SECONDARY BATTERIES

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A description of the Modern Apparatus for the Storage of Electrical Energy.

BY

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Illustrated.

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PREFACE.

This little treatise is neither intended for a text-book nor a scientific dissertation upon the theoretical considerations involved in the construction of apparatus used for the storage of electrical energy. It is merely an attempt to bring together and describe the recent commercial developments of Planté's original discovery—the lead secondary battery. My information has been derived from a variety of sources, mainly from electrical publications, the inventors or manufacturers of storage cells, and from personal experience obtained in the manufacture and management of this class of apparatus. Doubtless errors in the text will be found, some of which may be traced to the difficulty experienced in obtaining reliable information with reference to the methods of manufacture and capabilities of the different types of cell considered. In the treatment of my subject I deemed it advisable to divide it into five sections. Parts I., II., and III. deal with the construction and characteristics of the best-known types of storage cells; Part IV. contains information about the electrolyte employed in these cells and the instruments used for determining its density; and in the Appendix a few particulars and figures are given which I trust may be found of service to those who are not conversant with our present system of electrical measurement, or the technicalities of the manufacture of the materials usually employed in this class of apparatus.

In conclusion, my best thanks are due to my friend Mr. J. T. Ewen for assisting me in correcting the proof sheets, to Mr. C. H. W. Biggs for placing at my disposal a number of the diagrams, and otherwise affording facilities for acquiring information about my subject; and also to those inventors and manufacturers who have kindly given me particulars of their inventions or manufactures.

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CONTENTS.

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INTRODUCTORY.

Voltaic electric cells may be divided into two distinct types—viz., Primary and Secondary. In a primary cell the electrical energy is developed by the direct chemical decomposition of the excitant or electrolyte, and of one or both of its elements, the magnitude and rate of such electrical development being chiefly dependent upon the chemical activity of the materials employed. A secondary, storage, or accumulator cell is the name given to that class of apparatus which, although quite inert in itself, yet on the passage of an electric current through it, certain chemical changes are induced which render it capable of receiving, retaining, and redeveloping a certain amount of electrical energy, the ratio between that amount of energy put in and returned being dependent upon the chemical nature of the materials employed and the mechanical construction of the cell.

The idea of electrical storage is not new, as it may be traced back to the year 1801, when Gautherot demonstrated the fact that platinum or silver wires, when used in the electrolysis of saline solutions, developed secondary currents. A little later, Ritter constructed his secondary pile, which consisted of discs of copper separated by cloth moistened with sal ammoniac solution. From the combination of a number of these elements a shock was obtained after the pile had been joined for a few moments to the terminals of a powerful galvanic battery. Subsequently Volta, Davy, Becquerel, Marianini, and others found by experiment that such substances as gold, silver, and platinum, when subjected to electrolytic action in certain solutions, gave transitory secondary electric currents.

In the year 1842 Sir William Grove constructed his classical gas battery which acquired its power from the difference of the polarity of the gaseous constituents of water—viz., oxygen and hydrogen. The electrodes consisted of two strips of platinum foil immersed in a solution of sulphuric acid and water. With a battery of 50 of these cells Grove produced an electric arc-light, chemical decomposition, and many other similar effects with which we are now so familiar.

Michael Faraday, when electrolysing a solution of acetate of lead found that peroxide of lead was produced at the positive, and metallic lead at the negative pole of his electrolytic bath, and in his "Experimental Researches" he comments upon the high conductivity of the lead peroxide and its power of readily giving up its oxygen.

Wheatstone, De la Rue, and Niaudet all seem to have been well aware that peroxide of lead, or even minium, might be utilised as a powerful depolariser in certain forms of primary batteries.

Although earlier experimentalists are known to have found that certain substances, when subjected to the action of an electric current in an electrolysable solution, will store electric energy, Gaston Planté seems to have been the first to thoroughly appreciate the importance of this phenomenon; and there really seems to be some doubt as to whether he did not anticipate Camile Faure in foreseeing the great economy to be gained in point of time by applying salts of lead to the unformed lead plates. R. Jamins, in his work entitled "Recherches sur les Accumulators Electriques," says, "Le grand inconvénience de la pile Planté reside . . . dans la longue durée exigée pour sa formation. M. Planté avait bien supposé qu'en deposant du minium sur les electrodes en plomb, il reduisait le temp de la formation de ses couples; mais il ne parvint jamais a donner un adhérence suffisante au minium que recaillais et finissait par disparâitre." Again, Jablochkoff in a provisional application for a patent, No. 1,745, of 1881, says, "M. Gaston Planté proposed to apply to the metal or other electrodes (in a secondary battery) a layer of oxide, rendering the surface both rough and porous." On going carefully through the original work and Mr. Bedford Elwell's admirable translation of Planté's "Recherches sur l'Electricité," no mention was found of any process of applying an oxide to storage-battery elements for the purpose of rendering them rough and porous, nor were the alleged troubles experienced by Planté in causing the oxides to adhere to his plates, referred to.

On the commercial introduction of the Planté cell, and its subsequent development by Faure and others, much attention was given to the chemical and electrolytic action of an electric current on the elements during their formation, and also during their charge and discharge.

Dr. J. H. Gladstone and Prof. A. Tribe, in several communications to *Nature*, on January 5, March 16, July 13, and October 19, of 1882, and April 19, of 1883, have gone most carefully and ably into the subject of the chemistry of accumulator cells. Much also has been written on this subject by Dr. Silvanus Thompson, Dr. Oliver Lodge, Dr. Frankland, and Messrs. Desmond FitzGerald, Reckenzaun, and many others. A very valuable addition to the literature of this important subject has been recently made by two papers, entitled "Notes on the Chemistry of Secondary Cells," and "The Working Efficiency of Secondary Cells," by Prof. W. E. Ayrton, and Messrs. Lamb, Smith, and Woods.

The precise nature of the chemical changes involved in a lead sulphuric-acid cell, due to the action of an electric current, are not yet fully established, although enough is now known to enable those concerned in their commercial manufacture to construct cells of almost any capacity, and capable of giving any rate of discharge. It is now usual to speak of any given type of storage cells as being of so many ampere-hours capacity per pound of plates, or per pound of cell. In the latter case the precise nature of the electrolyte, and also whether the containing vessel is of glass, earthenware, metal, or wood, must of course be specified.

Since the year 1880 some 700 applications for British letters patent have been made for improvements in electric accumulators, and of these some hundreds have developed into full published patents. The great majority of the suggested improvements are of a mechanical nature, and relate more especially to (1) methods of accelerating the "formation" of the elements; (2) means of preventing the disintegration of the "active" material; and (3) attempts to prevent that great bugbear of all lead accumulators—the warping and buckling of the plates or grids.

It would be quite impossible in a treatise of this description to notice all the ingenious attempts which have been made to overcome the above-mentioned difficulties, but I shall endeavour to point out some of the improvements which at the present time appear to be meeting with most favour.

Storage batteries may be divided into two classes—viz., those in which the active material is formed from the substance of the element itself, either by direct chemical or electro-chemical action, and those in which the chemical formation is accelerated by the application of some easily reducible salt of lead. Elements of the former type are usually called "Planté," and those of the latter "Faure," or "pasted."

PART I.

Cells of the Plante Type.

Plante's Original Secondary Cell.—Planté's first lead elements were of an extremely simple nature, consisting merely of two long strips of thin sheet lead placed one upon the other. To prevent metallic contact between these strips, a long piece of coarse cloth or felt was placed between them. This compound plate was rolled up into the form of a spiral, as shown in Fig. 1, and was then immersed in a solution of one part by

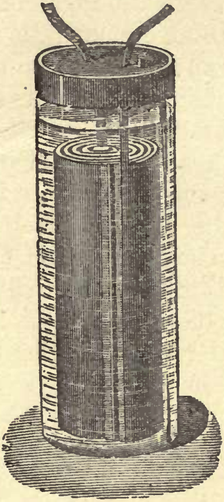

Fig. 1.—Planté Cell.

volume of pure sulphuric acid to 10 parts of water. The charging current was obtained from two Grove cells. It was with this form of cell that Planté made his original and brilliant experiments as described in his "Researches." The "forming" process, as suggested by Planté, was managed in the following way. The current from the primary battery was caused to pass through the secondary couple, until gas was freely given off from the plates. When the charging circuit was broken, a current of high intensity but short duration, was obtained from the accumulator. On examining the elements, that plate which had been joined to the positive pole of the primary cells was found to be coated with a thin film of peroxide of lead. The plate which had been joined to the negative pole of the primary battery was scarcely altered in appearance or even in electrical properties.

At each successive charging the peroxide on the positive plate sinks a little deeper into the metal. This "eating in" operation goes on until there is formed a sufficient thickness of oxide to protect the lead from further electrolytic action. In all cells of the Planté type little or no difficulty is experienced in "forming" the positive element. With the negative element, however, the case is very different. Here the active material is chemically spongy lead, and it is only by the repeated oxidising and deoxidising of the surface of the metal that the necessary depth of this finely-divided lead can be obtained. This, then, is the difficulty experienced in all forms of Planté cells. The usual method employed to produce the desired quantity of active spongy lead is by a system of charging, allowing to rest, and then reversing the current through the cell. By each reversal of current the peroxide is reduced by the nascent hydrogen liberated at its surface during the decomposition of the electrolyte, first into the lower oxide, and then into metallic lead in an extremely finely-divided state. At each successive reversal this oxidising and reducing action sinks more deeply into the substance of the lead, and by careful treatment any desired depth of active material may be obtained. In practice it is found necessary to allow a period of many days, or even weeks, to elapse before a reversal of polarity is effected; because if the peroxide is not allowed to assume a crystalline state before its reduction, the soft loose oxide is forced away from its support by the evolution of gas on the true metal surface of the element due to the current.

To accelerate the "formation," Planté tried a large number of experiments; the most successful being a preliminary treatment of the lead plates with very dilute nitric acid, to thoroughly scour and roughen the metal surfaces, and the application of heat to the cell during the formation, so as to open the pores of the metal and allow the electrolyte to penetrate more deeply into the lead.

Planté found by measurement with a voltmeter that his spiral form of storage cell gave a total current efficiency varying from 88 to 89 per cent. According to M. Geraldy such a cell, containing 1·445 kilogrammes of lead, could store 4·983 kilogram-metres of electrical energy, being at the rate of 3·45 kilogram-metres per kilogramme, or 11·329 foot-pounds per pound of lead.

As previously stated, the exact nature of the chemical changes in a secondary lead sulphuric-acid cell is not yet fully established; but it has been conclusively shown by Dr. Gladstone and Prof. Tribe that sulphate of lead ($PbSO_4$) enters largely into the composition of the active material on both elements in a discharged cell. Analysis has shown that the surfaces of the elements in a newly and fully charged Planté cell consist of nearly pure peroxide of lead (PbO_2) and spongy metallic lead (Pb) respectively on the positive and negative plates.

During the discharge, or if the cell be allowed to remain at rest, the sulphuric acid (H_2SO_4) in the solution enters into combination with the peroxide and spongy lead, and partially converts it into sulphate. The acid being continually abstracted from the electrolyte as the discharge proceeds, the density of the solution becomes less. In the charging operation this action is reversed, as the reducible sulphates of lead which have been formed are apparently decomposed, the acid being reinstated in the liquid and therefore causing an increase in its density. This peculiar alteration in the nature of the acid solution enables us to ascertain at any moment both the state of charge and the general condition of a cell, by simply finding its density or specific gravity by means of a suitable instrument.

De Meriten's Laminated Plates.—Many early experimenters with storage elements of the Planté type devoted much attention to methods of obtaining the maximum amount of active surface for a given weight of lead. Among the earliest of these was M. de

Meritens, who constructed plates made up of very thin lead laminæ, folded one upon another, somewhat like the leaves of a book, the whole being soldered to a stout framework of lead. By this means a rigid plate having a very extensive surface was obtained. Two of these compound plates were placed side by side in a box containing dilute sulphuric acid. A clear liquid space was left between the plates, and no felt, cloth, or other porous separating material of any kind was employed. These plates were then "formed" by the Planté method of charging and reversing, and owing to their comparatively large surface soon acquired a considerable current capacity.

Storage cells of this type seem remarkably well suited for purposes where a very high rate of discharge is required, but in cases where the cell has to retain its charge for a lengthened period, a considerable loss of efficiency is usually observed. This loss is doubtless due to a frittering away of the stored energy by rapid local action set up between the surfaces of the lead elements and the molecules of lead peroxide which are adhering to them.

It is well known that pure metallic zinc will not decompose water, even at such a high temperature as 100 deg. centigrade. Dr. Gladstone and Prof. Tribe, in their admirable researches on this subject, have shown that zinc on which copper has been deposited in a spongy condition was capable of splitting up the molecules of water even at ordinary temperatures, oxide of zinc being formed and hydrogen liberated. If placed in a solution of sulphuric acid and water, it started a very violent chemical action, sulphate of zinc and hydrogen gas being the result. They termed the two metals thus conjoined a *copper-zinc couple*, and they found that this agent was capable of bringing about other chemical changes which neither metal alone could effect. Users of primary batteries, and those conversant with electrolytic action, will at once understand the nature of this agent, and will readily recognise in its effects only an intensified form of that troublesome complaint with which we are so familiar, and which is usually known by electricians under the name of "local action."

In the Planté form of secondary cell the positive plate is a sheet of lead, upon which finely-divided peroxide of lead is distributed. The difference of potential developed by lead and lead peroxide when immersed in dilute sulphuric acid, is as nearly as may be two volts, while that developed by zinc and copper in the same liquid is about 0·7 of a volt. Messrs. Gladstone and Tribe were induced to think that the elements in a Planté cell acted very much in the same way as their copper-zinc couple, and by a series of experiments it was found to be so. They found that the lead peroxide couple decomposed the sulphuric acid with the production of sulphate of lead. The destruction of the peroxide of lead by this action means so much diminution of the available amount of electrical energy. In the early stages of "formation," and when the peroxide of lead on the metal is very thin and small in quantity, its transformation into the white sulphate goes on very rapidly and is frequently perceptible to the eye; but when the thickness of the coating is increased, the time required for the conversion is naturally too long for this kind of observation. During each period of repose which is recommended by Planté, the peroxide on the lead plate is completely, or almost completely, destroyed by local action with the formation of a proportionate amount of lead sulphate. In the next stage, when the current is reversed, the lead sulphate is reduced by the nascent hydrogen which is liberated by the electrolytic action, and the amount of finely-divided lead capable of being peroxidised is largely increased.

From their observations it becomes evident that a lead peroxide plate gradually loses its electrical energy by local action, the rate of such loss being varied according to the circumstances of its preparation, and the general condition of the cell. When elements are employed which have an extensive metallic surface with but a thin coating of peroxide, the relative amount of local action must necessarily be large in proportion to the amount of active material present, and therefore the cell will quickly lose its charge.

De Kabath Accumulator.—A form of cell somewhat similar to De Meriten's, has been devised by M. de Kabath, and has been somewhat extensively used in France of late years. As shown on an enlarged scale, in Fig. 2, it consists of a thin perforated-lead chamber, packed tightly in with a large number of lead strips. To increase the active surface and to allow for the free circulation of the electrolyte, each alternate strip is corrugated or fluted. The commercial form of cell, Fig. 3, is prepared in the following way: A number of lead strips, 1 centimetre wide, 50 centimetres long, and about 1 millimetre thick, are passed between grooved rollers by which they are corrugated in such a way that their length is reduced to 36 centimetres. Straight lengths of the same thickness and width, but 36 centimetres in length, are also prepared. A perforated-lead chamber, 8·5 centimetres wide, is then made, and into this are packed between 180 and 190 of these strips, arranged alternately one plain and one serrated. A perforated lead cover soldered on then completes the box, and a stout lead strip is also lead-burned into the frame for connecting purposes. The complete case now

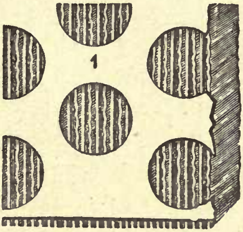

FIG. 2.—Kabath's Plate.

measures 38 centimetres in length, 9 centimetres in width, and a little over one centimetre in thickness, the weight of each element being about 2·2lbs. Twelve of these elements are then placed in a rectangular wooden box lined inside with hard rubber which is separated from the wood by a thin coating of insulation, made by melting arkanson with some paraffin wax.

The complete cell, Fig. 4, which is furnished with handles for convenience of transport, weighs about 84lbs. The formation is effected slowly, and in such a way that the peroxide may adhere as firmly as possible. The process is maintained for several days, the direction of the current kept flowing through the battery

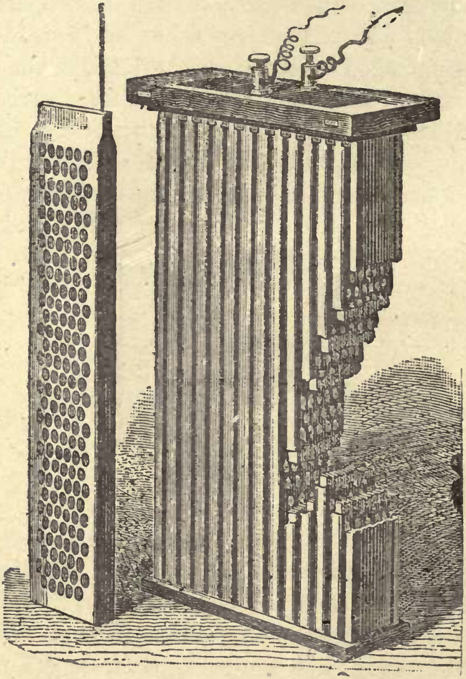

FIG. 3.—Kabath's Element.

being occasionally reversed. The electrolyte is composed of distilled water, to which one-tenth of sulphuric acid, quite free from iron and arsenic, is added. Sometimes one per cent. of nitric acid is added to the solution during the first 200 hours formation. To ascertain the amount of surface to be obtained by rolling a given weight of lead, De Kabath found by trial that one kilogramme of lead rolled out one millimetre thick exposes an active surface of 18 square decimetres; if rolled to $\frac{1}{10}$th of a millimetre, a surface equal to 180 square decimetres may be obtained.

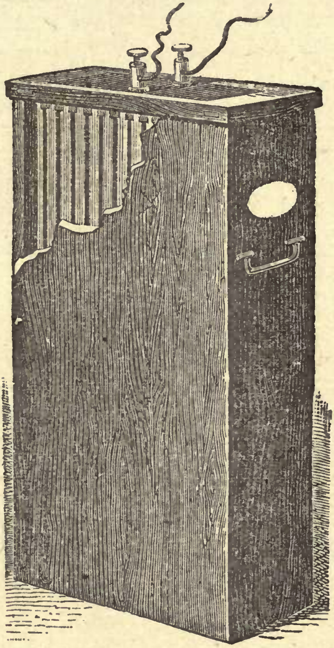
Fig. 4.—Kabath's Cell.

Table No. I., which appeared in the *Révue Industrielle,* is extremely interesting as it gives the whole history of the forming process, and shows by actual observation the capacity of a De Kabath accumulator at various periods of formation, from 75 hours up to 4,000.

TABLE NO. I.—DE KABATH'S ACCUMULATOR.

Number of hours of formation.	Capacity per kilogram of lead.		Weight of lead per horse-power in kilograms.	Energy stored in an accumulator.	
	Kilogram-metres.	Coulombs.		Kilogram-metres.	Horse-power hour.
75	750	5,000	360	15,750	0·058
100	850	5,500	317	17,850	0·065
150	1,000	6,250	270	21,000	0·078
200	1,200	7,350	225	25,200	0·093
300	1,500	9,050	180	31,500	0·116
400	1,750	10,500	154	36,750	0·135
500	2,000	12,000	135	42,000	0·155
600	2,250	13,500	120	47,250	0·175
700	2,500	15,100	105	52,500	0·194
800	2,750	16,400	98	57,750	0·213
900	3,000	17,500	90	63,000	0·233
1,000	3,250	19,000	83	88,250	0·253
1,200	3,750	22,000	72	78,750	0·292
1,400	4,250	25,000	61	89,250	0·330
1,600	4,750	28,000	57	99,750	0·369
1,800	5,250	31,000	51	110,250	0·408
2,000	5,750	34,000	47	120,750	0·447
2,200	6,250	37,000	43	131,250	0·486
2,400	6,750	40,000	40	141,750	0·525
2,600	7,250	43,000	37	152,250	0·564
2,800	7,750	46,000	34·8	162,750	0·603
3,000	8,250	49,000	32·8	172,250	0·642
3,200	8,750	52,000	31	183,750	0·680
3,400	9,250	55,000	29·2	194,250	0·719
3,600	9,750	58,000	27·6	204,750	0·758
3,800	10,250	61,000	26	215,250	0·797
4,000	10,750	64,000	25	225,750	0·836

These data were obtained from an ordinary commercial cell, whose total weight was 30 kilogrammes, made up as follows.

Elements, positive and negative	21 kilos.
Electrolyte, etc.	6 ,,
Wood case, with vulcanite lining	3 ,,
Total weight of battery	30 kilos.

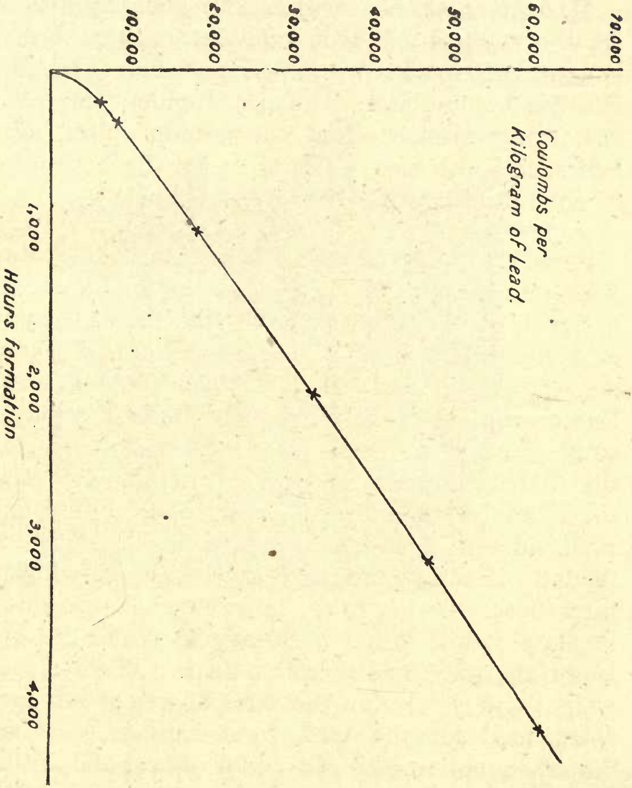

Fig. 5.—Curve, Kabath's Accumulator.

The curve shown in Fig. 5, which has been plotted from the figures as given in this table, may also be of interest, as it shows in a graphical manner the rate of increase in the current capacity of one kilogramme of lead when made up into this form of element, at any period from 75 to 4,000 hours.

M. de Kabath has written a very handy little book on the subject of accumulators, entitled "A Few Practical Remarks on the Formation and Use of Electric Accumulators." This pamphlet contains some useful information about the joining up of accumulators, and also several hints as to the best methods of commutating and discharging them.

Reynier's Accumulators.—The late Emile Reynier gave much attention to the production of secondary batteries of the Planté type. One of his early forms of plate consisted of a thin sheet of lead folded up zigzag fashion, and then encased by a stout cast-leaden ring. By this means he obtained a very large active surfaçe in each plate. During its formation the fluted interior of the positive plate expands considerably, but meeting with opposition from the rigid sides it does not warp or buckle, but merely tends to close in upon itself, and to partially fill up the interstices. Owing to the large expansion in this form of plate, it was found necessary to make the outside lead rim strong, and therefore heavy. To decrease the weight and yet retain the same degree of strength, he substituted for the lead, light iron or steel frames dipped in molten lead or an alloy of lead and antimony. Another form had a long lozenge-shaped hole in the middle of the element. This aperture gradually closed up as the fluted lead sheet expanded. Another and more recent form of battery devised by Reynier is now receiving much attention in France. He called his new battery an "elastic" accumulator, from the fact that means are taken to allow the elements to expand or contract during the charge and discharge without in any way damaging the plates. With this end in view he separated the electrodes by means of thin porous sheets of silica, which only slightly increase the internal resistance of the cells. Each cell contains one positive and two negative plates and four sheets of silica, the two end sheets being fluted so as to increase the space available for the electrolyte, the quantity of which however is small. The containing vessel is of sheet iron, lined with india-

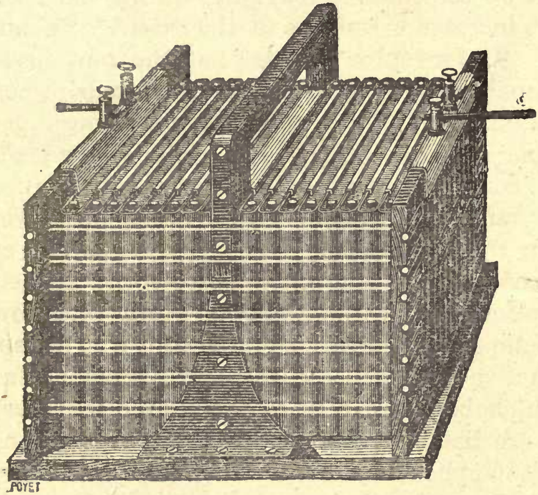

Fig. 6.—Reynier's Elastic Accumulator.

rubber, and is therefore both light and elastic. A still later type of containing vessel is made of pure lead, the necessary flexibility being obtained by surrounding the lead cell with an expansible corrugated case. The plates themselves are made up of very fine lead wires woven into a net, and slightly compressed into the desired shape. A battery of twenty elements is about 50 centimetres long, and during the charge the plates increase in volume to the extent of about 6 per cent. The inventor asserts that the new elastic cells are capable of giving an output of 30 ampere-hours per kilogramme of plate, or 20 ampere-hours per kilogramme of total weight. The cells as now made, Fig. 6, are composed of a number of elements connected in series, and placed between two rigid end pieces which are drawn tightly together by strong indiarubber springs. The contractions and expansions of the elements can take place freely without disintegrating them, owing to the action of the springs. The spring arrangement gives the active material considerable artificial elasticity, which enable these cells to be used for purposes where they are liable to receive rough treatment, and they are also applicable where cells are required to give a high output for a limited weight of cell.

The following data of a 15-cell Reynier elastic accumulator may serve as an indication of the capabilities of this form of battery:

Total electromotive force	32 volts.
Electromotive force at terminals ...	28 volts.
Safe rate of discharge.......	3 to 6 amperes.
Average available energy	150 watts.
Capacity	30 ampere-hours.
Work (available)......................	740 watt-hours.

Total weight of battery	110 pounds.

External dimensions of battery :

Length	16 inches.
Breadth...................................	12 ,,
Height	12 ,,

Several other forms of accumulator elements are due to Emile Reynier ; among these will be noticed the lead-wire plate as devised jointly by him and M. Siemen, and his lead-zinc battery.

Montaud's Elements.—The chief feature in Montaud's method of forming storage battery elements consists in coating plain or laminated lead plates with a thick covering of electrolysed lead. The electro-deposition of the lead is effected in a solution of potash and water heated to about the boiling point of water. As a current of many hundred amperes is used, the requisite thickness of deposited lead is obtained in about 30 minutes. On leaving the depositing bath, the plates are well washed, and to ensure adhesion they may be subjected to pressure. Lead, when treated in this manner, resembles the ordinary metallic sheet lead, but it is

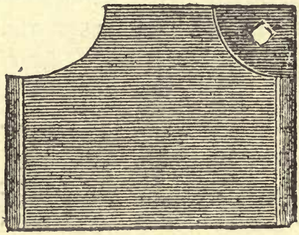

FIG. 7.—Montaud's Plate.

really in a chemically porous condition, and is therefore in a suitable state for being quickly converted into active material. The plates are of a rectangular form, sloped out at one corner, as shown in Fig. 7, and as two plates in juxtaposition are cut together, the sloping out of the one serves for the handle of the other when they are separated. This handle is doubled back on the plate, which is suspended in the bath, so that the part of the plate which has to be soldered does not need any special preparation. A hole pierced in this corner of the plate serves to receive a square ewter rod of lead or white metal, which connects the plates together and forms one of the poles of the accumulator. The plates and square conductors are lead-burned together by means of the oxy-hydrogen blowpipe flame. The elements are rigidly held at a distance apart of about one centimetre by means of two stout grooved wooden combs. To still further increase the rigidity, side combs are also employed. By means of these tight-fitting separators the plates are so firmly secured that it is possible to remove them from their containing cell without in any way displacing or otherwise injuring them. The elements, when finished, have the appearance shown in Fig. 8.

As the result of many experiments, M. Montaud found that with his form of elements he obtained the best results with a charging-current density of 10 amperes per square metre of active surface, and a discharging current of 20 amperes. In all cases he calculates the capacity of his commercial cells, not by the weight or thickness of the elements, but from the total amount of surface exposed, and accordingly they are classified in these terms. Thus they may have from one to 12 square metres of surface, and the number corresponding to the surface indicates its weight of useful lead, its rate of charge, its capacity, and its rate of discharge. For a "No. 10" accumulator we have an active surface of 10 square metres, a charging current of 100 amperes, and a useful discharging rate of 200 amperes. A square metre of lead of the thickness of one millimetre weighs about 11 kilograms. As both surfaces of the lead are utilised, their weight per square metre in the battery is reduced to 5·5 kilograms, so that a No. 10 requires 55 kilos of useful lead. It will now be

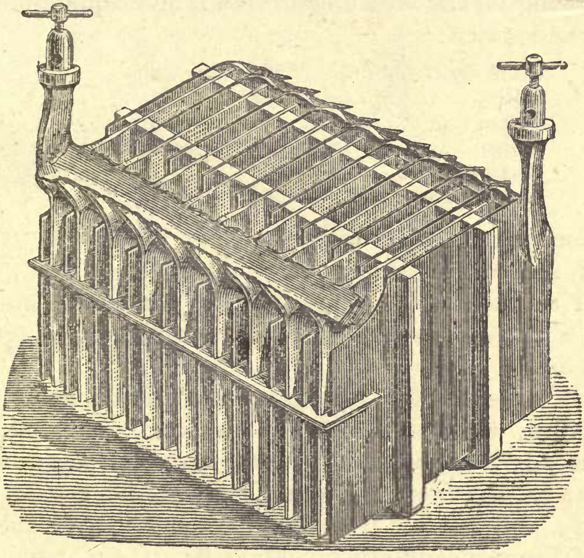

FIG. 8.—Montaud's Complete Element.

seen that, according to this rule, an increase in the thickness of the sheet lead would merely augment the weight of the cell, without affecting its capacity or its rate of charge and discharge.

According to some tests made with an early form of the Montaud elements, Dr. d'Arsonval obtained the following results with a cell containing 2 square metres of lead surface:

Useful capacity	40 ampere-hours.
Total	62 ,, ,,
Surface	2 square metres.
Charge	10 amps. per square metre.
Discharge	20 ,, ,, ,,
Useful weight of lead	10 kilograms.

Representing a total capacity of six ampere-hours per kilo., and of a discharge of 5 amperes per kilo., or a total capacity of 31 ampere-hours per square metre, and a useful capacity of 20 ampere-hours per square metre.

Subsequently the negative element was somewhat modified, with the result that an accumulator, having exactly 1·75 metres of active surface, acquired a current capacity of 87 ampere-hours, and on its comparison with a cell having 2 square metres of active surface the following results were obtained:

Useful weight of lead per square metre..........	5·5	kilos.
Total capacity of useful lead per kilo.	9·1	amp.-hours.
Total capacity per square metre......	50	,,
Useful capacity per kilo. of useful lead.........	6·23	,,
Useful capacity per square metre	34·30	,,
Current of charge per square metre	10	amperes.
Current of charge per kilo. of useful lead......	2	,,
Current of discharge per square metre	20	,,
Current of discharge per kilo. of useful lead	4·56	,,

Elwell and Parker's Cylindrical Elements.—Shortly after the introduction of the Planté cell Messrs. Elwell and Parker obtained a patent in this country for an improved form of circular element, which at the time was found to be of much service as a current regulator for the not too steady dynamos which were then being used on electric lighting circuits. These cells were prepared in this way. Perforated sheets of lead, weighing about 2lb. per square foot, were cut about 9in. wide, and were then rolled spirally into different size cylinders. These lead tubes were placed concentrically within a circular earthenware vessel, alternately a positive and then a negative. Each cylinder had burned to it a stout projecting lug which served

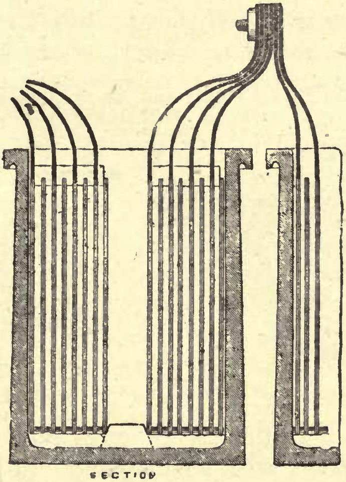

Fig. 9.—Elwell-Parker Cell.

to join the elements of like polarity together, as shown in the engraving, Fig. 9. A clear liquid space of about ½in. was allowed between each cylinder. To retain the elements in position, notched vulcanite frames were placed at their base, and grooved cross-bars of the same material were tightly wedged in at the top, as shown in the plan, Fig. 10. As the elements were merely held together by the screw clamp, Fig. 11, it was at all times an easy matter to take the cell apart and to reinstate it. The lead tubes being perforated, the electrolyte could freely circulate, and as the electrolytic action was very nearly uniform on all surfaces of the metal, buckling or warping of the elements seldom occurred. In the forming process the lead was first placed in a bath containing a mixture of dilute sulphuric and nitric acids, and was left in this to pickle for about twenty-four hours. This preliminary treatment was found to materially hasten the formation. To remove all traces of the mixed acids, the cylinders were thoroughly washed in water. By a system of charging and reversing in the ordinary dilute sulphuric

Elwell-Parker's Cell and Element Clamp.

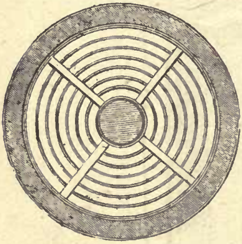

FIG. 10.

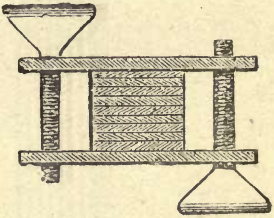

FIG. 11.

acid electrolyte, these elements soon acquired a considerable current capacity. If at any time the cells showed symptoms of sulphating, it was usual to run them down gradually, and then finally short-circuit them. After this the current was reversed, and in a few days the battery would be capable of taking its full original amount of current.

Cheswright's Improved Plante Elements.—This form of battery, as made by Messrs. Betts and Co., of Carcassonne, is somewhat novel in construction. The metal used for both elements is pure, specially refined, sheet lead. Each element is so constructed that its interior is quite hollow, and is divided into vertical chambers by thin lead partitions running throughout the whole length of the plates. By passing the lead sheets through suitably shaped rollers, each surface is closely corrugated into a series of raised dovetailed-shaped rims. By treating the sheet lead in this way a large increase in the amount of active surface is obtained, which is said to be at least four times as large as the corresponding surface of a piece of plain lead of the same dimensions. During the rolling process the lead is subjected to great pressure, which tends to close up the grain or pores of the metal, and make it both dense and elastic. The flutings on the spongy lead plate, Fig. 12, are made as close together as possible, while those on the peroxide plate, Fig. 13, are somewhat wider apart. During the formation of the positive plate the metal, as it is being converted into the peroxide, expands, and the active material wedges itself into the dovetailed grooves, thus securing itself against disintegrating influences. Owing to their elasticity these cells are said to be capable of withstanding very rough treatment. In building up the cells a number of these hollow plates are fitted into a stout wooden frame, and are held in their proper positions by means of massive cross-bars made from the substance of the plate, and being part of it. These cross-bars drop into recesses made in the top of the

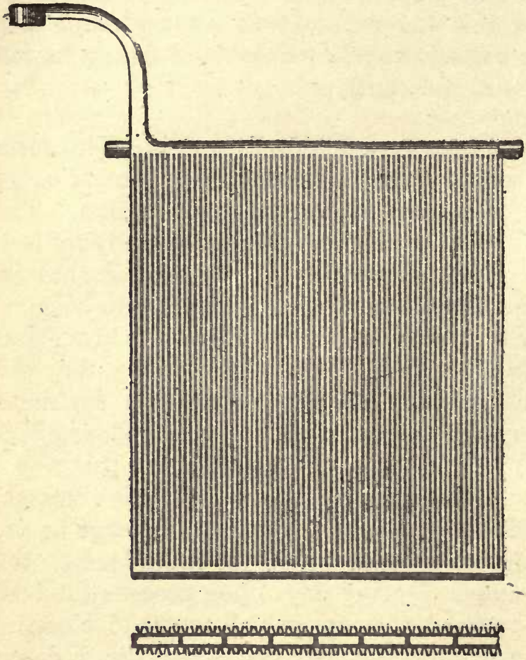

FIG. 12.—Cheswright's Spongy Lead Plate.

wood frame, and securely hold the plates in their respective positions. As the whole system of plates is firmly fixed in the supporting frame, they may at any time be removed from the glass containing-cell for inspection purposes without fear of damage.

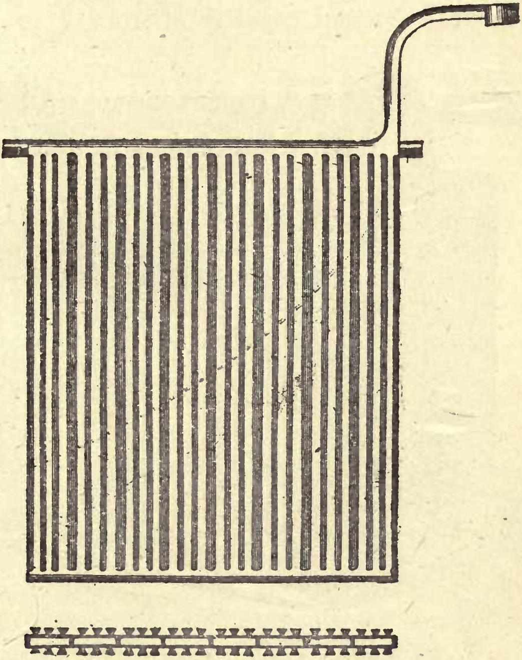

FIG. 13.—Cheswright's Peroxide Plate.

The advantage of this arrangement is very apparent, as a good method of quickly and safely removing storage-battery elements from their containing cells for the purpose of examining, cleaning, and repairing is very desirable. Fig. 14 shows the details of construction and conveys a good idea of the general appearance of a complete cell. These cells are said to have a current capacity of from 7 to 9 ampere-hours per kilogramme of plate—the capacity varying from the lower to the higher figure according to the dimensions of the cell. The working current efficiency is given as from 80 to 90 per cent. Table No. II., which has been supplied by the manufacturers, shows

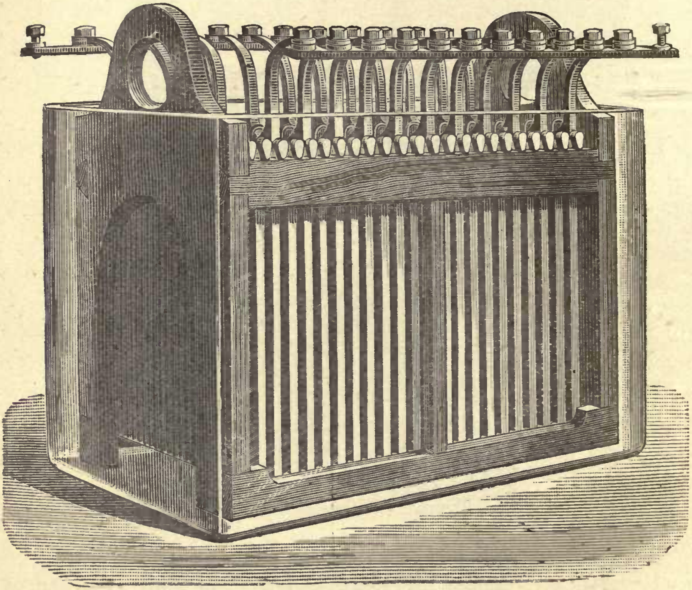
Fig. 14.—Cheswright's Complete Cell.

the total weight of the elements in each cell, their current capacity, and the rate of charge and discharge which is found to be the most economical.

TABLE II.

No.	Weight of plates.	Current capacity.	Rate of charge.	Rate of discharge.
	kilos.	amperes.	amperes.	amperes.
0	5	30	1 to 5	3
1	10	60	3 ,, 15	8
1½	15	90	4 ,, 22	12
2	20	130	5 ,, 30	15
3	30	195	6 ,, 45	23
4	40	260	8 ,, 60	30
5	50	325	12 ,, 75	38
10	100	675	25 ,, 150	75
20	200	1,500	50 ,, 300	150
50	500	3,750	125 ,, 750	275

Thus far, in considering the Planté type of storage cell, we have only mentioned those forms in which the active material has been produced by direct electrolytic action upon the substance of the lead element itself. Much however has been done in the way of accelerating the formation, by chemically converting the lead surfaces into some easily reducible salts, by utilising an agglomerated mass of mechanically divided lead, or by increasing the chemical porosity of metallic lead by alloying it with some metal or metals which can be readily eliminated.

In the year 1884, Prof. Tribe endeavoured to hasten formation by converting the surface of lead into sulphides, arsenides, or phosphides, and then reducing these salts into the form of spongy lead by electrolysis.

Schulz proposed coating lead electrodes of secondary batteries with a layer of sulphur, and then heating them until the sulphur combines with the lead to form a coating of lead sulphide. After being thus treated, the plates were placed in dilute sulphuric acid, and formed by the Planté process. By electrolysis the sulphur is converted into sulphuretted hydrogen and sulphurous acid gases, which escape, leaving a layer of porous lead on the electrodes.

Monnier's method of making lead plates porous and easily acted upon by the electric current, was to make an alloy of lead, with about 4 per cent. of zinc. This alloy was cast into any desired shape of plate, and was then subjected to the action of dilute sulphuric acid. When the zinc had quite dissolved out, the plates were found to be in such a condition that they could be readily converted into both positive and negative electrodes.

Messrs. FitzGerald, Beaumont, Biggs, and Crompton utilised alloys or mechanical mixtures of lead and other metals, such as zinc, tin, iron, antimony, etc., but so far little has come of these combinations.

Epstein's Method of Forming.—Epstein proposes to accelerate the formation of plain lead plates by placing them in a one per cent. solution of nitric acid and water. The solution is then heated until it boils, the boiling being continued until the lead plates have assumed a dull grey appearance, after which they are taken out of the solution and dried in the air. This treatment produces a greyish-yellow deposit of lead salts, which adheres firmly to the plates, and is insoluble in dilute sulphuric acid. In addition, it has the great advantage of being able to absorb the gases liberated in the formation process, so that the latter may proceed quickly and without the necessity of any reversals. Lead treated in this manner is made to serve for both positive and negative plates. In the process of forming positive electrodes, the former greyish-yellow

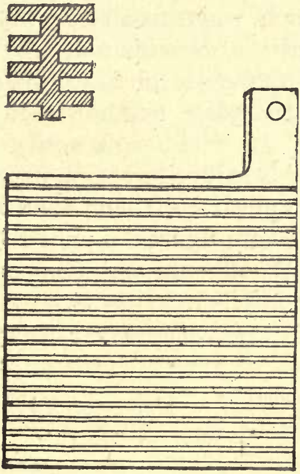

FIG. 15.—Epstein's Element.

colour changes into a deep dark brown, almost a bluish-black hue, and the process is completed as soon as the elements have attained that colour, and an abundant development of oxygen has taken place. The oxygen of the peroxide of lead produced on the positive elements which are to be changed to negative is absorbed by the effect of the electric current, and the bodies are reduced on their surface to porous metallic lead. The process of forming negative elements is finished when the deep dark brown, or bluish-black colour of the positive element used for the purpose has changed into a bluish-grey hue. It is said that only a few hours are necessary to form a plate by this method.

In Epstein's form of electrode which exposes a large surface, and which, when treated by his process, is said to quickly acquire a considerable electrical capacity, the increase in surface is obtained by deeply grooving both sides of the plate as shown in elevation and section in Fig. 15. The soft active material, after being "formed," is said to key itself between the ledges, and it does not appear to fall off even if the battery is roughly used. From figures supplied by the manufacturers, Messrs. Woodhouse and Rawson, the following table has been compiled.

TABLE NO. III.—EPSTEIN'S ACCUMULATOR.

Mark and number of plates.	Weight of plates.	Approximate external dimensions of box.			Working rate.		Capacity. Amp. hours.	Approximate weight of complete cell.
		Length inches.	Width inches.	Height inches.	Charge. Amp.	Discharge. Amp.		
R 3	52 lb.	15	3½	17	1 to 30	1 to 30	120 to 150	81lb.
,, 5	100 ,,	15	5½	17	1 ,, 60	1 ,, 60	240 ,, 300	155 ,,
,, 7	150 ,,	15	7½	17	1 ,, 90	1 ,, 90	360 ,, 450	225 ,,
,, 9	200 ,,	15	9½	17	1 ,, 120	1 ,, 120	480 ,, 600	295 ,,
,, 11	250 ,,	15	11½	17	1 ,, 130	1 ,, 150	600 ,, 750	368 ,,

The normal maximum rate of discharge is given as 30 amperes per positive plate, and for short periods this rate may safely be doubled. The capacity at the above rate of discharge is about 120 to 150 ampere-hours per positive plate; at half this rate the capacity is about 140 to 170 ampere-hours per positive plate. The liquid used is a 10 per cent. solution of sulphuric acid and water.

Woodward's Spongy Battery.—The plates in this type of battery are of a very porous or cellular nature. They are prepared by pouring molten lead upon common house salt, or other similar substance. While in a plastic condition the salt and lead are intimately mixed together and then compressed into the requisite shape. When set the soluble material is dissolved out. The result is a highly spongy element, which it is stated can be readily formed by the Planté method. The plates are mounted vertically in the containing cell, with the usual liquid space between each pair. Another development of this form of battery, said to be suitable for traction purposes, is made by placing the chemically porous plates horizontally, and interposing plates of porous earthenware or other suitable insulating material between them. Another form of element due to Woodward, consists of a perforated tube made of vulcanite, guttapercha, or other non-conducting material, which is filled in with lead filings, shavings, or turnings.

Lead-Wire and Spongy Lead Elements.—Several attempts have been made both in this country and abroad to form storage-battery elements of compressed masses, either of a coarse kind of lead wire, or lead mechanically divided into a fine woolly condition. Mr. Desmond FitzGerald has devoted some attention to this subject, and has succeeded in producing several forms of electrodes made up of lead in this finely-divided state. Watt, of Liverpool, reduced lead to a frothy or woolly state by simply blowing high-pressure steam through a jet of the molten metal. Messrs. Arnold, Tommasi, Tamine, and others wound fine lead wires round lead plates or rods to obtain increased surface. Wires varying from 1 to 2 millimetres in diameter have been tried with some success. By trial it has been found that 1 kilogramme of lead, if drawn out into a wire having a diameter of 1 millimetre, will present a surface of 35 square centimetres.

The idea of obtaining a large active surface within a small compass by the employment of lead wires of small diameter seems good, but in practice I believe the lead wire soon loses its mechanical strength, owing to its becoming peroxidised throughout its entire mass when under electrolytic action. As a result, the active material quickly disintegrates, and soon causes the electrodes to become useless.

Simmen has devised a simple method of manufacturing a kind of fine irregular-shaped lead wire. This wire is made by pouring highly-heated molten lead through a kind of metal cullender having a large number of fine perforations. As the metal runs through these holes in fine streams it is suddenly chilled by dropping into cold water. This sudden cooling causes the surface of the wire to break up and become rough. When lead is treated in this way it is both light and porous, and is easily acted upon either chemically or electrolytically. To form elements suitable for batteries, Simmen takes masses of this lead wire and then compresses them into blocks or slabs of any desired shape. These porous blocks are then placed within a perforated leaden chamber, Fig. 16. By expansion during its formation the wire mass tends to wedge itself tightly in the lead box. The metal receptacle acts as a support, and also as a conductor for carrying off the current. In the complete element the electrolyte can permeate throughout its interior, and the process of transforming the raw lead into both positive and negative plates is greatly accelerated.

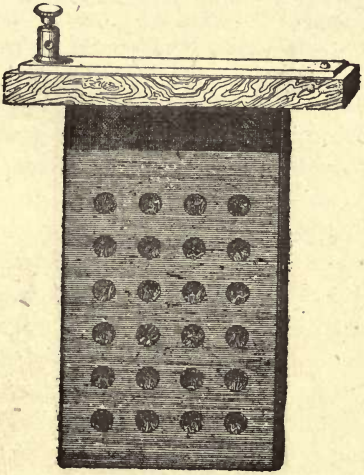

Fig. 16.—Simmen Plate.

The wire produced by Simmen's process is not of even diameter, but it is of a coarse and irregular nature, a peculiarity which renders it highly suitable to the construction of storage battery elements.

Owing to the eating through and ultimate destruction of these leaden containing chambers, the Simmen's agglomerated wire plates did not prove a success. A more lasting form, however, was devised by the joint labours of Messrs. Emile Reynier and Simmen. This plate, which is illustrated in Fig. 17, consists of a highly-compressed mass of lead wire, with a stout metal frame and supporting trunnions cast around it. The rigid metallic envelope effectually resists all distorting influences caused by the current, and is but slightly affected by the weakening action of the oxidisation. The average diameter of the wire in the positive element is

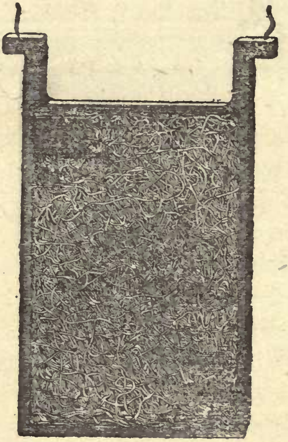

Fig. 17.—Simmen-Reynier Plate.

about 0·5 millimetres, and that of the negative 0·2 millimetres.

The following particulars of the Simmen-Reynier wire plates, given by Reynier, may be interesting:

Width of plate	140 millimetres.
Height ,,	245 ,,
Thickness ,,	4 ,,
Weight ,,	700 grammes.
Surface ,,	5·4 square decimetres.
Current capacity	17 ampere-hours.
Current capacity per kilogramme of plate	7·3 ,,

Dujardin's System of Formation.—The Dujardin elements are rendered active by a combined depositing and oxidising action performed by electrolysis in an alkaline bath of nitrates composed as follows: 10 kilogrammes of water, 2 kilogrammes of sulphuric acid, 1 kilogramme of alkaline nitrate (of soda, ammonia, potash, or other suitable alkali). By the passage of an electric current nitrate of lead is formed, and by the acid of the bath this is converted in a continuous manner into sulphate of lead and afterwards into peroxide of lead. In some hours, without discharging or reversing the current, the positive plates become covered with an adherent layer of crystalline peroxide of lead, which may be over a millimetre thick, and of great electrical capacity. In order to increase and regulate the formation of the salts of lead, it has been found that it is useful to introduce large volumes of air into the liquid. This may be effected either by forcing the air into the bath, by raising and lowering the plates, or by other convenient means; the reaction being thereby doubled whatever may be the composition of the bath. In order to facilitate the adhesion of the peroxide upon the plates, the latter are constructed of laminated lead. In a few hours the peroxide, which is formed at the expense of the lead, fills the interstices in the laminated plate.

To prevent the plates from coming into contact with each other in such a manner as to interfere with the free circulation of the electrolyte and gases, they are corrugated. The corrugations run obliquely across the plates, the obliquity of adjacent surfaces being in opposite directions. Instead of corrugating the plates, projecting points are sometimes raised upon them.

In Fig. 18 are shown the details of construction of a Dujardin element. In the diagram, A represents the surface of the plate, and B an edge view. The form and dimensions of the cellular space, C, may be varied to suit any requirements. The surfaces of the plates, D E, which are opposed to each other are shown opened out, the oblique lines indicating the direction of the corrugations, which in this position of the plates are all in the same direction; but if one plate be turned and laid with its face downwards, then the corrugations will be in opposite directions, and will cross each other, and will only be able to come into contact at points separated by the width of the corrugations. The projecting points, F, will serve to prevent too close contact between the strips.

As the expansion of the serrated strips, during their formation, may amount to fully ten per cent. of their total length, it is not wise to pack them in a rigid frame. To allow for this increase in their dimensions, the plates may be suspended from a bent connecting-

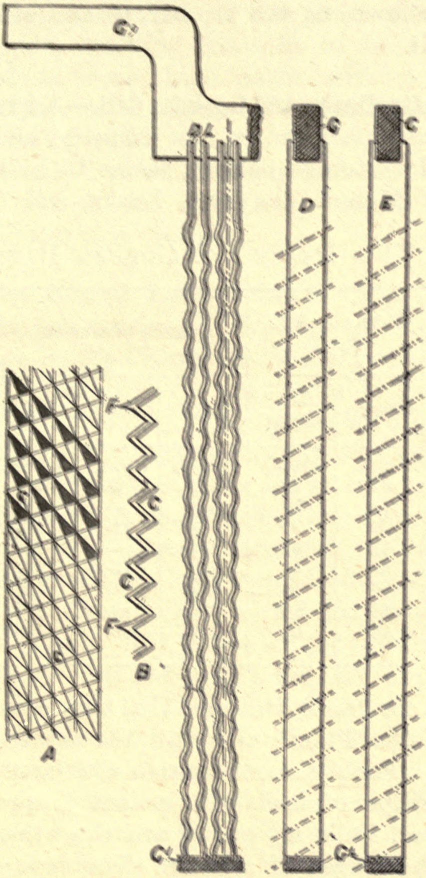

FIG. 18.—Dujardin Plate.

bar, G, as shown in the diagram, so that each plate is quite free to expand downwards. The strips may be secured, as shown, to the top bar, G, and also to the lower bar, G^1.

The Dujardin-Drake and Gorham Cell.—A form of cell now being manufactured in this country, and known as the "D. P." storage battery, seems to be the joint invention of Messrs. Dujardin, Drake, and Gorham.

TABLE NO. IV.—DRAKE AND GORHAM BATTERIES.

Distinguishing letter.	Capacity ampere-hours.	Normal rate in amperes.		Outside dimensions.			Weight of complete cell including acid.
		Charge.	Discharge.	Height.	Length.	Width.	
	Amp-hr.	Amps.	Amps.	inches.	inches.	inches.	lbs.
A	140	12	12	13½	8	12½	65
B	220	18	18	13½	—	12½	90
C	325	30	30	13½	11½	12½	120
D	430	42	42	13½	—	12½	156
E	500	48	48	13½	15	12½	170
F	580	54	54	13½	—	12½	190
G	660	60	60	13½	18	12½	220
H	725	66	66	13½	18	12½	240

It is claimed for these batteries that they combine the durability of the Planté cell with the capacity of the pasted form. Each element consists of a large number of narrow strips of lead with points or projections on their faces, built up one above the other in the fashion of the leaves of a book. The ends of these strips are lead-burned together, and suitable connecting lugs are cast on. In the commercial form of cell a number of these plates are mounted and held in position by means of insulating distance pieces and clamping bars. The construction of the plate affords a large working area, enabling the cells to be charged and discharged at very high rates without producing disintegration or buckling. The formation is effected by Dujardin's process.

Table No. IV. gives the sizes and capacities of this form of cell, which may now be obtained from Messrs. Drake and Gorham.

Crompton-Howell Accumulators.—The elements in these cells are composed of plates of highly porous lead, which by the Crompton-Howell process of manufacture is obtained in a very suitable form for this purpose. The structure of the plates is entirely crystalline, yet they are so porous that almost every individual crystal is freely bathed by the electrolyte, a very large surface of active material being thus presented. The active material, while being electrically deposited, forms a firmly adherent coating to the lead crystals, and as this deposit is formed right through the plate, it does not readily fall away. The plates are mounted on celluloid supports of the shape shown in Fig. 19. These supports rest on the bottom of the containing cells, and are so constructed that short-circuiting on the bottom of the cells is made very improbable. The positives of one cell and the negatives of the next are lead-burned with the oxy-hydrogen blow-pipe on to one bar which is fixed on insulators between the cells, thus providing for a very low resistance in the connections from cell to cell. An additional advantage attained by this method of coupling up is the ease with which any repairs may be effected without interruption of the working circuit, as new plates can be introduced or old ones removed without in any way interfering either with the

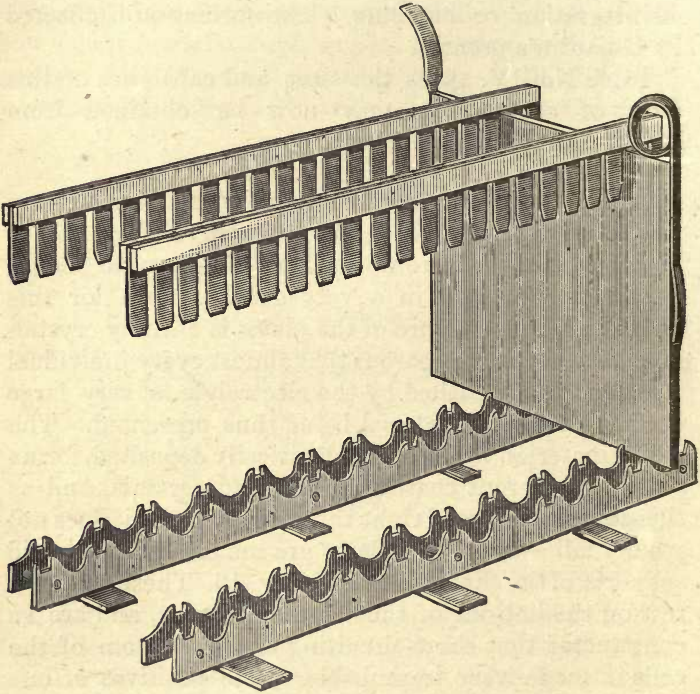

Fig. 19.—Celluloid Rest and Separator.

charge or discharge of the battery. During the electric formation no reversals are required, as the positive plate is converted directly into peroxide of lead, while the negative is reduced into the chemically spongy lead condition. To allow free and thorough circulation of the electrolyte, the plates are spaced widely apart. Many of these batteries are now in use in this country for central-station work, and they are also coming largely into use both for direct electric lighting and as regulators on main circuits. Owing to their very large active surface, this form of element is

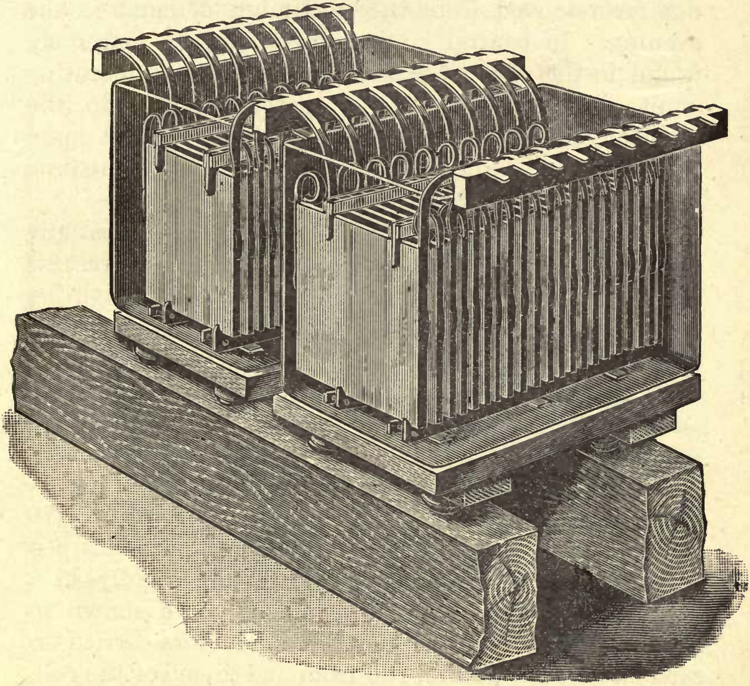

FIG. 20.—Crompton-Howell 21-plate Cell.

capable of maintaining a high rate of discharge—a very essential point, especially in central-station work, where, owing to fogs, etc., the load may suddenly vary from the ordinary light morning demand to an output not far removed from the maximum demand in the evening. In central station work they are extremely useful in the case of a breakdown of the generating plant, as if the cells be properly adjusted to the requirements of the station they may be relied upon to maintain the whole load of lamps for sufficient time to effect at least a temporary repair.

The Crompton-Howell cells are made of almost any capacity within reasonable limits. Fig. 20 represents a 21-plate cell as used for ordinary domestic lighting circuits. Fig. 21 shows a large 61-plate cell as supplied for central-station work. A few particulars of such a cell, capable of giving as high a discharge as 1,000 amperes, may possibly be of interest. The containing vessel is a lead-lined wooden trough, 4 feet 6 inches long by 12 inches wide and 12 inches deep. Each of the 61 plates have an active surface on either side of over 70 square inches. The width of the liquid space between the elements is 0·55in. The plates are rigidly held in position by the form of celluloid comb shown in Fig. 19. Two very massive lead conductors carried on earthenware insulators, run from end to end of the cell, and form the positive and negative poles. The electrolyte used is a solution of sulphuric acid and water, density about 1,250. From such a cell a rate of discharge of 1,000 amperes has been maintained for a period of 30 minutes, and without a very serious fall of potential at its poles being observed. Recently a most interesting report on this form of cell has been given by Prof. A. B. W. Kennedy. The battery under observation was one in use by the Westminster Electric Supply Company, and had been installed just eleven months. The following is an extract from Prof. Kennedy's report, dated Sept. 22nd, 1890:

"The battery consists of fifty-six cells, besides four extra cells, its capacity being nominally 500 ampere-hours. It has been several times discharged, both when under test and when a sudden fog has made great demands upon it, at the rate of 250 amperes for half-an-hour or more, and has stood this discharge without the plates showing any injury, and with no

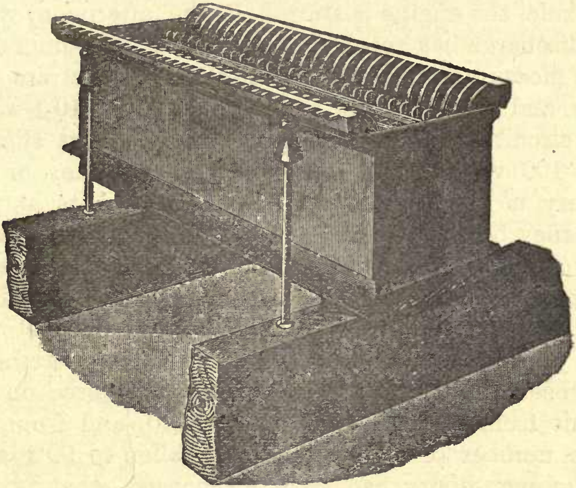

FIG. 21.—Crompton-Howell 61-plate Cell.

appreciable fall of electromotive force below 2 volts per cell. I found in February that the battery was being charged every day with 10 per cent. excess in ampere-hours over its discharge of the previous day. I have gradually had this excess reduced, until now it varies from 4 to 4½ per cent., and I have no reason to doubt that I can reduce it still further. The battery has often discharged more than 500 ampere-hours, but, as a rule, the engine is started in the afternoon, when the discharge has reached about 480 ampere-hours. I have measured very carefully the charging electromotive force, and find that its average value is 110·1 volts. The circuit takes current from the battery at slightly over 100 volts. The actual energy efficiency of the battery is therefore about 86½ per cent. (its ampere efficiency being 95 to 96 per cent.), and this is not on one occasion only, but is the average of many weeks' working. The battery is now in a better condition than it was when first set to work. I find, for instance, that yesterday at 11.30 a.m., after 323 ampere-hours had been discharged, the electromotive force on the circuit from 49 cells was exactly 100, and from the same number of cells it had only fallen to 99·1 after 450 ampere-hours had been discharged—that is, the electromotive force was still 2·02 volts per cell, and this is not an exceptional thing."

PART II.

Pasted or Faure Storage Cells.

Hitherto we have referred only to Planté's original form of lead cell, and its immediate developments. We shall now consider a more commercially important and popular type, usually known as "pasted" or Faure cells.

Camile Faure, seeing the great loss of time and the many inconveniences incidental to Planté's electrolytic method of producing the desired depth of active material upon ordinary lead plates, conceived the idea of accelerating their formation by applying a layer of chemically-prepared oxide of lead to their surfaces, and then converting it into active material by the action of an electric current. To this end he thinly coated lead plates with minium or litharge, made into a thick paste by the addition of acidulated water. When dry these plates were placed in a bath of dilute sulphuric acid, and then subjected to the electrolytic action of a moderately strong electric current. To prevent the disintegration of the lead salt, he interposed between the elements a thickness of porous felt or cloth. After the passage of the electric current, Faure found that the oxide on the positive plate was converted into peroxide of lead, while the salt on the negative had been reduced to finely-divided or porous lead.

The elements in Faure's first batteries were rolled up into the form of a spiral, but this shape was soon abandoned in favour of flat plates. The following data of one of the earliest of these cells will doubtless be of interest: The cell was made up of sixteen plates, 17 inches long by 12½ inches wide. The positive electrodes were $\frac{8}{100}$ths of an inch thick and the negative $\frac{4}{100}$ths. The total quantity of lead oxide pasted upon the elements weighed about 50lbs. To prevent the disintegration of the lead salts, the coated plates were wrapped up, first in parchment paper, and then in stout felt. When these elements were placed in a suitable receptacle, and with the addition of 16lbs. of dilute sulphuric acid, the total weight, including the containing cell, was about 135lbs. According to some tests made with a cell of these dimensions, the following results were obtained:

Duration of discharge.	Rate of discharge.	Total current output.
8 hours	22 amperes	176 ampere-hours.
12 ,,	21 ,,	250 ,, ,,
13 ,,	20 ,,	280 ,, ,,
14 ,,	19 ,,	299 ,, ,,

From these figures it will be seen that a discharge, averaging about 21 amperes, was maintained for a period of 14 hours. Although the current showed a tendency to drop, the discharge was carried on for a period of seven hours, when the output was found to be 5 amperes.

According to Emile Reynier, he found that a Faure cell, constructed on the original plan, and containing 56 kilogrammes of lead and oxide, was capable of storing 210,000 kilogrammetres of energy, or at the rate of 3,750 kilogrammetres per kilogramme of lead.

M. Geraldy found the value to be somewhat lower; he gave the energy capacity as 3,280 kilogrammetres per kilogramme of plate. According to some tests made by Sir William Thomson with one of Faure's first spiral cells, which weighed 75 kilogrammes (165lbs.), he found its storage capacity to be 2,000,000 foot-pounds, or energy to the extent of one horse-power hour.

The Faure Cell Theoretically Considered.—It is not within the province of this treatise to investigate the chemical actions involved in the forms of batteries under consideration, but it may help us somewhat if at this juncture we briefly consider the nature of the chemical changes which occur in such storage batteries as the lead peroxide cell of Faure. As previously stated much has been written on this subject, but so far no very satisfactory conclusions have been arrived at. As the practical experience of the last ten years tends to confirm the deductions of Dr. Gladstone and Professor Tribe with reference to the behaviour of electric storage cells, it will be of interest to give some extracts from their extremely lucid communications to *Nature* concerning their investigations.

As the result of a large number of experiments, Messrs. Gladstone and Tribe arrived at the conclusion that the minium in a Faure cell suffers decomposition according to the formula

$$Pb_3O_4 + 2H_2SO_4 = \underset{2}{PbO_{\cancel{3}}} + 2PbSO_4 + 2H_2O.$$

As both the lead sulphate ($PbSO_4$) and the lead peroxide (Pb_3O_4) are insoluble in dilute sulphuric acid, these changes take place merely at the surface, and require time to penetrate.

In a Faure battery it is evident that we are dealing with a plate that consists of a superficial layer of mixed peroxide and sulphate of lead; the thickness of this layer is dependent upon the time during which the sulphuric acid has been allowed to soak into the oxide of lead. The proper formation of a secondary battery is a matter evidently depending upon very careful adjustment of conditions.

In a lead accumulator it is evident that the energy stored up in the cell is determined mainly by the amount of peroxide of lead present. This appears to be obtained with the smallest amount of loss when the current is not too strong. From their experiments they obtained the best results when the current density was about 6½ milliamperes per square centimetre, calculated on the original surface of the lead plates.

There would seem to be no commensurate advantage in continuing the current after the oxygen has ceased to be absorbed pretty freely, because the presence of some unoxidised sulphate of lead, although it increases the resistance, rather impedes than promotes local action. On the other hand, however, it is necessary that the reduction of the minium on the opposing plate should be complete, because a mixture of lead peroxide and metallic lead would be peculiarly conducive to the production of lead sulphate and thus increase the resistance, while if any peroxide should escape destruction it would diminish the electromotive force of the cell. From the foregoing it would appear probable that the most economical arrangement would be obtained by making the minium to be hydrogenated, much smaller in amount than that to be oxidised. On trying the experiment with only half the quantity they obtained a most satisfactory result, as far as the charging was concerned. The lead peroxide was found to react both on the lead plate that supports it and on the lead on the opposite plate. This action, however, is no drawback, as, if it were not for the formation of a film of sulphate of lead on the surfaces of both plates, this action would quickly cause the cell to lose its charge; but the formation of sulphate no doubt also forms a serious obstacle to further local action.

Messrs. Gladstone and Tribe found that the initial electromotive force of the Faure cell, when freshly prepared, averaged 2·25 volts; but after being allowed to rest for some little time it was reduced to about 2·0 volts. This latter, they think, is the normal electromotive force of lead and lead peroxide when placed in dilute sulphuric acid, the higher electromotive force obtained at the outset probably being due to the hydrogen and oxygen occluded on the respective plates, which is quickly eliminated.

During a discharge, oxide of lead in the presence of sulphuric acid becomes sulphate of lead according to the equation

$$PbO + H_2SO_4 = PbSO_4 + H_2O.$$

To prove that the sulphate of lead formed on the discharge is reduced in the subsequent charging, the lead plate of a fully-discharged cell, which was found to have 51 per cent. of lead sulphate combined with the spongy lead, was subjected to a charging current of one ampere for a period of 60 hours, and on examination no trace of sulphate of lead was found. From this it may be concluded that during the alternate discharging and recharging of a Planté or Faure cell, sulphate of lead is alternately formed and reduced on the lead plate, and that the plate itself is not seriously corroded. It would, however, appear desirable not to allow the whole of the spongy lead to be reduced to the condition of sulphate during the discharge for two reasons—viz., first, because the supporting plate stands a chance of being itself acted upon and thereby weakened, if there is not a sufficient excess of spongy lead; and second, because the presence of this excess tends to facilitate the reduction of the sulphate.

It has already been shown that sulphate of lead is produced by the local action that occurs during repose between the peroxide and its metallic supporting plate. The same local action also takes place during the charging of the elements, this sulphate in its turn being attacked by the electrolytic oxygen. In this way the absorption of oxygen during the forming of the peroxide plate ought never to come to an end. It has been shown that nine cubic centimetres of oxygen liberated will form and oxidise 0·24 gramme of sulphate of lead.

When forming these cells, care should be taken that a sufficient quantity of sulphuric acid is placed in the electrolyte, so that some of it still remains in solution after all the available lead has been converted into sulphate. If all the acid is removed and only water is present, an oxide or hydrate will be produced which will be detrimental to the cell.

Under some circumstances a white sulphate of lead is formed either on the surface of the active material or upon its metallic support. This salt is evidently a basic sulphate of lead of the composition $2PbSO_4, PbO$.

By experiment it was found that minium, when treated with a considerable quantity of sulphuric acid, gave a mixture containing on analysis 18·5 per cent. of sulphate of lead. This mixture, when submitted to the reducing action of a current, yielded a mass of spongy lead that contained only a mere trace of sulphate.

Referring to Planté's statement that an elevation of temperature facilitates the formation of his cell, Messrs. Gladstone and Tribe found that the character of the chemical changes which take place at the negative plate led them to think it exceedingly probable that this increase in the rate of formation arose from an augmentation in the amount of local action. By experiment such was shown to be the case. Pairs of similar peroxide plates made on Planté's model were allowed to remain idle at 11° cent. and 50° cent. respectively, and the formation of the white sulphate was visibly more rapid at the higher than at the lower temperatures. The same was found to be true with negative plates prepared by Faure's process. Two plates of similar polarity were kept in repose for an hour, the one at 11° cent., and the other at 50° cent. On analysis it was found that respectively 2·6 and 7·4 per cent. of lead sulphate had been formed. On two other plates the proportions were 7·6 and 9·5 per cent. respectively. These observations, of course, do not by any means exclude the idea that an increase of temperature may also facilitate the other chemical changes that occur in the formation of a lead and lead-oxide cell. In the case of Planté's plain lead plate the rise of temperature may accelerate its formation by simply opening the pores of the metal and thereby allowing the electrolyte to permeate deeper into its substance.

From the results obtained by their investigations, Dr. Gladstone and Prof. Tribe were led to the following deductions—viz.:

1. In the Planté or Faure cells local action necessarily takes place on the peroxide plate, with the production of sulphate of lead.

2. The formation of this sulphate of lead is absolutely requisite in order that the charge should be retained for a sufficient time to be practically available.

3. The rapidity of loss during repose will depend upon the closeness of the sulphate of lead, and possibly upon other mechanical conditions.

Referring to the electromotive force required to form and charge storage cells, and also the proper current density to be employed, Dr. Silvanus Thompson considers that accumulator cells should be charged with only just sufficient electromotive force to overcome their reactions, otherwise the energy is lost in local heat. In the case of the decomposition of water the electromotive force of polarisation is 1·49 volts, therefore to decompose water, we must have an electromotive force of over this amount. The term "current density," as applied to accumulators, means "the amount of current per unit surface of the electrodes," and is calculated for either electrode (in the simple case of parallel plates) by dividing the total strength of the current in amperes by the area of that electrode as measured in square centimetres. When a high current density is employed, the oxygen comes off in the more highly electro-negative condition of ozone, and as a consequence more peroxide of hydrogen forms round the anode, whilst at the cathode the hydrogen which is evolved possesses in an unusual degree the active properties attributed by chemists to "nascent" hydrogen—that is to say, a large proportion of it probably is, at the moment of liberation, in some abnormal allotropic condition, bearing the same kind of relation to ordinary hydrogen as ozone bears to oxygen. The allotropic hydrogen is more oxidisable, the ozone more ready to oxidise, and their union would evolve more heat than the union of equal weights of ordinary hydrogen and ordinary oxygen. It requires greater electromotive force to keep them apart, and their own tendency to unite is greater.

The E.P.S. Batteries.—Owing to defects which speedily developed themselves in Faure's early pasted plates, they never came into commercial use. It was found that by repeated charging and discharging the loose lead salts tended to permeate through the pores of the felt, and thereby induced the formation of lead trees. These minute metallic bridges caused serious short-circuiting, and ultimately led to the destruction of the elements. The inert porous separating medium therefore had to be abandoned, and the short-circuiting difficulty was overcome by leaving a clear liquid space between each plate.

Many plans have been suggested and much ingenuity has been exercised in devising methods of holding active materials on to metallic accumulator elements. Messrs. Sellon, King, Volkmar, Phillippart, Parker, Swan, and others, have each taken out patents for various forms of grids, frames, or plates. These patents, combined with Faure's original discovery, constitute that group of inventions owned by the Electrical Power and Storage Company,* and known shortly as the E.P.S. patents. Accumulators made under the above patents have now been extensively used for many years, both in this country and abroad.

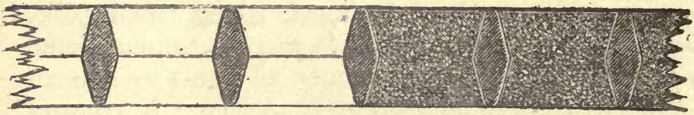

Fig. 22.—E.P.S. Grid.

After the experience gained from a very large number of experiments, the present form of grid, Fig. 22, was adopted. The usual method is to cast the grids in an iron or steel chill or mould. The elements now in use are perforated with a large number of square apertures; which are tapered inwards from both surfaces of the plate, thus forming a double dovetail. Owing to their peculiar shape, the pellets of active material tend to key themselves firmly into the countersunk holes. A still more recently improved plate, just introduced by this company, has a very thin perforated film of metal

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* E.P.S. batteries are now manufactured in England solely by the Foreign and Colonial Electrical Power Storage Company, Limited.

running across each aperture midway between its outer edges. The negative plates are made of pure lead, and the early form of positives of an alloy of lead and antimony. The antimony was introduced to make the grids hard and less liable to bend, and at the same time to prevent the "eating-in" action of the acid and current. The metal antimony is not dissolved by a sulphuric acid solution, nor is it much affected by the electrolytic action; the more recent positive grids are made of pure lead. When cast and cleaned up, the grids are filled in with a paste made by adding to minium, water acidulated with sulphuric acid. The paste is pressed into the apertures by means of a trowel, and the superfluous material is scraped off level with the outer surface of the grid. When dry the plates are placed in a bath containing dilute sulphuric acid, where they are partly formed, or what is known as "hardened," by means of an electric current. Minium is usually employed for the positive and litharge for the negative plates. After being hardened the plates are removed from the bath and placed into a suitable frame, and their connecting lugs are lead-burned together. When treated as above, the elements are fit for sale purposes. In all cases the actual forming is done by the purchasers.

As most of my readers are doubtless quite familiar with the various forms of these admirable batteries I shall not enter into the technicalities of their construction, but shall merely describe briefly the usual commercial types. The tabulated figures of capacities, dimensions, etc., are those as supplied by the manufacturers. Each type is represented by a distinctive letter, but this applies only to their form and not to their capacity, as cells of almost any capacity can be obtained.

Fig. 23 represents a complete cell of the type L, mounted in glass vessel. This form is much used for

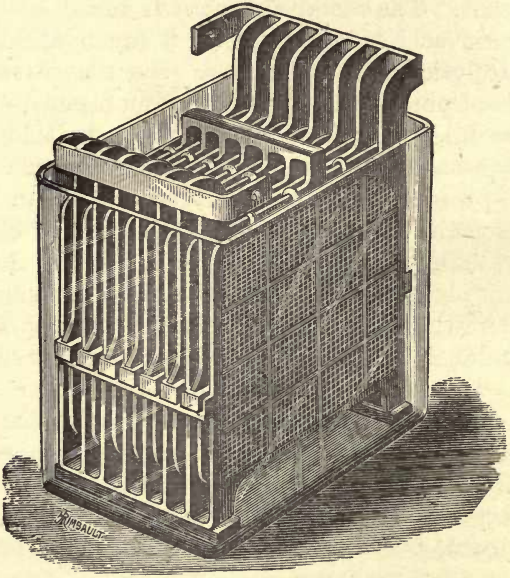

Fig. 23.—E.P.S. L-Type Battery.

domestic and general electric lighting. These batteries are usually sold in glass containing-vessels, but where they are likely to be used in exposed situations, as for such purposes as ship lighting, teak-wood cases are substituted for the glass. Table V. gives the complete data, and shows the capabilities of this class of E.P.S. battery.

In type C, Fig. 24, the plates are mounted in a strong wooden case, and each cell is supplied with a cover. This form of battery is specially constructed for train-lighting, and it is of such dimensions that it can be placed under the seats of the carriages.

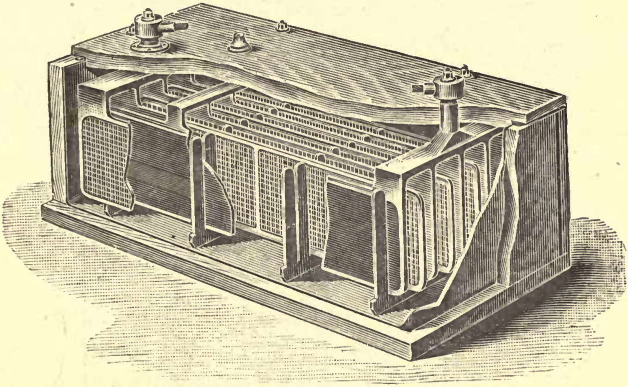

Fig. 24.—E.P.S. C-Type Battery.

Another form of battery capable of sustaining heavy discharges, and used for traction purposes, motor work, etc., is known as the T type, Figs. 25 and 26. These cells may be obtained either open or closed. As the figures for this class of cell are somewhat different than those as used for lighting purposes, Table VI. is here introduced giving all the necessary data.

A modified type is much used for running electric boats and launches. It is designed to fit compactly against the sides of the vessel; this is essential, as in

TABLE V.—L TYPE E.P.S. CELL.

DESCRIPTION OF CELL.		Weight of electrolyte.	WORKING RATE.		CAPACITY. Ampere-hours.	APPROXIMATE EXTERNAL DIMENSIONS.				Weight of cell complete with acid.
No. of plates.	Material of box.		Charge	Dis-charge		Length.	Width.	Height.	Height over all.	
		lbs.	amperes.	amperes		inches.	inches.	inches.	inches.	lbs.
7	Wood	18	10 to 13	1 to 13	130	5¼	13¼	18¼	20½	74
	Glass	25	10 ,, 13	1 ,, 13	130	5½	11½	13⅜	15¾	68
11	Wood	25	16 ,, 22	1 ,, 22	220	7½	13¼	18¼	20½	107
	Glass	35	16 ,, 22	1 ,, 22	220	8	11½	13⅜	15¾	101
15	Wood	35	25 ,, 30	1 ,, 30	330	9½	13½	18¼	20½	143
	Glass	47	25 ,, 30	1 ,, 30	330	9⅝	11¾	13⅜	15¾	128
23	Wood	53	33 ,, 46	1 ,, 46	500	14¾	13½	18¼	20½	228
	Glass	67	38 ,, 46	1 ,, 46	500	14¼	11¾	13¾	15⅞	211
31	Wood	70	50 ,, 60	1 ,, 60	660	19¼	13¾	18¼	20½	286
	Glass	88	50 ,, 60	1 ,, 60	660	18½	12	13¾	15⅞	265

TABLE VI.—T TYPE E.P.S. CELL.

DESCRIPTION OF CELL.		Weight of electrolyte.	WORKING RATE.		CAPACITY. Ampere-hours.	APPROXIMATE EXTERNAL DIMENSIONS.				Weight of complete cell with acid.
No. of plates.	Material of box.		Charge	Dis-charge		Length.	Width.	Height.	Height over all.	
		lbs.	amperes.	amperes.		inches.	inches.	inches.	inches.	lbs.
11	Wood (no lid) ...	10	16 to 20	1 to 20	66	6⅞	8¾	11⅝	13⅛	37
	,, (with lid)..	10	16 ,, 20	1 ,, 20	66	6⅞	8¾	11⅜	13⅜	38
	Ebonite (no lid)...	10	16 ,, 20	1 ,, 20	66	6	7¾	11	12¾	30
15	Wood (no lid) ...	14	24 ,, 28	1 ,, 30	95	8¾	8¾	11⅝	13⅛	52
	,, (with lid)...	14	24 ,, 28	1 ,, 30	95	8⅞	8¾	11⅜	13⅜	53
	Ebonite (no lid)..	14	24 ,, 28	1 ,, 30	95	8	7¾	11	12¾	42
19	Wood (no lid) ...	18	30 ,, 35	1 ,, 40	120	11	8⅞	11⅝	13⅛	65
	,, (with lid)...	18	30 ,, 35	1 ,, 40	120	11	8⅞	11⅜	13⅜	66
	Ebonite (no lid)...	18	30 ,, 35	1 ,, 40	120	10⅛	7¾	11	12¾	54
23	Wood (no lid) ...	22	38 ,, 42	1 ,, 50	145	13¼	8⅞	11⅝	13⅛	79
	,, (with lid)...	22	38 ,, 52	1 ,, 60	145	13¼	8⅞	11⅜	13⅜	80
	Ebonite (no lid)...	22	38 ,, 42	1 ,, 50	145	12¼	7¾	11	12¾	66

the case of electric launches the batteries are usually placed under the side seats. Many of the pleasure launches, now so popular, and frequently to be met with on the River Thames, plying between Hampton Court and Windsor, are propelled by the energy stored

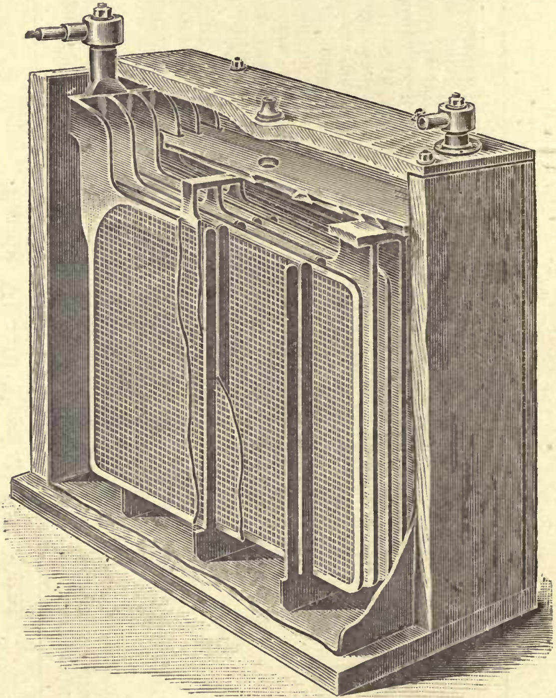

FIG. 25.—E.P.S. T-Type Battery.

in this form of cell, the necessary mechanical power being obtained through the medium of an Immisch's electric motor.* This type of battery has also been

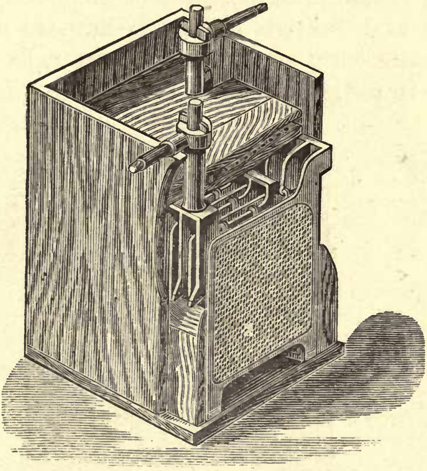

FIG. 26.—E.P.S. T-Type Battery.

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* The following are the particulars of an early form of small electric launch built for Mr. Pears and driven by a number of cells of this type. The vessel has been designed as a sea-going pinnace, 26ft. 6in. by 5ft. 4in. beam, and constructed to carry 15 persons. It has been specially built by Messrs. Sargent and Co., of Kew Bridge charging station, Chiswick, and has a mean draught of 18 inches and a displacement of 2¼ tons. The hull is carvel-built of bright mahogany in narrow widths. The launch—the "Pilot"—is steered by a tiller, and the switch controlling the electric power is flush with the after-deck, and within control of the steersman. Lead-lined compartments are arranged under the seats to receive forty E.P.S. T-type accumulators, which are said to hold sufficient electrical energy with one charge to propel the boat for about eight hours at the rate of eight miles per hour. The motor, which is fixed under a centre compartment in the boat, is calculated to develop 3 h.p. at 700 revolutions per minute. An uninterrupted space is left the entire length of the boat, which is entirely free from the disagreeable odours generally found on steam launches, as well as from oscillation, and many other inconveniences.

used with some success for actuating submarine boats.

A portable form, type V, Fig. 27, is made for working portable reading lamps, and is of much service for surgeons and dentists either to actuate small lamps or for cauterising purposes. These cells are usually made up in cases containing two, three, or four cells.

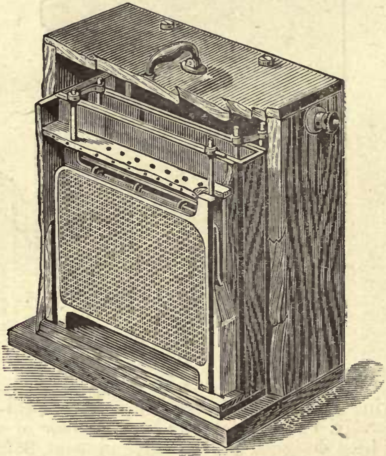

Fig. 27.—E.P.S. V-Type Battery.

In the event of the batteries being liable to receive much rough treatment, a perforated celluloid separator is inserted between each pair of plates. This screen, without materially increasing the internal resistance of the cell, is said to effectually prevent any loose particles of active material from bridging across from plate to plate, and thereby causing trouble.

The most recent development of the E.P.S. cell is a form known as the K pattern. In this cell, shown complete in Fig. 28, the space required per ampere discharge is said to be reduced to one-half when compared with the older types. The weight per ampere discharge is stated to be reduced to about two-fifths. The new cell appears to be strongly made, and is simple in construction. The positive elements are nearly double the thickness of the negatives, and are

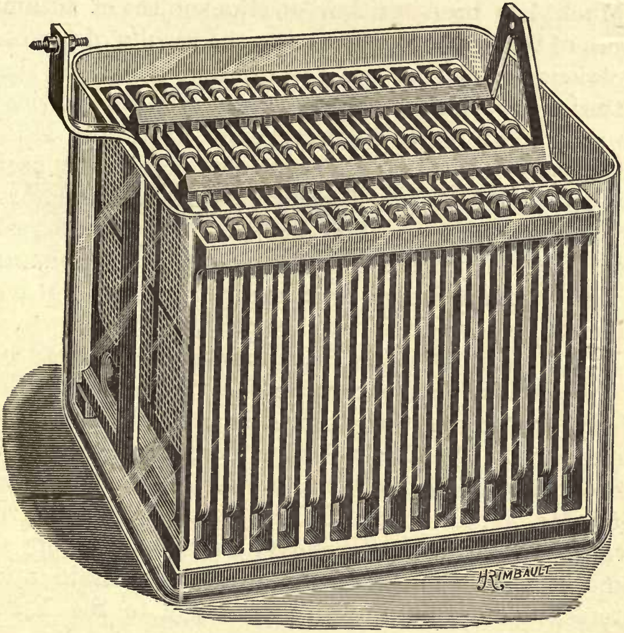

Fig. 28.—E.P.S. K-Type Battery.

of special construction. A clear liquid space of about three-eighths of an inch is allowed between each plate. To keep the elements rigid, and to hold them at a uniform distance apart, three U-shaped separators are pushed over each.

Much has been written on the subject of accumulators of this type, chiefly giving the results of personal experience gained in the specific application of these batteries for electric lighting and traction purposes. To those desirous of learning more about the E.P.S. batteries, a perusal of Sir David Salomon's very useful hand-book, entitled "Management of Accumulators," will be of interest. This book contains some really practical information on fitting up, charging, and testing accumulators, together with much general information as to their management.

In the year 1881, Dr. Silvanus Thompson read one of his always lucid papers on the "Storage of Electricity," before the Society of Arts in London. To the same society Dr. Oliver Lodge gave two lectures on "Secondary Batteries," in the year 1883. On May 1, 1889, Mr. W. H. Preece, F.R.S., read a most instructive paper, entitled "Secondary Batteries," before the same society. These communications contain much interesting information with reference to the E.P.S. type of batteries.

Drake and Gorham's Improved Grids.—To Messrs. Drake and Gorham is due the credit of several improvements, both in methods of manufacture and in the design of the metal holders for the oxides of lead. Owing to the increase in bulk of the minium during its conversion into the higher oxide, it tends to expand on both sides of the grid, occasionally to such an extent that the little pellets split in halves and fall out, thereby not only seriously decreasing the capacity of the cells, but frequently bridging across the plates and causing bad short-circuits. To prevent this, Drake and Gorham pass the ordinary cast-metal grids between rollers and burnish down the outer edges on both sides of the plates, thus forming a sort of double dovetail in each aperture.

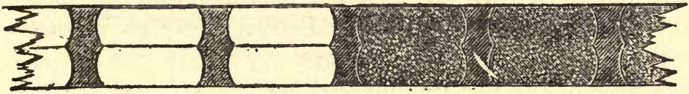

FIG. 29.—Drake and Gorham's Rolled Grid.

The effect of this rolling process is shown in section in Fig. 29. It is asserted that plates treated in this way are very rigid, and when filled the tendency of the active material to split or fall out is reduced to a minimum.

Eickemeyer's Storage Battery.—In this form of battery the cast-lead plates are provided with a number of polygonal holes, instead of the truncated squares. Each opening is filled in with oxide of lead made into a paste by the addition of acidulated water. The pasty mass is well pressed around plugs, which, when removed, leave circular openings in the centre of the pellets. Each plate has a projecting terminal and all are counterparts cast from the same pattern, so that when reversed in position and piled one on another with the terminals located alternately on opposite sides, the holes register with corresponding holes in all the plates throughout the pile. Between each two plates there is placed an insulating diaphragm, which is also provided with holes corresponding to those in the lead plates. With a battery thus constructed, each vertical line of holes constitutes a chamber for containing the electrolyte, and this is supplied by means of a funnel which tightly fits the feed aperture at the top. As the liquid falls to the bottom of the battery, it is distributed by way of lower channels and openings in the base-plate to the several cells, in which it rises with uniformity until all are properly filled. An extensive area of the porous material is thus exposed to the electrolyte, and the metallic lead of each grid is completely protected against the liquid except through the active material. Mr. Eickemeyer has designed various forms of this cell, all embodying the same principles, and resulting, it is claimed, in a cell of considerably reduced weight in proportion to its storage capacity.

In storage batteries where the grid form of plate is employed as a receptacle for the active material, some rather weak points have developed themselves. In the case of the negative element but few difficulties have occurred, as with these plates, if the apertures are properly filled in and then thoroughly formed, little or no mechanical alteration occurs either during formation or subsequent use. These electrodes show but little tendency to either bend or buckle. With the positive elements the case is somewhat different; here during the electrolytic formation, the lead oxides undergo a considerable amount of expansion, this increase in bulk being stated by some investigators to amount to somewhere between 5 and 10 per cent. of the original mass. Unless, therefore, proper precautions are taken to ensure a uniform expansion in the lead salts, the comparatively rigid grid is liable to suffer considerable distortion. To counteract this distorting influence, the grids may be made mechanically strong either by increasing their thickness or by introducing some hardening substance into the composition of the metal. If this be done, the inevitable increase in the bulk of the lead salts occurs laterally, and merely tends to cause the pellets to slightly bulge out on either side of the plate.

As already shown, the pellets of peroxide in the E.P.S. hard-metal grids are keyed in by the peculiar truncated shape of the holes. If the walls of these apertures are too acute, and if the expansion of the active material has not been allowed for, there is a tendency for the little masses of oxide to split in two and to drop out. By the process of burring as introduced by Messrs. Drake and Gorham, the splitting tendency is greatly minimised.

Many attempts have been made to overcome the above-mentioned difficulties. Among these are the methods of running molten metal round suitably-shaped masses of lead oxide or peroxide, or by casting each grid in two parts and then fixing them together in such a way that the largest part of the truncated holes in each part are coincident.*

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* Dr. Frankland, F.R.S., was the first to employ the method of running molten metal round compressed pellets of lead salts.

The Gadot Accumulator.—The elements in these accumulators are of the double-grid form, and are so proportioned that the percentage of active material has been increased to 54 per cent. of the total weight of the complete plate. In the most recent form of these cells the positive electrodes are very thick, and are said

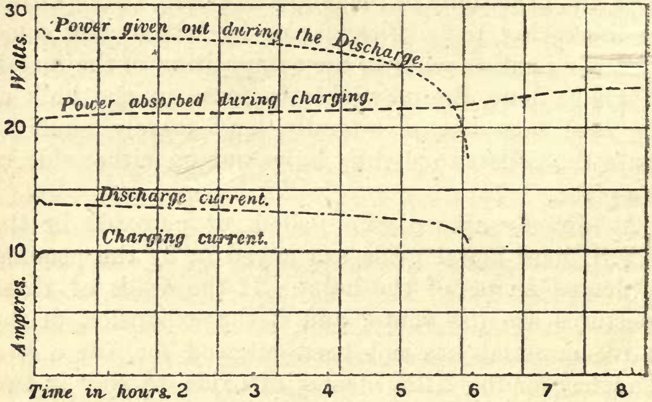

Fig. 30.—Gadot Accumulator (11 plates of 850 grammes).

Ampere-hours supplied	83	Efficiency, 83·2 per cent.	
,, ,, given out	69		
Watt-hours supplied	180·2	,, 70·1 ,,	
,, ,, given out	136·5		

to give an output of 21·75 ampere-hours per kilogramme of plate, when discharged at the rate of 1·5 amperes per kilogramme of plate. During some very interesting tests of this cell recently made in M. Hospitalier's laboratory at the Ecole de Physique et de Chemie, by Messrs. Chevalot and Delarivière, under the direction of M. Gaston Roux, the following results were obtained.

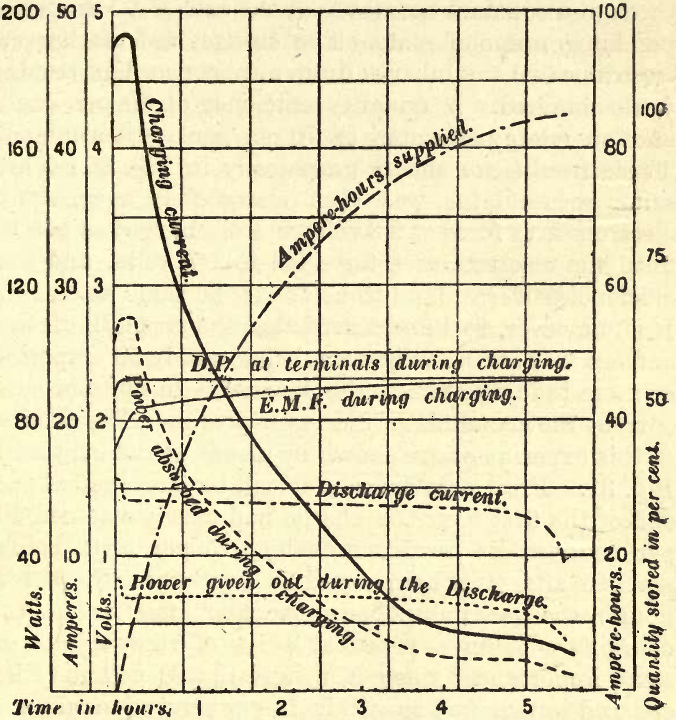

FIG. 31.—Gadot Accumulator (weight of plates, 9·35 kilogrammes) charged at a constant difference of potential of 2·28 volts; discharged on a constant resistance.

Ampere-hours	supplied	85·6	Efficiency, 86·2 per cent.
,, ,,	given out	73·8	
Watt-hours	supplied	192·6	,, 73·0 ,,
,, ,,	given out	140·7	

A Gadot accumulator, with plates weighing 9·35 kilogrammes, was charged with a constant current of about one ampere per kilogramme of plate, and discharged through a constant resistance at the rate of 1·5 amperes per kilogramme of plate. The charges and discharges were repeated a number of times until concordant results were obtained. A quantity efficiency of 80 per cent. and an energy efficiency of 70 per cent. was attained. These results are shown graphically in Fig. 30. This same accumulator was then charged at a constant electromotive force of 2·3 volts and discharged as before until the electromotive force fell to 1·7 volts, and the efficiencies were found to be about the same as before. It is, however, to be observed that the strength of the current was at first very great, being nearly 50 amperes, or more than five times the normal. In spite of this current the accumulator did not evolve gas. The results of this experiment are shown by means of the curves in Fig. 31. From this diagram it will be seen that at the end of the first hour the charge had nearly attained 50 per cent. of its maximum value, 75 per cent. being reached after two hours, and 83 per cent. after three hours, the maximum being reached after six hours' charging. From a practical point of view this is of some importance, since it means that a cell may be charged in this way to within 17 per cent. of maximum in three hours without injury, while to reach this state with a constant current would have taken 6½ hours. Moreover, the electromotive force required to charge a 52-cell battery is only 120 volts with the constant-potential method, but 135 volts when a constant current is employed.

Hagen's Improved Lead Frames.—Mr. Hagen, of Kalk, near Cologne, has recently devised a form of metal frame for holding the active material, which is said to be of less dead weight, but equally as strong, as the grids usually employed in this country. The frames can be made of any of the alloys now used for holding the lead salts. Each frame consists of two halves formed of ribs crossing each other at right angles, and leaving square apertures. Each rib is in the form of a triangular prism with its base outwards. The halves are not cast solid along the inner angle of the ribs, but are some little distance apart, and are merely held together where the ribs cross by a series of short cross-bars, the whole frame being cast in one piece. In this way a light but strong frame is obtained, which is not only capable of holding a large amount of active material, but holds it permanently, as it is prevented from falling out owing to the ribs being of a triangular section.

Under ordinary circumstances the proportion of the weight of the grid and the active material is as 1 is to 1, but when great lightness is desirable it may be reduced to the ratio of 2 to 3. The plates for stationary work develop, in an eight-hour discharge, about 4·5 ampere-hours per pound weight of the filled plates, and about 18·1 ampere-hours per pound of active material. The electromotive force of discharge is, for the first half of the discharge, constant at 1·98 to 2 volts per cell, and then falls gradually to 1·88 volts; after that it falls so quickly that it is not advisable to continue the discharge. A stationary battery of 160 ampere-hours capacity, and several smaller portable sets, have been in use for three years, the latter were employed for lighting baggage cars without springs. In spite of the fact that the former battery was frequently uncharged for a long time, and was at times half dry, and in other cases had to supply current up to 100 amperes for experiments, the plates show no change—neither loss of active material nor buckling.

Jacquet's Double Grid.—The brothers Jacquet, of Vernon, France, have devised a form of grid which appears to possess some rather novel features. Not being satisfied with the method of keying in the active material by making the elements in halves, and then joining them together either by soldering or riveting, they have worked out a plan for casting a complete double dovetailed element in one piece. Fig. 32 shows the appearance of this form of electrode. The grids are made of an unoxidisable white-metal alloy, and owing to their peculiar shape, are said to be far more rigid, and therefore much less liable to bend or buckle than most ordinary cast grids. When filling in the plates, the lead oxide paste, which is specially prepared, is very lightly pressed into the holes, the object being to allow room for expansion during the electrical formation. Owing to the mode of preparing the metal salts and the way in which they are applied, the result is said to be very satisfactory, as when finished the active material is very hard and porous,

FIG. 32.—Section of Jacquet's Grid.

and is but little liable to fall out even when subjected to very heavy rates of charging and discharging. On referring to the complete plate, Fig. 33, it will be seen that the apertures are placed diagonally instead of in the usual vertical position, and that the outer rim is very slight. This method of casting is said to give elasticity to the electrodes, and at the same time reduces their weight.

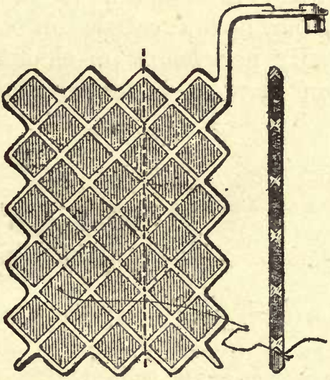

FIG. 33.—Jacquet's Grid.

In the commercial pattern of cell the plates are of the following dimensions and weight :

Length of plate	230 millimetres.
Breadth of plate	165 ,,
Thickness of plate	5 ,,
Weight of cast grid..................	450 grammes.
Weight of lead oxides.....	740 ,,
Weight of complete plate	1,190 ,,

From the figures given, it will be seen that one kilogramme of plate contains 622 grammes of active material, which is equivalent to 62 per cent. of its total weight.

As the current capacity of these cells, like most others, will vary according to the thickness and number of plates in the cells, and also according as to whether they are constructed for low or high rates of discharge, it is difficult to absolutely determine the actual current capacity for any given weight of complete cell. The makers, however, assert that as far as their experience carries them, they have succeeded in obtaining a higher current capacity per pound of element than can be obtained from any other known form of cast-grid element.

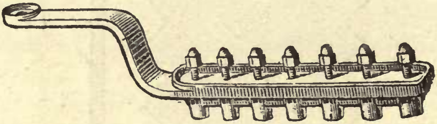

Fig. 34.—Jacquet's Connector.

To facilitate removals, the plates are not burned together, but are merely screwed or bolted to a cast-metal collector or pole-piece of the shape shown in the diagram, Fig. 34. All the plates are securely connected to the collector by means of white-metal clamping nuts, or nuts and bolts, and as the whole of the castings are made of the same alloy, there is but little likelihood of the junctions corroding. In Fig. 35 is shown a complete 13-plate cell of this type.

To minimise the injurious effects of buckling and warping, some success has been attained by making up the elements of a series of horizontal frames or troughs, which have been previously filled in with active material.

In 1882, J. Humphreys of Norwood devised a plate suitable for storage batteries which was composed of an open lattice form—that is to say, by connecting the sides of the framework of each plate with bars, either of a diagonal or oval section, such bars being arranged at an angle on the principle of a "Venetian" blind, and thereby exposing a maximum surface area of active material to the action of the liquid used in the cell.

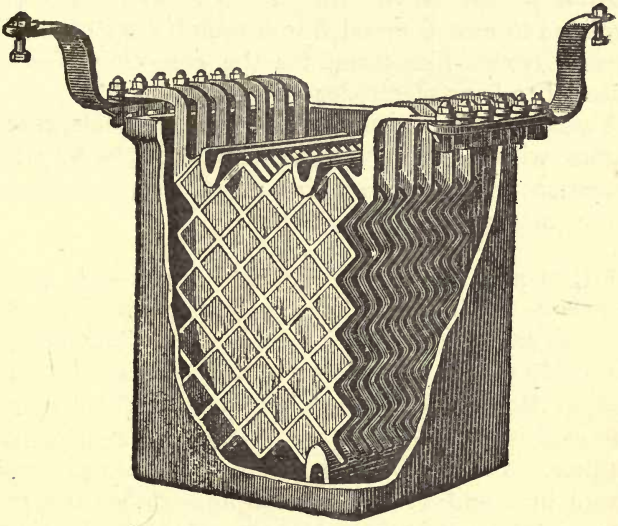

FIG. 35.—Jacquet's Complete Cell.

In 1883 Messrs. Tatham and Hollings devised an element which consisted of a leaden frame or holder built up of corrugated or channelled receptacles, or sheets of lead of a serpentine form, held together by vertical metal supports. In the year 1886 Gardner patented a method of forming electrodes suitable for secondary batteries, consisting of a frame fitted with horizontal troughs packed with lead oxides.

In a patent taken out in 1887 by Epstein, he proposed to cast a metal frame round a set of vertical bars of trough-like form, for the reception of active material to form electrodes in a storage cell.

Akester in the same year constructed element of frames with horizontal bars or pasted plates, whose interstices were packed with horsehair, or some similar porous material.

Pitkin and Holden's "Ladder" Plate.—Mr. Pitkin and Captain C. Holden have recently devised a form of element which seems to promise well. The elements are made up in the following fashion. Shallow cast lead, or lead and antimony troughs are filled in with the oxides of lead and are "formed" in the usual manner. From fifteen to twenty of these plates are placed in a suitable metal clamping frame, and made into one element by having their ends burned together by the blow-pipe flame, or by being treated with molten lead. In the finished elements, both positive and negative, there is a clear liquid space of about $\frac{1}{16}$in. between each little trough. This space is made by interleaving the lead trays with thin sheets of metal during the running together process, and afterwards removing them. A complete element looks very much like a ladder, hence its name.

In one form of cell three of these elements are mounted, Fig. 36. They are held firmly in their relative positions by means of vulcanite distance pieces, wedged vertically between them. From the arrangement of the plates all buckling or warping merely tends to bend them vertically, and not horizontally, therefore short-circuiting of the elements is very improbable. Although the internal resistance of this form of cell is somewhat higher than in those where the active surfaces are nearer or more directly exposed, yet they have a very large active surface, and as the space between each little plate is so small, detached scales of oxide other than those of small dimensions cannot leave the troughs; therefore they do no damage, but merely become inactive. In cases where batteries

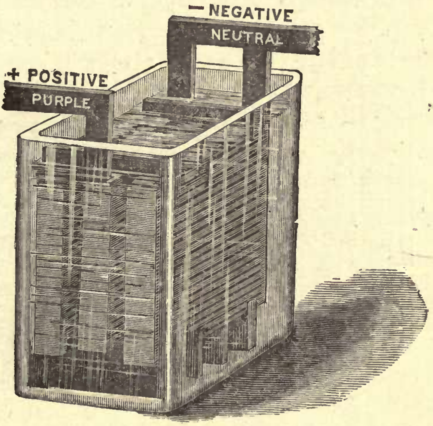

Fig. 36.—Pitkin and Holden's Cell.

are liable to receive much jolting or concussion this form of cell seems likely to be of service.

Ernst's Intercirculatory Storage Battery.—Quite recently an interesting form of element has been introduced in America by Mr. Victor Ernst. It is termed an "intercirculatory" battery, owing to the electrolyte being free to permeate through and act upon every particle of the active material. The fundamental principle involved in the new element is an absorbent core having an expansive action. This flexible core is made of asbestos fibre, wool, hair, or other similar substance. It ramifies through the interior of the active material in such a manner that the oxide or spongy lead is retained in close contact with the walls of the metallic holder or plate, giving perfect electrical

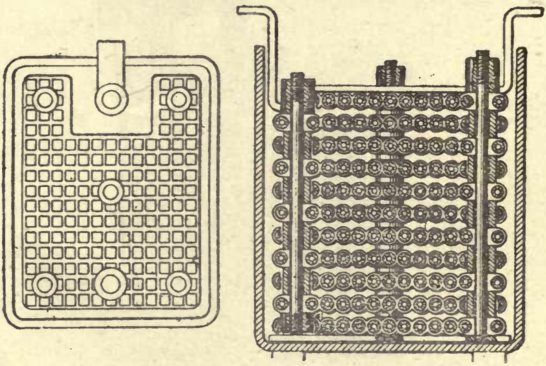

FIG. 37.—Ernst's Intercirculatory Battery.

contact and conductivity. The elastic core presents a yielding surface to the active material, so that any jolting or concussion occurring when the batteries are used for transition purposes does not tend to break up or dislodge the soft lead or oxide. An absorbent action is also obtained through the medium of the porous core, which causes the electrolyte to diffuse uniformly throughout the elements, thereby enabling the batteries to receive or maintain a high rate of charge or discharge without the internal resistance of the cell largely increasing. The increase in the internal resistance of cells is frequently due to surface exhaustion, caused by a too rapid rate of discharge. The battery elements, Fig. 37, are built up horizontally, being placed one above the other. No lead-burning or soldering of any kind enters into the construction of these plates, the elements being held together at the requisite distances apart by means of indiarubber washers and vulcanite nuts and bolts.

The Payen Accumulator.—In preparing his plates, M. Payen makes an intimate mixture of asbestos fibre and fused chloride of lead, and then pours the molten mass into a mould. The material crystallises as it cools, and a chloride of lead plate bound together by the asbestos fibre is the result. The plates are formed in two distinct operations. The chloride of lead is first of all transformed into spongy lead by being made the cathode to an ordinary lead plate as anode. The spongy lead plates are next formed in the ordinary manner, and are then ready to be used. Suitable metallic conductors are either cast or bent round these masses of active material to form both a conductor and a terminal.

Carpenter's Elements.—Mr. H. Carpenter, of New York, makes battery elements of hollow perforated lead boxes, packed well in with cerussite (native carbonate of lead), which is reduced by electrolysis to an oxide in the one case and spongy lead in the other.

Bailey's Series Battery.—This battery, designed by Mr. Mark Bailey, consists of a rectangular wooden box divided into separate cells by the battery plates. The plates are cast with square recesses for holding the active material. The opposite sides of each plate are of different polarities. The metal partitions constituting the cells are therefore in series, and no electrical connections whatever are required except at the two end plates. A light wooden frame, which has been treated with paraffin, is inserted between each plate to prevent buckling. A box 14 inches long, 4½ inches wide, and 6 inches deep will contain twenty-four plates—that is, twenty-four cells; and a battery of these dimensions, it is asserted, will maintain a discharge of 18 amperes at a potential of 48 volts. The great point in this form of battery is to prevent leakage of the solution from cell to cell. To this end the lead plates are let into grooves made in the sides of the wood containing-case, and a fillet of acid-proof cement is run in the interstices, serving to make each compartment liquid-tight.

Another modification of this form of cell consists of a number of circular grooved discs, filled in with active material, and built one upon the other. A specially moulded indiarubber ring and flange, about ¼in. thick, keep the elements a sufficient distance apart to allow room for the electrolyte. A hole in the centre of each plate permits a small vent tube to go down into each cell, thus forming an outlet for the gases when generated.

Knowles's Elements.—These elements, Fig. 38, consist of solid blocks of active material, firmly clamped between two perforated plates made of an inoxidisable alloy. These conducting plates are held together by

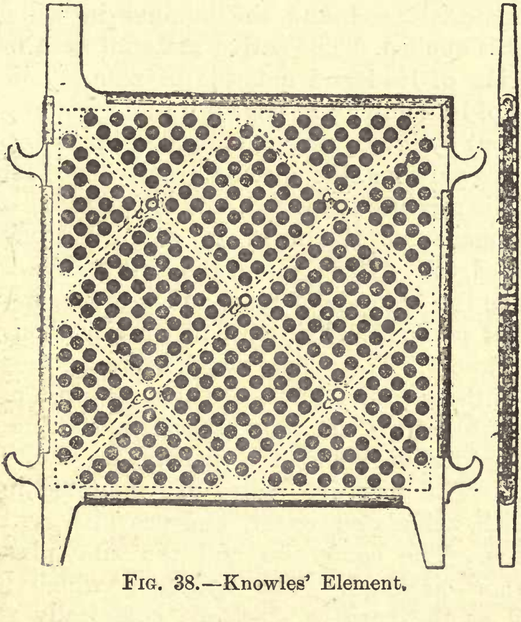

FIG. 38.—Knowles' Element.

rivets which pass through the active material. The perforations allow the electrolyte a fairly free access to the oxides and spongy lead. As the slabs of active material are free to expand or contract in any direction throughout their mass, these elements are said never to warp or buckle, even when seriously over-charged, or over-discharged.

Laurent-Cely Accumulator.—The chief features in this form of battery are the peculiar nature of the active material used, and the manner in which this material is applied. The active material is a mixture of chloride of lead and chloride of zinc. The fused chloride of lead employed has an initial specific gravity of 5·6; but by incorporating chloride of zinc with it in certain proportions, the specific gravity is reduced to 4·5. This mixture is melted, and is run into cast-iron moulds made in the form of small buttons with rounded edges. After cooling, the buttons are washed to remove the chloride of zinc, and are thus rendered somewhat porous. Their specific gravity then varies from 4·2 to 3·4. The pellets which serve for the manufacture of the negative plates are arranged in a metallic mould, into which an alloy of lead and antimony is run; this frame holds the pellets in the desired position. The negative plates are mounted in cells filled with acidulated water, and provided with zinc electrodes. The composite and the zinc plates are then short-circuited. The hydrogen which is disengaged at the positive electrode chemically reduces the chloride of lead, and there are thus obtained masses of spongy lead of a density of between 2·5 and

3·1. The density of ordinary sheet lead is usually about 11·35. The buttons used in the positive plates are first transformed into spongy lead, and then into oxide of lead by carefully heating them in the air. Both the positive and negative frames are made of an alloy of lead and antimony.

The Electric Battery Company's Cell.—The Electric Storage Battery Company, of Philadelphia, find that active material made from a chloride of lead gives the best results. To obtain the chloride, commercial lead is melted and converted into a finely-divided powder. The lead is then dissolved in nitric acid, and is precipitated by the addition of hydrochloric acid. The chloride is then thoroughly washed and brought to a molten state in a furnace. The fused mixture is poured into square moulds and allowed to cool. The square blocks of chloride so formed, and which are

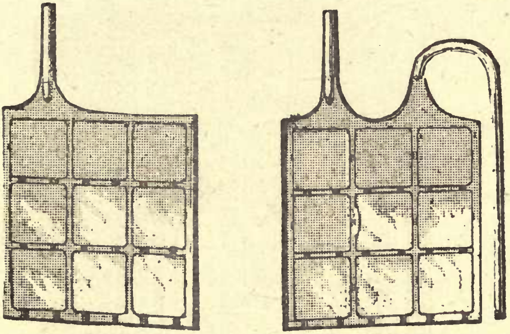

FIG. 39.—E. B. Co.'s Elements.

destined as the active matter in the plates, are then placed in a mould prepared for their reception, and a grid of lead is cast around them, binding the blocks into a compact plate, as shown in Fig. 39.

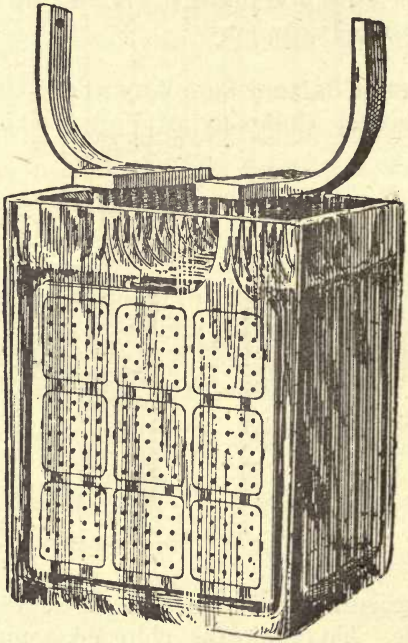

Fig. 40.—E. B. Co.'s Complete Cell.

The grids are then packed between zinc plates and placed in a tank containing dilute chloride of zinc. There is thus formed a voltaic couple, the action of which is to dissolve the zinc chloride, and to extract the chlorine from the lead chloride contained in the blocks. The last trace of chlorine is removed from the plates by washing them, then placing them in a vessel containing nitric acid and passing a current. This action also opens the pores and leaves a pure lead sponge in the grid. The plates for the positives are packed tightly between perforated ebonite boards and formed into peroxide in dilute sulphuric acid.

The standard cell, shown complete in Fig. 40, consists of nine positive and ten negative plates, having a capacity of 230 ampere-hours, and weighing when complete 34lbs. As a result, a capacity of 9·9 ampere-hours per pound of plate and 18 ampere-hours per pound of total active material is obtained. The plates are $5\frac{3}{4}$ inches wide and 6 inches high.

In the special street-car cell containing 19 plates, the weight of active material and of the grids is respectively $12\frac{1}{2}$lbs. and $10\frac{5}{8}$lbs.*

The Brush Secondary Battery.—This battery, Fig. 41, which is an American production, was devised by Mr. C. F. Brush, of Cleveland. Both elements are cast in lead, and have a number of narrow grooves on either side. After being chemically cleaned, the castings are immersed in a solution of acetate or

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* It may be noted that four cars on the Lehigh Avenue-street Railroad, in Philadelphia, have recently been operated continuously during a period of four months with cells of the car type. This road has numerous curves, and grades as heavy as $5\frac{1}{2}$ per cent. These have taxed the cells to their utmost, the 100 cells on each car frequently being discharged at the rate of 45 electrical horse-power. During the month of August, of 1891, these cars alone carried 59,000 passengers, with frequent loads of 100 passengers on a car. The batteries have frequently made runs of 63 miles with a single charge under these conditions, thus giving a good indication of their increased efficiency where the conditions are more favourable as to grades and curves.

nitrate of lead, or any other solution capable of depositing spongy lead when electrolysed. The plates under treatment are made the cathode in the depositing bath, while a stout piece of sheet lead constitutes the anode, or loss plate. After being subjected to electrolytic action until the requisite quantity of spongy lead has been deposited, the plates are taken out and thoroughly washed. When placed in the ordinary dilute sulphuric-acid solution, the electrolysed lead on the positive element is rapidly converted into peroxide by the current. Another method of rendering these plates active consists in filling in the grooves with sulphate of lead made into a paste with water or some saline solution. When dry and hard, the plates

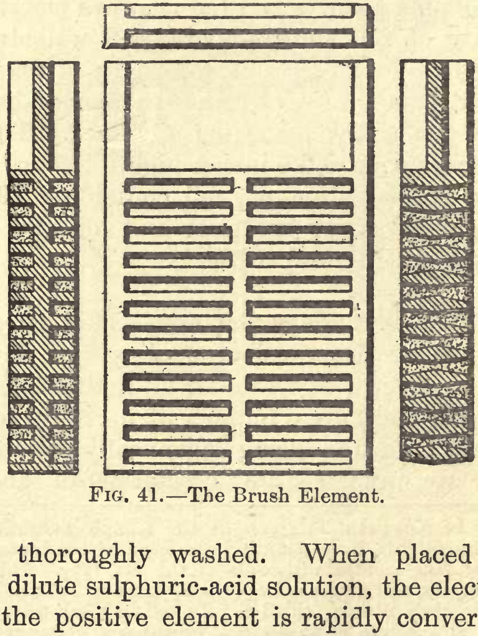

FIG. 41.—The Brush Element.

are placed horizontally in a vessel containing a solution of common salt, or ammonia, or any other salt in which sulphate of lead is somewhat soluble. A zinc plate is suspended in the solution, above each lead plate, and a metal wire joins the two. A galvanic couple is thus constituted, which sets up electrolytic action, and gradually reduces the sulphate of lead into the spongy metal. After being well washed, either in pure or acidulated water, the plates are placed in the containing-cells, dilute sulphuric acid is added, and by means of the current the spongy lead on the positive elements is rapidly transformed into peroxide.

Hering's Accumulator Elements.—Mr. Carl Hering has given some attention to methods of preventing the buckling and warping of secondary battery plates. To this end he constructs cells having but four elements, two positive and two negative, Fig. 42. The two outer plates are solid blocks of lead peroxide, such as may be made by mixing lead oxide in a solution of a salt of lead, pressing the mixture in a mould and forming it into the shape desired. The two inner blocks are of spongy lead. These blocks of porous metal and peroxide are not fastened permanently to any electrode: they are simply held in contact with contact plates made of lead or lead alloy, which lie against the flat sides of the blocks of active material, and project through the top of the cell. The means taken to secure proper contact are simple. Perforated straps of non-conducting material pass over the exposed surfaces of both positive and negative plates, keeping the plates firmly in contact with the movable electrodes, and at the same time preventing them from touching each other. These batteries can readily be taken apart; a single plate, if injured, can be removed and another can be substituted for it with little trouble; and, in addition, it may be noted that the active material is formed in a block by itself, with which contact is afterwards made,

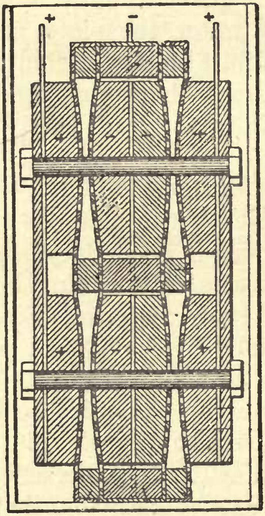

FIG. 42.—Hering's Elements.

instead of being mechanically applied to an electrode, as in the majority of other storage batteries. Owing to the relative smallness of the surfaces, the internal resistance of this type of cell must necessarily be somewhat high.

As this form of cell is but little known in this country, the following description of the processes involved in its manufacture may serve to throw some light upon this rather novel form of storage cell. The extract is from the New York *Electrical Engineer* of June 11th, 1890:

"For the preparation of the positive plate Mr. Hering employs a dry mixture of powdered peroxide, minium, and lead carbonate (or sulphate), which is mixed with a solution of acetate of lead to a stiff paste. This is then pressed into a mould and punctured in numerous places and dried in an oven. It is then hardened by immersion in sulphuric acid, after which it is mounted and formed.

"Secondary battery plates are usually formed in sulphuric acid. Mr. Hering prefers, however, to form them in an alkaline-sulphate solution—such as sodium or potassium sulphate—as this prevents in a degree the formation of the peculiar white growth around the supports, which attacks the latter when made of lead. After they are formed, such growths do not appear. The plates are furthermore strengthened and hardened by a process called 'treating.' This consists in immersing the plates in a solution of a soluble lead salt or compound—such, for instance, as acetate of lead—then drying them and afterward forming them again with a positive current, as usual. This may be repeated as often as desired, thereby giving the plate any degree of hardness and density. By this process of treatment, the soluble salt of lead on drying forms a thin coating on the surfaces of the porous spaces, and on its conversion to peroxide decreases the size of the porous spaces without diminishing their number.

"To still further strengthen the plates and render their surface very hard, Mr. Hering electroplates them, after they are formed, with peroxide of lead, by supporting them in a bath of soluble lead salt—such as the nitrate—together with a suitable cathode, and passing a current through this, making the plates the anode. They then become coated with a layer of deposited peroxide of lead, which is about as hard as highly-tempered steel.

"For preparing the negative plates of his battery, Mr. Hering passes a heavy current through an acid bath made of a soluble salt of lead—such, for instance, as the nitrate. The anode in this bath is a slab of lead, and the cathode, straps or wires of lead terminating in points. Aborescent crystals of lead will then be formed at the cathode in large quantities. These crystals are exceedingly thin, and possess the property, when fresh, of adhering to each other, or interlocking when pressed together, thus forming a very porous, tenacious mass which is soft, pliable, and fibrous, almost resembling a textile material. These crystals are gathered and kept under water until a sufficient quantity is obtained for a plate. They are then put into a mould and sufficient pressure applied to make them adhere to each other. By this means a porous, strongly coherent plate of finely-divided lead is obtained, which is said to be admirably adapted for the negatives of secondary batteries."

The Tudor Accumulator.—These accumulators, as manufactured by the Société Anonyme Belge pour l'Eclairage Public par l'Electricité, seem to have been received with much favour on the Continent.* The elements are not of the grid form, but consist of lead plates deeply grooved, made by being passed between a pair of suitably shaped rollers. The serrated plates are then coated, by electrolysis, with a thin layer of peroxide, and the interstices are filled in with the usual paste of lead oxides. The reason for treating the lead plates in this way is to prevent the formation of sulphate of lead and the junction of the metal holder and the active material.† After the above treatment the plates are allowed to dry, and are then again passed through

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* This accumulator has attained considerable vogue in Belgium, especially in connection with central station work. The Commune of Doltsain (Limburgh) has a central station which supplies current to 1,300 lamps, and it is provided with three batteries of 240 ampere-hour Tudor cells. The Compagnie Franco-Belge pour l'Eclairage Public par l'Electricité has four central stations in operation, and employs Tudor accumulators in all of them. The station in the Rue Montagne (Brussels), which has some 1,000 8-c.p. lamps and several arcs connected, possesses a battery of Tudor cells of 750 ampere-hours' capacity, and the station in the Passage du Nord (Brussels) is provided with two batteries of 756 ampere-hour cells. The Ghent Station has a battery of 590 ampere-hours capacity, and, finally, the Ninove Station has a 756 ampere-hour battery. As an example of the utility of a system of storage batteries, especially in central station work, the following instance may be cited : The battery at the Passage du Nord was recently exposed to very severe test. The boilers at this station are below the level of the roadway, and during a recent thaw the boiler-house was flooded, and for 24 hours no steam could be generated. The batteries consequently had to bear the full brunt of the load, and according to the registering ammeter curve 1,780 ampere-hours were taken out of them, or 17·6 per cent. more than their normal capacity.

† To ensure perfect contact between the active material and its metallic receptacle, and to prevent the formation of sulphate at the junction of the two materials, Messrs. FitzGerald and Hough, in 1889, obtained a British patent for a method of electrolytically producing a uniform film of peroxide of lead upon the entire surfaces of the metallic holders of both positive and negative elements. After the peroxidising process, the plates were filled and formed in the ordinary manner. By this device they found that the metallic supports were, in a great measure, protected from the evil effects of local and electrolytic action. The active material was in all cases found to be far more adherent, and less liable to scale and disintegrate.

smooth rollers. This last process closes up the grooves, and tends to key the active material in, and thus prevent scaling. The following table gives the weights, dimensions, and relative capacities of the different types of this cell:

TABLE VII.—TUDOR CELLS.

Type.	Ava'lable capacity in ampere-hours.	Maximum current in amperes.		Dimensions of cells.			Total weight in kilo-grammes.
		Charge.	Dis-charge.	Length. mm.	Breadth. mm.	Height. mm.	
I.	26	6	8	120	210	350	10
II.	39	9	12	170	210	350	15
III.	52	12	16	200	210	350	18
IV.	78	18	24	260	210	350	26
V.	91	21	28	300	210	350	30
VI.	120	24	32	230	340	450	41
VII.	150	30	40	270	340	450	50
VIII.	180	36	48	290	340	450	59
IX.	240	48	64	430	370	480	90
X.	270	54	72	420	420	550	110
XI.	360	72	96	500	420	550	130
XII.	450	90	120	580	420	550	160
XIII.	540	108	144	660	420	550	195
XIV.	630	126	168	740	420	550	230

As the results of some tests made by Prof. Kohlrausch on the Tudor cell, the following particulars are given:

Total weight of plates	29·3lbs.
Total surface of positive plates	1·29 square feet.
Quantity of electrolyte	6 pints.
Density of electrolyte when fully charged	1,147.
Normal charging current	5 amperes.
Normal discharging current	6·5 amperes.
Internal resistance of cell when charged	0·015 ohm.
Internal resistance of cell when discharged	0·02 ohm.
Capacity per pound of plate	1·6 ampere-hours.

A series of six ordinary charges and discharges showed an efficiency of 94 per cent. for current and 82·4 per cent. for energy. After the above results were obtained the cells were charged, and were then allowed to stand for some weeks ; the results at first obtained generally showed a loss of 7 ampere-hours, but after that a week's rest practically showed no further loss. When the cell was charged with a current of 8 amperes and discharged at a rate of 10 amperes, an efficiency of 77 per cent. and 64·7 per cent. for current and energy respectively was obtained. When discharged through a constant resistance, with a current beginning with 50 amperes, they gave 23·5 ampere-hours and 40·5 watt-hours, the current having fallen off at the end of the test to 40 amperes, and the electromotive force from 1·8 to 1·3 volts. They were then recharged, and discharged with 90 amperes, giving 20·1 ampere-hours and 32·7 watt-hours, the current falling to 62 amperes.

After the elements had been subjected to this heavy strain, and when recharged, they gave their normal discharge, and they were run down for a period of four days, starting at one ampere, until the electromotive force had fallen to 0·2 volt, and the density of the electrolyte was 1,100. The cell was then recharged until gas began to come off quite freely, and on discharge it then returned 46·8 ampere-hours, representing an efficiency of 90 per cent. for current, and 80 per cent. for energy.

The cell tested was not a new one, but was taken from a number that had been in use for some time ; the results, therefore, are more remarkable.

The Pollak Elements.—M. Charles Pollak has undertaken some researches with a view to giving a considerable storage capacity to elements of small dimensions and weight. As the active material the ordinary salts of lead are employed. To secure the perfect adhesion of the lead salts, the surfaces of the plates are worked up into a brush-like form by being passed between specially-constructed laminating rollers. The hair-like protrusions are about two millimetres high, and the interstices between the points about one millimetre apart. After the mechanical treatment, the plates are coated with electrolysed lead, thoroughly washed, and then covered with a layer of pasty sulphate or oxide of lead. When set and hard, the elements are formed in the usual dilute sulphuric acid bath. The total formation is accomplished in about 50 hours. When finished, the adhesion of the active material is found to be so perfect that the adhering surface of the superimposed layer is undistinguishable.

Such an accumulator, consisting of nine plates, four positive and five negative, was found to weigh 11·26 kilogrammes, including the connecting bars. After the cell had received 45 hours' formation at the rate of 16 amperes per hour, it was discharged at the rate of 13 amperes, which was kept constant, and gave a total capacity of 95·4 ampere-hours.

The following figures gives the fall of electromotive force at various periods during the discharge. It will be seen that the discharge was stopped when the electromotive force had fallen about 10 per cent. below the normal.

Time.		Current.		Potential.
0 hours	....	18 amperes.	....	2·12 volts.
1 ,,	....	18 ,,	....	2·08 ,,
2 ,,	....	18 ,,	....	2·00 ,,
3 ,,	....	18 ,,	....	2·00 ,,
4 ,,	....	18 ,,	....	2·00 ,,
5 ,,	....	18 ,,	....	1·90 ,,
5.18 ,,	....	18 ,,	....	1·80 ,,

The same cell recharged with a current of 16 amperes for seven hours gave 103·0 ampere-hours. The capacity of this cell is given as 9·13 ampere-hours per kilogramme of lead plate, and the current efficiency as 91·4 per cent.

Gibson's Battery.—The idea in this form of battery is to construct in a simple and economical way an accumulator capable of withstanding a considerable amount of rough treatment without the active material being jolted out or disintegrated. The original plates were formed from the ordinary rolled sheet lead. A large number of small loops were forced or stamped out from the substance of the sheet lead itself. Parallel rows of these projecting loops extended across the plate, each alternate row being a half loop in advance of the others. To add strength to the plates, the edges on all sides were turned up in the form of a rim. After the stamping process the elements were filled in to a uniform level, either with oxides of lead in the form of a paste, or the oxide merely damped and then pressed in. By the arrangement of loops, the active material is effectually keyed in. The present form of element is made of white metal, and is moulded in a chill. When setting up the cells, a number of vulcanite pins are studded over each plate and serve to keep them the requisite distance apart. It is asserted by the inventor that his form of cell gives a very large capacity per pound of plate, owing to the relatively large amount of active material on each metallic support.

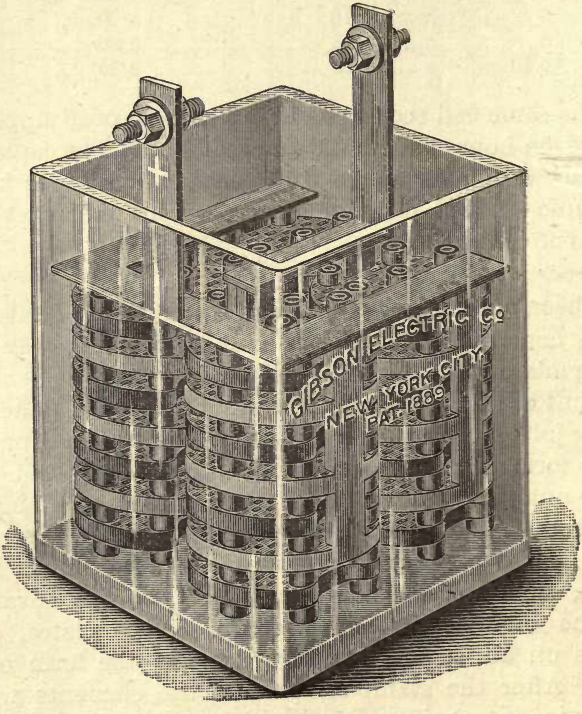

FIG. 43.—Gibson's Cell.

In the early form of this cell, Fig. 43, there were nine elements, four positive and five negative; these were built up horizontally one above the other. The amount of liquid space between each pair of plates was about equal to the thickness of the elements. A later pattern cell contains four groups of circular plates, all joined to a common connector, and built up in the same fashion as those in the original type.

The following table gives some particulars as to the capabilities of Gibson's cell.

Type.	Capacity in ampere-hours.	Length.	Width.	Height.	Approx. weight complete with acid.
		Inches	Inches	Inches	lbs.
76D	200	7¾	7¼	14	42
64D	165	7¾	7¼	12	38
52D	130	7¾	7¼	10	34
40D	100	7¾	7¼	8	31
28D	65	7¾	7¼	7¼	26
7D	15	4	4	6½	10

The Atlas Accumulator.—The "Atlas" storage battery, Fig. 44, is the name given to a new form of cell, which appears to be the joint invention of Messrs. Hering, Abdank-Abakanowicz, d'Arsonval, and Picou. The information obtainable with reference to this new form of cell, which appears to be of the horizontal type, is somewhat limited. Each cell is composed of a number of positive and negative plates placed one above the other, and interleaved with some perforated elastic material such as indiarubber, celluloid, or other similar substance. The plates are held in position and the elements of like polarity joined together by nuts and bolts made of an unoxidisable alloy of lead. Both elements seem to be composed of the ordinary active materials—viz., peroxide of lead and spongy lead. To increase the active surface, and allow for the free circulation of the electrolyte, each plate is pierced with a

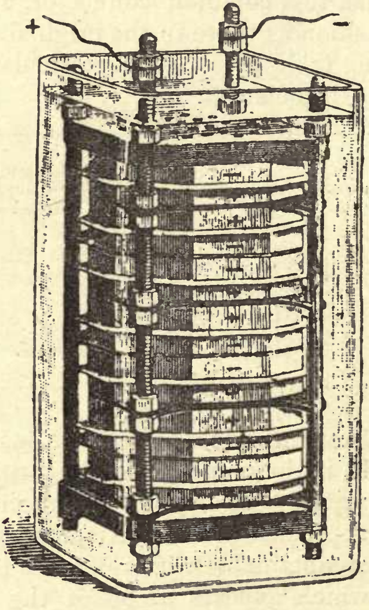

Fig. 44.—The Atlas Accumulator.

large number of holes. Owing to the method of clamping with the nuts and bolts, and to the insertion of the elastic medium, the elements are said to be quite unaffected by slight changes of dimensions, or by jolting or other disruptive influences.

At a recent meeting of the Société Internationale des Electriciens, in Paris, M. R. V. Picou read a paper on this accumulator, and gave the following particulars of a cell that had been under test :

Porosity of plates .... = 50 per cent.
Density of plates.................... .... = 4 ,, ,,
Capacity per pound of plate .... = 9 ampere-hours.
Discharging current .... = ·7 to 9 amps. per lb. of plate.
Dimensions of a 150 ampere-hour cell... = 6⅕ × 7⅕ × 13 inches.

The James Accumulator.—Mr. L. James has brought out an accumulator in which the positive plates consist of lead alloyed with one per cent. of cadmium, whilst the negative consist of lead alloyed with two per cent. of antimony. The plates are pierced with circular holes, in which the active matter is pasted. Those on the positive plates are filled with a mixture of 8·5 parts of minium, 1 part of litharge, 0·4 part of carded asbestos, and 0·1 part of powdered carbon. The holes in the negative plates are filled with a mixture of 9·4 parts of litharge, 0·1 part of sulphur, with 0·4 part of asbestos, and 0·1 part of powdered carbon. The cells are said to possess a great electric capacity, and can be subjected to great variations of the current without danger of buckling the plates.

Reckenzaun Storage Cell.—Mr. Reckenzaun's name has been associated with storage batteries for many years. Some time back he gave a series of very able articles in the *Electrical Review* on "The Durability of Storage Batteries," in which the important question of the efficiency and depreciation of storage batteries, especially when employed for traction purposes, was very fully considered. After many experiments had been made to ascertain the possibilities of constructing a plate which would withstand the very rapid variations of output, the jolting, and the rough handling which cells used for tramcar work are sure to be subjected to, Mr. Reckenzaun devised his porous cylinder element, Fig. 45. This plate, it is asserted, will not warp, and may even be bent into the form of a small tube without the active material falling out or even scaling. The porous cylinders are shaped in a mould, and are $\frac{3}{16}$ inch in

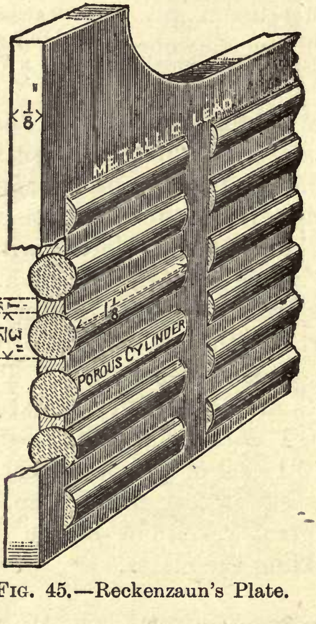

FIG. 45.—Reckenzaun's Plate.

diameter, and 1⅛ inches long. A number of these little pencils of active material are put into cavities in a metal chill ¼ inch distant from centre to centre, and molten lead is poured around them. As a result, a plate is produced whose metallic part is about ⅛ inch thick, so that a portion of the porous cylinders protrude on either side, and thus expose a large active surface to the electrolyte. During the electrolytic action each little porous rod expands, chiefly along its own axis which lies parallel to the surface of the plate, and therefore tends to elongate itself, but not to bend or buckle the plate. The increase in the diameter of the cylinders serves to make more effective contact with the metal support. As the metal employed is pure lead, and therefore very soft, it offers but little resistance to elongating influences.

There is another novel method of producing storage battery elements due to Mr. Reckenzaun. He found that lead, when placed within an electric arc, was quickly converted into an oxide. Working on this idea, he caused an electric arc to travel over the surface of a plain lead accumulator plate, and found that he could by this means transform the entire surface to any desired depth into peroxide of lead. The oxides formed in this manner do not appear to show any disposition to scale or fall off when placed in an acid solution, or when being subjected to electrolytic action.

In a lead storage-cell the water is slowly split up into its constituents, oxygen and hydrogen. The nascent oxygen liberated attacks the metal forming the positive element, and slowly oxidises it; and the hydrogen is either occluded by the spongy metal of the negative plate, or escapes into the air. By Mr. Reckenzaun's method the intense heat of the electric arc is utilised to induce rapid combination between the oxygen of the atmosphere and the lead, and produces in a few minutes the same amount of chemical combination that would take days or even weeks to bring about by the slow process of decomposing water by the electric current.

Frankland's Element.—Dr. E. Frankland employs as the active material in his plates, small flattened rods of lead salts prepared as follows: The lead oxides are moistened with dilute sulphuric acid, and while they are still in the pasty condition he moulds them into small cylinders or rods of convenient length and thickness, either by rolling, or forcing through a draw-plate, and then flattens them on opposite sides by pressure between two flat boards. After the flattened cylinders have become sufficiently dry and hard, they are placed in rows in a casting mould, of suitable dimensions to form the battery plates. The pellets of active material do not touch, but they are arranged at such distances apart, and from the edges of the mould, to allow sufficient space for the requisite quantity of metal to run in to impart adequate mechanical strength and rigidity to the element. Molten lead, or an alloy of lead and antimony, is then poured into the mould until the whole of the interstices between the little flattened cylinders are completely filled. In this manner an element is obtained in which the active material is entirely encased, except on the flattened sides of the cylinders, so that it cannot subsequently fall out during the charging and discharging operations, or even when subjected to considerable jolting.

Currie's Asbestos-Covered Elements.—A recent storage-battery plate of somewhat curious form is due to Mr. S. M. Currie, of America. The active material is in the form of a thin layer, no part of it being more than one-eighth of an inch thick; it is entirely encased, and therefore not exposed

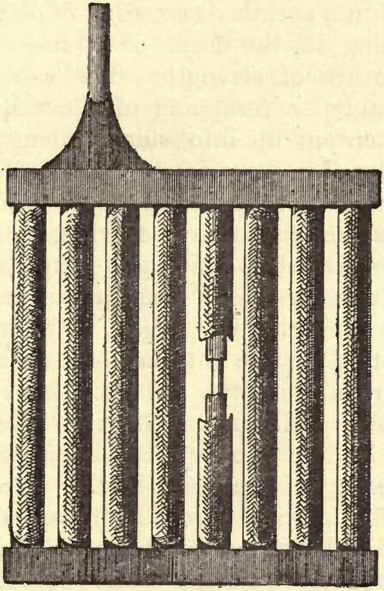

FIG. 46.—Currie's New Storage Battery Plate.

directly to the action of the electrolyte. In Fig. 46, a part of the supporting frame of the new element is shown exposed in the centre; but in the finished plates, all parts below the surface of the liquid are encased.

The principal feature of this form of plate, however, resides in the fact that the active material is entirely encased within a sheath or covering of asbestos. The covering being in the form of a tube ensures the essential feature of strength. The asbestos is first braided in tubular form and of the required thickness, and then cut up into suitable lengths, eight of which are placed in a special mould. Each tube, when placed in the mould, is supplied with a removable brass rod of the same length as the asbestos, but of considerably less diameter, which passes up its centre. By means of a suitable inlet a fused salt of lead, such, for instance, as the chloride of lead, is poured into the mould and fills up the intermediate spaces between the brass rods and the asbestos envelope. The rods are then withdrawn, leaving afterwards the chloride of lead in a compact cylindrical form, with an outer coating of braided asbestos. The next step is that of filling with pure lead, or an alloy of lead and antimony, the spaces lately occupied by the brass rods, and at one and the same operation casting on a connecting bar of the same metal to hold the rods the requisite distance apart and to form the necessary connections. The chloride is then reduced to porous lead by electrolysis, after which the plate is then ready to be fitted up and "formed." When formed in this manner these elements can be used in conjunction with positives of a similar type, or with flat positive plates of the ordinary type.

The asbestos coating does not appear to materially increase the internal resistance of the cell, as being of a highly porous nature, it offers but little obstruction to the free action of the electrolyte.

A number of cells, each consisting of ten positives of the above-described form, and eleven negatives of the ordinary flat type, have been subjected to most severe tests, as regards charging and discharging, and the way they maintain their current and electromotive force is said to be most promising. A plate, weighing about 1¾lbs., was subjected to continuous charging and discharging at the rate of 30 amperes, and at the end of one month the plate was found to be in excellent condition. This plate, which had a current capacity of 20 ampere-hours, was allowed to remain idle for a long period, and when at length it was again charged and run out it gave its original current capacity.

The Pumpelly Storage Battery.—This form of battery has been received with some favour in America. It is of the horizontal type, and of a semi-solid character, the elements being of the grid form. Each grid or plate is supplied with stout ferrules or lugs, cast on one side only, and so placed that the entire weight of the element rests upon them. These lugs serve also as connectors between the plates of like polarity. As the grids are placed one above the other, a cell is produced which is said to possess great mechanical strength, and is but little liable to be injuriously affected by any warping or buckling of its elements.

In storage cells where the vertical form of grid or plate is employed, trouble is sometimes caused by the gradual loss of mechanical strength in the elements, due to the eating-in effect of the electrolytic action. Repeated oxidising and deoxidising of the supporting frames tends to make them both spongy and soft, and renders them very liable to either break up or drop from their supports. When battery elements are disposed horizontally, little difficulty is experienced from this cause, as the plates may be made to rest upon any number of points, or upon their entire surface. In the Pumpelly cell the mechanical strength of the holders for the oxides is not relied upon, as in the cell there are no clear liquid spaces, and each plate rests upon, and is supported by, an highly porous elastic diaphragm.

In the cell under consideration the bottom plate is laid upon a foundation of celluloid fibre; upon this plate is placed a matting of celluloid, then another grid, and so on, throughout the series. The porous diaphragm is only of sufficient thickness to absorb as much of the electrolyte as will effect all the necessary chemical reactions involved in the operations of charging and discharging. With this method of construction the plate cannot warp, the active material is held firmly in position, and each particle is freely bathed by the electrolyte, the chances of circuiting are minimised, and the necessity of taking the cells apart for cleaning purposes is obviated.

In the process of manufacture of these cells, the interstices of the metal grids are filled with red lead or litharge in the form of a powder, the requisite hardness being obtained by hand pressure. When brushed off level and smooth, a layer of celluloid fibre is placed over the filled plate, and another grid is placed upon this and filled in the same way; the process is continued until the requisite number of elements are installed. When brought to this stage, the cell is connected to its charging source, the current is switched on, and the electrolyte is slowly poured in.

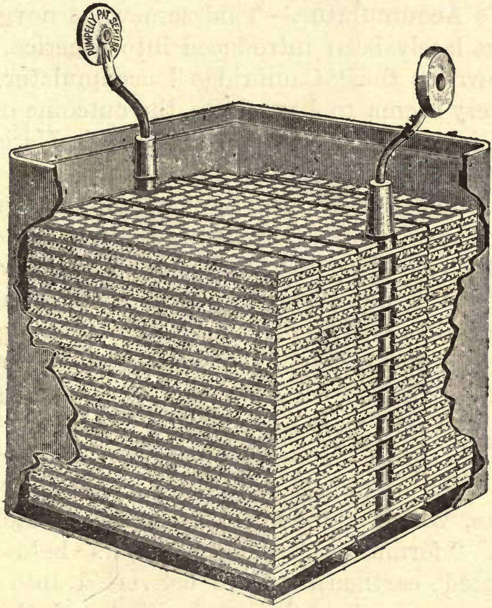

Fig. 47.—The Pumpelly Storage Battery.

The advantage claimed for the employment of the dry powdered oxides of lead is that greater porosity of the resulting active material is obtained.

A complete cell of this interesting type is represented in Fig. 47.

Hatch's Accumulator.—This somewhat novel form of cell has lately been introduced into America, where it is known as the "Cambridge" accumulator. The new battery seems to have been the outcome of some investigations carried out jointly by M. Hatch and Prof. C. H. Wiswell, of Boston, who were led to devise it when endeavouring to overcome the structural difficulties which usually beset the grid form of element. In this battery, metallic frames are not employed for supporting the active material, the lead salts being contained within the corrugations of a zigzag plate made of highly porous and open-grained earthenware. When the corrugations in the porous earthenware are filled in so as to present a flat and even surface, a number of these blocks are packed together, each adjacent pair of blocks being separated by a thin lead plate, which simply acts as a conductor. By electrical "formation," the lead salts held within the serrated earthenware are converted into active material—one surface being positive and the other negative. In a 200 ampere-hour cell, as shown in Fig. 48, the porous plates are seven inches square and half an inch thick. Each plate when dry weighs about ten ounces, and is capable of absorbing approximately five fluid ounces of water. The corrugations are about a quarter of an inch deep. The complete cell contains seven porous blocks and eight metal conductors, and when dry is said to weigh 28lbs., exclusive of its outside containing-cell. Owing

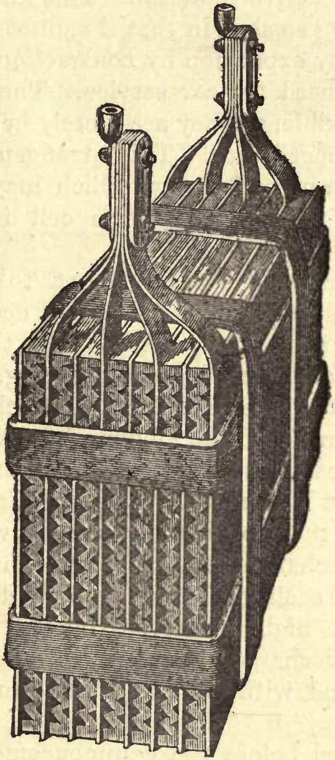

FIG. 48.—Hatch's Accumulator.

to the method of construction adopted, there is no possibility of the plates buckling, no matter how heavy the charge or discharge. Among the numerous advantages claimed for this type of cell are: the complete absence of short-circuiting, and the absolute control of the active material. This latter is provided for by its being so shut in that it cannot be thrown out of its place, by expansion by contraction, or by jolting if the cell be used for car service. The elements are somewhat flexible, as they are merely held together by stout indiarubber bands. This arrangement allows for any expansion or contraction which may occur during the forming process, or if the cell is being overworked.

As this semi-solid battery seems to depart somewhat from the orthodox lines, it occurred to the author that some particulars as to the working of these cells would be highly interesting. Accordingly he applied to the inventors, Messrs. Hatch and Wiswell, who kindly furnished the following data. The accompanying curves have also been kindly supplied by the Massachusetts Electrical Engineering Company. Fig. 49 represents the drop in the potential which occurred in the first discharges of three newly made-up experimental cells, each of which contained eight plates, seven inches high by seven inches wide. In all cases, the discharges were made through carbon resistances, and with a steady, uniform output of 10 amperes.

When tested before the commencement of the discharges, the open potentials of the cells marked Nos. 1, 2, and 3 were found to be respectively 2·24, 2·21, and 2·23 volts.

The internal resistances of the cells at the starting

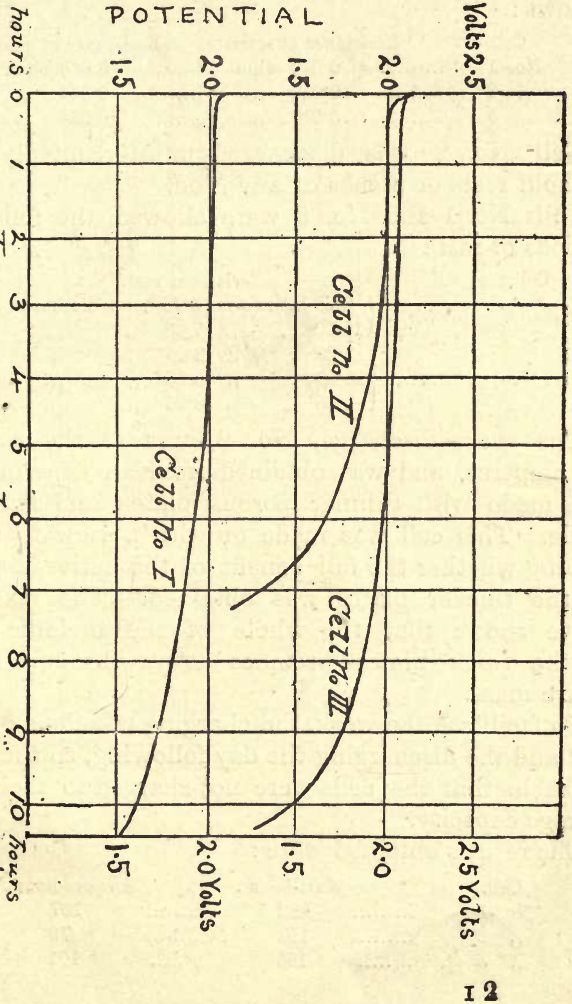

Fig. 49.—First Discharge Curves from Three New Hatch's Cells.

and termination of the discharges were found to be as follows:

Cell.	Resistance at start.	Resistance at finish.
No. 1	0·010 ohm	0·048 ohm.
,, 2	0·010 ,,	0·044 ,,
,, 3	0·010 ,,	0·034 ,,

Cell No. 2 was discharged uninterruptedly, and without rests or breaks of any kind.

Cells No. 1 and No. 3 were allowed the following periods of rest:

Cell.	Periods of rest.
No. 1	0·25 hours after 5·75 hours discharge. 15·00 ,, ,, 7·05 ,, ,,
,, 3	1·20 ,, ,, 2·05 ,, ,, 26·50 ,, ,, 5·05 ,, ,, 1·06 ,, ,, 8·05 ,, ,,

The short discharge, No. 2, was at the rate of 10 amperes, and was obtained from an experimental cell made with thinner porous plates and less lead oxide. This cell was made up with a view to ascertaining whether the full benefit of the active material in the thicker plates was obtained. The resultant curve shows that the whole of the metallic salts in the thick plates becomes active throughout its entire mass.

To facilitate the work, the charging was done on one day and the discharging the day following, so that it is probable that the cells were not charged to their full storage capacity.

The results obtained were:

Cell.	Watt-hours.	Ampere-hours.
No. 1	192	107
,, 2	132	71
,, 3	196	101

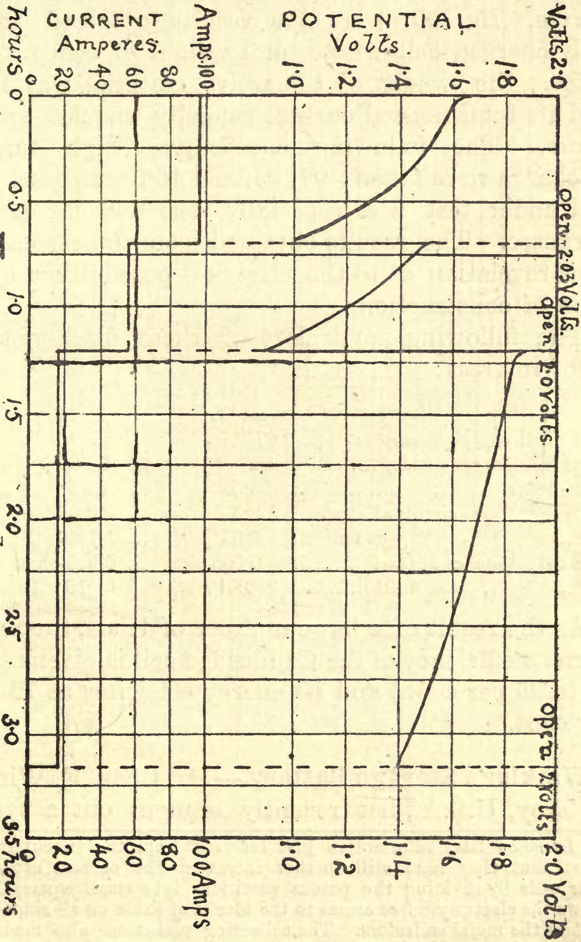

FIG. 50.—Three Consecutive Discharges from Hatch's Cell.

The fall of potential as shown in the discharge curves, Fig. 50, were the results obtained from a fully-charged cell whose total weight of elements was 28lbs.; the weight of the active material was 15lbs., and its total normal current capacity was 200 ampere-hours. The following consecutive high rates of discharge were taken: 97, 55, and 16·5 amperes. The cell under test was especially designed for traction purposes. The results obtained seem to be somewhat of a revelation as to the electrical possibilities of this form of construction.

The following particulars of these discharges will be of interest:

	Cell No. 1.	Cell No. 2.	Cell No. 3.
Rate of discharge in amperes	97	... 55	... 16·5
Ampere-hours obtained...............	68	... 27·5	... 32·1
Watt-hours ,, ...	94·5	... 35·0	.. 57·8
Voltage on open circuit at start ...	2·2	... 2·03	... 2·0
,, ,, at finish...	2·03	... 2·00	... 2·0
Internal resistance at start	0·005 ohm	... 0·009 ohm	... —
,, ,, at finish...........	0·010 ,,	... 0·018 ,,	... —

As the result of a large number of trials, the normal current efficiency of the Cambridge cell is given as from 92 to 95 per cent., and its energy efficiency as 72 to 74 per cent.*

Winkler's Storage Battery.—Mr. Chas. F. Winkler, of Troy, U.S.A., has recently brought out a type of

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* In some later information just received from the inventors, they assert that they have still further increased the current capacity of their cells by dividing the porous partitions into small squares, which allows the electrolyte free access to the blocks of oxide on all sides, except next to the metal collectors. The collecting plates are also made more efficient by constructing them of an unoxidisable white metal, which is quite unaffected by the acid solution.

storage cell, the construction of which he claims enables it to withstand without injury the hardest usage. The plan of construction will readily be seen by reference to Fig. 51, which represents respectively a section and side view of this form of element.

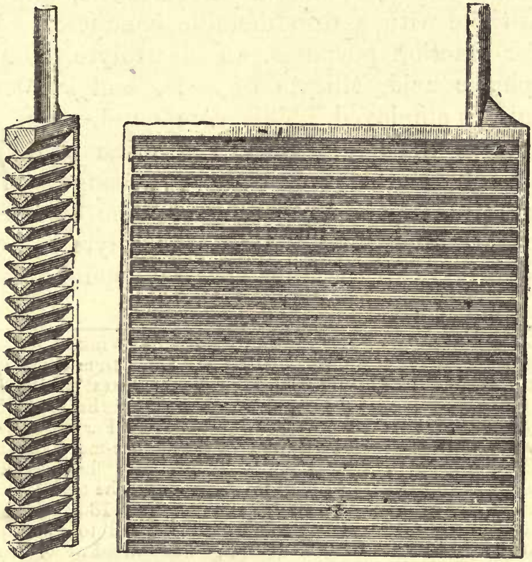

Fig. 51.—Winkler Element

The grid consists of a vertical row of V-shaped troughs, within which the active material is pasted. This method of construction gives the active material a considerable contact surface, and at the same time allows it to contract or expand without affecting the shape of the grid, and hence all tendency to buckle is avoided. The space between the troughs allows the electrolyte to circulate freely, and thus the active material is very evenly acted upon.

Where lightness is a desideratum, Winkler purposes making the troughs of an acid-proof, non-conducting material, such as celluloid or vulcanite, and then coating them with a thin metallic conductor. When used for traction purposes, an electrolyte composed of sulphuric acid, silicate of soda, and sulphate of ammonia, is employed. This compound, when newly mixed, is in the liquid form, but when poured into the cell and allowed to rest, it soon congeals into a gelatinous mass, and tends to keep the elements in their allotted position; and the electrolyte being in a semi-solid state, all possibility of its slopping or spilling is avoided.*

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* As an illustration of the capabilities of the Winkler battery, the following particulars of some recent trials are taken from the New York *Electrical Engineer* of 29th July, 1891: "On a recent test this battery was made to give successively 40, 45, and 60 amperes at the beginning, the time being about 10 to 15 seconds in each case. For an instant the battery was short-circuited, the pointer of the ampere-meter leaving the scale at 200 amperes. The battery was charged after the first discharge for 10½ hours at 10 amperes without intermission. The regular discharge was begun at 1.35 p.m., and continued at the rate of 18·5 amperes until between 6 p.m. and 6.15 p.m., when it gradually fell to 17 amperes at 6.30. After a rest of an hour the discharge was started at 17·5 amperes, and in 42 minutes it had dropped to 14·5, when the wires were disconnected. The entire discharge amounted to 97 ampere-hours, giving an efficiency for this discharge of 93 per cent. When the cell began to discharge the difference of potential was two volts, and at the end of the discharge 1·78 volts. In the cells arranged for this test the plates consisted of five positives and five negatives, and were new, having received their first or forming charge of 10 amperes for 26 hours. The following gives the weights of plate and active material:

Weight of plates alone	16lbs. 2ozs.
Weight of plates with active material	25lbs. 6ozs.
Weight of active material........	9lbs. 4ozs.

The Tommasi "Multitubular" Storage Battery.—The outer containing envelope of the elements in these batteries consists, as shown in Fig. 52, of perforated tubes or chambers, made of some non-conducting material, such as earthenware, vulcanite, or celluloid. Within each chamber is placed a central metallic conductor, which serves as a retaining core for the active material. The whole of the space between the conductor and exterior envelope is filled with lead salts, which are rendered active by the usual method of formation. If it be thought desirable to reduce the time required for the forming process, chemically-prepared peroxide may

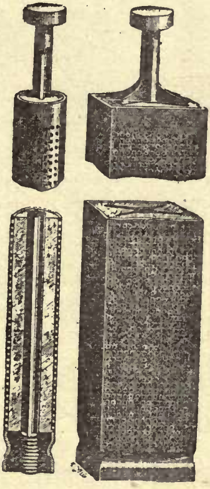

FIG. 52.—Tommasi Element.

be used in the positive electrode, and precipitated or spongy lead in the negative. At the base of each chamber an insulating plug is fixed, which effectually prevents the lead salts from falling out. The metallic core may be either plain, fluted, or in the form of a coarse screw. Fig. 53 shows in elevation and section some of the various shapes of cores utilised in these electrodes. In the complete cell, Fig. 54, the electrodes are fixed to an insulating cover or element board, and are placed alternately, first a positive and then a negative, and so on throughout the series. All the terminals of like polarity

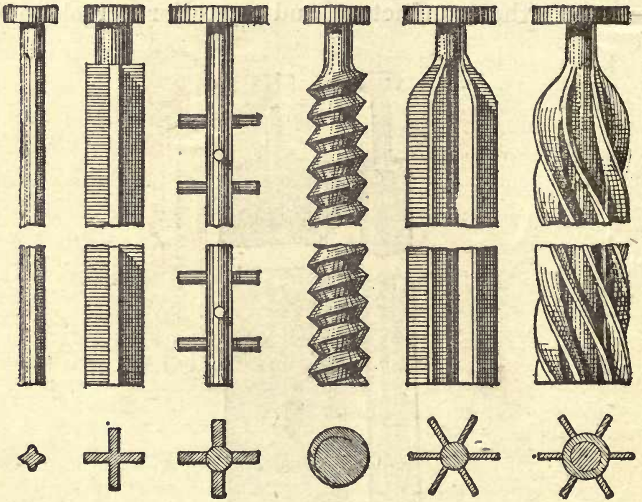

FIG. 53.—Cores for Tommasi Elements.

are joined up to form one pole, by means of stout metallic strips, made of some inoxidisable alloy. In cells constructed for traction purposes, the lower end of each electrode is inserted within an aperture, made in an insulating base-plate, as shown in Fig. 55. By this arrangement each electrode is securely and firmly held in position both at its top and bottom, and is therefore not at all liable to be displaced by jolting or concussion. Owing to the form of these elements the entire surface of the active material is freely bathed by the electrolyte, and any oscillation or movement of the cell tends to thoroughly mix the liquid so that troubles arising from differences of density do not occur.

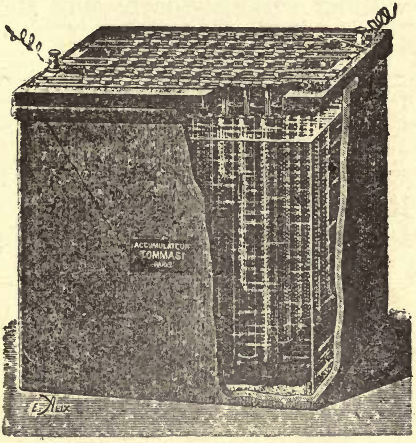

Fig. 54.—Tommasi Complete Cell.

In tubular cells constructed according to Tommasi's design, 77 per cent. of the total weight of each electrode is said to be active material, and a current capacity of 16 ampere-hours per kilogramme of plate may readily be obtained. From the cells specially constructed for traction purposes a rate of discharge of from 50 to 60 amperes per kilogramme may, it is stated, be taken from them without seriously decreasing their general efficiency. By reason of the thorough utilisation of the active material, the weight of one of these cells is claimed to be from two to six times and the volume from four to eight times less than that of an ordinary grid form of accumulator.

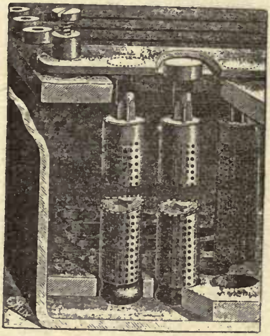

FIG. 55.—Tommasi Traction Cell.

In a recently-introduced form of Tommasi cell the elements are of rectangular instead of tubular shape. By this arrangement greater current capacity is said to be obtained within a given compass, and the internal resistance of the cell is considerably diminished. A complete set of elements of this improved type is represented in Fig. 56.

Results of some tests made with a multitubular Tommasi cell of the rectangular form containing nine

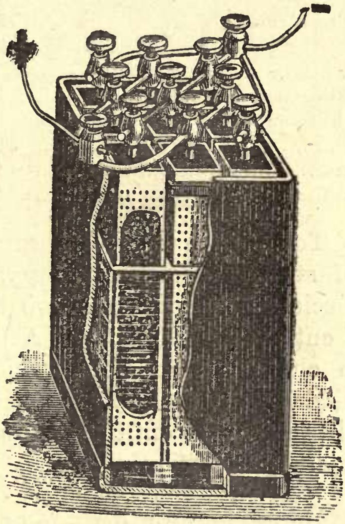

Fig. 56.—Tommasi Improved Cell.

positive and nine negative elements were published in the *Moniteur Industrie* of October 1, 1891, from which the following particulars are taken :

Height of cell	27 centimetres.
Width ,,	17 ,,
Breadth ,,	17 ,,
Total weight of cell	1,204 grammes.
,, ,, active material	816 ,,
Percentage of active material in plate	67·77 per cent.

The following results were obtained from this cell after it had received 220 hours of formation :

Starting electromotive force	2·4 volts
Working ,, ,,	2·0 ,,
Maximum charging current	100 amperes
Mean ,, ,,	25 ,,
Maximum discharging current	30 ,,
Mean ,, ,,	18 ,,
Working capacity	321 ampere-hours
Ampere-hours per kilogramme of plate	14·8
Ampere-hours per kilogramme of plates at rate of 0·5 ampere	357·6
Current efficiency	95 per cent.
Energy ,,	80 ,,

Dr. Donato Tommasi has devoted much attention to methods of storing electrical energy, and among his numerous scientific papers are two bearing upon this subject, entitled "Un nouvel Accumulateur à l'electrodes en charbon plombifère," and "Accumulateur Multitubulaire." In addition to these papers he has written a little treatise entitled "Traité des piles et des Accumulateur Electriques."

Pitkin's Portable Accumulators.—As many of these small storage cells, made up into the form of electric hand lamps, are to be found in various parts of this country, it may not be uninteresting to enter somewhat fully into the details of their construction.

The Pitkin elements are very simple in construction. They consist of small cast-metal plates, each having an outer raised rim on both its sides, and a number of small tapered pins of the same height studded over its entire surface. When taken from the casting mould, the raised pins are tapered outwards, but by a system of rolling or hammering their extremities are burred over. This burring process gives the pins the shape of a double dovetail, a form well suited to keying in the active material. As the amount of metal in each plate is small, they are found to hold a larger percentage of active material per pound of plate than the ordinary grid form of element; but this only applies to plates of small dimensions. In the filling-in operation, minium moistened with dilute sulphuric acid is pressed into the interstices of the plates by hand pressure. When set and dry, the elements are placed in an acid bath and "formed" by the usual method.

When making-up batteries, suitable, say, for portable mining lamps, five or seven plates are fitted into each cell respectively—two positive and three negative, or three positive and four negative. The containing-cells are made of hard rubber, and each has a ledge about half an inch from its top. Thin vulcanite covers are fitted to each cell, and rest upon these ledges. The elements are cast with projecting lugs, which, passing through holes in the covers, serve to hold them in their allotted positions. To retain the plates at the requisite distances apart, and to prevent bending and warping, small round vulcanite pins are screwed into the extremities of the positive plates, and are cut off of just sufficient length to allow them to slip tightly down between the two negative plates. When finally adjusted, the lugs of all the plates of the same polarity are lead-burned together. In the centre of each cover a small vent hole is drilled, which serves as a vent for the escape of gases as well as for filling-in purposes.

In the large miners' lamp, Fig. 57, four cells, prepared as described, are fitted into an oak or teak case. They are joined up in series by means of lead connecting strips, the vent holes are temporarily plugged up, and the whole is covered in with an acid-proof cement. The lantern usually consists of a deep parabolic reflector, spun up with a bottom flange for fixing purposes. A bevel-edged glass disc, mounted in a metal bezel, acts both as a cover and a protector, and is held tightly in position by means of a bayonet joint. Within the chamber formed by the reflector a small eight-volt incandescent glow lamp is firmly secured by means of two hooked terminals. A platinum loop is sealed into the top of the glow lamp, and is caught by a spiral

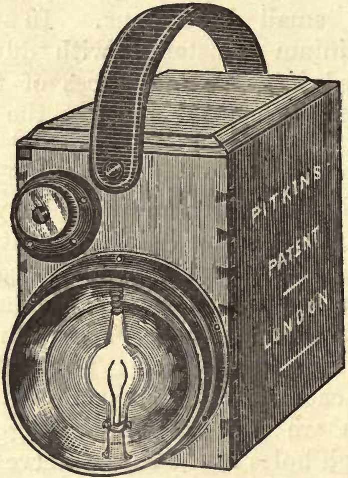

Fig. 57.—Pitkin's Miner's Lamp.

hook arrangement fixed at the top of the reflector, which serves to produce a little tension on the loop terminals of the lamp, and thus ensures good contact. A small circular rheostat having a resistance of about six ohms is placed in the main circuit between the battery and lamp. A movable arm, which is pivoted in the centre of the resistance cover, carries the current to the rheostat, serving both as a switch to throw the lamp in or out of action, and when turned round on to a small stud to cut the lamp out and complete the circuit direct from the battery to the charging terminals. By this arrangement, whenever the lamp is in action the charging circuit is incomplete, and therefore all danger arising from short-circuiting or sparking is avoided. This precaution is of some importance, more especially when the lamps are being used in fiery coal mines. The charging terminals are merely small brass studs, sunk in level with the surface of the wood case, with holes drilled in them to receive the charging-pins. All the connections are run in grooves made in the wood of the outer case, and are covered in with an insulating cement.

The variable resistance is found to be a very useful little adjunct, as, by its means, the potential at the lamp terminals can be nicely adjusted to suit variations in the resistance of different glow lamps; it may also be used to regulate the flow of current when the cells are giving an abnormal electromotive force, which is usually the case immediately after a recharge.

The complete lamp weighs 7½lbs., and with one charging will actuate its glow lamp for a period varying from eight to ten hours. The duration of the discharge varies according to the amount of current consumed in the glow lamp, which may range from 0·35 to 1·0 ampere. The lamp bulb is usually protected by a stout disc of plate glass, or, in cases where a concentrated light is required, by a bull s-eye lens.

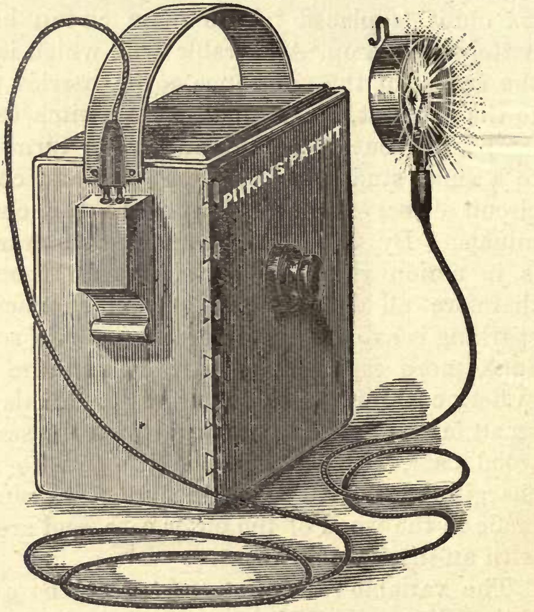

Fig. 58.—Pitkin's Battery and Detachable Lamp.

The actual intensity of light obtained from this battery is about 1·5 candle-power. This form of electric hand lamp is much used in coal mines, gunpowder mills, petroleum ships, and gas works, or under any circumstances where an absolutely safe light is an essential.

Another four-cell battery of the same dimensions, weight, and electrical capacity as the one just described, is made. This form of portable battery, Fig. 58, is rather more elaborately finished, and is supplied with a detachable lantern which is connected up to the battery by means of long silk-covered flexible twin wires. This battery is usually employed as a reading-lamp for the use of travellers.

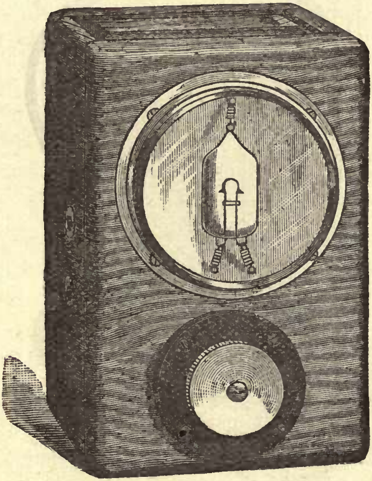

Fig. 59.—Pitkin's Pocket Lamp.

A very handy little electric lamp, called on account of its smallness a "pocket" lamp, is shown in Fig. 59. This compact little battery contains two cells, and weighs about 2lbs. When fully charged, it will incandesce a small 3·5-volt glow lamp, taking 0·5 ampere, for a period of six hours. The outer wood case is made either of polished oak or walnut. At the back of the containing-box a pair of folding handles are fixed. The little glow lamp filament is mounted in a flattened glass bulb, and is backed by a French silvered white reflector. Under the lantern bezel, a combined switch and rheostat is placed, which serves to bring the lamp in and out of action.

Fig. 60.—Surgeon's Battery and Lamp.

A similar two-cell battery—specially constructed for the use of surgeons, dentists, and microscopists—is shown in Fig. 60. This is of the same dimensions as the pocket battery, but it is not supplied with a fixed lantern.

The current is led from the cells to a very minute glow lamp, by means of flexible silk-covered conductors. If the lamp be mounted in a laryngoscope, the handle of the instrument is supplied with a switch for bringing the lamp in or out of action, and also a small sliding variable resistance, which is used for regulating the flow of current through the lamp, and thereby adjusting its luminosity.

Sometimes a circular concave mirror mounted in a light metal frame, is slipped over the lampholder. The mirror is fixed at an angle, and just clears the glow lamp. By this means the patient is protected from the heat effects of the light, and at the same time the light rays are projected upon the object under examination.

Charging Small Accumulators.—Those who are accustomed to work with large accumulators, such, for instance, as the cells now sold for ordinary lighting purposes, frequently experience some little difficulty in dealing with cells of so small a capacity and high internal resistance as those we have just been considering. As a rule, it is found that the tendency is not only to seriously overcharge them, but to force the current in at such a high rate that the active material is completely blown out of the plates. A few hints as to the most approved method of charging small electric hand lamps may not here be out of place. Although the instructions given relate more particularly to the Pitkin form of battery, yet much the same thing applies to very nearly all types of small storage cells, especially those of a portable nature.

When joining batteries to the charging source, whether it be dynamo, lighting circuit, or primary battery, care must be taken to have the connecting wires thoroughly clean. In all cases the lead coming from the positive pole of the charging source must be joined to the positive pole of the battery on charge.* This precaution is most essential, as a charge in the wrong direction may completely spoil the elements, especially if they be of the "pasted" type. In the case of a four-cell Pitkin hand lamp, which usually has a useful capacity of six ampere-hours, it is found that the charging current should not exceed one ampere for a period of from six to seven hours. A current strength of 0·6 ampere for a period of ten to twelve hours, and at a potential of 10 volts, gives, perhaps, the best results. When fully charged, the violent evolution of gas within the cells can be plainly heard, and this is an indication that the charging operation should cease. The generating source may be either a dynamo, primary battery, or thermopile.†

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* The positive pole of a dynamo or other current generator may readily be found by joining two small strips of sheet lead to the wires coming from its terminals, and then immersing them for a few moments in dilute sulphuric acid. The lead strip attached to the positive pole will quickly turn a rich chocolate colour, while the negative will assume a dark slate tint. Small books of pole-testing papers are made; by tearing a sheet out, and damping it, a red or brown spot will be made by the positive wire when the two terminals are placed upon it. Instruments termed "pole finders" are also made, and most of these rely for the indication either upon the deflection of a magnetic needle, or the chemical decomposition of some electrolysible solution. The positive charging terminal on portable secondary batteries is usually either marked with the plus sign, +, or is painted red.

† As a medium for charging small accumulators, thermopiles seem destined to be in great requisition. At the late Frankfort Electrical

Six Bunsen or Grove cells, having a capacity of about twenty fluid ounces (one pint) will, with one filling, and when joined up in series, give enough current to effec-

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Exhibition the Gulcher thermopile attracted much attention. A comprehensive account of this new thermo-electric generator appeared in the *Electrician* of October 23rd, 1891, and from this the following extracts are taken:

"This thermopile presents a new solution of the interesting but difficult problem of producing electric energy directly from heat. As hitherto constructed these apparatus have never been found of any practical use, owing partly to their short life and partly to their very low efficiency. Herr Gulcher's lately-patented thermopile, however, not only does away with these defects, but appears to be capable of competing with the dynamo.

"The piles exhibited are constructed for heating by gas, and are so arranged that overheating is rendered impossible, and, consequently, the pressure regulator (up to now a necessary appendage) is done away with. For comparison with the new type an old form of the apparatus is also shown. In the latter, six small gas flames burn outside each negative electrode (formed of a nickel tube); in the new form only one flame is used for each electrode, and this is placed inside the tube. If the pressure in the gas mains is increased, the only result is that these Bunsen flames become longer, and the extra length being beyond the extremities of the tubes the effect, so far as heating the latter is concerned, remains unaltered. As soon as the flames are lighted the apparatus requires no further attention. After about seven to ten minutes it is fully heated, and from that time the electromotive force remains constant, however the gas pressure may vary. . . . The weight is about 10 kilogrammes, and the number of elements 50: these are placed in two parallel rows on a slate bed, which forms the top of the gasholder. Each element, as already mentioned, consists of a small nickel tube, in which is placed a "one-hole" soapstone burner. A connecting-piece of nickel is soldered to this tube, and is connected to the prism-shaped positive electrode, formed of an infusible antimony alloy. In order to prevent any mechanical change, such as fissures, occurring in this alloy, and so changing the internal resistance, two steel rings are placed round the connecting tube. At the outer extremities of the positive electrodes are placed cooling-pieces of copper, which also serve to form the connections. The elements are insulated from one another by means of asbestos. The larger of the two forms gives four volts. The internal resistance being 0·4 ohm, the pile is capable of giving a current of five amperes on a circuit possessing the same resistance. The smaller pile contains twenty-five elements, and supplies the same current at half the volts. The consumption of gas are 200 and 100 litres per hour respectively, the cost being about ·36 and ·18 of a penny.

"It will thus be seen that these piles are well adapted for the electro-deposition of metals, and also for charging accumulators arranged in tually recharge a four-cell accumulator whose current capacity does not exceed six ampere-hours. Where the current from a dynamo is available, the secondary

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parallel. With the help of the latter they are very useful for telegraphic purposes, and can also be applied to running small electric light installations.

"One of the best primary batteries on the market might under very favourable circumstances give an electrical unit for 1s. 6d., but at a great trouble and nuisance in the handling of many gallons of chemicals. A price of about 3s. or 4s. a unit may be taken for ordinary batteries, and this agrees very well with the price per 1,000 'joulads' given in Mr. J. T. Sprague's 'Electricity.' The cost of gas per electrical unit comes to about 1½d. with an engine and dynamo, and eighteen times this is 2s. 3d. It appears, then, that although no satisfactory comparison can be made with the dynamo, the Gulcher thermopile competes well with batteries, and offers the very important advantage in that there are no chemicals to handle, jars to clean, etc."

In reply to some enquiries with reference to the results obtained with the new thermopile, the following extracts from Herr Gulcher's communication are given: "I mention that the results obtained from the thermopiles vary slightly, owing to some little differences in the composition of the alloy of antimony employed for the positive electrodes, the casting of which offers some difficulties. The figures given in the report are the average results of a number of thermopiles lately constructed. In order to show you how the results have been obtained, I will give you an example from my test-book.

"*Date of Measurement, October* 9, 1891.—Pile No. 98; number of elements in the pile, 50; gas consumed per hour during the test, 190 litres; electromotive force measured by a Siemens torsion galvanometer of a resistance of 1,000 ohms, 3·8 volts; difference of potential at the terminals with an external resistance of 0·5 ohm, 2·11 volts; current during the last test, 4·22 amperes. Calculated from these figures you obtain: The internal resistance of the pile when hot and on full load (3·80 − 2·11)/4·22 = 0·41 ohm. The current in an external circuit of equal resistance (0.41 ohm), 3·8/2 × ·41 = 4·634 amperes. Therefore, the total power of the pile = 4·634 × 3·8 = 17·61 watts with 190 litres or 92·7 watts per one cubic metre of gas; and the maximum available effective power of the pile = 8·805 watts with 190 litres or 46·34 watts per one cubic metre of gas.

"There are now three sizes of these small piles being constructed, which differ only in the number of elements according to their purpose—viz., 26, 50, and 66 elements. The latter is especially constructed for charging accumulators, and has an electromotive force of 4·6 to 5·2 volts, so that during charging it will work with its full effective power at a difference of potential of 2·3 to 2·6 volts."

From the measurements taken with an early form of pile, which had been under test for three months, the following results were obtained battery should be placed in series with one of the glow lamps as used in the installation.* This arrangement gives the best results, as the right electromotive force and current are secured. When an incandescent lamp cannot be used, it is best to place a small amperemeter in the circuit, as by its means the amount of current passing at any moment can be read off. To make up for evaporation, a little pure water should be added to the cells from time to time. If the batteries are in daily use, it is a good plan to change the solution about once every four or five weeks. Before doing this, the cells should be fully charged, and should on no account be allowed to remain dry for any length of time.

For export purposes, or if the batteries are liable to be inverted in transit, or to remain out of use for a lengthened period, the whole of the solution should be removed, the elements thoroughly rinsed with water, and then drained as dry as possible. A good charging solution is made by adding one part of chemically pure sulphuric acid, sp. gr. 1·85, to nine parts of water.

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with two single elements, one taken from the first and the other taken from the last row.

"*Date of Measurement, October* 20, 1890.—I. An element of the first row: Electromotive force, with an external resistance of 100 ohms (a Siemens torsion galvanometer), ·078 volt; difference of potential with an external resistance of ·300 ohm, ·034 volt; intensity of current during the last test, 11·33 amperes. Therefore, internal resistance of the element $= (\cdot078 - \cdot034)/11\cdot33 = \cdot0039$ ohm; and the current for the maximum effective power, $\cdot078/2 \times \cdot0039 = 10$ amperes. II. An element of the last row: Electromotive force, with an external resistance of 100 ohms (Siemens torsion galvanometer), ·044 volt; difference of potential, with an external resistance of ·002 ohm, ·021 volt; current during the last test, 10·5 amperes. Therefore, internal resistance of the element $= (\cdot044 - \cdot021)/10\cdot5 = \cdot0022$ ohm; and the current for the maximum effective power $\cdot044/2 \times \cdot0022 = 10$ amperes."

* Glow lamps as made by the Edison-Swan Company of 50, 75, and 100 volts, usually take currents varying from 0·6 to one ampere.

Bristöl's Portable Batteries.—Bristöl constructs elements suitable for small storage batteries by incorporating oxides of lead with binding material, such as asbestos fibre, animal hair, horn shavings, or some similar fibrous substance which is capable of giving the mass just sufficient cohesiveness to retain its shape without the aid of a metallic support. The salts of lead, when mixed with from one to three per cent. by weight of the fibrous material, are found to have sufficient mechanical strength to resist all ordinary disintegrating influences, either mechanical or electrical. When the binding material has been thoroughly incorporated with the metallic oxides, it is moistened and made into a stiff pasty mass, and pressed into moulds to give it the desired shape, and either a flattened lead wire or a platinum strip having lateral branches, is inserted within the soft mass to act as a conductor. When dry, the masses are "formed" in an acid bath by the usual method. When making up cells suitable for hand lamps, one positive and one negative element only are used. Distance-pieces of wood saturated with paraffin wax are placed between the plates to keep them the proper distance apart. In order to prevent the liquid splashing or leaking out, each cell is covered by a vulcanite lid, into which is fitted a hollow ebonite vent plug of special construction. During the charging operation the vent plug is removed, but when this valve is fixed the cells are practically sealed, and may be held in any position without the electrolyte escaping. The general appearance of the Bristöl element with the radiating metallic collector is shown in Fig. 61.

This form of element is found to be peculiarly suited to the requirements of an electric hand lamp. Several very neat, light, and compact safety lamps with cells of this type are now made. One form, shown in Figs. 62 and 63, is used as a miners' lamp. It weighs only 5lbs. 4ozs., and is said to run a 1·5 candle-power glow lamp for a period of from twelve to fifteen hours. This little lamp contains a four-cell accumulator, which is

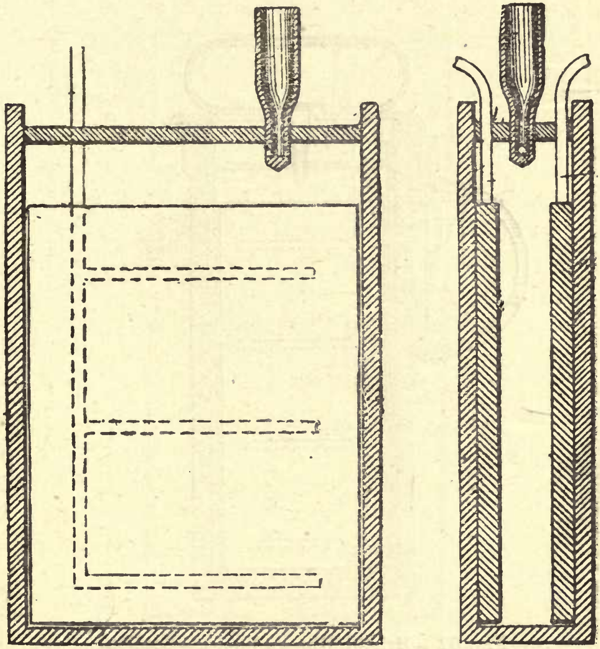

FIG. 61.—Bristöl Element and Containing Cell.

enclosed within a polished wood case. On one side of this case a glow lamp is fixed, and is protected by a strong glass dome, and is backed by a white reflector. The outside wood containing-box has a hinged metal lid with a projecting lug, which serves to cover one of the charging terminals; so that when the lid is closed the battery cannot be short-circuited. The metal cover is supplied with a simple form of lock, by which it may be secured. A small pin arrangement in the lock secures the glass dome, and prevents the incandes-

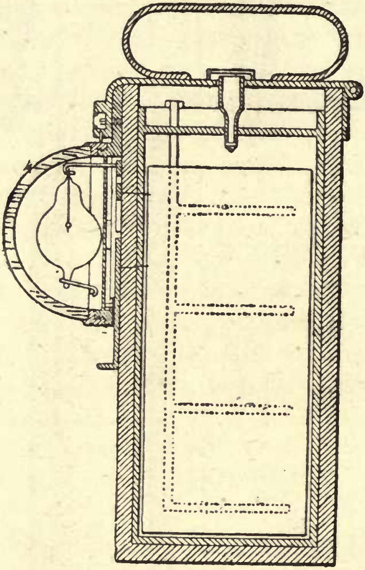

Fig. 62.—Bristöl Miner's Lamp.—Section.

cent lamp from being tampered with or removed. The glow lamp is held in position by two flexible terminals and a top spring. These elastic terminals are attached, the one to the positive pole of the battery and the other to an independent plate, between which and the negative terminal of the cells a small switch is placed.

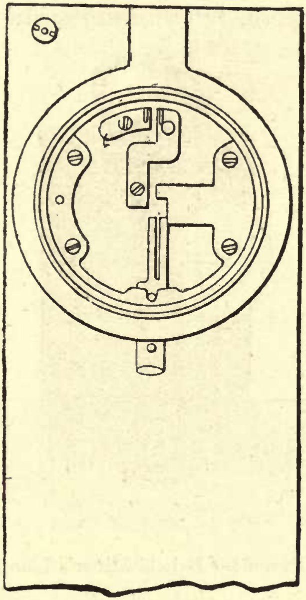
FIG. 63.—Bristöl Miner's Lamp, showing Connections.

In the diagram, Fig. 62, is shown a section of this battery in which the relative positions of the elements, lantern, and vent plug are indicated. Fig.

63 illustrates the method of making the connections behind the glow lamp; and Fig. 64 represents the complete lamp.

A three-cell hand lamp of this type was found to weigh just 4lbs.; it maintained a 5·5 volt lamp, taking 0·35 ampere, fully incandescent for a period of ten hours with one charge. The intensity of the light, as measured by a photometer, was 1·5 candle-power.

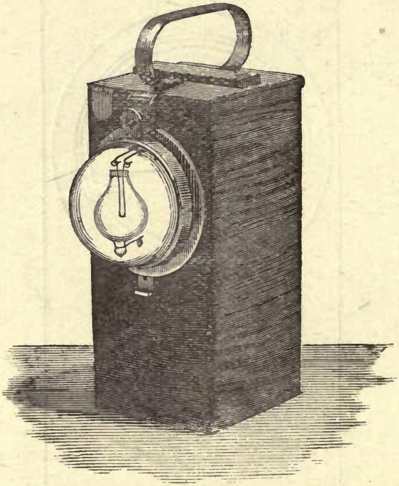

Fig. 64.—Bristöl Miner's Lamp.

An improved form of three-cell battery with a detachable lantern, as shown in Fig. 65, is now made. The advantages claimed for this battery are, that the brass collar which holds the protecting-dome is securely fixed to a polished ebonite base, and the lampholder, reflector, and switch are all combined.

Lately, an improved battery, said to be suitable for mining operations, has been introduced. The improvement consists chiefly in enclosing the cells within an outer casing of sheet steel, brass, or other metal. This metallic case is flanged at its top, so as to receive a lid, which is securely fixed to it by means of screws. On the lid is an opening surrounded by a vertical ridge. The vent plugs are so arranged that they protrude through the cover, and are protected by small pivoted metal discs. By this device the vent plugs may readily be inspected or removed during charging or for filling-in purposes. To prevent injury to the elements through jolting or concussion, a space of about a quarter of an inch is allowed between the vulcanite cell and its metallic sheath. This space is

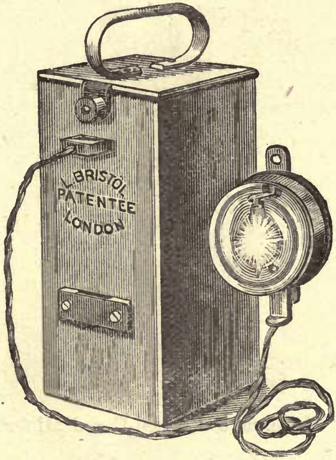

Fig. 65.—Bristöl Battery and Detachable Lamp.

usually filled in either with wooden plates or some more elastic material. The outer metal case constitutes the negative terminal of the battery. The switching arrangement is constructed to serve as a covering for the positive charging terminal, so that the charging operation can only be effected when the lamp is not in use. This lamp is shown in Fig. 66.

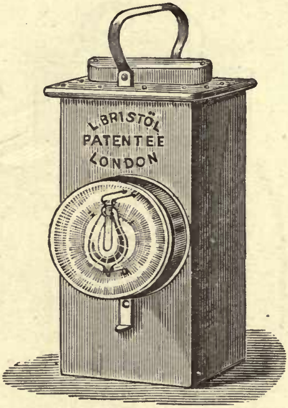

Fig. 66.—Bristöl's Metal-Cased Miner's Lamp.

In a communication lately received, Mr. Bristöl states that with his latest pattern of cell he can obtain from 4·5 to 5 ampere-hours capacity per pound of complete battery. As an indication of the absence of local action or leakage, some of these sealed cells have been known to retain their current for a period of eight months when left on open circuit. With regard to their durability he asserts that several batteries of this type constructed over three years ago, and which have been in daily use, are now in a most perfect condition.

Lithanode.—Probably no one in this country has given more thought and attention to the subject of storage batteries than Mr. Desmond FitzGerald. His paper, read before the British Association in September, 1886, on "Lithanode," and another delivered before the Institution of Electrical Engineers on March 10, 1886, entitled "Reversible Lead Batteries," together with many communications to the technical journals, have done much to throw light upon the vexed question of the chemical action due to electrolysis in lead storage-cells. As an active element for an accumulator, without a metallic or mechanical support of any kind, FitzGerald's lithanode certainly stands alone.

In his early experiments, FitzGerald found that he obtained the best results by incorporating oxides of lead with mixtures of pure glycerine, diluted with about twice its volume of water, or with a half-saturated solution of sulphate of ammonia, or with a solution of sulphuric or phosphoric acid. The advantages of these solutions over all others he had tried, is to be attributed to the fact that with aqueous mixtures the resulting compound of lead is hydrated, whereas when a combination with glycerine and sulphate of ammonia or acid solution is used, the resulting compound is necessarily anhydrous.

Lithanode may be regarded as the "active material" of the positive element of a lead secondary battery, this active material being isolated from the heavy lead support and obtained in the form of a conducting plate. Lithanode is not compressed peroxide of lead, as is sometimes supposed; for however strongly this lead peroxide may be compressed, the resulting mass will disintegrate when immersed in a liquid electrolyte. It is produced from the protoxide of lead (PbO), or litharge made into a pasty mass with a solution which causes the material to "set" so that it will no longer disintegrate when placed in a fluid.

In the commercial manufacture of lithanode, as carried out by the Mining and General Electric Lamp Company,* litharge is thoroughly incorporated with a solution of sulphate of ammonia. The soft pasty mass is pasted into a die-plate of the form of element required, and is then subjected to great pressure in a hydraulic press. These compressed plates are next transferred to a drying-room, where they remain for some days. When thoroughly set and hard, the plates are either superficially converted into peroxide by treating them with hypochlorite of magnesium, or other suitable chlorine compound, or they are mechanically coated with peroxide applied in a semi-fluid condition. This preliminary coating ensures uniform peroxidisation in the forming operation. The "forming" is effected in a bath of sulphate of magnesia, and is spread over a lengthened period, so that the electrolytic action may sink in gradually and evenly.

The amount of peroxide in the lithanode plate can be regulated by suitably proportioning the materials used, or by the depth of "formation." A small amount of sulphate of lead seems necessary to give it the requisite cohesiveness and mechanical strength. The

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* The Mining and General Electric Lamp Company, of Millbank-street, Westminster, are the sole proprietors of the whole of the lithanode patents, and in addition they hold Dr. Frankland's patents for active material and plates.

most recent form of plate is said to contain fully 90 per cent. of peroxide.

By the use of lithanode a positive plate which is not subject to "local action" may be constructed; an inoxidisable metal, such as platinum or gold, being in this case used for establishing contact with the plate. A great advantage is thus secured—namely, an element free from local action, and one which will retain its charge for any length of time, even when partly discharged and left immersed in dilute sulphuric acid.

When used as an element in a cell, the pole and collector is formed of a sheet of one of the above inoxidisable metals, which is tightly clamped to the slab by a vulcanite plate and screws. This metallic strip presses directly upon the active material, ensures good electrical contact, and is quite unaffected by the corrosive solution or electrolytic action.

Lithanode is only useful as a positive element; the negative may be of the ordinary grid form, filled in with spongy lead, or it may be zinc, or the special form of spongy lead plate as manufactured by the company.

In discharging a battery containing lithanode plates it is not advisable to run down the elements beyond the point at which the potential difference between them and a spongy lead element is 1·8 volts. The electrical capacity of lithanode, when used with the precautions indicated, is stated by FitzGerald to be almost exactly one ampere-hour per ounce, so that with an element weighing one pound we should expect to obtain a current capacity of 16 ampere-hours.

The rate of discharge obtainable with these batteries varies within very wide limits, and is regulated by the character of the lithanode, whether made hard, medium, or soft, the perfection of the contact, and the strength of the acid electrolyte. An ordinary rate of discharge per square inch of lithanode plate is $\frac{1}{14}$th of an ampere, but in some cases the rate may exceed $\frac{1}{9}$th of an ampere.

Mr. FitzGerald is still endeavouring to reduce the weight of his elements. In a communication lately received from him he says: "The capacity of the lithanode as now made, when worked at a moderate rate of discharge (continues until the electromotive force at the poles has fallen from 2 to 1·8 volts) is one ampere-hour per ounce. A plate seven inches by four inches, weighing twelve ounces, will maintain a discharge of three amperes for a period of two and a half hours without alteration in the external resistance; if the external resistance is slightly diminished from time to time, a rate of discharge of 4·4 amperes can be obtained during a period of two hours."

To meet all requirements, lithanode plates are made in three distinct types — "hard," "medium," and "soft or porous." The hard plates are said to be most suitable where strength and durability are an essential. The medium type are made for general use, while the soft or porous plates are especially constructed for purposes where a rapid rate of charge and discharge is required.

The electromotive force as developed by lithanode in conjunction with spongy lead, is 2·0 volts. With a combination of lithanode and zinc an electromotive force of 2·5 volts is obtained. The electrolyte found to be most suitable is a solution of sulphuric acid and water, density about 1,220.

The following table, as given by the makers, shows the current capacity, weight, and dimensions of their standard pattern plates :

Code number.	Dimensions.	Weight.	Approximate capacity.
1	7 × 4 × $\frac{1}{8}$ in.	12 ozs.	12 amp. hours.
2	7 × 4 × $\frac{3}{16}$ in.	16 ,,	16 ,,
3	7 × 4 × $\frac{1}{4}$ in.	24 ,,	24 ,,
4	4 × $2\frac{1}{2}$ × $\frac{1}{8}$ in.	4 ,,	4 ,,
5	$3\frac{1}{2}$ × $3\frac{1}{8}$ × $\frac{3}{16}$ in.	6 ,,	6 ,,

Lithanode Hand Lamps.—Owing to its lightness and freedom from local action, lithanode is admirably adapted for storing electrical energy in portable self-contained electric hand lamps. The most recent development in this way is the metal-cased lithanode lamps as manufactured by the Mining and General Electric Lamp Company. This form of lamp is said to be capable of withstanding, without injury, the rough treatment incidental to their employment in such places as coal mines, gas works, gunpowder mills, ships' holds, etc., where their mechanical strength is at times liable to be tested to their utmost limits.

Several patterns of these lamps are made. The ordinary miner's lamp, represented in Fig. 67, weighs about 4lbs. 4ozs., and when fully charged it will give a light equivalent to about one candle-power for a period of fully twelve hours. Fig. 68 illustrates a lamp of similar construction, but somewhat smaller and lighter. When tested, a combined battery and lamp of this description, weighing just 3lbs. 9ozs., was found to fully incandesce its glow lamp for a period of eleven hours. Another lamp with a metallic sheathing is constructed for occasional use, the light obtained being more powerful, but the length of run somewhat shorter. This form may be employed as an illuminant

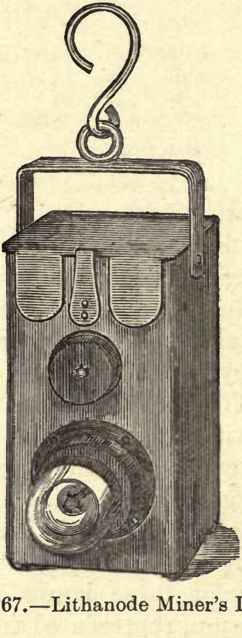


FIG. 67.—Lithanode Miner's Lamp.

in all cases where an oil lamp is a source of danger, such as in petroleum ships and stores, stables, theatres, and as a lantern for watchmen and firemen.

Each of the above lamps contains a small two-cell battery, mounted in an outer steel lead-coated protecting case. A circular switch serves to throw the lamp in and out of action. Insulated charging terminals are placed above the lantern bezel, and are covered by projecting lugs attached to the cover, so that when the lamp is in action the cells cannot be short-circuited, and therefore all possibility of sparking is avoided. When used in fiery coal-mines the metal bezel carrying the glass glow lamp protector is secured against removal by means of a lead locking-pin.

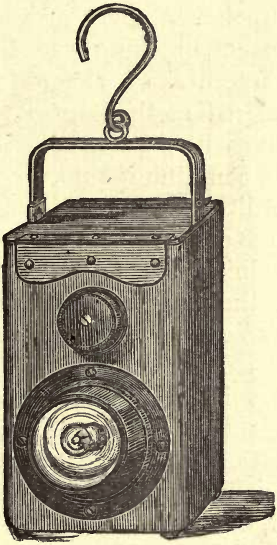


FIG. 68.—Lithanode Miner's Lamp.

It has been suggested that on the fracture of the glass bulb of an electric miner's lamp, the heat given out by the incandescent carbon filament would be sufficient to become a source of danger, should the lamp happen to be in an explosive atmosphere. As a safeguard against the possibility of this danger, various safety devices have been suggested. The above company at one time introduced a system of springs placed behind both the glow lamp and its glass protector, the idea being that should either receive a blow they, owing to their elastic mounting, would yield but not break. A lever arrangement was also tried as a means of breaking the continuity of the circuit on the fracture of the outer glass. Other makers have devised methods of flooding the incandescent filament with water immediately on the destruction of its containing bulb.

Other forms of lithanode batteries are made. Fig. 69 represents a three-cell battery mounted in a polished hard-wood containing-case, and fitted with a fixed lantern. Under the lantern bezel is placed a circular rheostat and switch, so that the intensity of the light may be varied at will. This class of combined battery and lamp is well suited for domestic, dental, medical, and scientific purposes. Sling and portable batteries fitted either with fixed or detachable lanterns are made. Specially-constructed cells for giving high rates of discharge can be obtained, and are said to be well suited for firing ordnance, blasting operations, and medical cautery.

In all these batteries the elements are firmly secured within the cells. Each compartment is sealed and is provided with an improved vent plug, which effectually prevents spilling of the electrolyte.

Some very neat and useful cells suitable for electrical testing purposes are manufactured by this company.

Fig. 70 illustrates a very simple cell of this description. It consists merely of two small plates, one lithanode and one spongy lead, placed within an ordinary test or sample tube. A sealing of insulating composition is run round the top of the elements and serves to prevent the escape of the fluid, and at the same time securely holds the elements in position. A small perforated plug allows for the escape of any gas generated. When a number of these simple cells are mounted in a suitable cabinet, a very effective method is afforded of

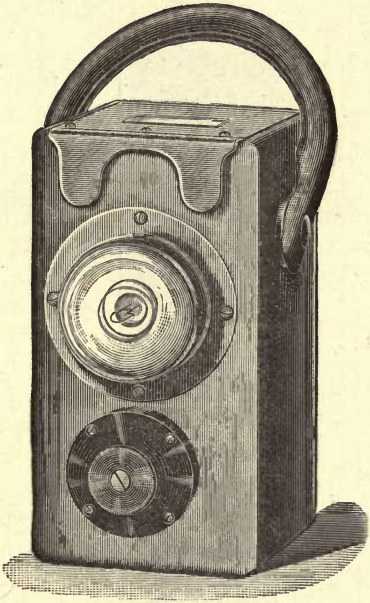


FIG. 69.—Lithanode Wood-Cased Hand Lamp.

obtaining any range of potential with a small and constant current—a very desirable acquisition in an electrical laboratory.

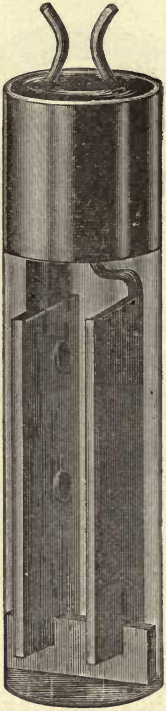
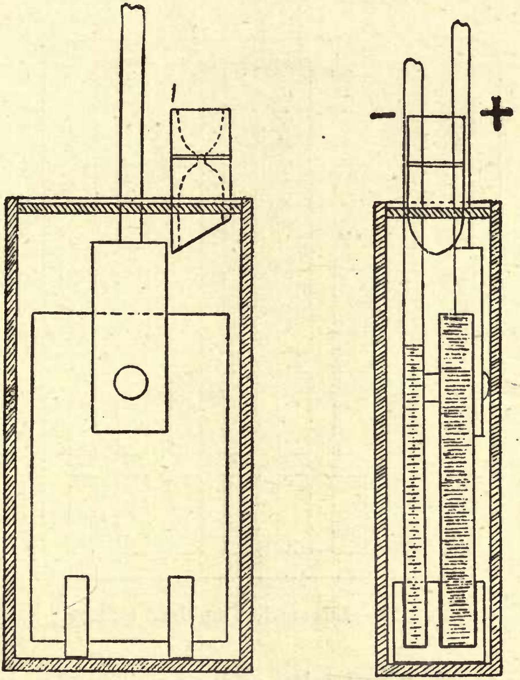


FIG. 70.—Lithanode Testing Cell.

A still smaller and more compact cell is shown full size in Figs. 71 and 72. This unique little cell weighs about 2½ ounces, and has a capacity of one ampere-hour when discharged at a rate of 0·1 ampere. As the working electromotive force of each cell is two volts, potentials varying from 100 to 500 volts can be obtained in a box of small dimensions and but little weight. Doubtless these cells will be much appreciated by electricians for insulation and cable testing.



Figs. 71 and 72.—Lithanode Testing Cell—Side and End Sections.

The Frankland Lithanode Cell.—Recently an improved form of Dr. Frankland's element has been devised, in which lithanode is used instead of the compressed pellets of lead salts, and a novel kind of spongy lead plate has been adopted.

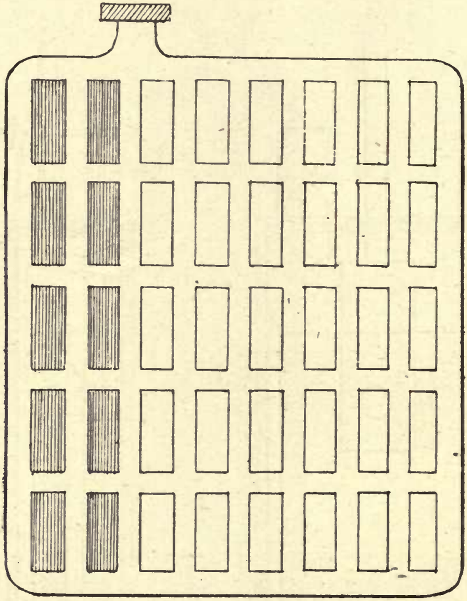


FIG. 73.—Lithanode-Frankland Cell.

The positive element, Fig. 73, is made up of a number of small moulded slabs of lithanode, whose outer edges are V-shaped. About forty of these little plates are placed in a suitable metallic frame or mould, and the interstices are entirely filled in with molten lead. Owing to the shape of the pellets they cannot fall out, and as they have been thoroughly "formed," and therefore expanded to their fullest dimensions, they exert no pressure on the metal frame and do not tend to bend it. These plates are said to be lighter than

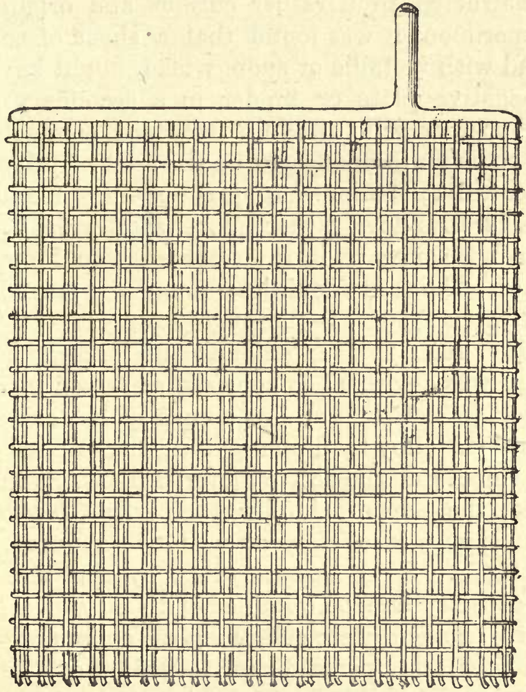


FIG. 74.—Copper Mesh Spongy-Lead Element.

the ordinary grid form of element, as the pellets of active material are large, and therefore the amount of inert metal is reduced. The negative element is constructed in a rather curious and original way. By experiment it was found that a sheet of copper, if covered with metallic or spongy lead, might be used as the negative plate or holder in a secondary couple. The copper, which forms an excellent conductor, was found to be quite unaffected by the acid solution, or by the electrolytic action. In practice it is found to be advisable to allow rather more spongy lead in the copper-mesh negatives than theory would appear to indicate. This is doubtless done to prevent local action when the cell is thoroughly run out.

Acting upon this experience the present form of element was devised. It consists, as shown in Fig. 74, of a double network of fine copper gauze, coated with lead or lead alloy by dipping it in the molten metal. Upon this frame the active material is pasted and compressed, the copper affording a perfect support, and thus a spongy lead element of much reduced weight is obtained. It is asserted that by this means the same capacity can be obtained with 50 per cent. less weight. In a complete cell, the glass containing-vessel, electrolyte, and peroxide plate being of the same weight as before, this improvement alone gives a gain of from 15 to 20 per cent. on the total weight of the cell. The electrolyte used with these elements is dilute sulphuric acid, sp. gr. 1,200.

As these improved cells are scarcely out of their experimental stage, definite particulars as to their capacity, weight, etc., can scarcely be given. The following table will serve to indicate approximately what may be expected from this new combination :

TABLE VIII.—FRANKLAND-LITHANODE CELLS.

Type.	No. of plates.	Size of plates.	Nature of containing cell.	Working Current.		Capa-city Amp. hrs.	Total wt.	External dimensions of cell.
				Charge.	Dis-charge.			
	inches	inches		amperes	amperes		lbs	inches
F.L.	7	8×7¼	glass	2 to 6	1 to 6	75	—	—
,,	,,	,,	teak	,,	,,			
,,	11	,,	glass	4 to 10	1 to 10	125	—	—
,,	,,	,,	teak	,,	,,			
,,	15	,,	glass	6 to 14	1 to 14	175	—	—
,,	,,	,,	teak	,,	,,			
,,	19	,,	glass	10 to 18	1 to 18	225	80	10½×8¼×9¼
,,	,,	,,	teak	,,	,,			
,,	23	,,	glass	15 to 22	1 to 22	275	—	—
,,	,,	,,	teak	,,	,,			
,,	7	12×9½	glass	10 to 15	1 to 15	170	73	15½×11½×6
,,	,,	—	teak	,,	,,			
,,	11	—	glass	16 to 22	1 to 25	285	99	15½×11½×8
,,	,,	—	teak	,,	,,			
,,	15	—	glass	25 to 35	1 to 35	400	135	15½×11½×10
,,	,,	—	teak	,,	,,			

Roberts' Clamped-Grid Elements.—In Roberts' double-grid elements each plate is composed of two white-metal half grids cast with truncated apertures, as shown in Fig. 75. After the interstices of these plates are filled with the usual lead oxides, the two half elements are clamped together by means of vulcanite nuts and bolts, and form one complete plate. With this method of construction, should the active material expand during its formation, it merely tends to push the grids apart and not to warp or bend them. The top supporting lugs are riveted into a stout cross-piece, which forms the terminal of one set of elements. The positive elements are somewhat shorter than the negative, and are prevented from touching the bottom of the glass by means of vulcanite shoes, which protrude somewhat from the base of the plate and are securely clamped to it. The whole system of elements is made quite rigid by being bolted together with vulcanite rods and loose ferrules, which slip over them, and are used as distance-pieces between the plates.

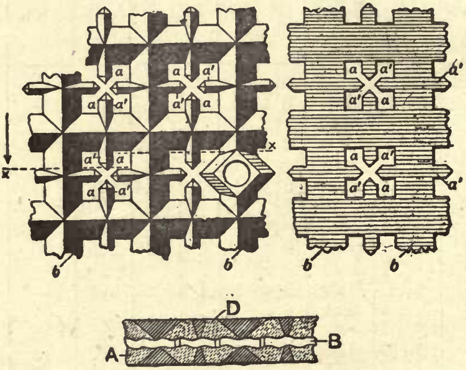


FIG. 75.—Details of Roberts' Clamped Grids.

PART III.

Lead-Zinc, Copper, Alkaline, and other Storage Batteries.

Sections I. and II. deal exclusively with storage cells of the lead and lead-peroxide types. In this section it is proposed to treat of some other types, which although not so well known as those already described, yet seem to warrant some little attention on account of the novelty of the methods of constructing them, or the promising results which have been obtained by their employment.

As previously stated, the value of peroxide of lead, when employed as a depolariser in certain forms of primary batteries, has been known and appreciated for many years. On the introduction of Planté's and Faure's peroxide cells the interest of electro-chemists was reawakened to this fact, and by experiment it was soon demonstrated that if a fully-charged peroxide of lead element, in conjunction with a zinc plate, be immersed in a solution of dilute sulphuric acid, a powerful electric current is obtained, which possesses a very high electromotive force. The chemical reactions involved in such a cell are doubtless of a somewhat complicated nature, but an analysis of the electrolyte of a discharged cell shows that the sulphuric acid combines with the zinc, forming sulphate of zinc which is retained in solution, and that the hydrogen gas liberated during the chemical combination attacks the oxygen in the lead peroxide and reduces it to the form of a lower oxide. In addition to this deoxidising process, there is the sulphating action of the lead salts which, as already explained, occurs during the discharging operations in all forms of lead-sulphuric-acid storage cells. During the recharging a reverse action seems to occur; the zinc is abstracted from its solution, and is deposited upon the zinc electrode, and at the same time the reduced lead oxide reacquires its lost oxygen.

The chemical reactions during the charging operation are probably fairly represented by the following equation:

$$PbSO_4 + ZnSO_4 + 2H_2O = PbO_2 + Zn + 2H_2SO_4.$$

According to Emile Reynier, the chemical reactions of a discharge have two phases, which may be stated thus: At the outset one equivalent of sulphate is carried to the negative element, as represented by the equation:

$$PbO_2 + Zn + 2H_2SO_4 = PbSO_4 + ZnSO_4 + 2H_2O.$$

During the second phase another equivalent of zinc is sulphated at the negative pole, and an equivalent of hydrogen reacts upon the positive element, during which operation the active material resolves itself into metallic lead and sulphuric acid, as shown by the following equation:

$$2PbSO_4 + Zn + H_2O = ZnSO_4 + 2Pb + H_2SO_4.$$

Immediately after a charge, the electromotive force developed by a zinc-peroxide couple, may reach 2·7 volts. During a discharge, the internal resistance of this form of cell is found to vary between very wide limits. At the commencement it is about the same as that of the lead-peroxide couple, but as the discharge proceeds the resistance is continually being augmented owing to the conversion of the highly conducting acid electrolyte into sulphate of zinc solution, which has a much higher specific resistance.

It has been found that if chemically pure zinc is immersed in pure dilute sulphuric acid, no combination occurs, the metal remaining quite unaffected. If, however, commercial zinc be used, which invariably contains, among other impurities, iron, lead, and arsenic, then the acid is found to quickly attack the zinc, and rapid combination occurs. This action is probably due to the formation of innumerable minute galvanic couples between the true metallic zinc and the iron, lead, or other impurities; so that when commercial zinc is used as an electrode in a lead-zinc cell, a considerable quantity of the electrical energy stored is dissipated owing to this form of local action. This loss of energy not only occurs while the cell is in action, but is always going on even if the cell be allowed to remain inactive, or during periods of repose. Thoroughly amalgamating the zinc is found to considerably reduce the tendency to local action.*

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* Referring to the insolubility of pure metals in pure acids, the following account of a new theory is extracted from a recent number of the *Electrician*: "The results of an investigation concerning the cause of the insolubility of pure metals in acids are contributed by Dr. Weeren to the current number of the *Berichte*. De la Rive, so long ago as the year 1830, pointed out that chemically pure zinc is almost perfectly insoluble in dilute sulphuric acid. Dr. Weeren's theory of the phenomenon is as follows: 'Chemically pure zinc and also many other metals in a state of purity are insoluble or only very slightly soluble in acids, because, at the moment of their introduction into the acid, they become surrounded by an atmosphere of condensed hydrogen, which under normal circumstances

Reynier's Lead-Zinc Cell.—Among the first to practically develop the lead-zinc storage cell was Emile Reynier. In his form of secondary cell he employed an ordinary Planté or Faure peroxide plate, in conjunction with thin sheets of lead on which a thick layer of electrolysed zinc had been deposited. By the utilisation of pure electrolysed zinc many of the difficulties arising from local action were eliminated. A battery of this description, introduced in the year 1884, was constructed as follows: Each cell contained four peroxide plates of the Planté type which presented an extensive active surface, and three negative elements made of smooth sheet lead and covered with electrolysed zinc which had been deposited from an acidulated bath of sulphate of zinc. When building up the cells, accidental contact between the electrodes was

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effectually protects the metal from further attack on the part of the acid.' The experiments from which this theory has been derived were briefly as follows. The amount of chemically pure zinc dissolved by the acid was first determined. In was next sought to determine what difference would be effected by performing the experiment *in vacuo*, when of course the escape of the hydrogen would be greatly facilitated. The solubility was found under these circumstances to be increased sevenfold. Next the experiment was performed at the boiling temperature of the dilute acid, first when ebullition was prevented by increasing the pressure, and secondly when ebullition was unhindered. In the first case, when ebullition was prevented, the solubility was practically the same as in the cold; while in the second case, with uninterrupted ebullition, the solubility was increased twenty-four times. Finally, experiments were made to ascertain the effect of introducing into the acid a small quantity of an oxidising agent capable of converting the hydrogen film to water. When a little chromic acid was thus introduced the solubility was increased one hundred and seventy-five times, and when hydrogen peroxide was employed the solubility was increased three-hundred-fold. The explanation of the ease with which the metal becomes attacked when the ordinary impurities are present is that the hydrogen is not then liberated upon the surface of the zinc, but rather upon the more electro-negative impurities, leaving the pure zinc itself open to the continued attack of the acid.

guarded against by the insertion of glass insulating tubes which were secured to the negative plates by

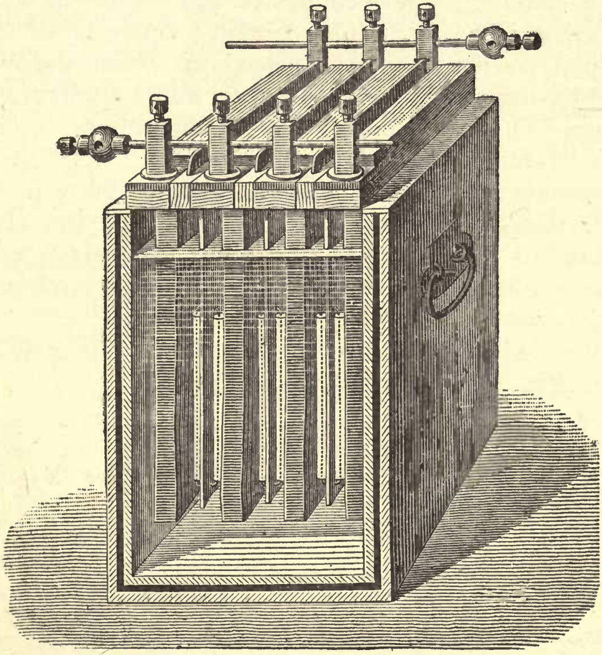


Fig. 76.—Reynier's Lead-Zinc Cell.

means of leaden strips. The seven electrodes were carried by cross-pieces of paraffined hard-wood, which rested on the edges of the containing-cell and served to keep the elements in position. These cross-pieces were made of sufficient width to just touch one another, and thus they served the double purpose of holder and cover. All the elements were provided with separate and substantial terminals. Two brass rods terminating in a clamping screw connected the terminals of like polarity. The containing-trough consisted of two oblong wooden receptacles placed one within the other, and having a clear space of several millimetres between them. This space was ultimately filled in with a semi-elastic, impervious, insulating cement. By careful insulation of the trough and all other parts of the cell, the employment of pure zinc, and the elimination of all impurities from the electrolyte, a cell was produced whose loss from leakage and local action was found to be exceedingly small.

The following particulars of a cell of this construction, Fig. 76, were given by M. Reynier.

Total area of active positive surface ...	200	square decimetres.
,, ,, ,, negative ,, ...	150	,, ,,
Weight of positive elements...............	8·2	kilogrammes.
,, negative ,, ...	1·4	,,
,, containing-trough	2·7	,,
,, electrolyte	4·4	,,
,, connectors	0·46	,,
Total weight of complete cell	17·16	,,

From a cell of this form of construction the following results were obtained :

Electromotive force	2·36 volts.
Mean internal resistance....................	0·02 ohm.
Rate of discharge	25 amperes.
,, charge	5 to 10 amperes.
Capacity of cell after 200 hours formation ...	152 ampere-hours.

The total amount of energy stored in this cell was found to be 130,000 kilogrammetres, or at the rate of

3000.0.

7,600 kilogrammetres per kilogramme of complete cell; according to Reynier a lead-zinc accumulator should store 15,600 kilogrammetres per kilogramme of cell, but as these cells when used commercially have to be constructed to withstand rough treatment, it is always advisable to make the elements much shorter and more massive than theory would appear to indicate. Reynier gave the following figures as the result of the calculated and practical weights of a cell whose capacity was 13,000 kilogrammetres of energy:

	Calculated Weight. Kilogrammes.	Actual Weight. Kilogrammes.
Lead	2·500	8·000
Zinc	0·550	1·390
Oxygen	0·180	0·180
Acid and water	4·140	4·400
Cell, etc.	1·105	3·160
	8·475	17·130

As the results of some comparisons made in the year 1884, M. Reynier gave the following figures as representing the relative storage capacity of various types of accumulators:

Planté's original	1,500	kilogrammetres	per kilogramme	of plate.
Faure's early form	3,000	,,	,,	,,
Faure's grid form	4,400	,,	,,	,,
Reynier's lead-zinc	7,600	,,	,,	,,

In a more recent form of lead-zinc cell introduced by Reynier, in which his fluted-lead positive plate was used in conjunction with a plate of chemically pure zinc, and with pure acid and distilled water as an electrolyte, local action was almost entirely eliminated. In this cell the zinc element was further protected against wasteful local action by the addition of small quantities of mercurial and ammonia salts to the electrolyte. By this means the zincs were always kept well amalgamated.

The late Emile Reynier seems to have given much attention to the subject of storage batteries. He communicated many papers on this subject to the French scientific societies. Among his numerous literary efforts were the following treatises: "Les Piles Electriques et Accumulateur," and "Traite de l'Accumulateur Voltaïque." The latter work is now translated into this language.

In the year 1884, Dr. Oliver Lodge obtained a patent in this country for the use of sulphate of mercury in storage batteries where zinc is employed as one of the elements. He also demonstrated, by experiment and trial, that a couple composed of peroxide of lead and zinc, when immersed in dilute sulphuric acid, gave a steady electromotive force of 2·5 volts, which he stated was the highest electromotive force that he had obtained from any practical voltaic cell.

M. d'Arsonval devised a lead-zinc accumulator, which was constructed somewhat after the fashion of the well-known Bunsen cell. Within a circular porous earthenware chamber, he placed a block of carbon or graphite, and surrounded this by a mass of very fine lead shot, which ultimately became active material by the usual method of electrolytic conversion. The negative element consisted of a tubular strip of zinc which encircled the porous pot, but did not quite touch it. As an electrolyte, very dilute sulphuric acid was used.

Lithanode, in conjunction with zinc, constitutes a convenient form of storage cell. If lithanode and a strip of zinc be placed in a solution of sulphuric acid of a specific gravity of 1·170, it is said to develop an electromotive force of 2·5 volts.

M. Tamine, of Brussels, uses in his lead-zinc accumulator a saturated solution of sulphate of zinc, to which is added a certain percentage of sulphuric acid, and a similar quantity of sulphate of ammonia. By the addition of the sulphate of ammonia, all sulphating of the elements during period of repose is said to be entirely prevented. With this form of electrolyte an electromotive force of 2·3 volts per cell is obtained.

Bailly's Battery.—M. Phillimond Bailly, of Ermond, France, introduced a lead-zinc storage battery whose positive elements consisted of masses of compressed lead-wool, while the negatives were sheets of zinc well amalgamated. In the construction of the positive electrodes, sheets of lead were divided into filaments or fringes, and interlaced with fine lead wire, or what Bailly termed lead-wool. This soft mass was subjected to heavy pressure, which made it somewhat solid and rigid. By this arrangement an element was constructed in which the lead collector permeated throughout the whole mass of the active material, and carried off the electrical energy freely and uniformly from all parts. The negative element consisted, as stated above, of a plain amalgamated sheet of zinc, or a compressed mass of zinc amalgam prepared by intimately mixing fragments of zinc or zinc filings with mercury, and then shaping it by pressing in a suitable mould. By this treatment the excess of mercury was expelled and recovered.

Hedges' Lead-Zinc Cell.—At the meeting of the British Association held in 1887, Mr. Killingworth Hedges exhibited a lead-zinc battery whose positive element was of the Planté type. It was designed to obtain the maximum amount of surface for the peroxide plate, while the total weight was much reduced and the available electromotive force increased by using a strip of zinc for the positive plate instead of lead, as in most modifications of the Planté cell. The peroxide plate was constructed on M. Bailly's method, the main conductor ramifying throughout the mass of the plate. A basketwork of lead-wool was tightly pressed into the space left between a porous pot or plate and the outside receptacle of the battery. This diaphragm offered but little resistance to the passage of the current as it was made of compressed sand, and it prevented any possibility of short circuit between the electrodes. The current was led from the zinc plate by causing it and its connecting wire to dip in mercury; this plan helps to keep up the amalgamation, and tends to stop local action. This seems to have been the first cell in which ordinary commercial sheet zinc was employed instead of lead or copper coated with zinc electrolytically. The action was stated to be as follows: The zinc is attacked by the sulphuric acid in the presence of the peroxide of lead, the latter acting as a depolariser; the reaction is much more energetic than in a lead-lead couple, and the available electromotive force is 2·5 volts. In discharging, the zinc plate dissolves in the dilute acid, and the sulphate of zinc formed is decomposed on recharging, metallic zinc being deposited on the zinc plate. Thus the zinc is never consumed, but is only dissolved and redeposited. A basket containing six of these cells, each of 60 ampere-hours' capacity, which will maintain six four-candle lamps for over eight hours, was shown and was said to weigh less than one hundredweight.

The Lalande and Chaperon Battery.—The partial reversibility of a copper-zinc voltaic couple has been known for many years, and this form of cell may be considered as a secondary or storage cell, inasmuch that when the electrical energy has been obtained from it by the destructive decomposition of the metallic zinc and the copper salts, it may be restored to approximately its original condition by the passage of an electric current through it. Viewed in this light, the copper-alkaline-zinc cell of Lalande and Chaperon, as it is reversible, may be considered as a form of accumulator. Hitherto but little seems to have been done in the way of utilising this cell as a medium for storing electrical energy, but as an economical primary generator it has been highly spoken of, and it appears to have met with some degree of commercial success. It may therefore be of interest to briefly consider this form of cell, as it may serve to throw some light upon the more distinct types of alkaline accumulators.

Messrs. Lalande and Chaperon having ascertained that oxide of copper was readily reduced to its metallic form when used in conjunction with zinc in an electrolyte of caustic potash, were enabled to construct several forms of cells which have been commercially employed with some measure of success. Their first copper elements were prepared by mixing small quantities of the oxy-chloride of magnesium with oxide of copper, and then, to ensure good electrical conductivity, this plastic mass was moulded on to a metallic support, and pressed into the desired shape. Electrodes constructed according to this method were found to expose a very large active surface, but as the resultant by-products were of little value, they were soon abandoned. Accordingly it occurred to the inventors that far more economical elements might be prepared by applying the copper oxides to a conductor which was placed horizontally, and in such a manner that the copper salts merely rested loosely and lightly upon it. Cells of the horizontal gravity type were accordingly made, and in these the zincs were suspended in the upper part so that the dense solution of zincate of potash, when formed, sunk by reason of its density to the bottom of the cell and remained there, while the lighter and more active solution was free to attack the suspended zinc. The chemical destruction of the zinc plates, when placed under these conditions, was found to go on with perfect uniformity, and by experiment it was demonstrated that a zinc element eight millimetres thick was consumed so regularly that it remained quite intact and continued to expose its original surface area until it became reduced to only two-tenths of a millimetre in thickness.

The inventors found that caustic soda gave apparently the same results as the potash, both as regards the electromotive force and internal resistance, but as soda salts are liable to creep, they preferred to employ the potash. The electromotive force developed by this cell is somewhat low, being only about 0·8 of a volt, but this is in a measure compensated for by a small internal resistance.

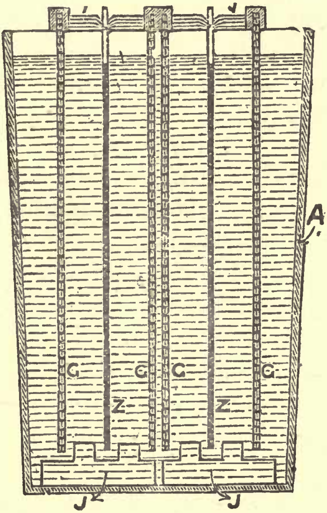


Fig. 77.—Lalande Electric Lighting Cell.

The following may be taken as representing the chemical reactions which occur during a discharge of the copper-potash-zinc cell:

$$2Zn + 2KHO + 3CuO = 2ZnKO_2 + 3Cu + H_2O.$$

When used as a primary battery, the separation of the different solutions, owing to their varying densities, is so defined as to permit of the removal of the heavy spent solution by means of a syphon, so that any disarrangement of the elements is unnecessary.

An early form of Lalande cell as used for domestic electric lighting, is illustrated in Fig. 77. In the diagram, A represents an iron containing-cell; Z Z are the zinc electrodes; G G G G are wire gauzes containing the CuO; I I are insulators supporting the zincs by means of the lugs as shown; and J J are insulating shoes, used as distance-pieces and separators.

An electric lighting plant installed in a City office in London consisted of twelve large iron trough cells of this type. The twelve cells were capable of holding 180 gallons of solution, and were divided up into two batteries of six cells, joined in series. This huge primary battery was made to charge a set of accumulators which gave the necessary potential to actuate a number of low-voltage incandescent lamps. Six cells only were used at one time, but as these were duplicated, it was possible to effect the charging of the storage cells continuously, as when one set were in action, the other could be replenished.

A form of Lalande cell of the horizontal type is shown in Fig. 78, and may be briefly described thus: The chamber, A, which constitutes the positive pole of the battery, is made of thin sheet iron, and is about 40 centimetres long, 20 centimetres wide, and 10 centimetres deep. The bottom of this containing-cell is covered with a layer of granulated copper oxide, and at its four corners are placed porcelain insulators, L, which serve to support the horizontal zinc plate, D, which is not allowed to touch either the copper salts or the metallic sides of the outer chamber. The solution used is one of potash in water. The terminals, C and M, are fixed respectively to the iron and zinc poles. To avoid a too rapid absorption of carbonic oxide from the air, either a thin layer of heavy petroleum is floated over the surface of the liquid, and this substance, being uninflammable and inodorous, forms a perfect air-proof sealing, or, better still, the battery is furnished with an air-tight wooden cover. This form of element is very compact, and occupies but little space.

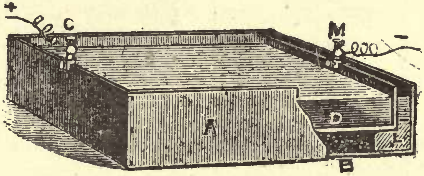
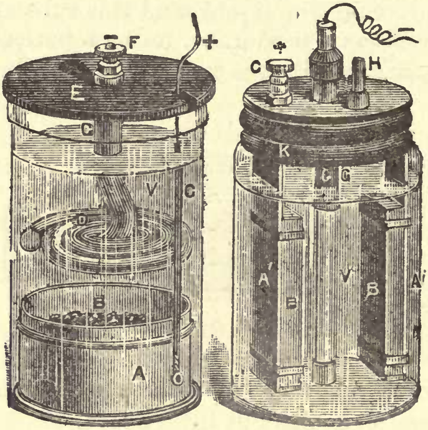


Fig. 78.—Lalande Cell. Horizontal Type.

In the annexed diagram two forms of portable Lalande and Chaperon cells are illustrated. On the left-hand side of the diagram, Fig. 79, a very simple arrangement of elements is shown. At the base of the outer glass containing-jar, V, is placed a shallow iron receptacle, A, which contains the copper oxide, B. To this metallic chamber an insulated copper wire is attached. The zinc element is formed of a thick strip of the metal coiled up in a flat spiral, D, and suspended from a wooden cover, E, which carries a terminal, F, fixed on to the end of the zinc. An indiarubber tube, G, covers the zinc wire at the place where it dips into the electrolyte, and serves to prevent the metal from being eaten away at this level. The charging solution contains from 30 to 40 per cent. of free potash. This arrangement is somewhat similar to a Calland primary cell, with this difference—that the depolarising element is solid and insoluble. To facilitate the recharging operation, a quantity of solid potash is placed within the chamber which holds the copper oxide, and then all that is necessary to bring the cell into action is merely to add the requisite quantity of water.



FIGS. 79 and 80.—Lalande Portable Cells.

Another form of copper-oxide element is made by compressing the copper salts into blocks or slabs. This is illustrated in Fig. 80. As shown, the glass jar, V, is provided with a tight-fitting copper cover, E. This cover carries two vertical plates of sheet iron, A A′, against which are fixed the blocks of copper salts, B B′. The terminal, C, is fixed to the cover, and constitutes the positive pole. The zinc element is formed of a zinc rod, D, which passes into a tube situated in the middle of the cover. The indiarubber covering, G, is folded back upon the tube so as to form an air-tight joint. A vent-plug, H, allows the escape of any gas generated within the cell, and acts as a kind of safety-valve. The copper cover is hermetically sealed by means of an indiarubber ring, K.

On the introduction of the Lalande and Chaperon battery into England it attracted much attention as, owing to the high commercial value of the by-products, it was thought to be an inexpensive means of obtaining a supply of electrical energy. Among others, Dr. Squire made an investigation as to its capabilities, and from his lengthy report the following is abstracted: "It is the distinguishing feature of the Lalande battery that the depolarising substance can be regenerated with the utmost facility. The battery consists of a plate of zinc immersed in a strong solution of caustic potash opposite the negative element. Unless the circuit is completed, nothing happens; but when this is done, and the battery is in action, the water of the solution is decomposed, the oxygen goes to the zinc, converting it into oxide of zinc, which dissolves in the caustic potash, while the hydrogen is liberated on the negative element. This negative and depolarising element consists of oxide of copper cemented together by means of a cement not acted upon by the solution. As the hydrogen arrives on the negative element, it unites with the oxygen of the oxide of copper, which is thereby reduced to the metallic condition, and the action goes on as long as there is any oxide of copper left. In order to regenerate the negative and depolarising element, nothing is necessary but to withdraw it from the cell, dry it, and heat it to a dull red heat in air. Under these circumstances the oxygen of the air combines with the copper, reproducing the oxide of copper from which we set out. This simple regeneration is most perfect, and I have examined the elements which have been repeatedly regenerated without finding in them the slightest deterioration."

When used as an accumulator, the recharging operation in the cell naturally reverses the order of the reactions; the reduced copper is again converted into oxide, while the mixed solutions of zinc and potash are decomposed and deposited zinc upon the zinc element is obtained.

As the results of their investigations, Messrs. Lalande and Chaperon were led to the following deductions. As a battery with a solid depolarising element, this form presents the advantages of only consuming its elements in direct proportion to the work it is called upon to do; amalgamated zinc and copper are, in fact, not attacked by the alkaline solution, and it is therefore very durable. Its electromotive force is nearly one volt, and its internal resistance is very low. The resistance may be estimated at one-third or one-fourth of an ohm per decimetre of exposed surface when the distance between the elements does not exceed five centimetres. With a depolarising surface double that of the zinc the battery will work without sensible polarisation almost until completely exhausted, even when under most unfavourable conditions. The transformation of the products, the change of the alkali into an alkaline salt of zinc, does not appear to perceptibly vary the internal resistance of the cell. This constancy is chiefly due to the progressive reduction of the depolarising electrode to the state of very conductive metal, which augments its conductivity and also its depolarising effect. Peroxide of manganese, which forms the basis of an excellent battery capable of giving a high electromotive force and but small current, possesses at first better conductivity than oxide of copper, but this property it soon loses, by reason of the reduction and transformation of the manganese salt into a lower oxide. It follows that the copper-zinc cell will give a current of large quantity when discharged through a low resistance, whilst under these conditions manganese cells are rapidly polarised.

The energy contained in a copper-zinc-potash cell is very large, and is far superior to that stored by a lead accumulator of the same weight and dimensions. As an electrolyte, potash may be employed in concentrated solutions of 30, 40, or even 60 per cent. Solid potash is found to dissolve oxide of zinc to the extent of more than one-third of its own weight. In these cells the weight of oxide of copper employed exceeds by nearly one-quarter the weight of zinc which is brought under action. The deposited copper absorbs oxygen quite readily by simple exposure to damp air, and can ther be used again. An oxidising flame produces the same result very rapidly. Lastly, by treating the exhausted cell as an accumulator—that is to say, by passing a current through it in the opposite direction—the various products are restored to their original condition; the copper absorbs oxygen, the alkali is revived, and the zinc is deposited.

The Thomson-Houston Zinc-Copper Cell.—Some years ago Professors Elihu Thomson and E. J. Houston, in a communication to the *Journal* of the Franklin Institute, suggested a form of storage cell which bears a striking analogy to Daniell's well-known gravity cell. In their communication they stated that the storage of electrical energy in lead cells was inconvenient and uneconomical for the following reasons:

1. The extent of conducting surface of the storage apparatus required to be acted on rendering it cumbrous.
2. The loss of energy due to evolution of gas during the operation of charging.
3. Lack of constancy and duration in the currents evolved after charging.
4. The limited capacity for storage due to the proportion of active material being but a fraction of that present.

In the system of electrical storage suggested by them, the duration of the electrolytic action, and the consequent capacity for storage, was said to be independent of extent of surface, and only depended upon the mass of material to be acted upon. In their method they employed a saturated solution of zinc sulphate, enclosed in a suitable vessel, at the bottom of which was placed a plate of copper, to which was connected an insulated conducting wire. Near the top of the vessel, and immersed in the zinc solution, was placed a second plate of copper, of hard carbon, or, in fact, of any metal or substance which is unchanged by contact with zinc sulphate solution, and less positive than metallic zinc. A storage battery so constructed is then ready for charging, which is effected by the passage through the cell of a current whose direction within the cell is from the lower to the upper plate. A porous diaphragm was inserted just below the top electrode, to prevent fragments of deposited zinc from falling on the lower plate, which may occur should the charging current be too rapid. This eventuality has to be carefully guarded against, as metallic zinc in conjunction with copper creates violent local action. Diffusive action of the solutions may be prevented by any of the means employed in gravity cells.

As one result of the passage of a current through this cell is the deposition of metallic zinc on the upper plate and the formation of a dense solution of sulphate of copper which overlays the lower plate, the duration of the charging action is limited by the amount of zinc sulphate present and the thickness of the copper element. The cell after charging constitutes a copper-zinc gravity cell, and continues a source of electrical energy until a reconversion of all the copper sulphate into zinc sulphate has been effected, metallic copper being deposited on the lower plate, and the deposit of zinc being removed from the upper. The cell may be covered to prevent evaporation, and since no new material need ever be added, a restoration to an active condition is at any time possible.

Copper-Zinc-Alkaline Storage Cells.—If finely-divided metallic copper be converted into the form of a plate by being subjected to a pressure of, say, from five hundred to a thousand atmospheres, a sheet of copper is produced which seems perfectly solid, yet is really very porous. Such a plate has all the characteristics of cast copper, the only difference being that it is considerably lighter in weight, and is capable of absorbing with great facility a large amount of nascent oxygen. The zinc-copper-potash cell, as devised by Michael Faraday, was found to polarise after it had been in action for a short time. The activity of the copper plate was in a great measure due to the small quantity of copper oxide which is usually found on the surface of commercial sheet metal. When Faraday's elements were exhausted—that is to say, when the potash solution became saturated with zinc, and the oxide disappeared from the surface of the copper—the cell could be regenerated by the passage of an electrical current through it. As oxide of copper formed under these conditions is soluble in the potash solution, copper was found to be deposited on the negative element at the same time as the zinc, and this gave rise to violent local action to such an extent that the regenerated cell soon became exhausted.

Messrs. Desmazures, Commelin, and Baillehache seem to have overcome most of the difficulties experienced in Faraday's original copper-zinc combination, the result being the production of a reversible couple which appears to promise exceedingly well. In the improved storage cell the positive element is composed of a mass of pure metallic copper, obtained by electrolytic reduction from a solution of copper oxide, in the form of a thick mud-like substance. This soft, pasty mass is subjected to a pressure of about one thousand atmospheres, the results being the production of an apparently solid block of copper, but which in reality is only about two-thirds the specific gravity of ordinary sheet copper, and is of a highly porous nature. Copper elements produced by this process are found to possess most of the essentials of a good depolariser, and at the same time they are of high electrical conductivity.

By the substitution of this porous copper for the dense metal sheet a couple is produced which gives fairly good results, as the copper, being dissolved less quickly by the alkaline solution, is not deposited so rapidly upon the zinc; still, the final results leave much to be desired. If, however, the copper element is covered with a porous material such as parchment paper, the regenerating process is said to be effected without any difficulty, as the whole of the dissolved zinc is deposited, and the porous copper freely absorbs the oxygen, a cell being thus produced which can be indefinitely regenerated. This was the plan finally adopted by Messrs. Desmazures, Commeline, and Baillehache.

According to M. Finot, who appears to have devoted some attention to this combination, the chemical reactions which occur during a discharge may be expressed by the following equation:

$$4Zn + 4KHO + 3CuO_2 = Zn + KO_2 + 3Cu + 2H_2O.$$

Finot asserts that it is not the dioxide of copper (CuO) which is reduced, but it is the peroxide (CuO_2).

Desmazures' copper accumulator is very simple in construction, and is made as follows: The positive element is a porous copper plate from two to three millimetres thick, around which an envelope of parchment is placed. The negative electrode is a frame of fine iron gauze. As the electrolyte a strong solution of zincate of potassium is used. The containing-chamber is made of thin tinned sheet steel. By this method of construction a light, rigid, and serviceable cell is produced which is but little liable to get out of order, and is not at all costly.

The solution usually employed is composed as follows:

Water	1,000	parts
Zinc	144·67	,,
Combined potash	200·82	,,
Free potash	313·72	,,

In the charging operation the zinc is abstracted from its solution, and is deposited in its metallic form upon the iron gauze; at the same time oxygen is developed, which enters into combination with the spongy copper and forms oxide of copper. During the discharge, the reverse action occurs, the zinc re-enters into solution, oxygen is taken from the copper oxide, and at length the couple becomes quite inert. By repeated charging and discharging, the plates are said not to lose mechanical strength; in fact, the copper element appears to become more rigid and stronger by repeated use.

The electromotive force as developed by this couple is rather low; its normal is between 0·8 and 0·9 volt, and it never exceeds 1·2 volts. A small cell measuring 10 inches by 4·5 inches by 10 inches, and weighing just 28lbs., is stated to have had a useful capacity of 150 ampere-hours. As much as 200 ampere-hours capacity has been obtained from a cell whose weight did not exceed 19lbs. According to some tests made by M. Mascart, the Desmazures alkaline cell gave an energy efficiency of 65 per cent., and the storage capacity of a battery weighing 37 kilogrammes was one electrical horse-power hour.

Some rather curious phenomena are observed when charging this accumulator. At the commencement the level of the electrolyte rises, and continues to rise until the moment of stopping the charging. When the cell is discharged the opposite phenomena occur: the level of the liquid gradually falls, and does not return to its original point until the cell is entirely discharged. These facts seem to indicate that a part at least of the oxygen must be occluded within the pores of the spongy copper, as if the gas combined with the copper the rise of the electrolyte would not occur at first, and the level would not be raised until the gas had ceased to combine with the copper. Then only the oxygen, on filling the pores of the metal, would increase the bulk of the solution. At the discharge, on the contrary, the oxygen ought to disappear immediately, and the liquid should regain its normal height almost as soon as the discharging circuit is completed. It is found, however, that this does not occur until the cell is entirely discharged.

As alkaline storage batteries do not give off any fumes or gases, they appear to be peculiarly suited to furnish the energy for propelling electric launches, submarine boats, and for similar purposes. Some trials made at Havre with the electrically-propelled launch, the "Gymnote," belonging to the French Navy, proved very successful when this form of storage cell was employed.

The accumulator used in these experiments contained six negative and five positive elements in each cell. The height of the plates was 56 centimetres, and their width 12·5 centimetres. The total active surface of the positive elements was 700 square centimetres. The dimensions of the metallic containing-chamber was 70 centimetres high, 15 centimetres wide, and eight centimetres deep. The quantity of zincate of potash solution used in each cell was six litres, and its weight was 18 kilogrammes.

The zinc-potash solution contains 150 grammes of zinc per litre, which is equivalent to 900 grammes per cell. This corresponds to a current capacity of 733 ampere-hours, if the whole of the zinc is precipitated. The rate of charge of the marine accumulator is given as from 30 to 35 amperes, and the maximum electrical pressure required is 1·2 volts per cell. The rate of discharge in the trial with the "Gymnote" was from 80 to 90 amperes, with a difference of potential per cell of from 0·75 to 0·80 volt.

According to some experiments made by M. Krebs with a motor driven by the alkaline battery, he obtained a current efficiency of 86·5 per cent., and an energy efficiency of 65 per cent. The rate of discharge in these experiments sometimes reached 100 amperes.

When these elements are newly mounted, the porous copper plates are frequently somewhat oxidised owing to having been exposed to the air. If they are charged under these conditions, the results are not quite satisfactory. It is therefore advisable to bring the plates into proper form by submitting them to a reducing current—*i.e.*, a current in the contrary direction to that used for charging.

It was thought that Desmazures' cell would answer admirably for actuating the glow lamp in a portable miners' electric lamp, and by substituting a thin plate of silver, made by the same precipitating and compressing process as that used with the copper, a large increase in available electromotive force was obtained, and light and compact batteries were made. For a given output the weight of the silver couple was found to be only about one-half of that of the copper. A portable hand lamp, constructed on this principle and weighing 3lbs., gave an output of fifty watt-hours, and of this total weight not more than 0·5lb. was silver.

In this particular kind of alkaline cell local action would doubtless occur, but under ordinary conditions it would be so slow that it might be disregarded. It has been ascertained that in the case of a miner's lamp made on this plan, local action would not mean a greater loss than five per cent. between the quantity of current put in the cell and the amount taken out, if the period between the two operations did not exceed twenty-four hours.

Entz and Phillips's Copper-Mesh Elements.—A new form of copper element, suitable for storage cells, comes from Schenectady, in America, and appears to have been arrived at by the joint labours of Entz and Phillips. This element consists of a copper core which is enveloped by a woven network of very fine copper wire. The interstices in the copper mesh are filled with oxide of copper. As an additional means of securing the copper oxide upon its support, there is braided around it a sheathing of insulating porous material, such as cotton or hemp. The porous insulator prevents metallic contact should the elements touch one another. The compound copper plate forms

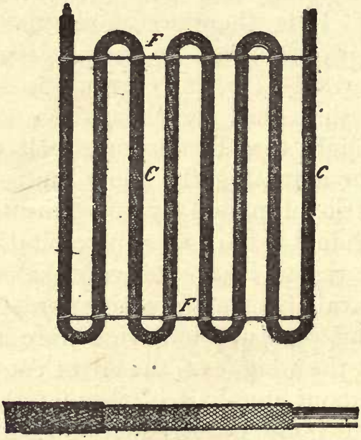


Fig. 81.—Entz and Phillips's Copper Element.

the positive element, and a sheet or rod of zinc constitutes the negative, dilute sulphuric acid being used as the electrolyte. During a discharge, the hydrogen liberated by the combination of the zinc and acid combines with the oxygen in the oxide of copper, reduces it, and leaves finely-divided metallic copper in the meshes of the element. To recharge the positive plate, it is either heated in air, or the requisite amount of oxygen is supplied to it by the ordinary electrolytic method. As the copper network is said to firmly retain the active material under all conditions, these elements are calculated to withstand very heavy discharging without being in any way injured.

In Fig. 81 is shown the commercial form of Entz and Phillips's element. In the diagram the metal core with its covering of copper gauze is shown, as well as the appearance of the mesh when filled with oxide of copper, and also when covered with its porous cotton sheathing.

Main's Lead-Zinc Storage Cell.—Appreciating the advantages to be derived by the employment of such cells as Reynier's lead-zinc combination, especially when used for traction purposes, Prof. W. Main, of South Brooklyn, U.S.A., has given some attention to methods of remedying certain of the defects which have been found to exist in this class of cell. The results he obtained from his experiments in this direction soon convinced him that most of the difficulties encountered by Reynier were due mainly to the fact that his plates were placed vertically in the electrolyte. The result of this arrangement was that the zinc plates, on account of differences of density in the solution, were unequally acted upon, and, indeed, were frequently cut away from their support. This phenomenon is sometimes noticed in primary battery cells where zinc is employed, that part situated at the top of the containing-cell being usually consumed considerably faster than that at the base. A remedy for this defect was recognised by Prof. Main, and applied by placing the zinc plates in a horizontal position, so that, notwithstanding differences in the density of the electrolyte, each separate plate is surrounded by a layer of liquid having the same specific gravity throughout.

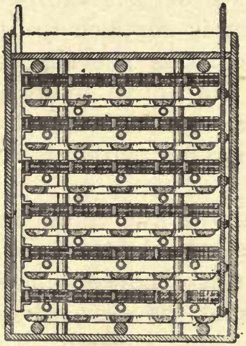


FIG. 82.—Main's Complete Cell.

The arrangement of elements that Main finally adopted is shown in Fig. 82, which represents a vertical section of the cell. The positive plate consists of two thick outer plates of lead, between which are held a number of very thin sheets of lead-foil. The laminated plates, when secured firmly together by means of rivets, are closely perforated, as shown in the diagram, Fig. 83. Elements when constructed in this manner are said to be both strong and rigid, and readily become active when subjected to electrolytic formation. As the laminæ are firmly secured by the thick outer plates, they are but little liable to disintegrate when formed and in use. The negative electrode, shown in Fig. 84, is a thin perforated copper dish, filled up with an amalgam of zinc and mercury. When in their containing-cell the elements are built up one above the other, alternately a lead and then a compound copper-zinc plate. To retain them the requisite distance apart, insulating washers are placed between the elements at stated intervals, and the whole system of plates is held firmly in position by

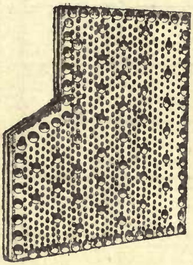


FIG. 83.—Main's Positive Element.

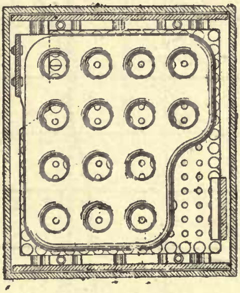


FIG. 84.—Main's Negative Element.

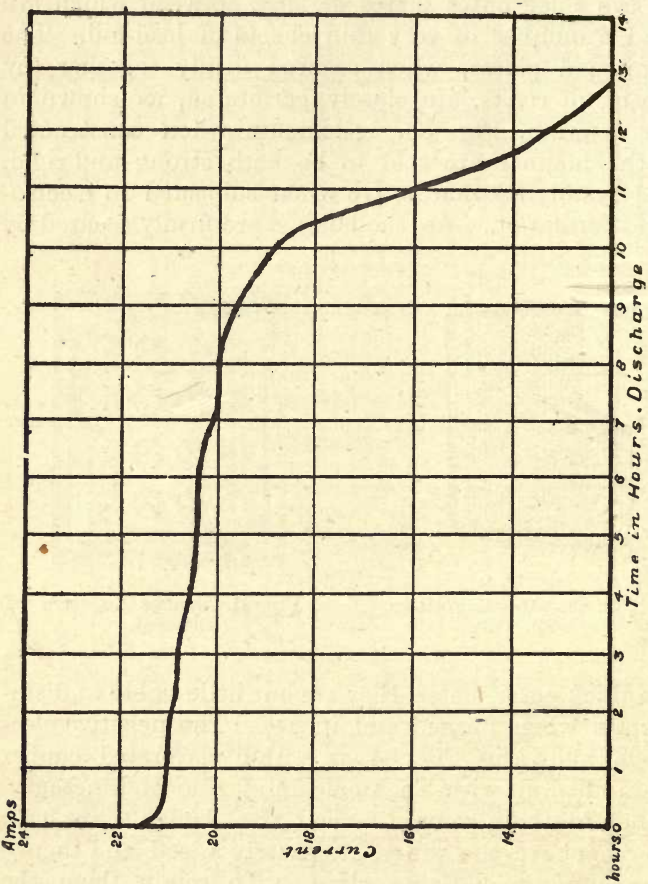


FIG. 85.—Mains Battery. Curve showing Fall of Current.

means of a clamping cover, as shown in the illustration of the complete cell.

According to the inventor, very few charges and

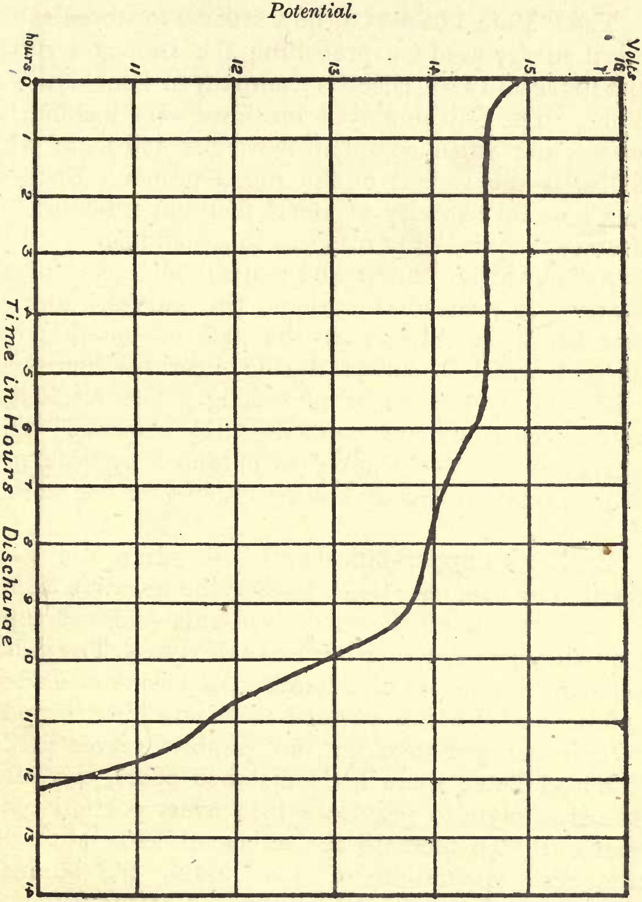


FIG. 86.—Main's Battery. Curve showing Fall of Potential.

discharges serve for the complete conversion of the zinc amalgam into a highly-porous and spongy mass, which has a great capacity for occluding hydrogen gas.

The "Main" battery is now utilised to store the electrical energy used for propelling the tramcars run by the River and Rail Electric Company in Brooklyn, New York. The cell employed on these cars has fourteen plates, and when complete it weighs 45lbs., of which 27lbs. is the weight of the metal proper. Each cell has a useful capacity of about 250 ampere-hours, and each car require sixty of them to actuate it.

As the arrangement and general character of this battery is somewhat curious, the curves, Figs. 85 and 86, which illustrates the fall of potential and current which occurred during a twelve hours' discharge, may not be uninteresting. The discharging rate at the commencement was 21¼ amperes. These curves are plotted from data obtained by tests made with a traction battery especially built for car work.

Barker's Copper-Zinc-Lead Cell.—In a storage cell devised by Professor G. F. Barker, the negative element is constructed of sheets of well-amalgamated copper and zinc held together by means of rivets. The positive element is built up of a number of sheets of lead-foil, whose surfaces are covered with powdered graphite. When clamped together the graphite serves to keep the lead plates some little distance apart, and allows the electrolyte to permeate into every portion of the element. To increase the active surface, and to allow the free circulation of the liquid, the laminated lead electrodes are closely perforated. It is found that no electromotive force is set up between the amalgamated sheets of copper and zinc, and therefore little or no local action occurs. The electrolyte used in this cell is an acid solution of sulphate of zinc.

During the charging operation the lead element becomes peroxidised, and crystalline metallic zinc is deposited upon the copper-zinc electrode. When thoroughly formed, it is stated that this type of cell gives a much higher current capacity per pound of plate than either a Planté or a Faure. When at rest, neither element, it is asserted, shows any signs of sulphating.

Kalischer's Battery.—In a communication to the Physical Society of Berlin, Dr. Kalischer described a form of lead-iron storage cell devised by himself. The elements were very simple, consisting only of a sheet of iron and a plate of well-amalgamated lead. The electrolyte was a concentrated solution of nitrate of lead. On the immersion of the iron plate in the lead solution no action occurred, but on the charging current being applied the solution was electrolysed, and the iron plate quickly became covered with an adherent deposit of peroxide of lead. The charging operation was continued until the greater part of the lead was abstracted from the nitrate solution, a condition which was indicated by the rapid evolution of gas at the negative electrode. At the beginning of the forming process, Kalischer found it best to avoid passing the current through the cell at a too high rate, otherwise the deposited peroxide of lead, or, more correctly, hydrated peroxide of lead, assumed a scaly and non-adherent texture, and tended to fall away from its support. In the first experiments a plain sheet of lead was employed as the negative electrode, but this was attended with some disadvantages. It was found that during the charging the deposited lead exhibited a tendency to form long crystals of such length as to bridge across the plates, with the consequent formation of short circuits; and also, the free nitric acid remaining in the solution after the separation of the lead, acted powerfully upon the lead electrode and quickly destroyed it. Dr. Kalischer stated that he had quite overcome these difficulties by thoroughly amalgamating the lead electrode previous to its immersion in the electrolyte.

The initial electromotive force derived from this couple was given as two volts, but after a few hours' action it usually fell to about 1·8 to 1·7 volts. In his experiments, Kalischer found his elements to be slightly recuperative. If discharged until the electromotive force had fallen to 1·7 volts, the accumulator, on being allowed twenty-four hours' rest, would again give nearly its initial potential.

An attempt was made to substitute a manganese solution for that of the nitrate of lead, but this did not prove successful, as the peroxide of manganese separated itself from the iron support in the form of loose scales. As the result of a number of tests made with this accumulator, it was ascertained that it could compare favourably with most forms of lead or lead-peroxide cells.

The "Marx" Liquid Accumulator.—In these pages all the forms of electrical storage apparatus that have been described, derive their activity from the chemical changes induced in the electrodes themselves, so that with all these storage batteries the same plates are used in both the charging and discharging operations. In the Marx liquid accumulator, the electrical energy appears to be stored, not in the electrodes, but in the electrolyte itself. The liquid employed, owing to this peculiar property, has been termed "electroline." If this substance be subjected to certain chemical changes, induced by the passage of a current through it, a number of reactions are determined, whereby electrical energy may be stored. In the new cell the electrodes or conductors may either be of metal, or of some inert semi-conducting material, such as carbon. When constructing an "electroline" cell four hundred and fifty grammes of chloride of iron are dissolved in nine hundred grammes of water to which has been added five hundred grammes of hydrochloric acid. In this solution two or three plates (when carbon is used there are two negative plates and one positive) are immersed, and are correspondingly connected to the negative and positive poles of the charging source. The passage of the current between the plates causes the decomposition of the liquid, which first turns greenish, then yellow, and ultimately yellowish brown. When all the chemical reactions are complete and the solution will not absorb further electrical energy, the conducting plates are removed, and the cell is said to be charged.

As previously stated, the orthodox types of storage cells will only return their charge with the same electrodes, but in this battery a change of electrodes is essential. The best results are obtained with plates of varying conductivity, such as a metal used in conjunction with carbon. A highly-porous carbon block placed between two zinc plates is said to give excellent results, or carbon with copper or iron may be used. When suitable conductors are immersed in the electroline, and the outer circuit is completed, an energetic current is developed, and the liquid decomposes, passing through the same series of colours as in the charging, but in inverse order, while it gradually loses its electrical activity. As no particulars as to the electromotive force developed, the current capacity, or the internal resistance of this cell are given, it must as yet be regarded only as an electrical curiosity.

Recently some rather novel primary batteries which bear a close resemblance to storage cells have been introduced, and as one or two of them appear to possess some interesting features it may be of advantage to briefly describe them.

The Tatlow Battery.—This cell consists of a zinc and lead-peroxide couple immersed in an electrolyte of dilute sulphuric acid. The positive element is made as follows: A cast-lead grid or other suitable leaden receptacle is filled with minium made into a paste by the addition of dilute sulphuric acid, or it may be filled with litharge moistened with a solution of acetate of lead. When the soft mass has solidified and is thoroughly dry, the plate is placed in a vessel containing a concentrated solution of chloride of lime. The lime reacts upon the lead salt, and gradually converts it into lead peroxide. The rapidity with which these reactions occur depend in a great measure upon the temperature of the "forming" solution. On the completion of the oxidising process, the plates are thoroughly washed in water, and are then ready for use in the cell. If a plate prepared in this way is placed in dilute sulphuric acid, and in conjunction with a negative element such as zinc, then an electromotive force of from 2 to 2·3 volts is obtained. When the peroxide plate is exhausted, it may be thoroughly revived by again placing it in the hypochlorite solution. This operation may be repeated again and again without the active material being in any way deteriorated. In the regenerating bath it is absolutely essential that there should be enough free lime to keep the liquid distinctly alkaline.

During the process of regeneration in the hypochlorite solution, the reactions are said to involve the formation of a lead or lead-calcium hypochloride, but probably the reactions are of a somewhat complex nature. The hydrogen produced by the action of the acid solution upon the zinc element when the peroxide plate is used in the primary electricity generator, is quickly oxidised by the oxygen, so that polarisation does not occur until the supply of oxygen in the positive element is quite exhausted.

The "Osbo" Battery.—This battery, which appears to possess some rather novel features, is constructed as follows: The cell is of the carbon-zinc single-fluid type, and it involves the use of a reoxidising apparatus for reviving the depolariser, which is reduced to an inert condition by the nascent hydrogen generated during the working of the battery. Besides the outer chamber and the elements, each cell contains a porous earthenware tube having a number of perforations in its base. This tube is sealed by means of a stopper. When the cell is to be brought into action, a small bag containing a depolariser is inserted within the porous tube, which is then sealed. Chemical action is set up as soon as the liquid reaches the depolarising bag, resulting in the liberation of oxygen gas which reoxidises the reduced element.

The reoxidising bag contains a special mixture of chloride of lime with a few crystals of nitrate of nickel; this mixture, when acted upon by water, disengages oxygen quite freely, more especially if slightly heated. The requisite heat is provided by the battery solution, as in consequence of the chemical action it is always somewhat above the temperature of the surrounding air. In this battery there is neither smell nor fumes, and as the zincs are thoroughly amalgamated no action occurs when it is on open circuit. If it were not for the formation of zinc salts in the working of the cell, the same solution might be used indefinitely, but in practice it has to be changed occasionally, not because the depolariser becomes exhausted, but because the solution itself becomes saturated with zinc salts. Theoretically, the battery may be said to run by the consumption of zinc and chloride of lime.

Jablochkoff's Anti-Accumulator. — This curious form of cell, due to M. Jablochkoff, was described by him in a communication made to the French Academy of Sciences. The anti-accumulator, so called on account of its elements being regenerated by local action, consists of three dissimilar electrodes: it comprises, first, an oxidisable metal which forms the first electrode; then a plate of a slightly oxidisable metal capable of being polarised; and, lastly, another electrode consisting of tubes of very porous carbon. Among the various patterns tried, the most successful cell was one made up as follows: The first element was a flat dish of thin sheet lead, in which was placed a number of fragments of an easily oxidisable metal such as sodium, sodium-amalgam, zinc, iron, or some similar material. On the top of the granulated metal a layer of some spongy inert material, such as cloth or wood sawdust, was spread. Two operations may then occur. If sodium were used it was not found necessary to introduce water, as this substance is highly deliquescent, and quickly absorbs moisture from the atmosphere, thereby forming caustic soda; but if the metal employed were zinc or iron, then the spongy mass had to be moistened with a solution containing either common salt, or, better still, chloride of calcium, which will both attract and retain water. Lastly, the electrode of porous carbon tubes is placed upon the moist, spongy mass.

The action set up in this apparatus may be described thus: When the elements are on open circuit there are established a series of local currents between the oxidisable metal and the electrode upon which it rests. The latter is therefore polarised, and its potential rises until its counter electromotive force has reached that of the oxidisable metal; the local action is then either totally arrested, or reduced to a minimum. If it be thought desirable to utilise the exterior current, all that is necessary is to join the electrode thus polarised to the carbon electrode; the discharge then begins, the local currents are redeveloped, and tend to restore the charge to the electrode as fast as it is carried off.

The electromotive force obtained from the anti-accumulator has been found to vary according to the nature of the materials employed; thus with sodium-amalgam, 2·2 volts have been obtained; with zinc, 1·6 volts; and with iron, 1·1 volts. The internal resistance of a cell having an active surface of one square decimetre varies between 0·25 and 0·5 ohm, the resistance varying according to the thickness of the spongy material employed, and the degree of moisture it contains. The battery may be worked without change of active material for a period of many months, it only being necessary to renew the liquid from time to time. This may readily be effected by steeping the elements in water, allowing them to drain, and then immersing them in a solution of chloride of calcium. If the current is to be utilised for lighting purposes or for actuating motors, then the liquid must be renewed about every twenty to thirty hours.

Jablochkoff asserts that in his new battery the active materials are only consumed when current is being taken from the cells, and that during the discharge no fumes or vapours of any description are given off. He also affirms that by the employment of this combination electrical energy to the extent of one horse-power hour may be obtained at an expenditure of only a few centimes.

PART IV.

Solid Storage Cells.—The Electrolyte and Apparatus for Measuring its Density.

Element Separators.—Numerous devices have been suggested for keeping accumulator electrodes the requisite distance apart, and also for preventing them from buckling, or being otherwise distorted. Planté's and Faure's original spiral plates were separated by means of thick felt or cloth. This separating medium, however, was soon abandoned, for reasons already explained. In the earlier forms of E.P.S. grid, the separators consisted of indiarubber buttons studded over the plates at stated intervals. Round, square, and diagonally-shaped vulcanite projecting pins, screwed into either the positive or negative plates, have been tried. Methods of retaining the plates in position, by means of metal pins or lugs cast on the edges of the elements, and fitting into insulating cross-bars, have met with some success. Perforated and corrugated vulcanite or celluloid sheets, and porous earthenware plates, have also been used. An excellent separator, introduced by Messrs. Crompton and Howell, is illustrated in Part I., page 52. The most simple and effectual of the many plans suggested seems to be the employment of vulcanite, glass, or celluloid strips, bent into a **U**-shape, and pushed down over the plates. Two or three of these distance-pieces between each pair of elements is considered sufficient for cells used for ordinary lighting purposes.

Storage Cells for Electric Traction.—The idea of locomotion by means of electricity is just now attracting much attention, and it therefore behoves electrical engineers to seriously consider the many different systems now being advocated, so as to determine which of the proposed systems is the most feasible, safe, and economical. Much may be said in favour of conveying the electricity through overhead conductors, along one or both of the carriage rails, or by separate insulated high conductivity conductors, or of the method of "picking up" the current from underground mains. If, however, a storage battery can be devised which shall be capable of withstanding the excessive electrical strain incidental to a rapid and irregular rate of discharging, and the mechanically disruptive effect which always seems to attend concussion and jolting and greatly tells upon accumulators when used for such purposes, then the self-contained storage-battery system will be found to compare most favourably with any of them, both in point of simplicity and economy.

When devising cells suitable, say, for heavy tramcar work, many difficulties arise. Owing to the initial cost, a small number of cells must suffice, and they must therefore be constructed to run many hours with one charge, and they must also be capable of being quickly recharged and reinstated. The external resistance of the cells should be low and their capacity great, for they not only have to develop sufficient electrical energy to carry the car over irregular, undulating, and rough roads, on which at times the pulling power of the horses ordinarily employed is strained to its utmost limits, but they have to carry their own dead-weight. The additional weight of the battery may probably represent fully 50 per cent. of the total weight of the combined car, motors, gearing, cells, and passengers. A reduction therefore of one pound in the weight of the batteries, if the energy storing capacity remains the same, represents a gain equivalent to that amount of energy required to carry one and a half pounds of complete car.

For these reasons it will be seen that weight is a most important consideration. In the cells the metal grids or plates must be strong and rigid to withstand the jolting and oscillation, and they should be so constructed that the pellets of active material are not liable to fall out. Strength of grid usually means increased weight. To keep the plates secure, distance-pieces or similar devices must be introduced. The employment of insulating bars, frames, or distance-pieces placed between the elements tends to reduce their active surface, increases the internal resistance of the cell, decreases the solution space, and adds to the weight, so that these should be avoided as much as possible.

Solid Storage Cells.—Much attention has recently been given to the production of so-called solid batteries. In this new type of cell the usual plan is to fill up the liquid space, either with some highly porous and absorbent compound, ultimately to be made conducting by the addition of acidulated water, or by an acid gelatinous mass. The semi-solid batteries of Messrs. Hatch and Pumpelly have already been dealt with (pp. 117 and 120). As examples of the more nearly solid cells we shall consider those devised by Mr. Barber-Starkey and Dr. Schoop.

One great drawback to the employment of a viscous, gelatinous, or solid, yet porous, electrolyte, resides in the fact that when such substances are interposed between the plates no free circulation of the conducting liquid is possible. In secondary cells the activity of the elements depend entirely upon chemical action, and as the electrolyte is the medium through which all the necessary reactions take place, it seems probable that anything which would prevent its free access to all parts of the active material, or in any way impede its circulation, must be detrimental to the cell and lead to loss of efficiency.

Barber-Starkey's Solid Cell.—Mr. Barber-Starkey has succeeded in making cells of the ordinary grid form mechanically solid by filling in the space between the plates with a dry mixture of sawdust and plaster of Paris, and then rendering it conductive by saturating it with dilute sulphuric acid. By trial he found that the proportions of these materials which gave the best results were as follows :

Plaster of Paris	1 part.
Wood sawdust	2·5 parts.

The plaster used should be the ordinary commercial article, and the sawdust should be that obtained from a non-resinous wood, such as white pine. On the liquid being added to this porous mass it quickly solidifies, and when in this condition it is said to effectually keep the elements from warping or buckling, and also to prevent the pellets of active material from detaching themselves from the grids.

A number of cells in Mr. Barber-Starkey's private electric lighting installation were treated in this way, and were then fully charged up and allowed to remain idle for many months. On the cells being tested after this period of rest they gave their full potential, and in every other respect they appeared to be in excellent condition. More recently a practical trial of this form of cell has been made on some electrically-driven cars in the Barking-road, London. A whole set of ordinary E.P.S. traction cells, after being treated on the plan suggested by Mr. Barber-Starkey, were used daily, for regular work, for a period extending over a few months. Some loss of current capacity and general efficiency seems to have been experienced, and ultimately the cells had to be abandoned.

Schoop's Solid Cell.—A form of solid storage cell devised by Dr. Paul Schoop has deservedly attracted much attention. The novelty in this battery consists not so much in the construction of the plates as in the electrolyte, which is of a solid gelatinous nature. The elements are of the grid form, and contain only about two-thirds the quantity of active material usually employed. The electrolyte is made by adding dilute sulphuric acid to a solution of silicate of sodium. In preparing this electrolyte, three volumes of a solution of pure sulphuric acid and water, specific gravity 1,250, are mixed with one volume of dilute silicate of sodium, specific gravity 1,180. This mixture, when newly prepared, is quite fluid, but it gradually becomes more and more viscous, and in the space of about two hours assumes a gelatinous form. After a period of twenty-four hours the maximum stiffness is apparently reached. When thoroughly set, the mass is a hard jelly-like substance of a slightly bluish tint. When under electrolytic action no alteration in its appearance is apparent. If bubbles of gas are disengaged at the plates, they merely push the gelatine away and escape upwards; and the elastic material immediately closes behind them, re-establishing contact with the plate. On the cell arriving at its state of full charge, a small quantity of the acid solution is forced out, and floats on the top of the gelatine; during the discharge, however, this liquid is gradually reabsorbed, and finally disappears.

Some elaborate tests of the Schoop cell have been made at the Hanover University by Prof. Kohlrausch. In these tests, the cell selected was one specially designed for portable work—such as driving cars, train lighting, and similar rough work. The following are the particulars of this cell:

Number of plates	17	
Thickness	2·5	millimetres
Weight of plates	8	kilogrammes
,, electrolyte	3	,,
,, containing-cell	0·7	,,
Total weight of cell	11·7	,,
Outside length box	125	millimetres
,, breadth	160	,,
,, height	205	,,
Total outside height of cell	250	,,

These trials were made with a view to ascertaining the behaviour of the new electrolyte when subjected to a long and continuous course of rough and irregular treatment. At the outset, the cell was regularly charged and discharged with a normal current of 10 amperes. This operation was carried on for some little time, and at length the cell was fully charged, and was then allowed to remain inactive for a period of one month. When again tested it was found that with a charge of a little more than 52 ampere-hours it gave indications of having received its full complement of current. As the capacity originally was 73 ampere-hours, it is evident that a considerable percentage of this energy must have disappeared during the period of rest. On again discharging, and then recharging at the normal rate, the cell gave an output of 72 ampere-hours, thus clearly showing that no material deterioration had occurred in either of the elements. After a series of trials made to determine the capacity of the cell at various rates of discharge, its polarity was reversed, and a current of 124 ampere-hours passed through it. At the termination of this most irregular and trying operation, the polarity of the elements was found to be completely reversed, and it gave a difference of potential of fully two volts at its terminals. After undergoing a further series of charges and discharges, the current was again put through the cell in its original direction, and it was once more submitted to a system of capacity tests.

At the termination of these trials, which extended over a period of many months, the cell was taken to pieces, and on examination the gelatine proved to be in excellent condition. The grids gave no indication of deterioration either by warping or buckling, while the pellets of active material did not show the least sign of looseness or tendency to come out. The cell under test was shown to have a capacity of 70 ampere-hours if the discharge rate did not exceed 10 amperes. Under normal conditions the current efficiency was given as 89 per cent.

Professor Kohlrausch thinks it possible that with the gelatinous electrolyte, the plates if in daily use may last for at least two years, giving their full current capacity; and after that period they may still be expected to do good and useful work for an additional period of three years.

TABLE IX.—RESULTS OBTAINED BY CHARGING IN DILUTE SULPHURIC ACID ELECTROLYTE.

E.M.F.	Rate of discharge in amperes.	Number of hours discharge.	Work given out in watt-hours.
1·94	—	—	—
2·08	35	—	—
2·12	30	After ¼ hour.	15·9
2·13	30	,, ½ ,,	31·87
2·14	30	,, 1 ,,	63·97
2·14	22	,, 2 ,,	119·61
2·14	19	,, 3 ,,	160·27
2·14	14	,, 4 ,,	190·23
2·14	12	,, 5 ,,	215·91
2·14	11	,, 6 ,,	239·45
2·14	8·5	,, 7 ,,	257·64
2·14	8·0	,, 8 ,,	274·76
2·14	6·0	,, 9 ,,	287·60
2·14	6·0	,, 10 ,,	300·44

Some interesting comparisons have been made by Dr. Schoop with reference to the relative efficiencies of his cells when filled with the gelatinous electrolyte and with the ordinary fluid solution. Table IX. gives the charging data when the cell was filled with dilute sulphuric acid of 1,185 density. In Table X. particulars are given of the charging when the gelatinous electrolyte was used. Table XI. shows the comparative results of the two discharges.

TABLE X.—RESULTS OBTAINED BY CHARGING IN GELATINOUS ELECTROLYTE.

E.M.F.	Rate of discharge in amperes.	Number of hours discharge.	Work given out in watt-hours.
1·84	—	—	—
2·19	34	—	—
2·18	33	After ¼ hour.	18·0
2·18	31	" ½ "	34·4
2·185	29	" 1 "	66·1
2·18	25	" 2 "	120·6
2·18	20	" 3 "	164·2
2·19	17	" 4 "	201·4
2·21	13	" 5 "	230·1
2·19	8	" 6 "	247·6
2·185	6	" 7 "	260·7
2·19	6	" 8 "	273·8
2·19	5½	" 9 "	285·8

The charging was performed with a constant electromotive force between the poles of the cell, which Dr. Schoop considers far preferable to the method of charging with a constant current.

In both cases the discharging current was maintained constant at 10 amperes.

The cell from which these results were obtained consisted of seven positive and eight negative plates, each element being approximately $\frac{7}{64}$ths of an inch thick. The total weight of the cell, including the electrolyte, was about 17lbs.

TABLE XI.—COMPARISON OF DISCHARGES.

Dilute Sulphuric Acid.			Gelatinous Electrolyte.		
E.M.F.	Number of hours discharge.	Work given out in watt-hours	E.M.F.	Number of hours discharge.	Work given out in watt-hours.
1·98	—	—	1·895	—	—
1·96	After 1 hour	19·6	1·89	After 1 hour	18·9
1·96	,, 3 ,,	58·8	1·89	,, 3 ,,	56·7
1·95	,, 5 ,,	97·8	1·86	,, 5 ,,	93·9
1·93	,, 7 ,,	136·4	1·84	,, 7 ,,	130·7
1·92	,, 9 ,,	174·8	1·80	,, 9 ,,	166·7
1·88	,, 11 ,,	212·4	1·76	,, 10 ,,	184·3
1·87	,, 12 ,,	231·1	—	—	—
1·83	,, 13 ,,	249·4	—	—	—

Dr. Schoop has ascertained that besides sulphuric acid, nitric, hydrochloric, or in fact nearly all acids, will mix and form gelatinous silicous acid. Salts of ammonia and other similar salts appear to answer equally as well as the acids.

Sulphating and its Removal.—One of the chief causes of loss of efficiency in lead accumulator cells is due to sulphating. This troublesome white sulphate of lead usually forms on the exposed parts of the metal support, on the surface of the active material, or just where it is least wanted, which is at the junction of the metal support and the peroxide. The formation of this sulphate is probably due either to impurities in the oxide employed, deleterious substances in the lead or lead alloy used for the frames, or chemical impurities in the sulphuric acid or water.* If a cell be allowed to remain idle and without charge, its elements frequently sulphate. A suggested cure is to charge at a somewhat higher rate than the normal, and to continue the charging some little time after the cells freely give off gas. This process usually either reduces the sulphate into the peroxide, or causes it to fall away from the plates.

Mr. Barker-Starkey found that by adding a small quantity of carbonate of soda to the acid electrolyte, it not only reduced the tendency of the elements to sulphate, but rapidly removed this salt when already formed. This action is probably due to the conversion of the sulphate first into carbonate of lead, and then into the peroxide, or it may be owing to the fact that sulphate of lead is sparingly soluble in a solution of sulphate of sodium.

As the results of some experiments made by Dr. J. H. Gladstone and Mr. Hibbert with a view to ascertain the effect of adding sulphate of soda to storage battery solutions, they concluded that the addition of sodium sulphate to the ordinary acid electrolyte has a distinctly beneficial effect upon the working of the cell. They ascertained that on the addition of the soda salt a large proportion of the sodium sulphate is formed in close contact with the lead sulphate on the peroxide plate, and that this formation was favourable to the reduction of

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* In a paper by Mr. G. H. Robertson, entitled "Secondary Batteries," read before the Society of Arts on December 3rd, 1891, will be found much valuable information with reference to the part played by the electrolyte in a lead storage cell; and in a communication to the Royal Society by the same author, published in the *Electrician*, No. 682, vol. xxvii., will be found a summary of the chemical investigations already made with regard to accumulators.

the latter substance, as a paste made of equal parts of minium and lead sulphate is more readily reduced in a solution of sodium sulphate than in dilute sulphuric acid.

Mr. W. H. Preece, F.R.S., seems to have given the acid-soda electrolyte a good deal of attention, and has put it to some thoroughly practical tests. One trial consisted in taking six new accumulator cells, which were made as nearly as possible identical in every respect, and using in each different solutions, composed of various percentages of sulphuric acid and water, and sulphate of sodium.

The sulphate of sodium solution used was prepared by carefully adding strong sulphuric acid to a saturated solution of commercial carbonate of soda. The addition of acid was continued until carbonic acid gas ceased to be given off, and all effervescence was stopped.

The following table shows the composition of the various mixtures tried. The first column indicates the number of the cell.

No. of Cell.	Quantity of Sulphuric Acid Solution.	Quantity of Sulphate of Sodium Solution.	Quantity of Water.
1	5 pints.	5 pints.	15 pints.
2	5 ,,	4 ,,	16 ,,
3	5 ,,	3 ,,	17 ,,
4	5 ,,	2 ,,	18 ,,
5	5 ,,	1 ,,	19 ,,
6	5 ,,	none.	20 ,,

The six cells were then filled respectively with these solutions, and were carefully charged and discharged continually for a period of twelve months. On the expiration of this term the elements were thoroughly examined. The cells containing solutions numbered from 1 to 5 were found to be in a much better condition than No. 6, which only contained the dilute acid without the soda sulphate. Solution No. 5 seems to have given by far the best results. In this cell the plates were found to be in perfect condition, and did not show the slightest signs of sulphating.

As an example of the beneficial results to be derived from the use of an acid-soda solution, the following may be worthy of mention. It is said that at the Central News Office in Ludgate-hill, London, a number of large lighting cells had been lying idle and dry for about two years. The plates were found to be thickly encrusted with a hard white sulphate. With the ordinary electrolyte, and a charging current of from 10 to 15 amperes, no improvement was observed after two charges of eight hours per day; but after adding about half a pint of strong carbonate of soda solution to each cell, and with the same amount of current going in as before, the plates soon improved, and in a few days all the elements presented a beautiful appearance.

When removing sulphate by this method, it is much the best way to take out the desulphating solution after the plates have been brought to a healthy condition, and to replace it by the ordinary dilute acid electrolyte, otherwise the negative plates are said to deteriorate.

The Electrolyte.—Those accustomed to working with secondary cells can usually obtain a fair conception as to their state of charge and general condition by simple inspection. When fully charged, the positive plates* are of a very dark greyish-brown tint, and the negatives of a dark slate colour. During the discharge both plates gradually turn a somewhat lighter shade. When quite exhausted, the plus elements are a light chocolate hue, and the minus a light slate. Should the colour of the peroxide plate change to a drab, it indicates either that the polarity of the cell has been reversed, or that the active material is becoming badly sulphated.

The usual and more accurate method of ascertaining at any time the condition of a cell as to charge, is to measure the density of the electrolyte by means of a hydrometer, or, as they are sometimes termed, an acidometer. In a newly set up cell, as soon as the acid electrolyte is added, a large percentage of the sulphuric acid is quickly absorbed by the active material, and goes to form sulphate of lead in both plates. During the "formation" and subsequent charging, the reducible sulphate formed is reconverted into either oxide or spongy lead, and the acid is reinstated in the solution, the density therefore rising. Different makers specify different densities of solution. The usual thing for a starting electrolyte is a density of about 1,180. With such a solution the density may vary from 1,150 to 1,200,

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* In this treatise whenever allusion is made to the anode, plus or positive plate, element, or electrode, that which contains the peroxide of lead is referred to. When speaking of the cathode, minus or negative plate, element, or electrode, that which holds the reduced oxide or spongy lead is indicated.

or even 1,250, when the cell changes from a condition of no charge to full charge. Some advocate acid solutions having densities as high as 1,400 to 1,500, but with solutions containing as much acid as these, although the conductivity of the liquid is greatly increased, the tendency of the active materials and metallic supports to become injuriously sulphated is greatly increased.

Hydrometers, or Acidometers.—The acidometers employed to test storage cells are usually made of glass or vulcanite, or some material which is unaffected by the corrosive action of the solution. When the density requires to be read off with great accuracy, Beaumé's or Twaddell's standard instruments are used. In using Twaddell hydrometers for liquids heavier than water, to reduce the readings on these instruments to degrees of density, the number read off on the scale has to be multiplied by five and the product affixed to unity, after the decimal point. The ordinary commercial form of density indicator as now used, is either a plain cylindrical or flattened bulb tube terminating with a thin hollow stem. The instrument is weighted with fine lead shot or mercury, and a calibrated paper scale is made and is sealed within the stem. The usual range is from 1,100 to 1,250, taking the density of pure water at 60 deg. Fahr. as 1,000. The usual form of the instrument is shown in Fig. 87.

Hicks's Glass-Bead Hydrometer.—A new form of hydrometer, very useful for testing the density of the solution in cells, has been brought out by Mr. J. Hicks.

This instrument is a development of the old-fashioned glass bead arrangement used by gaugers for determining the strength of spirits. In gauging spirits a number of glass beads, having more or less weight in

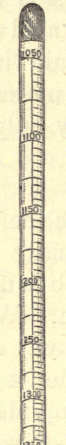

FIG. 87.—Ordinary Hydrometer.

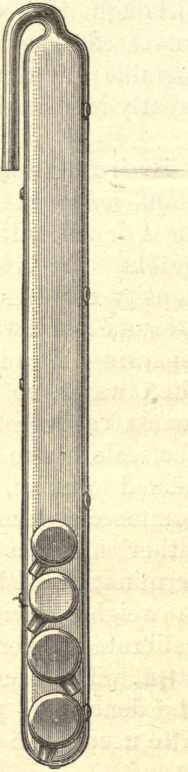

FIG. 88.—Hicks's Hydrometer.

comparison with their volume, are taken, and by actual trial are classified and marked. To find the specific gravity of the liquid under test, these beads are tried one after another until two are found, one of which just sinks while the other just floats. The density is ascertained by taking the mean of the numbers on these two beads. Occasionally, it is found that one of the beads show no tendency to either sink or float. The liquid then has exactly the density marked on this bead. The improved hydrometer devised by Mr. Hicks is illustrated in Fig. 88, and consists of a perforated flat glass tube, of such a size as to easily slip between the edge of the plates and the glass containing-cell. Within the tube are either three or four small flattened specific gravity beads, of different colours, and placed one above the other, the lightest uppermost. These coloured floats are capable of freely rising and falling in the tube, which they nearly fit. The beads may be balanced to any desired density. In the four-bead tube the top float, which is coloured green, will float when the specific gravity reaches 1,150, the next, a violet one, at 1,170, then a blue at 1,190, and a red at 1,200. The densities are plainly marked on the back of each float.

Holden's Hydrometer.—Some years ago M. Legay, of Levallois-Perret, in order to obtain greater sensibility in density indicators, employed a small weighted cylindrical glass bulb having a long thin stem, which moved up or down in front of a graduated fixed scale. A very sensitive and useful form of hydrometer working on this principle has been introduced in this country

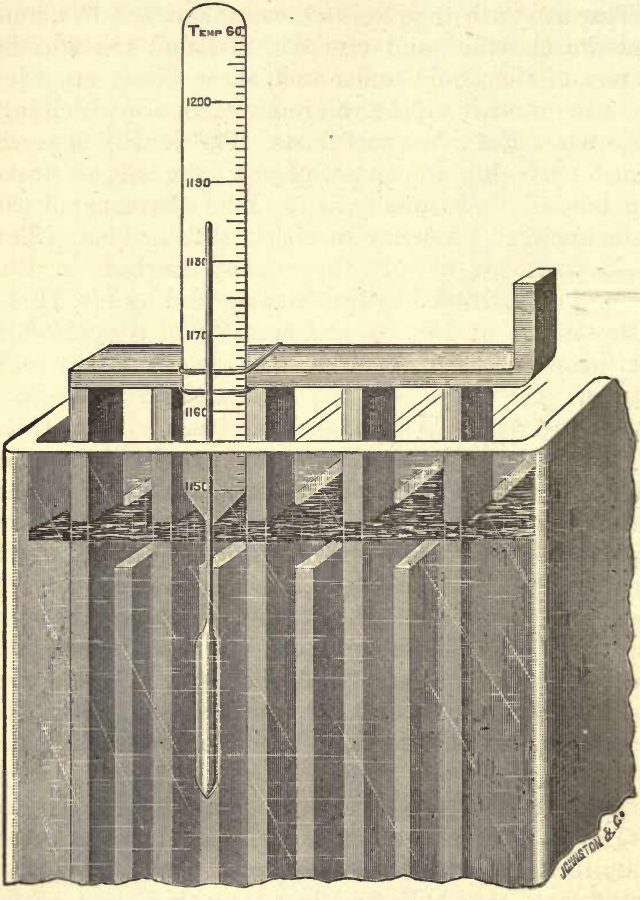

Fig. 89.—Holden's Hydrometer.

by Captain C. Holden, R.A. This density indicator is represented in an ordinary battery cell in Fig. 89.

The new instrument consists essentially of a light glass float, with a long narrow glass stem, which is free to move in front of a fixed scale.

The float is cylindrical and about eight inches long; this terminates in a thin rod, between eight inches and nine inches in length. Owing to the large relative difference between the amount of displacement of the bulb and stem, these instruments may be made to have a very open range. A difference in the scale reading of seven inches may readily be obtained with an alteration of density of from 1,150 to 1,200. The densities are not marked upon the glass float, but are pointed off on a vulcanite scale. The scale may be fixed to a lug or connector of the battery elements by means of an indiarubber band, or some other clamping arrangement. The lower end of the scale is **V**-shaped, and in adjusting the point must be brought down to just touch the surface of the liquid. The float moves freely up and down in front of the fixed scale. The readings are taken from the top of the pointer.

Owing to the great sensibility of these instruments, the temperature of the solution should be taken into account if very accurate measurements are required. For this purpose a thermometer should be placed in the solution, and then by reference to a table of temperature corrections, the densities may be read off to any required degree of accuracy. The scale may have a sliding arrangement affixed to it, which by adjustment can be made to give offhand the necessary corrections. When used as a check in a "master" cell, if the requisite data as to density, true current capacity, and internal resistance be known, then the scale may be calibrated in terms of ampere-hours, and may be used as a check either in the charging or discharging operation.

These instruments can be made either in glass or vulcanite; they are extremely accurate, easily visible, and do not stick to the sides of the cell.

Owing to its high sensibility, a most interesting experiment may be made with this form of hydrometer. If one of the most sensitive of these instruments be placed in a cell from which a very large current is being taken, the gradual subsidence of the pointer may readily be observed. For such small changes of density to become visible, it is necessary that the hydrometer employed should be of the highest sensibility.

Parker's Charge Indicator.—Some six years ago Mr. Thomas Parker devised a form of hydrometer which indicated degrees of density on a fixed scale, and was employed to show by simple inspection the state of charge or discharge of an accumulator cell. In construction, the instrument was very simple, consisting merely of a long and thin cylindrical glass bulb, suspended in the electrolyte by means of a thin platinum wire whose end was attached to the extremity of a delicately-balanced lever. This lever was made to actuate a pointer which travelled over a suitably graduated circular scale pointed off in terms either of degrees of density or ampere-hours.

The Volk Accumulator Indicator.—Mr. Magnus Volk is just introducing a neat little instrument for indicating the condition of a cell by simple inspection.

The apparatus consists of a light glass cylindrical bulb of sufficient length to reach nearly from the top to the bottom of the electrolyte. By this arrangement the average density of the solution is obtained. The bulb is submerged at all times, so any difference in the level of the liquid does not interfere with the readings of the instrument. The glass bulb is suspended in the electrolyte from the end of a frictionless jointed spring arm, by means of a very fine platinum wire. A suitable pointer is fixed on the moving arm of the instrument, and travels over a scale which may be divided either into degrees of density, or any arbitrary divisions suitable for the work of the cell. The scale is usually pointed off in terms of ampere-hours, which may be used to afford an approximate indication of the number of ampere-hours taken from the cell at any given period. A double reading scale may be used, which gives degrees of density and also the corresponding current indication. The instruments may be made of any reasonable range, say, from 1,150 to 1,200, or from 1,170 to 1,250.

To prevent the acid spray or fumes from affecting the metal work of the instrument, it is wholly covered by a tightly-fitted case, only a small hole being left to give free play to the suspension wire. The scale readings may be taken by means of a small mirror placed at any desired angle, if the instrument is used where the cells are in inaccessible positions.

The Crova and Garbe Density Balance.—Messrs. Crova and Garbe have devised a form of balance which is said to be extremely useful for accurate determinations of the mean density of the fluid used in storage cells. The arrangement consists of a balanced rod on which a level is permanently fixed. From both extremities of this rod similar density-indicating bulbs are suspended. One of the bulbs is immersed in a vessel containing a standard solution made up to the mean density of the accumulator electrolyte, and the other is placed within the storage cell liquid. Any alteration of density occurring in the secondary cell due to either charge, discharge, or absorption of the acid by the active material, is quickly indicated by the movement of the air bubble in the fixed level. By the employment of this device a very sensitive density balance is obtained, and one quite free from all errors due to changes of temperature in the atmosphere, a somewhat important consideration where accurate measurements are required.

The Roux Density and Charge Indicator.—M. G. Roux, in a communication to "La Société Internationale des Electriciens," on November 5th, 1890, gave a most comprehensive account of the various methods employed for indicating the state of charge of an accumulator, describing at the same time his own improved density and charge indicator.

Roux demonstrated the fact that the density of the liquid in different parts of the same storage cell frequently varies to such an extent as to vitiate the measurements obtained by the ordinary form of hydrometer. He showed that it was essential, if correct measurements were sought, to make the bulb of the densiometer of sufficient length to reach nearly from the top to the bottom of the electrolyte. An instrument constructed on this principle would be found to measure as nearly as possible the mean density of the bulk of the liquid. Accordingly the Roux instrument was finally constructed as shown in

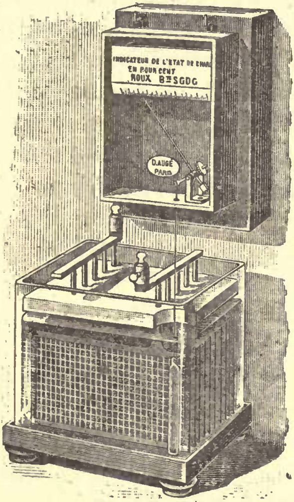

Fig. 90.—The Roux Density and Charge Indicator.

Fig. 90. As will be seen from this diagram, a long cylindrical float made of glass is suspended, by means of a thin platinum wire, from the end of an arm which is fixed to a pivoted spindle. To the movable spindle is attached a light pointer, which moves freely in front of a stationary horizontal scale. The movable

mechanism is balanced by a screwed counterpoise weight, which also serves as a means of adjusting the sensibility of the instrument, and for bringing the pointer to the true zero. The scale is divided into one hundred equal parts, and, as this method of calibration is found to give divisions of proportional density, the instrument is direct reading, and no additional corrections or calculations are needed. The zero mark, which in reality is the 100 point, is so arranged that it is covered by the pointer when the cell has received its full complement of charge, and if the relative position of the pointer be noted at stated intervals during the discharging operation, the true value of the scale readings in terms of ampere-hours may be accurately obtained.

By a series of trials made with an ampere-meter in circuit, Roux found that this type of instrument would accurately indicate the state of charge of a cell to within 3 per cent. of its total current capacity. By a suitable arrangement of contact studs on the scale, the pointer can be made to complete an electric circuit at any determined point or points, and thereby an aural or visual alarm may be obtained whenever the cell reaches any stipulated condition.

Spray Arresters.—In a storage cell, if the active materials are accurately proportioned, and the exposed surfaces so arranged that all the necessary chemical reactions may occur without hindrance, and if the electrical energy be put in and withdrawn at a proper rate, then no gases of any kind should be driven off until all the possible chemical changes are completed and the cell has absorbed its full charge. In practice, however, these conditions are rarely realised, and consequently it is found that gas is given off at all times, not only when the cell is being charged or discharged, but also when it is at rest. As the minute bubbles of gas are liberated from the plates they rapidly ascend, and on reaching the surface of the liquid they are released from the compressing effect of the dense solution and rapidly expand, thereby causing miniature explosions. The result of the bursting of these globules of gas is that part of the electrolyte is thrown into air, and forms a troublesome and corrosive vapour or spray. Not only does this spraying action continually tend to diminish the quantity of fluid in the cell, but it also has a most injurious effect upon all connections and metallic fittings within the neighbourhood of the cell. Unless an accumulator-room be well ventilated, the atmosphere quickly becomes so impregnated with this acid vapour that it produces an exceedingly irritating and probably deleterious effect upon the lungs. To prevent its escape, or to minimise the injurious effects of this acid spray, many spray-arresting devices have been suggested.

To arrest spray, curved glass plates placed with their concave sides downwards are sometimes used. These bent glass plates are put on the top of the cell, and act as a partial cover, and as the acid vapour condenses and collects in the form of beads it runs down to the middle of the glass, and then ultimately drops in the vessel again. Another plan is to place a layer of oil upon the liquid, which not only checks all spraying tendencies, but prevents the loss of the liquid due to surface evaporation. One great drawback to the employment of this device resides in the fact that the oil interferes considerably with the use of density-testing apparatus. A plan which is free from the above objection is to spread a layer of granulated cork on the surface of the liquid. This material does not sink below the surface, it hinders spraying, and it is not affected by the acid solution.

An excellent plan for preventing loss of fluid arising from any cause, is to completely cover the surface of the electrolyte with paraffin wax or some similar acid-proof insulating material. The covering-in operation is extremely simple, and may be managed in the following way. The ordinary electrolyte is poured into the cell until it reaches to within about an inch from the top of the glass jar. The insulating wax or compound is melted in a ladle and then carefully run on to the surface of the liquid. On reaching the cold solution it immediately sets and soon solidifies. When cold and hard a small aperture of about one inch in diameter is made in any suitable position. Part of the solution is now withdrawn by means of a syphon so as to leave some little air space between the bottom of the wax cover and the top of the liquid. When cells are sealed in this fashion the only exit for spray is through the small aperture made through the wax, and as a consequence but little escapes into the air. It is advisable to make the orifice in such a position that a hydrometer may be inserted through it and into the solution below, so that the necessary density tests may be made.

Destroying Acid Vapour in Accumulator Rooms.—To neutralise and prevent the accumulation of acid vapour in battery-rooms, nothing can be better than a good system of thorough and rapid ventilation; failing this the evil effect of the acid may be minimised by the fumes of a powerful alkali such as ammonia, which will readily combine with the sulphuric acid to form sulphate of ammonia, an inert and harmless salt. If the use of liquid ammonia is objectionable, the granulated carbonate of ammonia will do equally well. The ammonia fumes are best obtained by placing dilute ammonia in shallow dishes, so that an extensive evaporating surface is obtained. In the same way the corroding dew which is so frequently deposited upon the lugs and connectors of storage battery elements may readily be neutralised by the application of a solution of ammonia, or even common washing soda. A good method of protecting metal-work in battery-rooms is to smear it over evenly with vaseline.

Insulating Cells.—Wherever a number of open cells are in use, unless great precautions are taken, electrical leakage between the cells invariably occurs. This leakage is in a great measure due to the semi-conducting nature of the thin layer of moisture which is so frequently found to cover all parts, not only of the glass containing-cell, but the unimmersed parts of the elements, and even the shelves on which the cells rest. To prevent this waste of energy, the outside of the cells should occasionally be well cleaned and thoroughly dried. If a little vaseline or tallow be then rubbed over them, it will have a most beneficial effect.

The shelves, or support for the cells, should either be well varnished or coated with paraffin wax. Electrical leakage is greatly reduced if each cell is mounted on a glass or earthenware insulator.

A form of oil insulator introduced by Messrs. Johnson and Phillips, is now being received with much favour. This insulator, which appears to possess most of the essentials of a moisture interceptor and electrical non-conductor, is illustrated in Fig. 91.

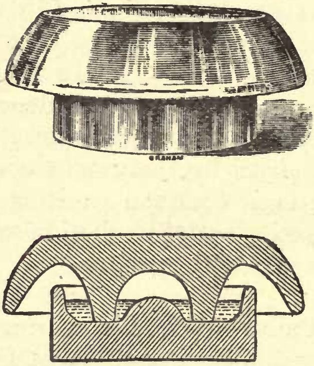

FIG. 91.—Oil Insulator.

As shown in the diagram, the insulator is of a mushroom shape. The lower cup contains a small quantity of some non-evaporating oil, and as the conductive moisture cannot bridge across this, a nearly perfect insulating medium is obtained. The new insulators are made of various sizes, and may be obtained in earthenware or glass. Those made of glass are found to give the best results.

APPENDIX.

TABLE FOR THE CONVERSION OF MEASURES.

One metre = 39·37 inches = 3·28 feet.

One decimetre = 3·937 inches.

One centimetre = 0·39 inch.

One millimetre = 0·039 inch.

One yard = 0·9144 metre.

One foot = 0·3048 metre.

One inch = 2·54 centimetres = 0·254 decimetre.

One kilogramme = 2·2 pounds.

One pound = 453·6 grammes.

One gramme = 0·099 ounce = 15·432 grains.

One milligramme = 0·154 grain.

One grain = 0·0648 gramme.

One hundredweight = nearly 51 kilogrammes.

One thousand kilogrammes = nearly one English ton.

One gramme = the weight of one cubic centimetre of pure water at 4 deg. C.

One litre = one cubic decimetre.

One pint = 1·761 litres.

One gallon contains approximately 4·5 litres.

One kilogrammetre = 7·233 foot-pounds.

One foot-pound = 0·138 kilogrammetre.

One cubic inch of distilled water weighs 252·5 grains.

One cubic foot of distilled water weighs 1,000 ounces or 62·5lbs.

Sixteen cubic feet of water weigh about 1,000lbs.

The density of distilled water when at a temperature of 60 deg. F. is usually taken as unity for comparison with liquids heavier than water.

The density of pure concentrated sulphuric acid at a temperature of 0 deg. C. is 1,854. The density of pure nitric acid at the same temperature is 1,559.

Taking the density of atmospheric air at 0 deg. C. and at a barometric pressure of 76 centimetres, as unity, then the density of dry hydrogen is 0·0693, and of oxygen 1·1056.

Thermometric Scales.—The thermometers most extensively employed for the measurement of differences of temperature are the Fahrenheit, the Centigrade, and the Réaumur. They are calibrated as follows:

	Freezing point.	Boiling point.
Fahrenheit	32 deg.	212 deg.
Centigrade	0 ,,	100 ,,
Réaumur	0 ,,	80 ,,

Calling the three scales F., C., and R., these may readily be transposed by the simple proportion method—thus:

$$F : C : R :: 180 : 100 : 80 = 9 : 5 : 4; \text{ hence}$$

$$(1)\ F = \tfrac{9}{5} C, = \tfrac{9}{4} R.$$

$$(2)\ C = \tfrac{5}{4} R, = \tfrac{5}{9} F.$$

$$(3)\ R = \tfrac{4}{9} F, = \tfrac{4}{5} C.$$

Lead and its Impurities.[*]—As the quality of the lead employed in the manufacture of storage cells is

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[*] See "Bloxam's Chemistry."

of some importance, especially if the active material is derived directly from the substance of the metal itself, it is very desirable to obtain some knowledge of the properties and general characteristics of this metal. A few words here as to the nature of the various native lead ores from whence we obtain our lead supply, and the method of extraction, may therefore not be out of place.

The chemical symbol for lead is Pb, and its atomic weight when compared with hydrogen is 207. In this country our supply of the metal is chiefly obtained from its most abundant ore, usually known as galena. This mineral is a sulphide of lead, having the formula PbS, and is found principally in Cumberland, Derbyshire, and Cornwall. Usually considerable quantities of sulphide of silver are present in galena, and in many of the specimens the sulphides of bismuth and antimony are found. Both in the United States of America and in Spain a carbonate of lead ($PbO.CO_2$), known as white lead ore, is frequently obtained in its native condition. The sulphate of lead ($PbO.SO_3$) is very abundant in Australia, and is largely imported into this country.

The usual method of extracting the lead from galena is effected by taking advantage of the circumstance that when a combination of a metal with oxygen is raised to a high temperature in contact with a sulphide of the same metal the oxygen and sulphide unite, and the metal is liberated.

Some varieties of lead, particularly those obtained from Spanish ores, are known as hard-lead, their hardness being chiefly due to the presence of antimony. Impurities of this character are usually eliminated by a process of calcination, which is purposely spread over a considerable period. During this operation the metallic impurities are converted into oxides, and come away with the dross. This scum, or dross, is commercially known as antimonide of lead, and this, when reduced to a metallic state, yields an alloy of lead with sometimes as much as from 30 to 40 per cent. of the metal antimony. The hard metal obtained from this process is known as type-metal, an alloy much used by type-founders.

The following analysis gives the percentage composition of ordinary hard lead (Bloxam):

	English.	Spanish.
Pure lead	99·27	95·81
Antimony	0·57	3·66
Copper	0·10	0·32
Iron	0·06	0·21
	100·00	100·00

As previously stated, most native lead ores contain a certain percentage of silver. The method usually employed for the abstraction of this valuable metal is known as Pattinson's desilvering process. Pattinson found that when lead containing a small percentage of silver is melted and then allowed to cool, the metal being in the meantime constantly stirred, a considerable quantity of the lead separates out in the form of crystals which only contain a mere trace of silver, almost the whole of this metal being left behind in that portion which still remains liquid. By repeated melting, stirring, allowing to cool, and skimming, the whole bulk of the lead is removed, until at last a very rich alloy of silver and lead, together with copper and other metallic impurities, is left.

Simple Test for Copper and Silver in Lead.—If a small quantity of lead be placed in a clean bone-ash cupel, and heated in a muffle until the whole of the lead is oxidised and absorbed within the pores of the bone-ash, any silver that may have been present in the metal will be found in the form of a small globule. Should copper be present the bone-ash will show a green stain after cooling. If the lead be free from metallic impurities only a yellow stain will be left.

In the manufacture of acids and corrosive solutions, and other operations where a metal capable of resisting the action of acids is required, leaden vessels are largely employed. Neither concentrated sulphuric, hydrochloric, nitric, or hydrofluoric acid will act upon lead at normal temperatures. One of the best solvents for this metal is nitric acid, reduced to a density of about 1,200 by the addition of water. The addition of this amount of water is found to be necessary, since nitrate of lead, which is insoluble in nitric acid of greater strength, would be liable to attach itself to the surface of the metal, and by this means protect it from further action.

If very finely-divided lead be thrown into the air, it immediately takes fire, combining with the oxygen of the atmosphere to form oxide of lead. This curious property of finely-divided lead may in a measure account for the heating effect which is usually produced when a fully-charged spongy lead accumulator plate is withdrawn from the electrolyte and freely exposed to the air.

Oxides of Lead.*—Lead combines with oxygen to form five distinct oxides—viz.:

Sub-oxide of lead, or plumbous oxide	Pb_2O
Oxide of lead, litharge, or plumbic oxide	PbO
Red oxide of lead, minium, or triplumbic oxide	Pb_3O_4
Diplumbic oxide	Pb_2O_3
Puce, peroxide, or monoplumbic dioxide	PbO_2

Sub-Oxide or Plumbous Oxide is a black powder, usually formed by heating lead oxalate to a somewhat high temperature. It is readily decomposed when heated in dilute acid, and is converted into the monoxide when burnt in air. This lead salt is but little used in storage-battery work.

Oxide of Lead, Litharge, or Plumbic Oxide is sometimes found native as lead ochre, and may be artificially made by heating the carbonate or oxalate. It is usually prepared on a large scale by heating lead in air. When the metal is only moderately heated, the oxide forms a yellow powder which is known as massicot, but at a higher temperature the oxide melts, and on cooling it forms a brownish scaly mass, which is called flake litharge. The scaly pieces are afterwards ground between stones under water, forming buff or levigated litharge.

The litharge of commerce often has a reddish-yellow colour, due to the presence of some of the red oxide of lead; and frequently from one to three per cent. of

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* See Bloxam and Miller's works on chemistry.

finely-divided metallic lead is found mixed with it. When heated to dull redness, litharge assumes a dark-brown colour, and becomes yellow again on cooling. At a bright-red heat it fuses and readily attacks clay crucibles, forming silicate of lead. Litharge is a most powerful base, and has a strong tendency to form basic salts. Hot solution of alkalies, such as potash or soda, readily dissolve it, and on cooling, it crystallises out in form of beautiful pink crystals.

Red Lead, Minium, or Triplumbic Oxide, is also occasionally found native, but it is usually prepared on a commercial scale, by heating litharge in air to about 600 deg. Fahr., at which temperature it absorbs oxygen and becomes converted into minium. The litharge or massicot used for this purpose is prepared by being heated in a reverberatory furnace to a temperature insufficient to fuse the oxide which is formed. During the process the first and last portions are rejected, as they contain iron and other metals more easily oxidisable than lead. The intermediate product is ground to a very fine powder, and then suspended in water to separate the coarser particles from the finer, which, when dried, are heated on iron trays placed in a reverberatory furnace, until the desired colour has been obtained. Minium (the name "minium" was originally applied to cinnabar, which was extensively adulterated with red lead) is largely used in the manufacture of glass, so that it is necessary to have it free from the oxides of iron, copper, etc., which would give an unpleasant tint to the glass. On heating red lead it temporarily darkens, becoming almost black, and at red heat it loses oxygen, and is converted into the protoxide.

When minium is treated with dilute nitric acid, nitrate of lead ($PbO.N_2O_5$) is obtained in solution, and peroxide of lead (PbO_2) is left in the form of a brown powder, showing that minium is probably a compound salt composed of the oxide and peroxide of lead.

Minium obtained by heating litharge in air until no further increase in its weight is observed, has the composition $2PbO.PbO_2$, or Pb_3O_4, which appears to represent pure minium. Commercial minium has frequently a composition corresponding to $3PbO.PbO_2$, but if it be treated with potash, PbO is dissolved out, and $2PbO.PbO_2$ remains. Minium liberates some of its oxygen when raised to a red heat, becoming PbO, hence the necessity for keeping it below a temperature of 600 deg. F. during its manufacture. The tetroxide of lead is thoroughly soluble in glacial acetic acid, forming a mixture of acetates. This solution acts as an oxidising agent, decolourising indigo, and changing sulphurous acid into sulphuric acid.

Diplumbic Oxide, or Lead Sesquioxide, is obtained by mixing a solution of tetroxide oxide of lead dissolved in acetic acid, with dilute ammonia. It is an orange-red powder, which is decomposed on heating, and is reduced by oxalic acid. It readily dissolves in hydrochloric acid, but the solution quickly eliminates the chlorine, and lead chloride is obtained. So far this salt has scarcely entered into the construction of electric storage cells.

Peroxide of Lead, Puce Oxide, or Plumbic Dioxide, is the true active material in all forms of lead storage cells. This lead salt is found native as the mineral plattnerite. It is a heavy lead ore, forming black, lustrous, six-sided prisms. It may be prepared from the red oxide by boiling it in fine powder, with nitric acid diluted with five parts of water, or by treating the carbonate when suspended in water with a stream of chlorine gas, and then thoroughly washing and drying it. It is reduced to a lower oxide on heating, or by exposure to bright sunlight. This salt readily imparts oxygen to other substances: it becomes heated to redness when thrown into sulphur dioxide, and takes fire when triturated with sulphur—hence this oxide is a common ingredient in lucifer match composition. When used in primary or secondary batteries it readily imparts its oxygen to nascent hydrogen, forming water, and thus it acts as a powerful depolariser. When robbed of its oxygen, it readily becomes reoxidised if subjected to the action of nascent oxygen liberated by the electrolytic decomposition of water.

Plumbic Hydrates, PbH_2O_2 and $3PbOH_2O$, are two definite white hydrates, and may be obtained by precipitating solutions such as the nitrate or acetate of lead with alkalies, such as ammonia. When moist, these compounds absorb carbon dioxide from the air, and become anhydrous on being heated to about 150 deg. C.

Prevention of Lead Poisoning.—Workmen employed in the manufacture of lead or lead salts are always liable to lead poisoning, both by inhaling the dust and by contact of the materials with the hands. Various preventatives for this have been employed, and of these the most simple seems to be a careful washing of the hands in petroleum. It is said that three washings a day are sufficient to prevent all serious danger of poisoning. The benzole in the petroleum appears to scour the skin and remove the loose lead dust, and the fatty substance in the oil fills up the pores of the skin and prevents the absorption of the deleterious salts.

The employment of petroleum has given such good results that it has been proposed to use this material as a guard against poisoning in other industries where the salts of copper or mercury are employed.

In a communication made by M. Melsens to the Académie des Sciences, reference was made to the excellent effect produced by iodide of potassium in all cases of lead or mercurial poisoning. He stated that this substance, by rendering soluble the metal accumulated in the system, invariably caused all the symptoms of the malady to disappear, and, moreover, this salt acts as a preventative. A small daily dose of iodide of potassium is said to effectually ensure workmen against deleterious effects when working with lead or mercury salts.

Sulphuric Acid.*—Sulphuric acid plays a most important part in the economy of lead storage cells. Some of the troubles which beset accumulators may

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* For a full description of the methods of manufacturing sulphuric acid see Watts's Dictionary of Chemistry, or Roscoe's, Thorp's, or Bloxam's works on chemistry.

doubtless be traced to impurities in the acid used in making up the electrolyte or in moistening the lead salts. A brief glance at the processes involved in the production of this most potent agent, may enable us to more readily detect and eliminate such impurities as are to be met with in the commercial article.

Nordhausen Sulphuric Acid. — Nordhausen sulphuric acid, better known as Nordhausen oil of vitriol, was first made by the alchemist, Basil Valentine, some four centuries ago. Valentine subjected sulphate of iron (commonly known as green vitriol) to distillation, and by this means he obtained a heavy corrosive liquid which he termed *oil of vitriol.* The process of manufacture as devised by Valentine is now extensively employed at Nordhausen in Saxony, hence the name Nordhausen acid, and consists in exposing crystals of sulphate of iron ($FeO.SO_3.7H_2O$) to the air, so that they may absorb the oxygen of the atmosphere and become converted into the basic persulphate of iron as represented by the equation :

$$2(FeO.SO_3) + O = Fe_2O_3.2SO_3.$$

After the necessary exposure this salt is dried and is distilled in earthenware retorts, the oil of vitriol being condensed in suitable receivers.

On the application of heat to the basic persulphate of iron, the acid separates itself from the base, and if the salts were thoroughly dry the anhydrous sulphuric acid would distil over, but there is always sufficient moisture left in the persulphate to effect combination with the anhydrous acid—thus sulphuric acid is the result. Nordhausen oil of vitriol is fairly represented by the formula $H_2O.SO_3$, or, shortly, H_2SO_4. After the distilling process is completed a residue consisting of peroxide of iron (Fe_2O_3) is found in the retorts. This material, known as colcotha, when ground into a fine powder, is much used for polishing glass and metals.

The sulphate of iron employed in the manufacture of Nordhausen acid is obtained chiefly from iron pyrites (FeS_2). The mineral found to be most suitable is a particular variety known as white or efflorescent pyrites.

The Nordhausen acid is much heavier than the English, its specific gravity being about 1·9. It is easily distinguished from the home-made article by its fuming on being exposed to the air. These white fumes are due to the escape of anhydrous sulphuric acid vapour.

English Oil of Vitriol.—When sulphur is burnt in air, sulphur dioxide is the chief product; but when sulphurous acid acts upon hydrated nitric acid in the presence of water, sulphuric acid, in conjunction with nitric oxide, is formed according to the following equation:

$$SO_2 + N_2O_3 + H_2O = H_2OSO_3 + 2NO.$$

Nitric oxide, when brought into contact with the oxygen of the atmosphere, combines with it to form nitric peroxide, NO_2. If, however, nitric peroxide meets with sulphur dioxide and water, it is again transformed into nitric oxide, with the formation of sulphuric acid, as shown by the equation

$$NO_2 + SO_2 + H_2O = NO + H_2OSO_3.$$

From this it would appear that nitric oxide may be employed to absorb oxygen from the air, and then to convey it to the sulphur dioxide; therefore theory would indicate that an unlimited quantity of sulphurous acid, if supplied with air and water, would be converted into sulphuric acid by a given quantity of nitric oxide.

In the commercial manufacture of sulphuric acid, sulphur is slowly burnt on an iron plate, which really forms the base of the furnace. Air is admitted into the chamber by means of a suitable door, which so regulates the amount of air, that when the sulphur is once ignited it may go on burning and producing sulphur dioxide with considerable regularity. Upon this iron base-plate is also placed a receptacle containing a mixture of nitrate of sodium and sulphuric acid, which generates nitric acid. The sulphur dioxide and nitric acid vapour are conveyed into a large mixing-chamber, which sometimes has a capacity of many thousands of cubic feet. Into this chamber a number of jets of steam are continually being driven. In the reactions which now occur, the nitric acid is quickly reduced to nitric oxide, and a succession of changes take place, the result being that dilute sulphuric acid collects on the floor of the mixing-chamber, from whence it is drawn off into large leaden evaporating pans.

The dilute acid as it comes from the leaden mixing-chamber has a density of about 1,500. By evaporation in a series of shallow lead pans it is concentrated until its density reaches 1,700. This acid is technically known as "brown acid," as it contains a number of organic impurities which impart a dark brown colour to it. Platinum or glass retorts are employed for the further concentration of this acid.

Properties of Sulphuric Acid.—The characteristic properties of concentrated sulphuric acid are very marked. Its freedom from odour, oily appearance, and great weight, distinguish it from most other liquids. The pure concentrated commercial acid has a density which usually reaches 1,842, and its boiling point is about 640 deg. F. The absolutely pure acid is perfectly colourless, but usually even that used in laboratories has a peculiar greyish colour, due to slight traces of organic matter. Sulphuric acid is exceedingly hydroscopic, and when exposed to the air it rapidly increases in bulk owing to absorption of atmospheric moisture.

Some very useful and interesting particulars of the relative percentages, densities, and electrical conductivities of various mixtures of sulphuric acid and water when used as an electrolyte in a storage cell, has been given by M. G. Roux.* From the figures given, Table XIV. has been compiled. In this table will be found the quantitative mixtures of acid and water, its relative density and the amount of acid per litre of solution, the percentage and specific resistance, and

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* See paper entitled "Les Indicateurs de l'état de charge des accumulateurs," communicated to the Société Internationale des Electriciens on November 5th, 1890.

TABLE XII.—DENSITIES OF VARIOUS SOLUTIONS OF SULPHURIC ACID AND WATER AT 15 DEG. C. OR 59 DEG. F. (J. KOBB).

Degrees Baumé.	Densities.	100 parts by weight contain—		
		SO_3 per cent.	H_2SO_4 per cent.	Acid at 60 deg. Baumé.
0	1,000	0·7	0·9	1·2
1	1,007	1·5	1·9	2·4
2	1,014	2·3	2·8	3·6
3	1,022	3·1	3·8	4·9
4	1,029	3·9	4·8	6·1
5	1,037	4·7	5·8	7·4
6	1,045	5·6	6·8	8·7
7	1,052	6·4	7·8	10·0
8	1,060	7·2	8·8	11·3
9	1,067	8·0	9·8	12·6
10	1,075	8·8	10·8	13·8
11	1,083	9·7	11·9	15·2
12	1,091	10·6	13·0	16·7
13	1,100	11·5	14·1	18·1
14	1,108	12·4	15·2	19·5
15	1,116	13·2	16·2	20·7
16	1,125	14·1	17·3	22·2
17	1,134	15·1	18·5	23·7
18	1,142	16·0	19·6	25·1
19	1,152	17·0	20·8	26·6
20	1,162	18·0	22·2	28·4
21	1,171	19·0	23·3	29·8
22	1,180	20·0	24·5	31·4
23	1,190	21·1	25·8	33·0
24	1,200	22·1	27·1	34·7
25	1,210	23·2	28·4	36·4
26	1,220	24·2	29·6	37·9
27	1,231	25·3	31·0	39·7
28	1,241	26·3	32·2	41·2
29	1,252	27·3	33·4	42·8
30	1,263	28·3	34·7	44·4
31	1,274	29·4	36·0	46·1
32	1,285	30·5	37·4	47·9
33	1,297	31·7	38·8	49·7
34	1,308	32·8	40·2	51·1
35	1,320	33·9	41·6	53·3
36	1,332	35·1	43·0	55·1
37	1,345	36·2	44·4	56·9
38	1,357	37·2	45·5	58·3
39	1,370	38·3	46·9	60·0
40	1,383	39·5	48·3	61·9
41	1,397	40·7	49·8	63·8
42	1,410	41·8	51·2	65·6
43	1,424	42·9	52·8	67·4
44	1,438	44·1	54·0	69·1
45	1,453	45·2	55·4	70·9
46	1,468	46·4	56·9	72·9
47	1,483	47·6	58·3	74·7
48	1,498	48·7	59·6	76·3
49	1,514	49·8	61·0	78·1
50	1,530	51·0	62·5	80·0
51	1,540	52·2	64·0	82·0
52	1,563	53·5	65·5	83·9
53	1,580	54·9	67·0	85·8
54	1,597	56·0	68·6	87·8
55	1,615	57·1	70·0	89·6
56	1,634	58·4	71·6	91·7
57	1,652	59·7	73·2	93·7
58	1,672	61·0	74·7	95·7
59	1,691	62·4	76·4	97·8
60	1,711	63·8	78·1	100·0
61	1,732	65·2	79·9	102·3
62	1,753	66·7	81·7	104·6
63	1,774	68·7	84·1	107·7
64	1,796	70·6	86·5	110·8
65	1,819	73·2	89·7	114·8
66	1,842	81·6	100·0	128·0

TABLE XIII.—DENSITY EQUIVALENTS TO CALIBRATIONS ON TWADDELL'S STANDARD ACID HYDROMETERS AT 60 DEG. F.

Degrees, Twaddell.	Densities.	Degrees, Twaddell.	Densities.	Degrees, Twaddell.	Densities.	Degrees, Twaddell.	Densities.	Degrees, Twaddell.	Densities.
0	1,000	35	1,175	70	1,350	104	1,520	139	1,695
1	1,005	36	1,180			105	1,525	140	1,700
2	1,010	37	1,185	71	1,355	106	1,530		
3	1,015	38	1,190	72	1,360	107	1,535	141	1,705
4	1,020	39	1,195	73	1,365	108	1,540	142	1,710
5	1,025	40	1,200	74	1,370	109	1,545	143	1,715
6	1,030			75	1,375	110	1,550	144	1,720
7	1,035	41	1,205	76	1,380			145	1,725
8	1,040	42	1,210	77	1,385	111	1,555	146	1,730
9	1,045	43	1,215	78	1,390	112	1,560	147	1,735
10	1,050	44	1,220	79	1,395	113	1,565	148	1,740
		45	1,225	80	1,400	114	1,570	149	1,745
11	1,055	46	1,230			115	1,575	150	1,750
12	1,060	47	1,235	81	1,405	116	1,580		
13	1,065	48	1,240	82	1,410	117	1,585	151	1,755
14	1,070	49	1,245	83	1,415	118	1,590	152	1,760
15	1,075	50	1,250	84	1,420	119	1,595	153	1,765
16	1,080			85	1,425	120	1,600	154	1,770
17	1,085	51	1,255	86	1,430			155	1,775
18	1,090	52	1,260	87	1,435	121	1,605	156	1,780
19	1,095	53	1,265	88	1,440	122	1,610	157	1,785
20	1,100	54	1,270	89	1,445	123	1,615	158	1,790
		55	1,275	90	1,450	124	1,620	159	1,795
21	1,105	56	1,280			125	1,625	160	1,800
22	1,110	57	1,285	91	1,455	126	1,630		
23	1,115	58	1,290	92	1,460	127	1,635	161	1,805
24	1,120	59	1,295	93	1,465	128	1,640	162	1,810
25	1,125	60	1,300	94	1,470	129	1,645	163	1,815
26	1,130			95	1,475	130	1,650	164	1,820
27	1,135	61	1,305	96	1,480			165	1,825
28	1,140	62	1,310	97	1,485	131	1,655	166	1,830
29	1,445	63	1,315	98	1,490	132	1,660	167	1,835
30	1,150	64	1,320	99	1,495	133	1,665	168	1,840
		65	1,325	100	1,500	134	1,670	169	1,845
31	1,155	66	1,330			135	1,675	170	1,850
32	1,160	67	1,335	101	1,505	136	1,680		
33	1,165	68	1,340	102	1,510	137	1,685		
34	1,170	69	1,345	103	1,515	138	1,690		

also the electromotive force as developed by a Planté cell when its electrolyte is in various conditions. The electrolyte used was made with distilled water and pure concentrated sulphuric acid. The temperature at which the observations were taken was 16 deg. C.

TABLE XIV.—PLANTE CELL AT VARIOUS PERIODS OF DISCHARGE.

Volume of water to one volume of sulphuric acid.	Density.	Weight in grammes of acid per litre of solution.	Percentage of acid.	Specific resistance in ohms.	Open electromotive force of Planté cell.
4·0	1,222	387·0	31·68	0·825	2·105
4·5	1,200	351·0	29·24	0·853	2·085
5·0	1,183	320·0	27·10	0·882	2·065
5·5	1,169	296·0	25·24	0·911	2·050
6·0	1,158	273·8	23·63	0·940	2·035
6·5	1,149	255·4	22·22	0·970	2·022
7·0	1,141	239·3	20·97	1·010	2·010
7·5	1,134	225·1	19·85	1·040	2·000
8·0	1,128	212·5	18·85	1·072	1·992
8·5	1,120	201·0	17·94	1·095	—
9·0	1,113	190·5	17·11	1·125	—

Some very masterly investigations on the nature and theory of solutions, especially those of sulphuric acid and water, have been made by Professor S. U. Pickering.

The following three sets of curves, which appeared in the *Philosophical Magazine* for May, 1890, are given as the results of some of Professor Pickering's investigations. These curves are exceedingly interesting, as they illustrate in a most graphic manner the

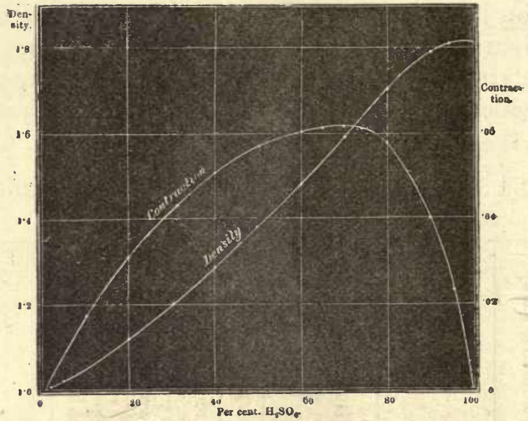

FIG. 92.—Pickering's Density and Contraction Curves.

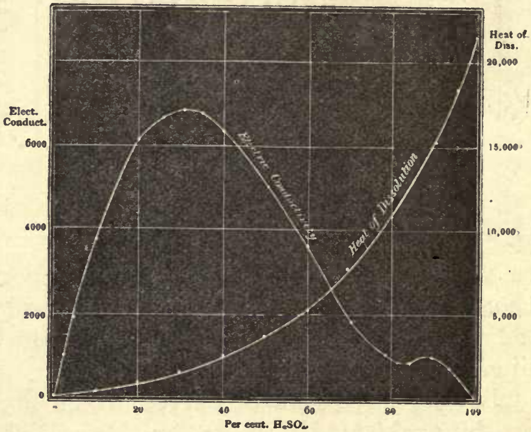

FIG. 93.—Pickering's Conductivity and Heat of Dissolution Curves.

density and electrical conductivity of all solutions of sulphuric acid and water.

Fig. 92 shows the comparative density, as well as the amount of contraction which occurs in all solutions of sulphuric acid and water of from 0 to 100 per cent.

Fig. 93 illustrates the relative electrical conductivity and also the heat of dissolution.

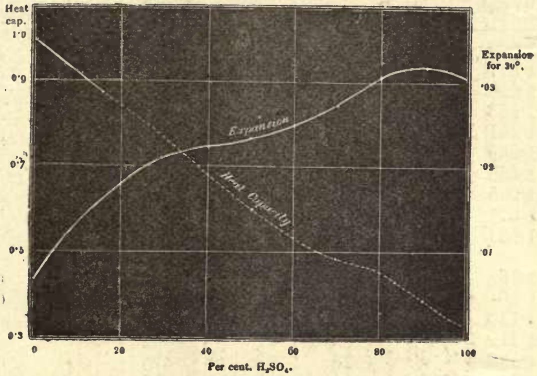

Fig. 94.—Pickering's Expansion and Heat Capacity Curves.

Fig. 94 gives the amount of expansion which occurs for a rise of temperature 30 deg. C., and also the heat capacities of all percentages of acid and water.

TABLE XV.—DENSITY AND PERCENTAGE BY WEIGHT OF SULPHATE OF ZINC IN AQUEOUS SOLUTIONS, TAKEN AT 15 DEG. C., OR 59 DEG. F. (GERLACH).

Density.	Percentage.	Density.	Percentage.
1·0288	5	1·2310	35
1·0593	10	1.2709	40
1·0905	15	1·3100	45
1·1236	20	1·3522	50
1·1574	25	1·3986	55
1·1933	30	1·4451	60

Table XVI.—Density and Percentage by Weight of Caustic Potash in Aqueous Solutions at 15 deg. C., or 59 deg. F.

Density.	Percentage.	Density.	Percentage.
1·009	1	1·300	31
1·017	2	1·311	32
1·025	3	1·324	33
1·033	4	1·336	34
1·041	5	1·349	35
1·049	6	1·361	36
1·058	7	1·374	37
1·065	8	1·387	38
1·074	9	1·400	39
1·083	10	1·412	40
1·092	11	1·425	41
1·101	12	1·438	42
1·110	13	1·450	43
1·119	14	1·462	44
1·128	15	1·475	45
1·137	16	1·488	46
1·146	17	1·499	47
1·155	18	1·511	48
1·166	19	1·525	49
1·177	20	1·539	50
1·188	21	1·552	51
1·198	22	1·565	52
1·209	23	1·578	53
1·220	24	1·590	54
1·230	25	1·604	55
1·241	26	1·618	56
1·252	27	1·630	57
1·264	28	1·642	58
1·276	29	1·655	59
1·288	30	1·667	60

TABLE XVII.—DENSITY AND PERCENTAGE BY WEIGHT OF CAUSTIC SODA IN AQUEOUS SOLUTIONS AT 15 DEG. C., OR 59 DEG. F.

Density.	Percentage.	Density.	Percentage.
1·012	1	1·343	31
1·023	2	1·353	32
1·035	3	1·363	33
1·048	4	1·374	34
1·057	5	1·384	35
1·070	6	1·395	36
1·081	7	1·405	37
1·092	8	1·415	38
1·103	9	1·426	39
1·115	10	1·437	40
1·126	11	1·447	41
1·135	12	1·457	42
1·148	13	1·468	43
1·159	14	1·478	44
1·170	15	1·488	45
1·181	16	1·499	46
1·192	17	1·509	47
1·202	18	1·519	48
1·213	19	1·529	49
1·225	20	1·530	50
1·236	21	1·540	51
1·247	22	1·560	52
1·258	23	1·570	53
1·269	24	1·580	54
1·279	25	1·591	55
1·290	26	1·601	56
1·300	27	1·611	57
1·311	28	1·622	58
1·322	29	1·633	59
1·333	30	1·643	60

TABLE XVIII.—DENSITY AND PERCENTAGE BY WEIGHT OF SULPHATE OF COPPER IN AQUEOUS SOLUTIONS, TAKEN AT 15 DEG. C., OR 59 DEG. F. (GERLACH).

Density.	Percentage.	Density.	Percentage.
1·0126	2	1·0923	14
1·0254	4	1·1063	16
1·0384	6	1·1208	18
1·0516	8	1·1354	20
1·0649	10	1·1501	22
1·0785	12	1·1559	24

TABLE XIX.—SPECIFIC GRAVITY OF VARIOUS METALS AT A TEMPERATURE OF 60 DEG. F. (FOWNE).

Metal.	*Specific Gravity.*	*Metal.*	*Specific Gravity.*
Platinum	20·98	Iron	7·79
Gold	19·26	Molybdenum	7·40
Tungsten	17·60	Tin	7.29
Mercury	13·57	Zinc	6·86 to 7·1
Palladium	11·30 to 11·8	Manganese	6·85
Lead	11·35	Antimony	6·70
Silver	10·47	Tellurium	6·11
Bismuth	9·82	Arsenic	5·88
Uranium	9·00	Titanium	5·30
Copper	8·89	Aluminium	2·60
Cadmium	8·60	Magnesium	1·70
Cobalt	8·54	Sodium	0·972
Nickel	8·28	Potassium	0·865

This table is based upon the specific gravity of pure water at 60 deg. F., which is taken as unity. As will be seen, the differences in the specific gravity of the various metals are exceedingly wide, and pass from potassium and sodium, which are lighter than water, to platinum, which is nearly twenty-one times heavier than an equal bulk of that fluid.

The following table shows the relative conductivity, which is the reciprocal of resistance, at normal temperature of some metals used in the construction of accumulators:

Metal.	Relative Conductivity.
Silver, annealed	1·000
Copper, ,,	1·063
,, rolled	1·086
Aluminium, annealed	1·935
Zinc, rolled	3·741
Platinum	6·022
Iron, annealed	6·460
Tin, rolled	8·784
Lead, ,,	13·050
Antimony, rolled	23·600
Mercury	63·730

The following table shows the approximate relative conductivity per unit surface and at normal temperatures of some insulating materials used in storage cells:

Material.	Relative Conductivity.
Mica	1
Guttapercha	5·34
Flint glass	12·14
Ebonite	333·33
Paraffin wax	404·80

Electrical Units.—The *ohm* is the unit of electrical resistance. The resistance to the passage of a current offered by a uniform column of pure mercury 104·82 centimetres long and one square millimetre in sectional area, at a temperature of 0 deg. C., is one B.A. ohm.

Commercial copies of the ohm are usually made of wire wound on a spool and supplied with massive low-resistance terminals. The metals most commonly employed in the manufacture of these standards are platinum, platino-iridium alloy, German silver, or platinoid.

The *volt* is the practical unit of electromotive force or difference of potential. It may be defined as that electrical pressure, or electromotive force (E.M.F.), which is required to maintain a current of one ampere through a resistance of one ohm.

A newly made-up Daniell cell gives approximately an electromotive force of one volt, or about one-half the electrical pressure developed at the poles of a storage cell of the Planté type. Standard Daniell cells are to be obtained, but the most convenient form of standard cell is the sulphate of mercury and zinc couple of Latimer Clark. The E.M.F. of this cell varies from 1·471 to 1·435 volts with a range of temperature of 0 deg. to 32 deg. C.

The *ampere* is taken as unity in determining the rate of flow of an electric current — that is, that amount of current flowing in a wire of a resistance of one ohm, between the two ends of which a difference of potential of one volt is maintained, is called one ampere.

One ampere in one hour will deposit 1·174 grammes of copper, 4·074 grammes of silver, and will decompose 0·3357 grammes of acidulated water. An ordinary 16 candle-power 100-volt Edison-Swan lamp requires from 0·6 to 0·8 ampere to fully incandesce it.

A *coulomb* is the name given to that amount of electricity which is developed in a period of one second at a rate of flow of one ampere; 3,600 coulombs represents a current of one ampere-hour.

This quantity unit, the coulomb, is very useful for expressing the amount of electrical energy which a primary or secondary cell is capable of yielding. It is much used in the comparison of different types of accumulators, whose relative merits may be expressed in terms of so many coulombs, or more usually ampere-hours capacity per pound of plate, of complete cell, or per unit area of exposed active surface.

The rate at which electrical energy is being consumed, or at which work is being performed, is expressed in terms of the *watt.* This measurement is obtained by taking the product of the electromotive force and the current—*e.g.*, if a cell is being discharged at a rate of 20 amperes, and at an electromotive force of two volts at its poles, then the rate at which its energy is being given out per second is $20 \times 2 = 40$ watts; if this discharge be maintained for a period of one hour, then the total energy is equivalent to $20 \times 2 \times 3{,}600 = 14{,}400$, or 40 watt-hours. In an efficient glow lamp an expenditure of 3·5 watts at its terminals should produce a luminosity of one candle-power.

The term *kilowatt* is used to designate an activity of 1,000 watts. One electrical horse-power hour is represented by 746 watt-hours. When alluding to the energy storage capacity of an accumulator cell it is usual to express it in terms of watt-hours, or if the cell be large in electrical horse-power hours.

Ohm's Law.—In our present system of electrical measurements, based as they are on what is known as Ohm's law, if two quantities be given, the third and unknown may always be found by a simple algebraical equation.

Thus, if C stands for current,
E stands for electromotive force,
R stands for resistance,

then Ohm's law may be stated thus:

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

and

$$E = C \, . \, R,$$

and

$$R = \frac{E}{C}.$$

Measuring the Internal Resistance of Voltaic Cells.—The internal resistance of a cell depends upon the total active surface area of the opposing plates, the nature of the electrolyte and its condition and temperature, and the distance between the plates.

There are many methods for determining the internal resistance of batteries. If the cells be as nearly as possible of the same dimensions, capacity, and state of charge, then two cells may be placed in opposition (poles of like polarity joined together) and their joint resistance may be measured by the ordinary Wheatstone bridge method. If the cells be exactly similar, then one-half the resistance indicated will represent the resistance of each cell.

A far more reliable and accurate means of ascertaining the internal resistance of cells is the differential method, as expressed by the following formula:

$$r = \frac{D - D'}{D} R$$

where r is the resistance required, D and D′ are the values of deflections obtained on a high-resistance sensitive galvanometer, and R expresses the value of a small but known resistance, used as a shunt.

When making tests by this method, a high-resistance potential galvanometer should be used, and one whose scale readings are either of uniform value, or whose tangents are strictly proportional to the angle of the deflections. To determine *r* we have to obtain a deflection, D, when the cell is on open circuit, and then obtain another reading, D′, when the cell is shunted by R, then by the formula given the internal resistance may be ascertained. The shunt resistance, R, should be small in comparison with the galvanometer coils. Good results may be obtained if the resistance of the galvanometer is, say, 5,000 ohms, and the shunt not more than one to five ohms.

Capacity and Efficiency of Storage Cells.—The *total current, or energy capacity*, of a storage cell is the maximum amount of current or electrical energy which it is capable of storing, without reference to any loss that may occur by it being allowed to remain idle, nor does it take into account the rate or manner of its discharge.

The *working current, or energy capacity*, is that amount of current, or electrical energy, which can be obtained from the cell at any specified rate of discharge. When estimating this, the discharge is always stopped as soon as the cell ceases to do useful work. The working capacity of storage cells may vary between very wide limits.

The *absolute current, or energy efficiency*, of an accumulator cell is the ratio between that amount of current or energy put into it and that obtained by a total discharge, without reference either to its rate of charge or discharge, or to the time allowed to elapse between these operations.

The *working current, or energy efficiency*, of a storage cell is the ratio between the value of the current or energy expended in the charging operation, and that obtained when the cell is discharged at any specified rate.

In a lead storage cell, if the surface and quantity of active material be accurately proportioned, and if the discharge be commenced immediately after the termination of the charge, then a current efficiency of as much as 98 per cent. may be obtained, provided the rate of discharge is low and well regulated. In practice it is found that low rates of discharge are not economical, and as the current efficiency always decreases as the discharge rate increases, it is found that the normal current efficiency seldoms exceeds 90 per cent., and averages about 85 per cent.

As the normal discharging electromotive force of a lead secondary cell never exceeds 2 volts, and as an electromotive force of from 2·4 to 2·5 volts is required at its poles to overcome both its opposing electromotive force and its internal resistance, there is clearly an initial loss of 20 per cent. between the energy required to charge it and that given out during its discharge. As shown, the normal discharging potential never exceeds two volts, and as this pressure is continually being reduced as the rate of discharge increases, it follows that an energy efficiency of 80 per cent. can never be realised. As a matter of fact, a maximum of 75 and a mean of 60 per cent. is the usual energy efficiency of lead-sulphuric-acid storage cells.

INDEX.