

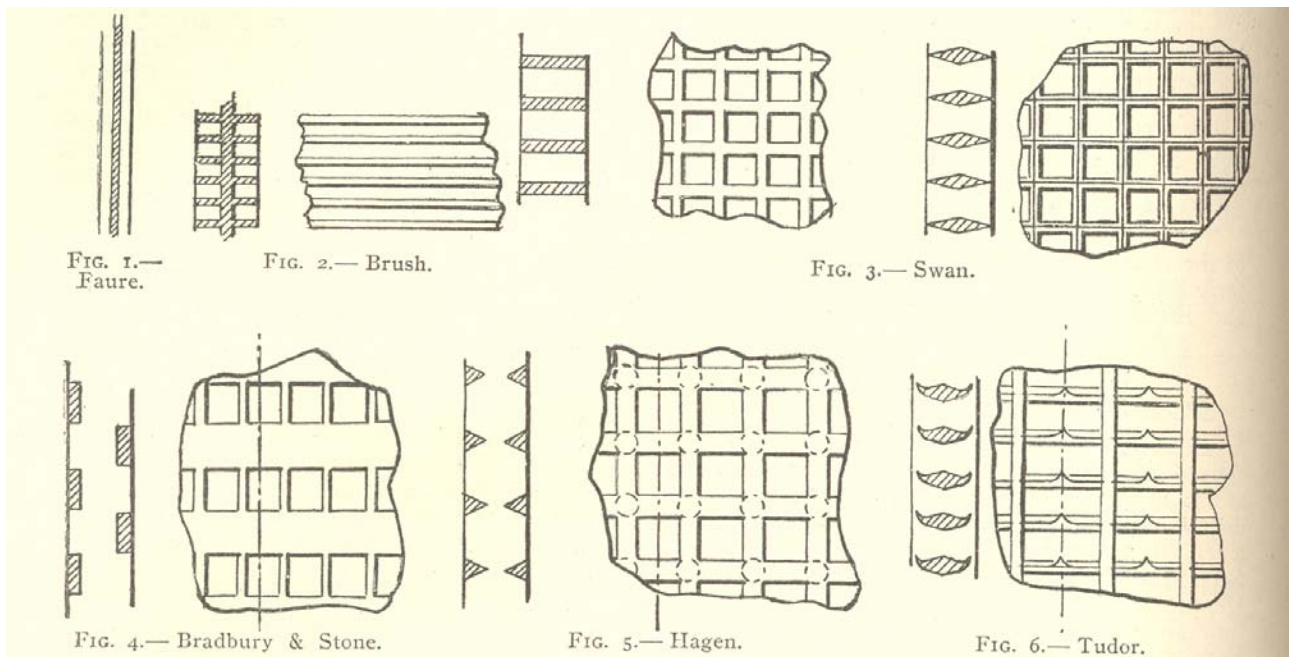
Electric Storage Battery, The. The principle of the electric storage battery was known as far back as 1801, for in that year Gautherot discovered the secondary current obtained from a cell which consisted of two silver or platinum electrodes immersed in a common salt solution. He first charged the cell by passing a current through it; then breaking the charging current, he connected the two plates to the terminals of a galvanometer and obtained a momentary deflection, indicating a flow of current in the reverse direction to the original charging current. This, then, may be said to have been the discovery of the principle of the storage battery, but it was nothing more, since 41 years elapsed before anything noteworthy, more, was done toward its development. In 1842, however, Sir William Grove constructed his famous gas battery, which was a long step ahead in the direction of a commercial accumulator. Grove's battery consisted of a pair of platinum strips immersed in dilute sulphuric acid, each strip surrounded on the top and sides by a closed glass tube which collected the gas developed in charge, and kept each gas in contact both with its respective electrode, and with some of the adjoining acid surface. If this apparatus, after having current passed through it for some time, be connected to a galvanometer, it will yield a small current in the reverse direction for a considerable time, or until the oxygen and hydrogen developed by the charge have gradually become absorbed by the platinum and have recombined to form water. It will be seen that this cell was a very great advance over the experiment of Gautherot, but yet it was absolutely without practical value as a storage battery, and a great deal of thought and labor expended since Grove's time have failed to further develop it.

It remained for one Gaston Plante, a Frenchman, in 1860, to make the one more important step which immediately demonstrated the wonderful possibilities of the storage battery, and which set other inventors to work all over the world. His experiment consisted in making a cell which had lead strips instead of platinum, immersed in dilute sulphuric acid, as was used by Gautherot; this cell being charged by a current would yield a very considerable reverse or "secondary" current. Plante's important discovery, however, was that each time such a cell was charged and discharged the amount of the secondary current, or the "capacity," of the cell increased; and further experiments showed that by not merely discharging the cell but by charging it up in the reverse direction each time, the capacity was brought up even more rapidly. Plante was thus enabled to make secondary cells having enough capacity to give them great commercial importance, and since the changes and improvements which have been introduced since his time are all directly along the same lines and all involve the same fundamental principles, it is eminently fitting and proper that to Plante has been attributed the honor of inventing the storage battery. Examining his results carefully, Plante found that the lead plate which was connected to the carbon or negative pole of the primary battery, became coated

with a film of dark brown peroxide of lead, and the lead plate connected to the zinc terminal of his primary cell was coated with spongy metallic lead. Each time the current in the secondary cell was reversed a little more of the solid metallic lead of the plate became peroxidized, and the gradual accumulation of this film of "active material" on both plates, caused the increase in capacity. Plante arranged a large series of cells through which he continually passed a current, first in one direction, then in the other, the duration of the charges gradually increasing, and by this treatment, in course of time, his plates accumulated a considerable thickness of active porous lead and lead peroxide upon their respective surfaces, and after one or two months of the treatment (which he called formation) were ready to be used. It will readily be seen that this forming process for converting the solid lead into active material was very troublesome and expensive, and it was in overcoming this difficulty that the next great step ahead was taken. While Plante's batteries might have been of great commercial value, the very limited use of electricity at that time necessarily curtailed its usefulness very much, and it was not until the development of the dynamo that the real need for a storage battery was felt. It was in response to this need that Camille A. Faure, in 1881, patented a method for making storage batteries, by which the long forming process of Plante was entirely obviated. Instead of chemically attacking the surface of the metallic lead plate, Faure covered the surface with lead oxide in the first instance. A single charge then was sufficient to convert this into lead peroxide upon the one plate and metallic lead upon the other. This invention, which is virtually the last great stride toward the perfection of the storage battery, is commonly credited to Faure, but incorrectly so, since Charles F. Brush, in America, working independently of Faure, arrived at the same principle at almost the same time, so that in this country priority was given to him, and it is Brush's patent which has ever since controlled the so-called "pasted" plate throughout the United States. All battery plates made to this day are either after the Plante type, where part of the metallic lead plate is chemically acted upon to produce the active material, or else after the Faure-Brush, or pasted type, where the active material, usually in the form of an oxide of lead, forms an integral part of the original plate. It must not be understood from this that no improvements have been made in recent years, but rather that each improvement taken singly has been of relatively small importance, and that the vast number of these, and the constant perfection of detail, have collectively made an immense difference to its practical performance.

Some of these refinements of design and detail are as follows:

Faure's original plates consisted of plain sheets of lead, sometimes roughened on the surface, upon which was spread or pasted the lead oxide intended to become active material. It was soon found, however, that in practice this arrangement was entirely inadequate, since the lead peroxide on the positive plate



Figs 1 to 12 are types of grid for pasted plates. Shaded portions represent lead, un-shaded portions active material.

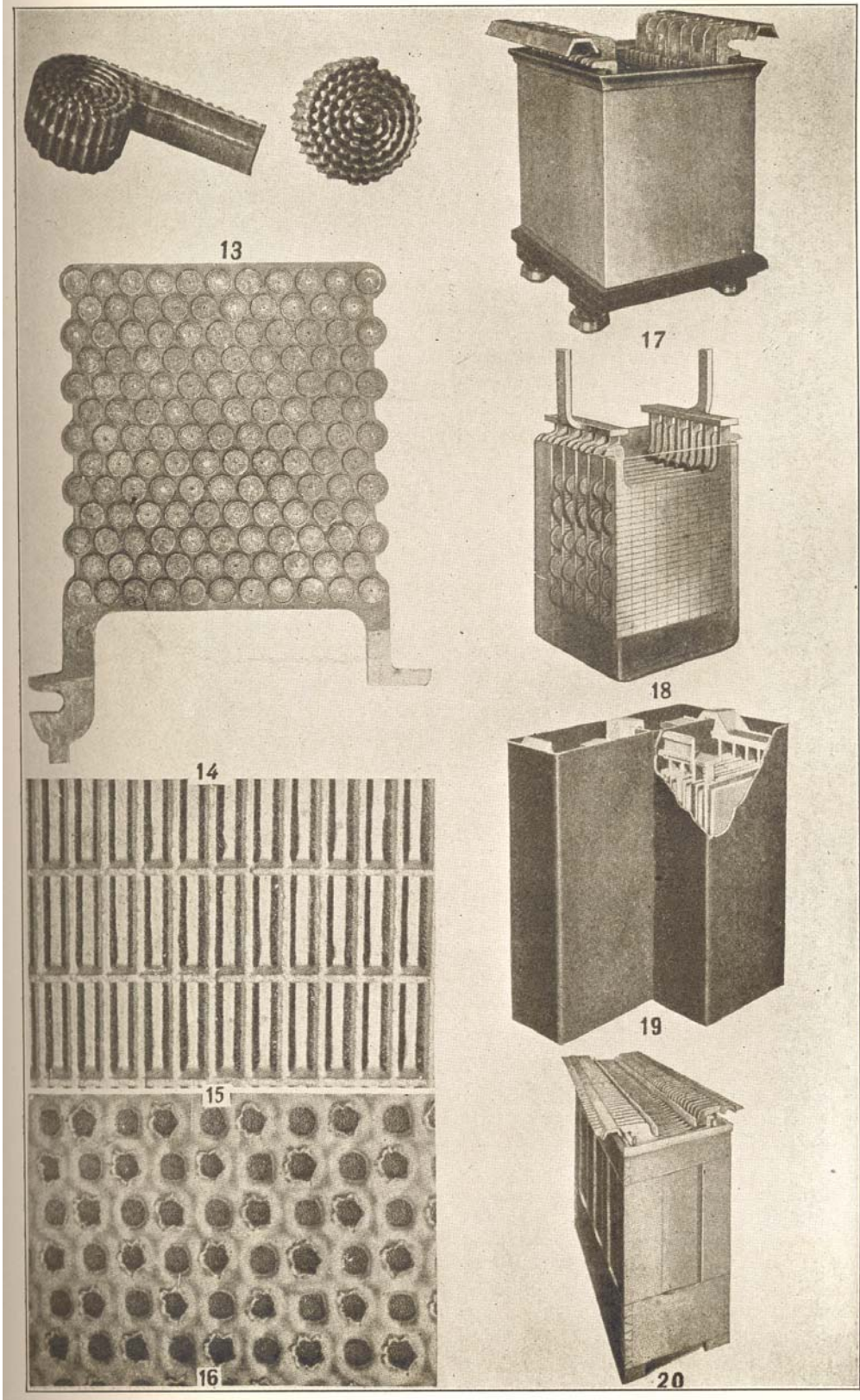
quickly lost its hold upon the supporting sheet and fell away from it.

In order to meet this difficulty, Swan, in England, and Brush, in America, at about the same time, devised a variety of grid plates, whose object was to provide means of locking the material fast. These grids were either like a flat plate with a number of deep grooves extending into its surface (Fig. 2), or else like a flat plate having a number of holes entirely through it (Fig. 3); the lead oxide intended to become active material being worked into the openings in either case and there held by the large surface of contact with the grid. But with a few years experience it was found that neither of these two expedients was sufficient for practical purposes, and many inventors set to work to construct grids which would effectively retain the active material, and particularly the lead peroxide upon the positive plates. The number of different forms of grid thus brought out almost surpasses belief, and a few only of the most important are here illustrated (Figs. 1 to 9).

These examples, selected from among the types of pasted plates which have been most successful, show the general tendency toward that construction of grid which will have the best grip upon the active material and which will make it as difficult as possible for the latter either to lose electrical contact with the grid or to fall to the bottom of the cell. In some cases, as the Tudor plates illustrated, the grids after being cast have been passed through rolls which turn over a part of each fin so as to give it a grip on the material; in other cases the grids have been cast with holes bigger in the middle section than at either surface; and in still others, notably the chloride plate, the active material made into small blocks has been placed in the mold

and the lead grid cast around it. Finally in the latest type of pasted plate two grids, each having a perforated sheet of lead cast on one side are riveted together with the sheet of lead on the outside, thus forming a number of completely enclosed pockets which hold the active material (Fig. 9).

Quite soon after the storage battery came into extensive use it began to be found that in spite of all possible precautions in the design of the grids, the peroxide of lead on the positive plates would always become soft on the surface and would gradually wash away, leaving the empty grid with little or no capacity. This inherent defect of the pasted positive led manufacturers to seek a remedy in the older or Plante type for their positives, and in this they were so successful that except for small batteries for automobiles and some few other cases where lightness is a great factor, the Plante type of positive is now always used. Its advantages consist in the facts that, (1) the peroxide being a very thin layer and very close grained, and also being protected from the wash of the electrolyte by reason of its location in the grooves or interstices of the plate, is not readily washed away as is the material of a pasted plate; and (2) that as the peroxide becomes very gradually disintegrated through use its place is continually filled by the fresh peroxide slowly "formed" by the working of the cell upon the surface of the main grid. The pure Plante plate made by casting a grid with very fine channels extending from one side to the other (Fig. 10), is the standard on the continent of Europe, it having but the one fault, liability to become bent or "budded" with use, to the extreme detriment of the battery.



For explanation of figures, see article.

In America, however, the type known as the "Manchester" positive has been the most successful. This plate with its prototypes is here illustrated (Figs. 11 to

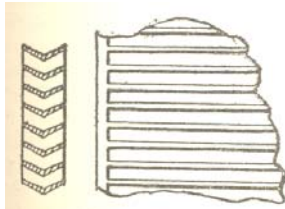


FIG. 7 - Winkler

14), and its distinctive feature is the combination of a stiff alloy grid with pure lead spirals or buttons, which furnish the active material. Since the peroxide of lead is "formed" by an electro-chemical process from the pure lead buttons, this plate is distinctly of the Plante type, but having the great advantage that it is very stiff and practically free from buckling, and its consequent

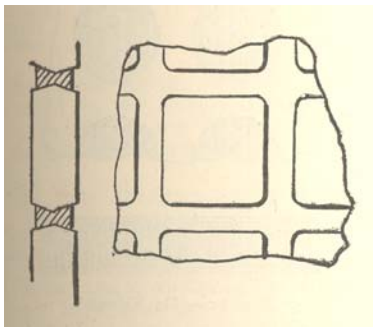


FIG. 8 - Chloride

evils, which are so common with the soft lead type. The grid for the Manchester plate is a casting of lead-antimony alloy, having a number of holes three quarters of an inch in diameter placed as close together as possible and extending all the way through. Into each hole is forced a "button" of pure lead which offers a large surface to the acid; each lead button is made by coiling up a piece of transversely corrugated lead strip or ribbon made by forcing solid lead under pressure through a suitable slot or die; the corrugations being put on by a pair of toothed rolls.

The Plante plates consisting entirely of soft lead, are made by several different processes; by sawing the slots on both sides; by working into the surface a number of steel disks which cut into and squeeze out the metal between them, but do not remove any; by working over the surface with a sharp tool which takes a series of cuts, each time turning up a shaving at right angles to the surface but not detaching it; by rolling the lead between suitable corrugated rolls; and lastly by casting. The casting process is by far the best of all these, since it is the only one by which the plate can be made with stiffening ribs around the edges or wherever else desired. The product of all these processes is a flat plate from one quarter to a half inch in thickness, composed of a number of thin leaves lying in planes at right angles to the plane of the plate and

spaced between 15 and 35 per inch, exposing to the acid a surface from five to ten times that of a plain plate of the same outside dimensions.

As the positive plates made after Plante's method came into increasing demand, manufacturers found that the process of formation was exceedingly slow and expensive and hence they set to work to try to cheapen it. To this end they subjected the plates to be formed to the action of some chemical which would easily attack the surface and leave there a porous layer of a lead salt which could readily be "formed" into peroxide by the oxidizing agency of an electric current. Swan thus exposed his plates to the action of acetic and carbonic acid fumes, and thus covered his surfaces with white lead, while Dujardin dipped his plates into nitric acid and thus formed a layer of lead nitrate; the plates covered with a layer by either of these processes were set up in dilute sulphuric acid and there subjected to the action of a current which converted the porous layer into peroxide. It was soon discovered after this,

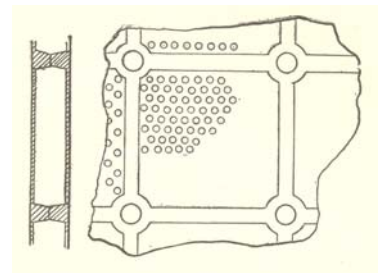


FIG. 9 - Box

that these two operations would be carried out together and that it was thus possible, by adding a suitable amount of nitric acid to the sulphuric acid electrolyte, to form lead nitrate on the surface of the plate and simultaneously by the passage of a continuous current to oxidize the nitrate to lead peroxide. It is now known that the addition of almost any solvent of lead to a sulphuric acid electrolyte will very greatly facilitate the forming of plates therein, so that the process which took Plante several months is now done in as many days, nitric acid being the solvent most commonly used.

It has been stated above that the Faure, or pasted type of positive plate, is now used only for automobile work, where lightness is a primary factor, and as illustration of a plate of this kind, the so-called "exide" may be cited (Fig. 15). The grid, as will be seen, consists of a number of small lead alloy bars running parallel, and placed at the two surfaces of the plate in such manner that a bar on one side comes opposite to a blank space on the other. The active material inside the bars is held in so tightly that it can work out only as it disintegrates into very fine particles, as is normally incident to its use; and moreover, the wash of the electrolyte in the cell is much lessened by the lead bars on the surface of the plate.

The life of any plate of this kind is not so long as that of the Plante plate, but its capacity for the same

weight is considerably higher, so that for the class of work mentioned it fills a very important place.

In the early days of storage batteries both Plante and Faure used positive and negative plates of identical construction, and any form of positive described above may be used as a negative; but the conditions

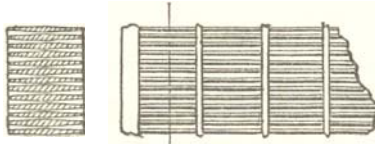
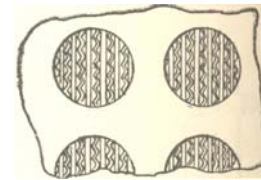


FIG. 10 - Tudor Positive

under which the two plates operate are so different that it is now almost universal to use a special design for each. The main difference is that the metallic sponge lead constituting the negative active material is quite a tenacious substance compared to lead peroxide, and consequently it does not yield to the wash of the electrolyte, and only in cases of the most flagrant abuse does it ever become softened so as to drop off from the grid. Under these circumstances, many of the grids (Figs. 1 to 9) which are quite inadequate to retain the lead peroxide of a positive plate are quite capable of making good negatives, and are in fact so used. The two forms of oxide grid (Figs. 15 and 16) are among the best for small light batteries, while the box grid (Fig. 9) is the most largely used for central station work. This plate is made in two halves riveted together and completely surrounding the active material, the acid having access by means of a large number of small holes through the sheet which covers the sides. Under ordinary circumstances it is impossible for the sponge lead to work out of these perforations, so that the life of this type is much greater than that of any other heretofore developed.

Both Plante and Faure in their earlier experiments assembled their batteries by rolling up together in the form of a wide spiral the two sheets of lead which were to serve as positive and negative plates. The two sheets were insulated by means of pieces of felt rolled between them, and the whole group was immersed in the sulphuric acid electrolyte contained in a suitable glass vessel. But this form of cell was soon found very difficult to operate, since the felt gave no security against the plates becoming short-circuited, and it was frequently necessary to remove the whole element from the Jar, unroll it, and substitute fresh felt, a matter of great inconvenience. To obviate this defect it has ever since been the practice to use plain flat plates anywhere between one eighth and one half inch in thickness, which either hang from the top or rest on the bottom of the jar, with a small space - one eighth to a half inch between their adjacent surfaces. The plates are maintained in their proper position by the "separators"; either a pair of glass tubes or hard rubber strips between each pair of plates or else a thin sheet of insulating material such as perforated hard rubber. Formerly the glass tubes were most frequently used in

large cells, and the perforated rubber sheets in small ones, but a recent development is the use of thin wooden diaphragms between the plates, which possess the great advantage that the particles of lead peroxide which are always present in the electrolyte, can never



Lead Rib.

FIG. 11 - De Kabath

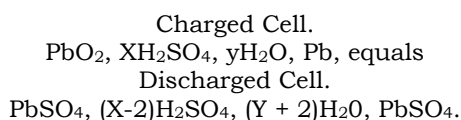
deposit between the plates so as to bridge across and short-circuit them, as often happens with the older types.

The alternate plates in a cell are electrically connected together, the two sets thus resulting constituting the two poles, and considerable care is necessary in order that all the connections may be permanent; the only satisfactory way is to use lead throughout, and to melt or "burn" together the joints with an oxy-hydrogen flame. There is then nothing that the acid can corrode and no cracks into which it can work its way so as to spoil a contact. The vessels used for retaining the electrolyte are principally of four kinds, according to the use they are to be put to; hard rubber jars for vehicle and other portable batteries; glass jars for small stationary plants; hard sheet-lead tanks, or lead-lined wooden boxes for medium and large station plants. The plates in the rubber jars rest upon ribs at the bottom; those in glass rest upon the edges of the jars; while in the large alloy and lead-lined tanks they rest or hang by suitable hooks or "lugs" upon glass plates which fit into the end of the cell and stand upon the bottom. (See Figs. 17, 18, 19 and 20.)

Thus far the theoretical side of the storage battery has not been considered, it will therefore be briefly discussed here.

As has been already mentioned, when a battery is fully charged the active material on the positive plates consists of lead peroxide PbO_2 , while that on the negative is porous metallic lead. Knowing that a current passing through weak sulphuric acid liberates oxygen at the pole where it enters the liquid and hydrogen where it leaves, the early investigators supposed that on discharge the oxygen generated at the negative by the discharging current combined with the metallic lead there to produce lead monoxide, while the hydrogen generated at the positive combined with the lead peroxide to form monoxide and water. On charging the cell the reverse process was supposed to occur; namely, the lead monoxide on the positive plate became converted by the oxygen there liberated into peroxide, while that at the negative was reduced by the hydrogen liberated to the state of metallic lead.

But later investigators, notably Gladstone and Tribe, noticed that the density of the sulphuric acid electrolyte always changed when a cell was either charged or discharged, rising on the former and dropping in the latter case. The amount of this change in density which they noticed was much greater than could be accounted for by the old theory, and hence they were led to examine into the chemical composition of the active material at various stages of charge and discharge. Doing this they found that both plates on discharge instead of being converted into lead monoxide were changed to lead sulphate, and hence the drop in density of the acid. Putting these reactions into the form of a chemical equation, we have:



That this reaction represents approximately the changes taking place in the storage cell is now generally acknowledged, but one thing which the equation does not account for is the fact that it is never possible to obtain anything like the full theoretical capacity from a cell. That is, experience has shown that after one half – at the utmost – of the active material has been turned to sulphate, the e.m.f. of the cell has dropped to zero and we can get no further current from it. The exact reason for this is not easy to give with certainty, but it is generally supposed that as lead sulphate is a very poor conductor it is necessary that a considerable amount of lead peroxide and metallic lead respectively be left in the two plates in order that the active material as a whole shall be a conductor.

If the thermo-chemical equivalents of the above equation be considered it is found that a thermal change of 85,700 to 87,700 heat units is involved; and the temperature coefficient of a storage cell is .022 percent per degree Fahrenheit. The well known equation of Helmholtz,

$$E = \frac{U}{23073} + T \frac{de}{dt}$$

(where E is the voltage of the cell, U the heat energy of the chemical reactions involved, T the absolute temperature, and $\frac{de}{dt}$ the temperature coefficient), gives

from these values 1.96-2.01 volt as the e.m.f. of a storage cell at 63° Fahrenheit; while the observed e.m.f. is 1.99-2.01, an agreement which greatly strengthens the theory. Applying to storage batteries the osmotic theory of Nernst, the German investigators Liebenow and Dolezalek conclude that the energy of the discharge is derived from the tendency of the ions of lead peroxide and of metallic lead to go into solution, and surprising as it seems at first sight this view appears to be gaining ground. At various times a great deal of most interesting work has been done upon the theory of storage batteries, yet it must be admitted that the theoretical

development is far behind the practical up to the present time, and it is safe to say that, as in the case of most useful inventions, if the pioneers in the art had waited for a full theoretical knowledge the invention would never have been made.

Properties. – The fundamental property of a storage cell is its capability of storing energy, as the name implies. As has been pointed out, the source of the current of the battery is chiefly chemical energy. On the discharge of the cell this is converted directly into electrical energy, whereas on the charge the original chemical constituents are reproduced, with a consequent absorption of energy. The useful energy given out by the cell during discharge is of course never quite equal to that put in during the charge; both the quantity of electricity and its P.D. (that is, the difference of potential between the terminals of the cell) being smaller than in the former case. When a cell is discharging at constant current, its P.D. continually falls off until it reaches zero, the drop being very much more rapid as the end approaches. These phenomena are very much more easily understood by reference to the accompanying illustration (Fig. 21), in which the abscissæ represent time in hours and the ordinates show the P.D. between the terminals. The cell has not been completely discharged until the P.D. reaches zero, but since the latter end of the discharge would be of very little value, and beside this it is found very injurious to the cell to completely exhaust it, the usual practice is to stop the discharge when the voltage reaches some definite value, usually 1.8 for the normal rate, 1.7 for the hour rate, and the “capacity” is the number of ampere hours given out to this point. Similarly when a cell is charged with constant current the P.D. gradually rises as illustrated in the upper curve (Fig. 21), but here it will be noticed that there is quite a definite point when the charge is completed, namely when the P.D. reaches a maximum value, as at the point marked “B”; this point “B” shows that the plates have absorbed as much oxygen and hydrogen as they can hold, and if the cell be examined at this time these gases are found to be liberated in large quantities, causing a boiling or “gassing” that is very characteristic of the charged cell.

The capacity of the cell, that is the number of ampere hours it can give out on discharge is generally the measure of its useful size, and is the chief property by which it is bought and sold. A consideration of some of the most important points bearing on capacity is therefore of the highest importance. Firstly, the capacity of an individual cell is by no means constant, as might at first thought be assumed. The capacity at any given rate of discharge varies directly as the temperature, and at constant temperature inversely with the rate of discharge. Within the ordinary range of working temperatures the capacity varies very nearly 1 per cent for every two degrees above or below 70° Fahrenheit.

Inasmuch as the energy of the cell is derived from the chemical substances which compose it, it would seem that the energy obtainable at a given tempera-

ture would be quite independent of the rate of discharge; such, however, is not the case, for when a high discharge rate is used the active material at the sur-

down to the lowest weight, the amount of acid is very small and the capacity consequently varies but little with rate. In the case of a cell with a large excess of acid the capacity varies nearly inversely as the square root of the rate of discharge, whereas in the case of automobile batteries it is much more nearly constant, being sometimes as low as the fifth root of the current; both these rules holding only within the ordinary range of currents. The variation of capacity with the rate is also somewhat dependent upon the type of plate used, since with very thin or very porous plates the acid is able to attack all parts of the active material more readily than with a thick or very compact one; but the effect of different kinds of plates upon this phenomenon is not so marked as might be expected.

In stating the capacity of a battery it is thus necessary to specify the rate at which it is to discharge, and the rate ordinarily assumed is that which a battery of stationary type can maintain for eight hours; or for three or four hours if of the vehicle type. In the lightest types of vehicle batteries it is found possible to obtain about 15 ampere hours per pound of active material, or 26 per cent of the theoretical capacity, but when the lead grids, acid, jar, connecting straps, and other accessories are included beside the active material, it is found that practically the best attainable for commercial conditions is five to six ampere hours per pound total weight of cell; while in the large station types about one third this figure is attained.

A few words with particular regard to the electrolyte may be in place here. The two main functions of the electrolyte are first as a conductor of the current from one plate to the other, and secondly to furnish sulphuric acid, which shall enter into combination with the active material of the two plates on discharge. So far as the first function is concerned it would be preferable to use sulphuric acid solution of about 1.25 specific gravity, since that density gives the greatest conductivity. So far as regards the second function, the greater the density of the acid the better, since this would mean that a smaller total weight of electrolyte would furnish the necessary amount of acid for the discharge of the plates. But, unfortunately, there is a third consideration which must be given due weight, and that is the physical effect of the acid upon the plates. It is found that as acid above 1.2 specific gravity is used it begins to have an injurious effect upon the plates, whereas if under 1.15 it fails to carry out properly the second function, and in consequence the full capacity of the plates is not available. For ordinary usage, therefore, the electrolyte is used which shall be about 1.2 specific

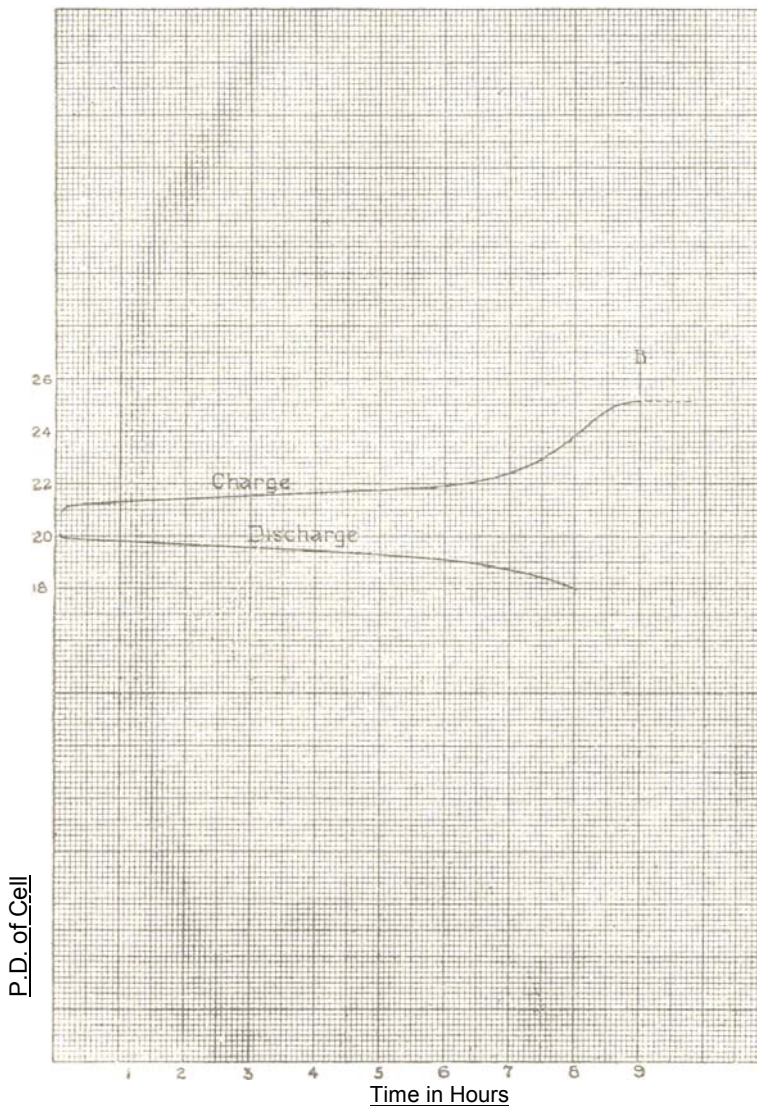


FIG. 21

face of the plate becomes quickly sulphated and forms a partial shield which prevents the acid from acting upon the material throughout the mass of the plate. On this account all types of lead storage battery give considerably less capacity at high rates of discharge than at low but the amount of variation depends largely upon the construction of the cell.

Secondly, from the chemical equation of the discharge of the battery it follows that the amount of sulphuric acid available puts a limitation upon the capacity of the plates, and hence if the amount of acid in the cell be very small, so that at even high rates it is all used up, the capacity can be no higher at a low rate. This condition is never fully realized in practice, but in small cells for automobile use, where everything is cut

gravity in the charged condition of the cell, and in such amount that on discharge of the cell it will drop to about 1.15. In the automobile cells, however, it is usual to use acid that is somewhat heavier than this – as high as 1,250° to 1,300° – in order that a smaller amount of it may suffice to furnish the necessary lead sulphate on discharge; the slightly less endurance of the plates being more than made up for the smaller total weight of the cell.

The mean P.D. of a battery on discharge may be taken at 1.9 volts, so that the maximum energy capacity is – for the vehicle type – about 10 to 12 watt hours per pound; or, in other words, if all the energy of the cell could be expended in lifting the latter it would raise it 26,600 to 31,900 feet high. The magnitude of this figure is perhaps better realized by noting that it is about 100 times as great as the amount of energy which can be stored in a pound of elastic rubber, and 1,700 times as great as the amount that can be stored in a pound of steel wire having an elastic limit of 60,000 pounds per square inch.

The next important property of a battery is commonly its efficiency, and this is one the determination of which requires considerable care. Two curves of charge and discharge (Fig. 21) are sufficient to give the efficiency, but a chance for error lies in the fact that it is difficult to tell whether both of these curves will represent the performance of the battery for a continued period. It is found always necessary to charge for a greater number of ampere hours than are taken out on discharge, and the only way to tell how much this "overcharge" must be is to run a battery continuously for some; time and carefully measure each charge and discharge. By carrying this out it is found that from 5 to 10 per cent more must be put in, in order to keep the battery in a properly charged condition than is taken out. Furthermore, as these same curves illustrate, the mean voltage on charge is considerably higher than on discharge, and here is another source of loss. Taking the battery working at its eight hour or normal rate, the mean charge voltage will approximate 2.21, the mean discharge 1.91; summarizing, then, the voltage efficiency is 86 ½ percent, the ampere hour efficiency is 92 ½ percent, and the watt hour efficiency 80 percent.

This last figure, the energy efficiency, is that which may be commonly obtained from a battery continually worked to its full normal rate capacity. A battery on the other hand, performing "regulating" work, that is, the steadying of a load which is subject to very large fluctuations of short duration, is called upon to alternately discharge and charge at rates as high as four to eight times the normal, lasting, however, for fractions of a minute only. Working at this service it is usual to give an overcharge once in several days, or once a week, and in the interval the battery is working at an ampere hour efficiency of almost unity, since the plates, being always only partly charged can always take up all of the charging current without the development of any gas. The periodic overcharge reduces the mean efficiency somewhat, so that 94 to 96 per-

cent is usually obtained in this kind of service. The voltage efficiency in this case is not materially different from that already considered, for while on the one hand the loss due to internal resistance is higher, on the other hand the successive cycles of charge and discharge follow each other so closely that the P.D. has not time to reach its ultimate value before the current is reversed and another value sought. The mean voltage which a battery maintains under these conditions, commonly called its "floating point," lies between 2.05 and 2.1 per cell; and the shorter the intervals of charge and discharge and the lower the current the less is the departure from this mean value, while long intervals and higher currents cause the voltage to fall more on discharge and rise more on charge with intervals such as commonly occur of from a quarter of a minute to a minute duration, and with current rates of four times the normal, the variation may be taken as 5 to 8 per cent on both sides of the floating point, and the watt hour (or energy) efficiency will then approximate 90 per cent.

To summarize the whole question, the efficiency of a storage battery in practical operation is usually between 75 and 90 per cent, the former figure applying where current rates are high and the battery plates large, and where full capacity is used, the latter where, though the current may be high, the duration of each discharge is very brief; and the efficiency attainable in any given case is also somewhat dependent upon the temperature, type, and general condition of the battery.

The resistance is frequently an important consideration in the operation of a large battery plant, and it is the remarkably low value of this quantity which makes it possible to draw from a storage cell a very much heavier current than from a primary cell of similar dimensions. Depending upon the size and type of plates, the separation, and the condition of a cell as to whether charged or discharged, the resistance varies between .03 and .08 ohms, divided by the normal or eight hour rate of the battery in amperes, the lower value holding nearly constant throughout most of the discharge followed by a rapid rise near the end. The resistance here referred to may be called the virtual resistance, being obtained from two readings of the cell voltage, first with current flowing and second on open circuit, and the difference between these two readings, termed the "drop," divided by the current, gives the virtual resistance. This virtual resistance is composed of two main factors, the resistance proper of the electrolyte, the plates, connections, etc., and a certain polarization resistance at the surface of the plates, and the accurate measurement of each of these factors separately is a matter of so much difficulty that it is seldom attempted.

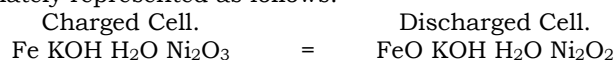
Storage Batteries Other Than Lead. – Thus far there has been considered but one genus of storage battery; namely, that using lead or lead compounds as the active material, and dilute sulphuric acid as the electrolyte. To the present time no storage cell using other constituents than these has come into any ex-

tensive use, but there are three other classes which deserve to be noticed. The first class, the zinc-lead cell, may be regarded as a cross between the ordinary primary cell and the lead storage cell, since in the matter of a negative it follows the former class, and in the matter of a positive the latter, while the electrolyte is sulphuric acid, used sometimes with the primary, always with the lead storage battery. Upon discharge the zinc constituting the negative is dissolved to form zinc sulphate, while the lead peroxide on the positive is reduced and converted into sulphate. Since it is always troublesome to continually dissolve and re-deposit the material of a plate without destroying its original shape, a plan frequently adopted in this class of battery is to deposit the zinc upon a thin pool of mercury in the bottom of the jar, which keeps it always fully amalgamated and tends to prevent its dissolving by local action. This expedient, however, necessitates an awkward construction of cell, with very high resistance, and it is found in practice to have a very low efficiency beside, though it has the advantage of giving a very high P.D. of between 2 and 2.25 volts. This class of cell is applicable only where low currents are used and where weight is not a great factor.

The second class of storage battery, other than lead, is known as the copper-zinc, and its chief distinction from those heretofore considered is the use of an aqueous solution of caustic potash as electrolyte. The negative, as in the last class, consists of metallic zinc which dissolves on discharge, but the positive is composed of cuprous oxide, which on discharge simply becomes reduced to the metallic state. This class possesses the disadvantage of the first class, that it is very troublesome to dissolve and re-deposit the zinc continually without its becoming very lumpy and uneven, and moreover the cupric oxide which may be formed on overcharge is slightly soluble and may thus cause a great deal of trouble. A further drawback incident to this class is its exceedingly low P.D. of only .8 volt.

The third class holds much the same relation, to the copper-zinc as the lead cell holds to the lead-zinc,

for it uses caustic potash solution as electrolyte, but replaces the soluble zinc negative by a grid pasted with an insoluble metallic sponge. Upon discharge, the metallic sponge becomes oxidized, while the metallic oxide on the positive becomes reduced, and on charge the original condition is reproduced. A great many experiments have been made, notably by Edison in this country and Jungner in Sweden, to determine the best active materials to use in this class of battery, but so far apparently without any very definite result. For the negative, iron and cadmium have been somewhat successful, while for the positive, nickel, cobalt, copper and silver have been recommended. The chemical reactions taking place in a cell of this class are approximately represented as follows:



It will be noticed that this reaction is very simple and direct as compared with the reactions of any of the other classes of storage batteries, since the electrolyte maintains its composition unchanged and acts simply as a means of transporting oxygen from one plate to the other. The energy of the discharge is derived solely from the greater affinity of iron than nickel for oxygen, and consequently this class, is often called the "oxygen lift" battery. The advantages claimed for this class of battery are greater capacity per unit weight, and longer life, against which must be counted the low P.D. of only 1 to 1.25 volts; and up to the present time the claims have not been commercially demonstrated, so the ultimate success of the class yet remains to be determined,

The lead storage cell on the other hand, in spite of some inherent faults, possesses such well established valuable qualities that it is constantly proving itself a commercial necessity, and is now recognized both in this country and in Europe as a standard piece of electrical equipment, in just the same light as are boilers, engines, and dynamos. See BATTERY; DYNAMO; ELECTRIC BATTERIES. HERBERT LLOYD, F.eS.,

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