] [illegible] lead [illegible] be attained [illegible] only [illegible] [illegible] ances, and consequently [illegible] current must be reversed. [illegible] cell [illegible] capacity before mentioned, the charging [illegible] place only in its proper direction. [illegible] takes place in accordance with [illegible] by ex-periments, and [illegible] therefore [illegible] [illegible] tive it is [illegible] over other methods [illegible] of other, and detrimental [illegible] liable [illegible] when the active material [illegible] cell [illegible] applied to the plates before [illegible]. [illegible], how-ever, the disadvantage [illegible] time of formation and a greater expenditure of electrical energy.

We will now take up the formation of plates composed of ac-tive material formed outside [illegible] cell and [illegible]. This method of construction is due to Faure. [illegible] by mixing lead peroxide [illegible] with dilute sulphuric acid, and

applying this to lead plates. This [illegible] allowed [illegible] for several hours, during which time the sulphuric acid [illegible] with the lead peroxide forming lead sulphate [illegible] the lead [illegible], which hardens. This of course, is not a suitable [illegible] for its uses in the cell so the plates are placed in a solution of dilute sulphuric acid, and by means of [illegible] electrolysis [illegible] of the forming current. This current converts the sulphate to lead peroxide on the positive plate, and [illegible] lead on the negative plate. It is [illegible] of the [illegible] conditions that are more favorable to this action, [illegible] been shown by experiment that if strong currents are used, there will be a large part of the current used in the [illegible] of water, and that this current is [illegible] lost as far as [illegible] in the formation of the plates is concerned. This is explained by the fact that at the beginning [illegible] the cell [illegible] solution of lead sulphate, [illegible] electrolysis takes place, and [illegible] the deposition of lead at the first and no hydrogen, [illegible] which accompanies the evolution of hydrogen [illegible]. If we employ the strong currents [illegible] ions in the immediate vicinity of the electrode are [illegible] more rapidly than they can be [illegible] diffusion, since the mass of sulphate diffuses only slowly. The result is that the concentration of the lead ion [illegible] while the potential increases. This action will continue until the necessary potential has been obtained for the evolution of hydrogen, at which point that action will take place. These facts would point to the conclusion [illegible] would take place more rapidly in a neutral electrolyte than in the acid. This gives the formation of the negative pla

and we will next [illegible] the formation [illegible] [illegible].

In this case we must determine the conditions that will be most favorable to the liberation of the lead peroxide, and at the same time reduce the liberation of oxygen to a minimum. [illegible] the influence of the concentration of the acid [illegible] than in the case of the generation of lead sponge. The [illegible] which to be obtained [illegible] [illegible] lead peroxide. This fact [illegible] the [illegible] of the acid concentration small. [illegible] the formation [illegible] possible [illegible] of forming current the formation should be [illegible] in a neutral solution [illegible] aluminum [illegible]. This is useful in the neutralization [illegible] is liberated, and this [illegible] of [illegible] magnesium or aluminum.

Having [illegible] naturally wish to know [illegible] will be useful, or to know its efficiency, [illegible] efficiency of a cell [illegible], [illegible] conditions to be [illegible] it is [illegible] impossible to obtain [illegible] efficiency [illegible], it is necessary to distinguish between the efficiency of the cell taken from the standpoint of [illegible] the quantity of electricity. The [illegible] efficiency, and is generally [illegible], but in practice, a [illegible] of efficiency may be obtained as high as .94 [illegible]. [illegible] slight losses in the current [illegible] due to the self-discharge of the plates. It has been observed that the [illegible] efficiency

decreases only very slightly with increased current density. [illegible] noticeable change does not appear until very high currents are used and the currents become [illegible] in the formation of gas. The degree of efficiency is also affected by the presence of impurities in the acid, and in the case of very impure acid [illegible] as low as .7. This so called efficiency is of much less importance than the efficiency proper. The efficiency proper is the ratio of the work that may be done by the battery after charge to the work that must be put into the battery to bring it to the charged state. These efficiencies, or the work done to the work input are obtained by plotting the curves for charge and discharge on the same sheet of paper. Then the area enclosed by the curve, the axis of ordinates, and the axis of abscissae represents the work done, and the ratio of these two areas gives the efficiency of the cell. The ratio obtained in this manner varies from [illegible] to [illegible] per cent. The losses that occur in the cell are, as we have seen, due to the polarization at the electrodes, and also due to the loss in voltage of the cell. The loss in voltage due to the internal resistance of the cell is very slight on account of the small internal resistance. There is another loss in the cell that appears in the form of heat. This heat is not work changed directly into heat according to Joule's law, but is the heat of dilution of the acid in the cell. This is due to the continual dilution of the acid as the water is produced by electrolysis in the cell, and as this water diffuses through the other acid in the cell there is a heating effect present. If a current of constant strength is used, the E.M.F. of the cell is also constant, so we infer that the concentration difference in the plates is also constant.

Therefore, the acid is replaced or carried away just as fast as it is consumed or formed by the cell. Now since the rate of equalization, is proportional to the current, and since the rate of formation is proportional to the flowing current, the energy loss becomes $e = C\frac{f}{k} I^2 t$ volt-coulombs. Where C is a constant depending on the cell under test. This is the relation of the efficiency to the mechanical construction of the cell, and is dependent in a great measure to the porosity of the cell. From this reasoning it will be seen that we will obtain a condition of minimum energy loss when we use a more dilute solution during the period of charge, and a more concentrated solution during the discharge, since the acid in the mass of material is more concentrated during the charge, and lessconcentrated during the dischar Following this line of argument, we see that for a condition of good operation the acid should be used at the concentration of maximum conductivity. This point is at a specific gravity of abo 1224, This points to the fact that the conductivity of the electrolyte is the determining factor for the efficiency of the cell, as well as for the capacity. The investigations of Heim show that the maximum efficiency is obtained by using acid of a 20 per cent solution, when measured in a charged condition. Other experiments, however, point to the use of 70 per cent acid, measured in a charged condition. From the previous discussion on the effect of the conductivity of the acid on the penetration of the action into the interior of the active mass, it will also follow that when the acid used is of the maximum conductivity, the current can spread itself upon a maximum area, and therefore the polarization becomes a minimum; hence the efficiency is a maximum.

Temperature also has an effect on the efficiency of the cell.

This effect has been seen to be proportional to the rise in temperature, and also that the efficiency falls off on the addition of substances such as gelatinous silicic acid. In order to get an exact expression for the efficiency of the cell, it would be necessary to introduce the quantity showing the effect of the shrinkage of the pores of the active mass. There is, however, a lack of sufficient measurements to accurately determine the shrinkage of these pores, so this equation may not be derived. We can, however, get an expression that will give us an approximation of the relations existing between current and the loss of work. If we take the Joulean effect as being included in a constant in the equation, we may consider the loss of work as being proportional to the square of the current.

We have now studied all of the actions that affect the action and operation of the cell, and have made an attempt to account for them theoretically, so that we must now take up the study of the ways of measuring these various quantities. The best proof of our theoretical derivations and reasoning is the subjection of them to experimental proof. This, of course, must be carried out along more exact lines of measurements. We must first determine some standard of measurements of the different quantities that we have placed before us, and then all of our measurements on the cells must be based on a comparison by these measurements. One of the first quantities that confronts us is the measurement of the E.M.F. of the cell. The ordinary way of measurement is by means of a voltmeter, but if we are to use these measurements for comparison with the results derived by theoretical computation, we must have some more accurate means of measurement, since a voltmeter is accurate only to .0001 volt.

[illegible] of this instrument [illegible] Co., [illegible] precision voltmeter. It is, however, [illegible] of the ordinary voltmeter. The [illegible] potentiometer [illegible] more preferable method, but [illegible] objection that it is affected by the earth's field, and [illegible] disturbance by other outside magnetic fields. [illegible] accurate means [illegible] circuits of the cell. [illegible] simple plan [illegible] the [illegible], [illegible] while [illegible] the cell is discharged to the limit which [illegible] be [illegible] the [illegible] potential is [illegible] during the discharge, at intervals, [illegible] load [illegible] of the [illegible] above. [illegible] the cell is charged [illegible] preferably from [illegible] current may be drawn. This [illegible] battery. If the results [illegible] curves [illegible] co-ordinate paper, the area enclosed b[illegible] charge curves will represent the loss of electrical energy in the cell. These areas may be determined either by [illegible] planimeter, or of by counting the small squares contained, the latter method is preferable.

The measurement of the internal resistance of the cell is not as simple a matter as would appear at first glance. The presupposition would naturally be that it could be measured in the same manner as an outer circuit [illegible], but as the internal resistance of the cell is so small, the contact resistance of the connections makes itself felt to a considerable degree. The best method that has been devised is the method employing the use of an alternating current and a telephone. This method makes use also of

a slide-wire bridge. This bridge is adjusted, after making the proper corrections, until there is a point reached at which the telephone gives the minimum sound. This is the condition of balance. Two cells are needed in this method, and arranged in such a manner that their E. M. F's. oppose each other. This prevents their discharge through the slide-wire of the bridge. By this method it is possible to measure resistances down to .001 ohm.

PART II.

Particular Types of Cells.

Having now considered and discussed the general action of the accumulator, we will turn our attention to the particular type of cell that has been employed for this thesis. The cell was furnished for this purpose through the courtesy of the UNIVERSAL ELECTRIC STORAGE BATTERY COMPANY.

"Construction":

The cell is that is designated by the manufacturers as their "Automobile Type" of cell. In their catalogue they list this type as "Type E" having 11 plates. This is also rated at 100 ampere hours capacity at a four hour rate of discharge. As I have just stated, the cell contains 11 plates, of 5-3/4" x 9-5/8" size, of which six are negative plates, and five are positive plates.

The negative plate is constructed of a lead grid of the size mentioned, and the spaces are filled with a composition of litharge, mixed with a dilute solution of sulphuric acid. This mixture is placed in the plates in the form of a paste, and then the plates are placed in a rack, and allowed to stand for twenty four hours. Then they are considered as sufficiently "set" to be placed in the cell for which they are designated.

The construction of the positive plates, which is considered by the company to be the principal strong point of the cell, is of a somewhat different character. In this case there is a very different construction used. To begin with, the plates are constructed of a number of small grids. These grids are in the shape of a rectangle, having a dove-tail at each end. They are of the same formation as if a piece of sheet lead about 1/4 inch wide was folded into the shape of a rectangle, with its ends joined. The grid-bars are placed in it, or rather cast in it in so somewhat the same manner as the rungs of a ladder are placed in it. These small grids are filled with a paste of lead peroxide mixed with dilute sulphuric acid. These are allowed to stand for about the same length of time as the negatives. Then these small grids are taken to alperson who places them face to face, with the surfaces of the peroxide facing each other. Between each of the grids is placed a piece of cellulose paper next to the surface of the peroxide, and between the papers is placed a wooden strip with corrugated sides. The cellulose paper is placed there for the purpose of retaining the active material when it becomes granular through the electrolytic action of the cell. The wood strip is used to separate the surfaces of the peroxide so that the acid may have free access to them. The corrugations assist the circulation of the acid, and increase the diffusion coefficient of the cell. This will be seen, from our recent argument on that point to be of advantage to the action in the cell. After a sufficient number of these small grids have been placed together to make up a plate of the requisite height, they are placed in a frame or mould, and an outer strip of lead is cast around them. Then they are finished up and allowed to stand for a short length of thi

of time, when they are placed in a cell and the connecting lugs are burned on. This burning operation is rather a delicate operation and must be performed with great care so as not to over heat the plate. The negatives are subjected to a like treatment. The two sets of plates, positive and negative, are then placed in a forming bath. The operation of forming the plates is the ticklish part of the manufacture of a battery. There will be, in every lot, a number of cells that will not "come up". That is to say, their voltage does not rise with the rest of the lot. This fact means that cells, in the process of formation, need constant watching, and frequent readings of the voltage of each cell must be taken. The cells that are"slow" must then be taken out of the lot, and subjected to an additional charge on the formation. The operation of forming is carried on in a large room which is open to the air on all sides. The reason for this is on account of the large quantities of gas that are evolved when a large number of cells are being formed at the same time. They are not formed in the jars in which they are to be used, as is generally supposed, but are placed in large earthen jars with very thick walls. The reason for this is on account of the large quantity of heat that is developed during the formation, and this would injure rubber jars, and if they were of glass they would probably crack. In commercial forming, the voltage of the cells is taken with an ordinary voltmeter, and these readings are considered as being sufficiently accurate.

The type of cell taht is used in this test, is put up in a rubber jar, having cast in the bottom, rubber strips in the shape of triangular prisms. The edge of these prisms is placed up, and the plates are allowed to rest on it. The object of this strip

is to keep the plates off the bottom of the jar. There is quite a considerable deposit of "mud" in the bottom, and if the plates were allowed to come in contact with this, it would form a local circuit in the cell, with a consequent discharge of the cell. This mud is composed, in most cells, of a deposit of the active material that becomes loosened, through the electrolytic action of the current, and falls to the bottom. In the cell under test, it was found that the active material was put into the plates in such a way that it did not become loosened readily, and hence there was very little deposit of it. There was, however, a great quantity of the "mud". This was due to the action of the acid on the cellulose paper used in the separators. The plates, being in such close proximity, have to be separated from each other in some manner. In this cell this was done in the following manner. After the plates were placed together, there was inserted between them, a piece of perforated rubber. This was about 1/14 inch in thickness, but it had corrugations on one side. Thus, the perforations were placed directly against the negative plate, while the corrugations were placed against the positive plates. Now it is known that the active material in the positive plates becomes loosened much more readily than that of the negatives. Thus it was necessary to provide some other means of keeping it in place. This was accomplished by placing next the positive plate, a cellulose separator. This practically amounts to a sheet of paper, since it is very thin. The action of the battery, in our test showed that this cellulose was inefficient, since after about 30 discharges, there was no trace of it left between the plates when they were taken out for observation. This, then was what composed the greater part of the "mud" that gathered in the bottom of

[illegible] heat
[illegible] temperature.
[illegible]
[illegible]

the jar. This paper was supposed to have been treated in such a manner, before its insertion into the cell, that the action in the cell would not injure it. Now this rapid destruction of the paper, indicates either one of two things. Either the paper is not the right kind of substance to use for this purpose, or it was not properly prepared. We are inclined to the latter assumption, since we have seen it very successfully used in other cells. We would, however, recommend the use of thin wood separators in place of this paper for this type of cell. We make this recommendation in view of the conditions that the cell is required to meet. It is distinctly an "Automobile cell". This fact is shown by the heavy construction, which is evidently designed to stand hard usage. Now in automobile operation, a cell has to meet conditions that are not to be encountered in any other field in which the storage battery is used. It must be able, if necessary, to meet a condition of considerable over-discharge, without injuring the cell to any appreciable extent. It must be able also, to be charged at high currents, and at short time rates. This must be accomplished without very great gas formation, as this is waste of energy. It must be highly efficient. Now it is evident that it is a difficult matter to obtain a cell that will not fall down in some one of these requirements, and it is for this reason that the construction employed in this cell has been adopted. The very construction of the positive plates makes them secure as far as any loosening of the active material, due to the shaking of the cell, is concerned. The plates are placed in a jar that they fit rather tightly, and there is no room for them to shake around in it. This small jar has also another advantage, and that is the economy in the amount of the acid needed for each cell. At first

glance it would seem as if this was too small a factor to notice, but in the manufacture of large quantities of cells, any item that will cause a saving, no matter how small, is not to be overlooked. There is, however, a disadvantage to be considered in this connection, and that is the temperature effect in small jars. From the discussion on the theory of the cell, it will be seen that the effect of temperature is a large one, and therefore is worthy of consideration. The manufacturers allow a rise of 100 degrees F for their cells, and guarantee that if the temperature be kept within this limit, there will be no injury [illegible] from it. They also claim that the efficiency of the cell is highest between ordinary temperatures and this limit, therefore, if the cell will radiate the heat generated sufficiently fast to keep the temperature down to this limit, the test of the cell will show that this size of jar is allright for use.

TESTS:

In making our tests of the cell, we endeavored to keep the conditions the same as would be met in actual practice. To this end we made all of our tests in the small jars, and subjected the cell to all the varying conditions of load. We made several runs, both charge and discharge, at the different rates, and compared the results thus obtained with the manufacturers rating at these rates. To get a satisfactory comparison, we found it necessary to obtain the manufacturers rates of charge and discharge for different times of charge and discharge. Then we obtained their voltage and acid density limits, as well as their temperature limits. In making our tests, then, we kept ourselves strictly within these limits in order to get values that would give a good comparison.

A curve was obtained from the different runs, in which we plotted current rate as ordinates, and time as abscissae. This will give the current necessary for either charge or discharge for any given time rate. Curves were also obtained for the following:

Abscissae	Ordinates.
Time	E.M.F.
"	Current

These were obtained for both charge and discharge. We also plotted another curve with time of discharge as abscissae, and the capacity of the cell in ampere hours as ordinates. We ran all these tests at 150, 100, 75, 50, 25, 15 ampere rates, determining the capacity of the cell in ampere hours in each case. We allowed the voltage to fall only to 1.75 on discharge, and allowed it to rise only to 2.6 on each charge. The density was allowed to rise to 1300 on charge, and to fall to 1200 on discharge. The temperature was kept below 100 F.

Tables giving the data obtained in these runs, and the curves compiled from them will be found hereafter, and a discussion will follow, showing the various characteristics of the cell.

Life Test:

Another test that was attempted was a test intended to show the life of the cell. From the curve of rates we obtained the current necessary to charge the cell in one hour, and also the current necessary to discharge it in one hour. Following these values, we designed an apparatus which would automatically charge the cell for one hour, and then throw it over and discharge it for one hour. This was accomplished by means of a self-winding clock, two relays, and a solenoid switch. The solenoid

write [illegible] all [illegible]. [illegible] that will operate on 110 volt [illegible] current. [illegible] designed that it would lift [illegible] 110 [illegible], [illegible] [illegible] when it [illegible] full [illegible], [illegible] this [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] current, [illegible] graph [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] cells [illegible] through the cloth [illegible] [illegible] [illegible] [illegible] apparatus [illegible] and every other day, [illegible] efficiency of the cell. [illegible] regret [illegible] state that, [illegible] some difficulti[illegible]

construction [illegible] [illegible] [illegible] [illegible]. [illegible] [illegible] able to [illegible] [illegible] life that in ti[illegible] [illegible] [illegible] it by [illegible] [illegible] [illegible] [illegible]. but an appendix containing data of [illegible] [illegible] have been able [illegible] [illegible].

[illegible]

[illegible]	Gravity.	[illegible]	[illegible]	[illegible]	Gravity.	[illegible]
0.1	1500	[illegible]	[illegible]	0.1	[illegible]	[illegible]
0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.115	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.105	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.015	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]0.50
1.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.78	[illegible]150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
			[illegible]	1.70	[illegible]	[illegible]

[illegible]	Gravity.	[illegible]	[illegible]	[illegible]	Gravity.	[illegible]
[illegible]	1100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
			[illegible]	[illegible]	[illegible]	[illegible]

DATA (continued),

OF [illegible] DISCHARGE.

No. 1.				No. 2.		
E. M. F.	Gravity.	Temp.	Time. Hours	E. M. F.	Gravity.	Temp.
2.1[illegible]	[illegible]	[illegible]	0.0.	[illegible]	[illegible]	[illegible]
2.0[illegible]	[illegible]	[illegible]	.5	[illegible]	[illegible]	[illegible]
2.0[illegible]	[illegible]	[illegible]	1.0	[illegible]	[illegible]	[illegible]
2.0[illegible]	[illegible]	[illegible]	1.5	[illegible]	[illegible]	[illegible]
2.01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.74	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	1150	[illegible]	[illegible]			

[illegible] (continued)

OF [illegible] CHART.

# 1.				# [illegible].		
[illegible].F.	Gravity.	Temp.	Time Hours.	[illegible].F.	Gravity.	Temp.
1.7	1100	[illegible]		1.7	1100	[illegible]
1.8	1110	[illegible]	1.0	1.8	1110	[illegible]
1.9	1120	[illegible]	1.5	[illegible]	1110	[illegible]
1.91	1130	[illegible]	2.0	[illegible]	[illegible]	[illegible]
1.9[illegible]	1140	[illegible]	2.5	1.[illegible]	[illegible]	[illegible]
1.9[illegible]	1150	[illegible]	3.0	1.[illegible]	[illegible]	[illegible]
1.9[illegible]	1160	[illegible]	3.5	[illegible]	[illegible]	[illegible]
2.00	1170	[illegible]	4.0	[illegible]	[illegible]	[illegible]
2.10	[illegible]	[illegible]	4.5	2.00	[illegible]	[illegible]
2.11	[illegible]	[illegible]	5.0	[illegible]	1100	[illegible]
2.12	[illegible]	[illegible].75	[illegible]	[illegible]	[illegible]	[illegible]
2.14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].75
2.20	1[illegible]00	[illegible]	[illegible]	[illegible]1	1500	[illegible]
2.[illegible]	1[illegible]00	[illegible]	[illegible]	[illegible]5	[illegible]	[illegible]
2.[illegible]0	1[illegible]00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.[illegible]	1[illegible]00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.[illegible]0	[illegible]	[illegible]	10.0	[illegible]	[illegible]	[illegible]
2.[illegible]	[illegible]	[illegible]	10.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]5	10.[illegible]	[illegible]	[illegible]	[illegible]

DATA (continued)

50 AMPERE DISCHARGE.

# 1.				# 2.		
E.M.F.	Gravity.	Temp.	Time. hours.	E.M.F.	Gravity.	Temp.
1.99	1200	24.5		1.99	1200	26
1.98	1198	24.5	.25	1.98	[illegible]	26
1.97	1200	24.5	.50	1.97	1200	26
1.955	[illegible]	24.6	.75	1.96	1197	26.3
1.94	[illegible]	24.6	1.25	1.935	1197	26.5
1.91	1195	24.6	1.50	1.910	[illegible]	26.4
1.90	[illegible]	24.5	1.75	1.890	[illegible]	26.5
1.88	1195	24.5	2.00	1.86	1192	26.5
1.86	1190	24.5	2.25	1.855	1190	26.7
1.84	[illegible]	[illegible]	2.50	1.825	1190	[illegible]
1.805	1180	25.0	2.75	1.805	[illegible]	27.0
1.755	1175	25.0	3.00	1.750	[illegible]	27.5
1.70	1165	25.0	3.25	1.700	[illegible]	27.0

DATA (continued)

50 AMPERE CHARGE.

No. 1.				No. 2.		
E.M.F.	Gravity.	Temp.	Time. hours.	E.M.F.	Gravity.	Temp.
1.79	1175	26.0		1.79	1175	27.5
1.90	1175	26.0	.5	1.8[illegible]	1175	27.5
1.91	1176	26.0	1.0	1.91	1177	27.5
1.95	1178	26.0	1.5	1.95	1177	27.5
1.964	1178	26.1	2.0	1.97	1177	27.5
1.98	1178	26.1	2.5	1.98	1178	27.
1.90	1180	26.5	3.0	1.95	1178	27.0
1.99	1180	[illegible]	3.5	1.99	1180	27.5
2.01	1182	26.5	4.0	2.02	1181	28.0
2.15	1184	26.0	4.5	2.15	[illegible]	28.0
2.10	1184	26.5	5.0	2.30	1182	28.5
2.27	1186	26.5	5.5	2.35	1190	28.5
2.30	1191	26.5	6.0	2.50	1195	28.5
2.36	1192	26.5	6.5	2.55	1[illegible]	28.5
2.40	1200	26.5	7.0	2.[illegible]0	1200	28.5
2.45	1200	27.5	7.5	2.[illegible]5	1200	28.5
2.48	1200	27.5	8.0	2.50	1200	28.5
2.54	1200	27.5	8.5	2.40	1200	2[illegible].5
2.60	1200	27.5	9.0			

DATA (continued)

[illegible]

#1. #5.

Sp. Gr.	Gravity.	[illegible]	Time, Hours.	Sp. Gr.	Gravity.	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
1.750	[illegible]		[illegible]	[illegible]	[illegible]	
1.700	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

Sp. Gr.	Gravity.	[illegible]	Time, Hours.	Sp. Gr.	Gravity.	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
2.00	[illegible]		[illegible]	[illegible]	[illegible]	
2.11	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
2.50	[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DATA (Continued)

[illegible]

#1.					#2.	
[illegible].F.	Gravity.	Temp.	Time. xxxxz. min.	[illegible]	Gravity.	Temp.
1.[illegible]	[illegible]	[illegible]		1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	5	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	10	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	15	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	25	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	70.00	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	71.0	[illegible]	1.[illegible]	[illegible]	71.0
1.[illegible]	[illegible]	71.0	[illegible]	1.[illegible]	[illegible]	71.5
1.740	[illegible]	71.5	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	[illegible]	[illegible]

[illegible]

1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	15	1.[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible].10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	105	[illegible]	[illegible]	[illegible]
[illegible].4[illegible]	1700	[illegible]	[illegible]	[illegible].50	1700	[illegible]
2.[illegible]	1[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]

DATA (Continued)

150 AMPERE DISCHARGE.

# 1.				# 2.		
E.M.F.	Gravity.	Temp.	Time. Min.	E.M.F.	Gravity.	Temp.
2.10	1200	67.0	00	2.10	1200	67.0
1.94	1200	67.0	05	[illegible]	1200	67.5
[illegible]	1200	67.0	[illegible]	[illegible]	1200	67.5
[illegible]	1200	67.0	[illegible]	[illegible]	1200	[illegible]
[illegible]	1200	67.5	10	[illegible]	1200	68.0
[illegible]	1200	68.0	15	[illegible]	1200	[illegible]
1.775	1200	68.0	[illegible]	[illegible]	1200	[illegible]
1.755	1200	[illegible]	[illegible]	[illegible]	1200	[illegible]
1.745	1200	[illegible]	[illegible]	[illegible]	12700	[illegible]
1.750	1200	69.0	[illegible]	[illegible]	1200	70.0
1.718	1200	70.0	[illegible]	[illegible]	1195	70.5
1.700	1195	71.0	[illegible]	1.700	[illegible]	71.0

150 AMPERE CHARGE.

E.M.F.	Gravity.	Temp.	Time. Min.	E.M.F.	Gravity.	Temp.
[illegible]	1195	71.5	00	[illegible]	1195	[illegible]
1.91	1195	72.0	05	[illegible]	1195	72.0
[illegible]	1195	72.5	10	1.94	1195	72.0
[illegible]	1200	73.0	15	[illegible]	1200	[illegible]
1.95	1200	73.5	20	[illegible]	1200	[illegible]
[illegible]	1200	74.0	25	[illegible]	1200	74.0
[illegible]	1200	74.5	30	2.05	1200	74.5
1.97	1200	75.0	35	[illegible]	1200	75.0
2.05	1200	75.5	40	[illegible]	1200	75.5
2.10	1200	76.0	45	[illegible]	1200	76.0
2.40	1200	77.0	55	2.45	1200	77.0
2.60	1200	78.0	65	[illegible]	1200	78.0

[illegible]

This [illegible] compiled from the curves obtained from the charge and discharge of the cells individually. The efficiency is expressed by the ratio of the area under the discharge curve to the area under the charge curve, [illegible] same scale. This efficiency is [illegible]watt-hour efficiency.

Discharge [illegible]		[illegible]	Charge [illegible]			
#1.	#2.	[illegible]	#1.	#2.	#1. Eff.	#2. Eff.
1[illegible]	1[illegible]	[illegible]	1[illegible]	1[illegible]	[illegible]	[illegible]
1[illegible]	1[illegible]	1[illegible]	1[illegible]	1[illegible]	[illegible]	[illegible].1
[illegible]	[illegible]	–	[illegible]	[illegible]	[illegible].1	[illegible].0
[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]
8.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Judging from [illegible] is higher for [illegible] but [illegible] supposition. [illegible] true, [illegible] things, but [illegible] [illegible] of the discharge [illegible] [illegible] [illegible] [illegible] large [illegible] In [illegible] [illegible] increases. It will be seen [illegible] (current) increases, the capacity of the cell falls, [illegible] comparison [illegible] efficiency curve, [illegible] efficiency varies inversely as the capacity.

[illegible] [illegible] seem that the capacity varies inversely as the rate, and the coefficient varies inversely as the capacity, [illegible] the coefficient varying directly as the rate. Which seems conforming to the conditions existing.

APPENDIX.

At the end of 45 runs, cell #2 was rendered useless. The was caused by the voltmeter wires, the copper sulphating and dropping down into the cell. The copper formed on the negative plate, acting as a positive thus short circuiting the cell internally.

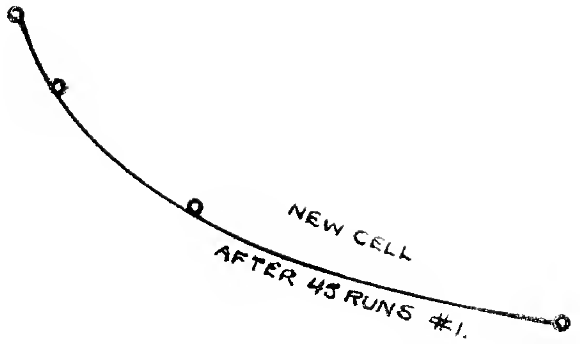
At this stage, we took a new set of rate and capacity curves to determine any changes that had taken place in the capacity of the cell. This was done for the different rates a as before, with the exception that 150 amps. could not be gotten out of cell # 2, because of the low voltage a rheostat could not be obtained to regulate the current at a 150 ampere discharge rate. A six inch carbon rheostat was used in the first case and was all right where the two cells were in series. The rates taken were the 100, 75. 50, and 25 ampere rates.

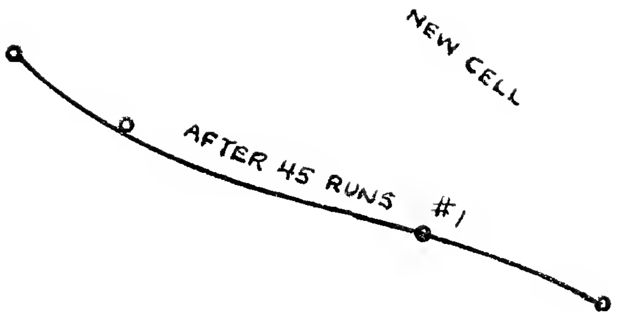
It was noted that the capacity was materially decreased. Curves were platted on the same sheet with the first rate and capacity curves, for comparison. See curves.

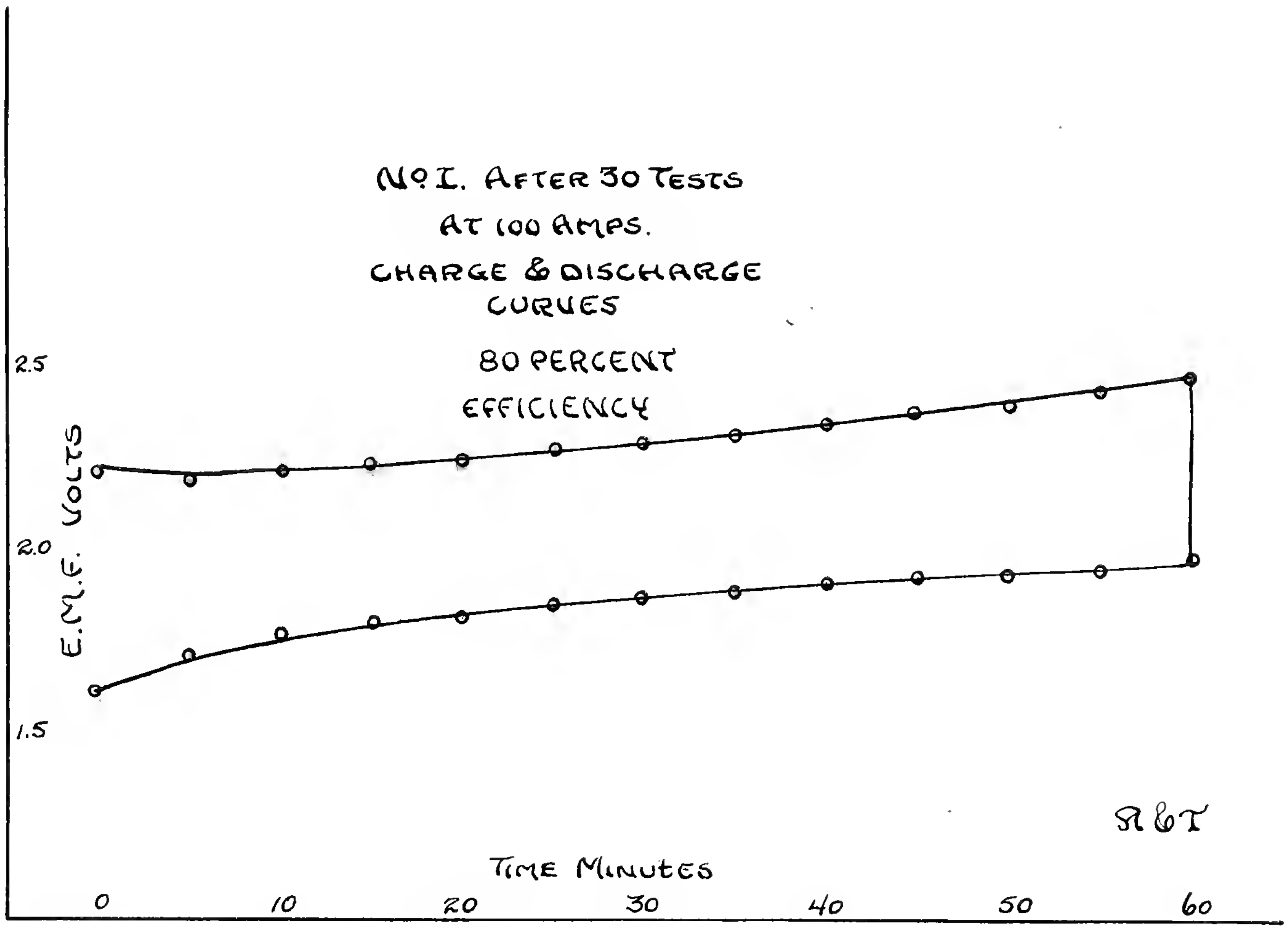
The method of obtaining the efficiency was to take the ratio of the output in watts, to the inputw in watts. The area of the charge and discharge curves were integrated by means of a planimeter, and if the curve of ordinates were started at 1.5 the area from 0 to 1.5 was added on to each of the charge and discharge areas. (The charge and discharge areas are the areas under the charge and discharge curves, This method as are all the other methods, is rather approximate on account of the varying conditions that are going on in the cell, To get a true efficiency, the voltage on charge should come to

2.55 volts, the gravity should come up to what it was at the beginning of the discharge, the temperature should return to the starting point. All these conditions cannot be fullfilled simultaneously, hence the approximation. (Note. The voltage that the cell is discharged down to each time should be the same)

The latest method of charging storage cells is by the gravity method. A recording hydrometer is put in one of the cells of the set, and when they are charge up to the proper mark, the power is shut off. This indicates that the accurate indicator of the condition of a cell is the hydrometer reading.

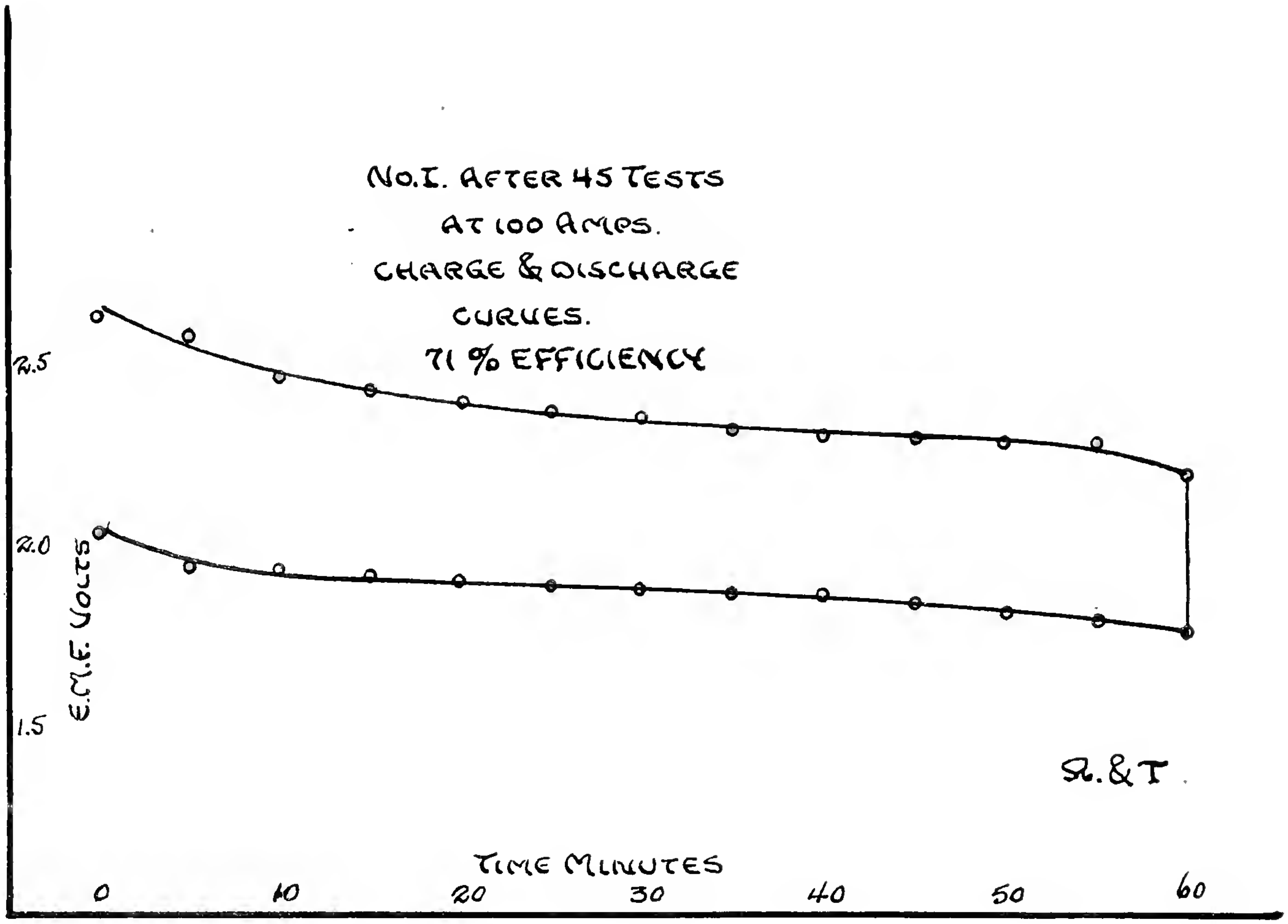

NEW CELL
AFTER 45 RUNS #1.


NEW CELL
AFTER 45 RUNS
#1



No. I. After 30 Tests
At 100 Amps.
Charge & Discharge
Curves

80 Percent
Efficiency



No.I. AFTER 45 TESTS
AT 100 AMPS.
CHARGE & DISCHARGE
CURVES.
71 % EFFICIENCY