VOLTAIC ELECTRICITY.

CHAPTER VI.

Electrical Phenomena Discovered by Galvani—Origin of the Voltaic Pile—Science of the Voltaic Battery—Ohm's Mathematical Formulæ—Chemical and Electrical Action of the Battery—The Daniell, the Smee, the Bunsen, the Grove and the Chester Voltaic Batteries—Comparative Intensity and Quantity of the Grove, Daniell, and Smee Batteries.

ELECTRICAL PHENOMENA DISCOVERED BY GALVANI.

That remarkable form of electricity, known by the name of *Galvanism* or *Voltaism*, owes it origin to an accidental circumstance connected with some experiments on animal irritability, which were being carried on by Galvani, a professor of anatomy at Bologna, in the year 1790. It happened that the wife of the professor, being consumptive, was advised to take as a nutritive article of food, some soup, made of the flesh of *frogs:* several of these animals, recently killed and skinned, were lying on a table in the laboratory, close to an electrical machine, with which a pupil of the professor was making experiments. While the machine was in action, he chanced to touch the bare nerve of the leg of one of the frogs with the blade of a knife that he held in his hand, when, suddenly, the whole limb was thrown into violent convulsions. Galvani was not himself present when this occurred; but received the account from his wife, and being struck with the singularity of the phenomenon, he lost no time in repeating the experiment, and investigating the cause: he found that it was only when a spark was drawn from the prime conductor, and when the knife or any other good conductor was in contact with the nerve, that the contractions took place; and pursuing the investigation with unwearied industry, he at length discovered that the effect was independent of the electrical machine, and might be equally well produced by making a metallic communication between the *outside muscle* and *crural nerve*. He did not for one moment suppose that the manifestation of electricity was the result of the chemical action upon the metals.

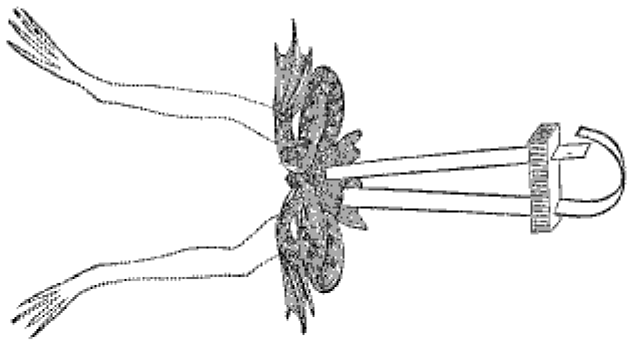
Galvani had previously entertained notions respecting the agency of electricity, in producing muscular action: these new experiments, therefore, as they seemed to favor his views, had with him more than ordinary interest. He immediately ascribed the convulsive movement in the limb to electrical agency, and explained them by comparing the muscle of an animal to a Leyden vial, charged by the accumulation of electricity on its surface, while he imagined that the nerve belonging to it performed the function of a wire, communicating with the interior of the vial, which would, of course, be charged *negatively*. In this state of things, if a communication by a good conductor were made between the muscle and nerve, a restoration of the electric equilibrium, and a contraction of the fibres, would ensue.

It is curious to notice how frequently the progress of discovery in the sciences is influenced by fortuitous circumstances, and in no case is it more striking than in the present. Had Galvani been as good an electrician as he was anatomist, it is probable that the convulsions of the frog would have occasioned him no surprise; he would immediately have seen that the animal formed part of a system of bodies under *induction*, and he would have considered the movements of the limbs of the frog, as evidence of nothing more than a high electroscopic sensibility in its nerves.

To perform the experiment with the frog's legs successfully, the legs of the frog are to be left attached to the spine by the crural nerves alone, and then a copper and a zinc wire being either twisted or soldered together at one end, the nerves are to be touched with one wire, while the other is to be applied to the muscles of the leg. Figure 1 shows the arrangement. There are several ways of varying this experiment. If a piece of copper, as a penny, be laid on a sheet of zinc, and if a common garden snail be put to crawl on the latter, he will be observed to shrink in his horns and contract his body whenever he comes into contact with the penny: indeed, after one or two contacts he will be observed to avoid the copper in his journey over the zinc.

The experiments of Galvani excited much attention among the men of science of that period: they were repeated and varied in almost every country in Europe, and ascribed to various causes. Some imagined them the effect of a new and unknown agent: others adopted the views of the discoverer, and recognized them as peculiar modifications of electricity. The hypothetical agent which passed under the name of the

Fig. 1.



"nervous fluid," now gave way to electricity, which, for a time, reigned as the *vital principle*, by which "the decrees of the understanding, and the dictates of the will, were conveyed from the organs of the brain to the obedient member of the body;" and this theory for a time so fascinated physiologists, that it was with difficulty that the explanations of *Volta*, viz. that the electric excitement is due to the mutual contact of two dissimilar metals—that by the contact the natural electricity was decomposed, the positive fluid passing to one metal, and the negative one to the other—and that the muscle of the frog merely played the part of a conductor—obtained assent.

ORIGIN OF THE VOLTAIC PILE.

It is to Professor Volta, of Pavia, that we are indebted for the first galvanic or voltaic instrument, viz. the *voltaic pile;* it was described by him in the Philosophical Transactions of 1800, and to him, therefore, the merit of laying the foundation of this highly interesting branch of science is due. The main difference between common and voltaic electricity (which are modifications of the same force) will be found to be this: the first produces its effects by a comparatively small quantity of electricity, insulated, in a high state of *tension*, having remarkable attractive and repulsive energies, and power to force its way through obstructing media: the latter is more intimately associated with other bodies, is in *enormous quantity*, but rarely attains a high state of tension, and exhibits its effects while flowing in a continuous stream along conducting bodies.

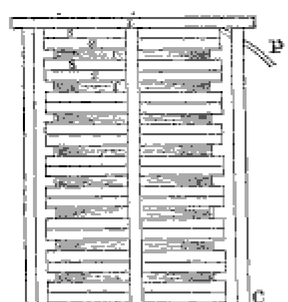
Galvani was an anatomist and not an electrician. He was firmly impressed with the idea that the convulsion of the frog's limb was owing to muscular action caused by animal electricity. He advocated this theory with the utmost zeal, and his whole efforts were directed toward maintaining this error. Electricians doubted the correctness of Galvani's philosophy, and on the other hand physiologists gave countenance to his notions, and throughout the continent they contended that the convulsions were produced by animal electricity.

The extraordinary zeal that was displayed by Galvani and his friends to maintain their physiological theory, caused electricians to investigate its correctness, and among them was Volta, of Pavia. In this state of the question Galvani died, at the close of the year 1798.

Two years after the death of Galvani, Volta produced his "pile" which demonstrated the correctness of his theory, as mainly advocated by him for several years previous. The electricians rejoiced over the practical illustration exhibited by the voltaic pile. It dispelled all faith in the erroneous reasonings of Galvani and his friends, that the motion of the frog was by animal electricity. Volta's triumphant success in demonstrating that the convulsions were produced by chemical action of the metals, was received with great joy by the electricians. It was a contest between anatomists and electricians, and the latter were the victors. The most strange part of the history was, that the achievement of Volta, was called *Galvanism* instead of *Voltaism*, as more modernly termed.

The original instrument of Volta is shown in fig. 2. It consists of a series of silver and zinc plates, arranged one above the other, with moistened flannel or pasteboard between each pair. A series of thirty or forty alternations of plates, four inches square, will cause the gold leaf electroscope to diverge; the zinc end with the positive, and the silver with the negative electricity; a shock will also be felt on touching the extreme plates with the finger, when moistened with water. This latter effect is much increased when the flannel, or pasteboard, is moistened with *salt* and water; in this case a small spark will be decomposed; from this we learn that the increase of chemical action, by the addition of

Fig. 2.



the salt, materially increases the *quantity* of electricity set in motion; but the pile will not in any sensible manner increase the divergence of the gold leaves,—its *intensity*, therefore, is not materially augmented.

The pile, represented by fig. 2, is connected at each end with a wire; A B C is the frame to hold the plates; *s s* are the silver plates, and *z z* are zinc plates; I I are the moistened flannels, and *i i* the top and bottom end boards; P, the positive pole, is connected with the wire at the top, and at the bottom N, the negative, to the wire. This was the voltaic pile as originally introduced by that distinguished philosopher Volta, of Pavia, in the year 1800.

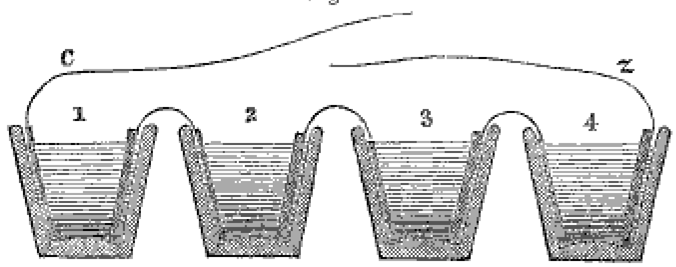
In order to increase the *intensity* of the voltaic or electric current, it is necessary to increase the number of the plates; and to develop the greater *quantity* current, it is attained by the increase of the size of the plates. The centre of the battery or column is *neutral*, but the ends are in opposite electrical states; the zinc extremity negative, and the gold, silver, platinum or other metallic applications, positive.

THE SCIENCE OF THE VOLTAIC BATTERY.

The action of the voltaic pile gradually diminishes from the time it is first put together, until at length the effect appears to cease. This diminution of power is more rapid in proportion to the energy given to the pile in the first instance by the larger quantity of acid mixed with the water. To restore the original energy, it is necessary to decompose the pile, to clean the zinc and copper disks, and to moisten the cloths again. Such an apparatus is therefore attended with much trouble. To obviate it, Volta contrived another arrangement, which he called *à couronne de tasses*. He connected a piece of zinc to a piece of copper by soldering to them a short length of bent copper wire. Having procured a number of such connected plates, he put them into a row of glasses containing acidulated water, taking care so to dispose them that the zinc and the copper connected together should be in separate glasses, in the manner represented in figure 3.

To the copper plate in glass 1, a wire is attached to serve as a conductor for forming connection. In the same glass there is a zinc plate connected with the copper immersed in glass 2. In this manner each glass contains a zinc and copper plate connected by a wire, which are kept apart in the fluid, and the series may be continued to any extent. By bringing the wire attached to the first plate in connection with a similar wire soldered to the zinc plate in the last glass of the series, the action immediately commences, and it is more or less intense according to the number of plates. This arrangement is, in

Fig. 3.



many respects, very superior to the pile. A much larger quantity of fluid can be brought to act on each plate, consequently the effect does not so rapidly diminish; the plates can be readily removed when the apparatus is not wanted, and the acidulated water may remain ready for the immersion of the plates when experiments are renewed.

The arrangement *à couronne de tasses*, as invented by Volta, continues, with some modifications for convenience in use, to form the voltaic battery that is most generally employed. A series of this kind, consisting of one hundred plates of copper and zinc four inches square, will generate electricity in sufficient quantity to exhibit in a powerful manner most of the phenomena of frictional electricity.

The metals that excite electricity by their mutual actions are ranged in the following order; those placed first acting in reference to those beneath as copper does to zinc.

Platinum.	Mercury.	Tin.
Gold.	Copper.	Iron.
Silver.	Lead.	Zinc.

Any two of the foregoing series will constitute what is termed a voltaic circuit. Thus zinc will excite voltaic action in combination with iron; iron will take the place of zinc when combined with tin; and tin will take the place of iron when combined with copper. The energies of these combinations increase as the metals are more distant from each other in the scale, the most powerful practical combination being zinc and platinum, the most incorrodible of all metals.

Though two plates are necessary in such an arrangement, only one of them is active in the excitement of electricity, the other plate serving merely as a conductor to collect the force generated. A metal plate is generally used for that purpose, because metals conduct electricity much better than other substances exposing an equal surface to the fluids in which they are immersed; but other conductors may be used, and when a proportionately larger surface is exposed to compensate for inferior conducting power, they answer as well, and in some instances even better than metal plates.

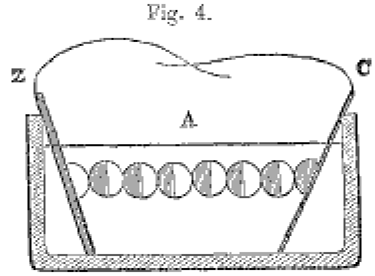
The chemical action that gives rise to the excitement of electricity, takes place during the decomposition of the liquid in which the plates are immersed. It is essential, therefore, to the formation of an active voltaic arrangement, that the liquid employed should be capable of being decomposed. Water is most conveniently applicable for the purpose. Its elements, oxygen and hydrogen, are separated by the superior affinity of the oxygen for the zinc; especially when that affinity is heightened by the connection of the zinc with an incorrodible metal, to which the hydrogen gas of the decomposed molecules of water is attracted. Whether the electricity evolved be the cause or merely the effect of chemical action is at present unknown. In whichever way the phenomenon be regarded, the electricity appears to be excited at the surface of the active plate, thence to be transferred to the conducting plate, and back again through the connecting wire to the zinc, forming what is termed an electric current. The terms "electric fluid" and "electric current," which are frequently employed in describing electrical phenomena, are calculated to mislead the student into the supposition that electricity is known to be a fluid, and that it flows in a rapid stream along the wires. Such terms, it should be understood, are founded merely on an assumed analogy of the electric force to fluid bodies. The nature of that force is unknown, and whether its transmission be in the form of a current, or by vibrations, or by any other means, is undetermined. At the meeting of the British Association for the Advancement of Science at Swansea, a discussion arose on the nature of electricity, and Dr. Faraday was called on to give his opinion. He then said, "There was a time when I thought I knew something about the matter: but the longer I live, and the more carefully I study the subject, the more convinced I am of my total ignorance of the nature of electricity." After such an avowal from the most eminent electrician of the age, it is almost useless to say that any terms which seem to designate the form of electricity are merely to be considered as convenient conventional expressions.

Water being a very imperfect conductor, it offers so much resistance to the passage of the electric current that a very small quantity of voltaic electricity can be excited when water alone is employed; especially when the plates are at a considerable distance apart. By the addition of an acid or a neutral salt to the water, the conducting power is greatly increased, and the excitement is augmented in a corresponding degree. It is a disputed point whether the increased action from the addition of acids arises from the improved conducting power alone, or whether it is to be attributed also to the increased affinity of the oxygen to the zinc. The effect is most probably owing to the joint effort of the two forces.

In the opinion of Faraday, the conduction of electricity through liquids is accompanied by, if it be not owing to, the successive decomposition of the intervening particles. When a copper and zinc plate, for example, are connected together and immersed in diluted acid, the oxygen in the particle of liquid contiguous to the plate enters into combination with the metal, and its equivalent quantity of hydrogen is disengaged. The hydrogen is not immediately liberated, but is transferred from particle to particle of the liquid in a continuous chain till it reaches the conducting plate, where, not meeting with any more liquid particles to which it can be transferred, it is liberated in the gaseous form. The intervening particles are supposed to undergo temporary decomposition during this transfer from plate to plate, and to assume a polar condition, the oxygen and hydrogen occupying opposing places in each particle of liquid.

The annexed diagram, fig. 4, shows, in an exaggerated form, the chain of particles of water through which the decomposing influence is supposed to be transmitted. Voltaic action having been established through water in the vessel A from the zinc plate Z to the copper plate at C, the particles between the two metals are thrown into a polar state; the oxygen of each being directed toward Z, and the hydrogen toward C. The zinc plate absorbs the oxygen of the particle nearest to it, and the liberated hydrogen combines with the oxygen of the next adjoining particle, and in this manner a continuous interchange takes place. According to this view of the conducting power of fluids, no fluid can conduct electricity unless it be capable of being decomposed; the conduction being necessarily accompanied by a train of successively decomposed particles.

Fig. 4.



OHM'S MATHEMATICAL FORMULÆ.

The causes that obstruct the development of electricity in a current, have been minutely investigated by Professor Ohm, of Nuremburg, who has reduced them to mathematical formulæ. The free development of electricity is opposed, in the first place, by the affinity of the elements of the exciting liquid for each other, tending to resist decomposition; secondly, by the imperfect conduction of the fluid itself; and in the third place, by the resistance of the conducting wires. As the formulæ deduced by Professor Ohm from these investigations have received general acceptance among electricians, it is desirable to insert them:

"E = electromotive force, equivalent to the affinity of the exciting liquid for the generating metal, and corresponding to the amount of electricity which would appear in current if all opposing causes were removed.

"R = resistance opposed to E by the contents of the cell, arising for the most part from the affinity of the elements of the exciting liquid for each other.

"r = external resistance, arising chiefly from the imperfectly conducting nature of the wires used to convey the current.

"a = active force, or the amount of electricity which really reaches the end of the conducting wire.

$$a = \frac{E}{R + r}$$

"The theoretical value of E is diminished materially in practice by the affinity of the conducting plate for the ingredient of the exciting fluid, which tends to combine with the generating plate; this affinity, however weak, is still seldom absolutely null. The mutual affinity of the separated elements of the fluid evolved at the surfaces of the plates also lessens the intensity of E.

"The internal resistance, R, varies directly with the distance, D, between the two plates, and is inversely as the area of the section, S, of the exciting liquid. Thus the real resistance is equal to the former divided by the latter, or

$$R = \frac{D}{S}$$

"r, or the external resistance, so far as it is dependent on the conducting wire, varies *inversely* as the square of the diameter of the wire, S, and directly as its length l, or

$$r = \frac{l}{S}$$

From these formulæ are deduced the following general laws:

1st. The electro-motive force of a voltaic circuit varies with the number of the elements, and with the nature of the metals and liquids which constitute each element; but it is in no degree dependent on the dimensions of any of their parts.

2d. The resistance of each element is directly proportional to the distances of the plates from each other in the liquid, and to the specific resistance of the liquid; and it is also inversely proportional to the surface of the plates in contact with the liquids.

3d. The resistance of the connecting wire of the circuit is directly proportional to its section.

It must be remarked that the foregoing estimate of electrical force and resistance does not take into account the actual loss of electricity by the want of proper direction. The chemical action that converts any given quantity of zinc into a metallic salt, develops, with the best arrangement, a given quantity of electricity. Let it be assumed that one ounce of zinc will generate an amount of electricity equivalent to 1000; that quantity will not be diminished by the resistances considered by Professor Ohm. Those resistances relate exclusively to the time in which a given amount of electricity can be generated, and have no relation to actual loss of electric force. Thus, in a well-constructed voltaic apparatus no more electricity is generated than can flow in a current through the conducting wire. If the resistance to the current be increased by diminishing the thickness of the wire or by adding to its length, the action of the generating-plate is diminished in a corresponding degree, so that if only half the electricity is developed, only half the quantity of zinc is consumed; and to whatever extent the resistances are increased the ounce of zinc will, theoretically at least, produce its equivalent of electricity, though in a longer time.

CHEMICAL AND ELECTRICAL ACTION OF THE BATTERY.

In practice, however, an actual loss of electricity does generally occur, arising principally from what is called "local action" in the generating-plate. If a plate of zinc were perfectly pure and homogeneous, no chemical action would ensue when it was immersed in diluted acid. But zinc, as it is commonly procured, contains copper, iron, and other impurities, which serve to set up voltaic action over its whole surface when exposed to diluted acids, which cause a rapid decomposition of the liquid. The positive and negative electricities thus generated immediately combine, and are neutralized imperceptibly, and thus so much electric force is absolutely lost. This local action is in a great measure, though not entirely, prevented by amalgamating the zinc plates with mercury: this is readily done by first dipping them in diluted sulphuric acid, and then sprinkling a few drops of mercury on the surface and rubbing them over with a cork. The effect of amalgamation is to produce a homogeneous surface, and to protect the zinc from the action of the diluted acid until the affinity of the liquid for the metal is increased by the agency of the conducting plate.

The electricity generated by a single pair of plates possesses a very low degree of intensity. The *quantity* is only limited by the size of the plates, but no increase of size alone will add to the *intensity* of the force. Thus, though a pair of large zinc and copper plates, excited by diluted sulphuric acid, will fuse any of the metals, they cannot decompose a drop of water; because in the latter case the force is not sufficiently energetic to overcome the resistance of the fluid.

In tracing the course of the electric current thus established, no notice has been taken of the action of the second zinc plate. If that be considered as inactive, except as a conductor, the quantity of electricity transmitted would be very small, owing to the resistance of the imperfectly conducting liquid. But the zinc plate in the second cell is acted on by the diluted acid equally with that in the first; and the effect is to nearly double the energy of the electric current excited by the action of the acid on the first zinc plate.

According to this view of the action of a voltaic battery consisting of two pairs of plates, the electricity excited by the first zinc is transferred to the second, where its force is doubled by the excitement of an equal quantity, and both united traverse the wire of the return circuit. On arriving at the first zinc, half the quantity is parted with; but an equal quantity of fresh electricity is excited, and is carried on to the second zinc, where the same process is repeated; and thus the electrical equilibrium is continually disturbed and restored after traversing the wires that connect the plates at the ends. When greater numbers of zinc and copper plates are united in a series, a similar transference of electricity from place to place takes place with a progressively increasing *quantity* and *intensity* of force, the action being continued as long as the series remains unbroken, or until the fluid becomes saturated with sulphate of zinc, and further chemical action is prevented.

It is necessary to state that the preceding explanation of the action of the voltaic battery differs from the view taken of it by Dr. Faraday, and after him by most other writers on the subject. In the opinion of Dr. Faraday, addition to the number of plates in a series occasions no addition to the *quantity* of electricity generated by the first pair of plates, but merely serves to give increased *intensity* to that quantity. Thus the most powerful effects produced by a voltaic battery consisting of 1000 pairs of plates are assumed to be caused by the same *quantity* of electricity that is excited by a single pair only of the series; the exalted action in the former case being attributed to an increase of intensity without any addition to quantity.

This view of the nature of the action of the voltaic battery is supported by numerous ingeniously-contrived and apposite experiments; but though fully disposed to pay the highest possible respect to so great an authority as Dr. Faraday, an opinion is entertained that he has failed to establish the position that increased intensity is not accompanied by addition to quantity.

THE CRUIKSHANK VOLTAIC BATTERY.

There are many arrangements of voltaic batteries for the development of accumulated electric force in different modes, but they all depend on the same principle. The most compact is Cruikshank's modification of the voltaic pile, fig. 5.

Fig. 5.

Zinc and copper plates of equal size are soldered together, and then cemented into a wooden trough. Each pair of plates is fixed less than half an inch from each other, care being taken that all the zinc and copper surfaces are turned the same way. The compartments between the plates form water-tight cells, into which diluted acid, or other exciting liquid, is poured. A piece of wire is introduced at each end to complete the circuit through any substances to be subjected to the voltaic action.

A series of fifty small double plates may be cemented into a trough two and a half feet long; and two such batteries, with plates two inches square, will give a rapid succession of smart shocks, and will exhibit most of the phenomena of voltaic electricity. The disadvantages of a battery of this kind are, that the exciting liquid cannot be emptied at the end of each experiment without much trouble, and there is some difficulty in cleaning the plates when they become corroded. By emptying the cells as soon as possible and washing them with water, a battery of this construction may, however, be kept in order for a considerable time; and when voltaic electricity of high intensity and small quantity is required, a Cruikshank battery with plates about two inches square, is very convenient.

Fig. 6.

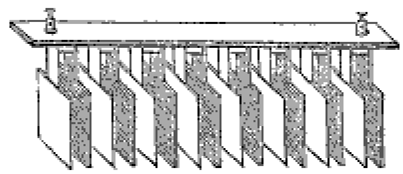


Fig. 7.

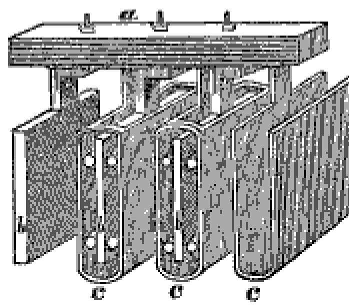
Figs. 6 and 7 represent the full battery. Fig. 7 is the trough divided into cells insulated each from the other. Fig. 6 is a wooden board having attached to it copper and zinc plates, the white are copper and the dark, zinc. These plates fit into the cells, and may or may not rest upon the bottom

The original form of the trough has been recently very extensively used for the electric telegraph, though made of other materials than earthenware. Most of the batteries of the Electric Telegraph Company, until very recently, were constructed in wooden troughs, with partitions of slate made water-tight by means of marine glue. These, again, are being supplanted by troughs made of gutta-percha, which are very much lighter, and the cells can be more effectually prevented from leaking. The plates of these batteries are connected by strips of copper, which are bent into arches, so as to admit of each unattached pair of plates being inserted into separate cells. The zinc plates are well amalgamated, and are allowed to remain in the cells day and night, the local action being in a great measure prevented by filling each cell with fine sand, and by using sulphuric acid diluted with about twelve parts of water. A voltaic battery, with sand and diluted sulphuric acid, will continue in good action, with occasional additions of acid, for two months before the zinc plates require to be cleaned or re-amalgamated.

Batteries in which graphite is substituted for plates of copper, have been introduced by Mr. C. V. Walker in working the electric telegraphs of the Southeastern Railway Company, and with very good results. One of these batteries of twelve pairs, of which a record was taken, was kept in daily action for ninety-seven weeks without having been washed or having the sand changed. It was supplied with about a dessert-spoonful of acid-water twenty-one times during the period it was in action, and six times with merely warm water. In one instance it did duty for seventy-seven days without having been touched.

Dr. Wollaston contrived the arrangement shown in fig. 8 for obtaining the greatest amount of power from a given surface of zinc. The copper plates C C C are doubled, so as to expose a conducting surface to both sides of the zinc plates, B B B. The plates are also brought as close together as possible without actual contact. They are secured to a bar of wood, and are kept apart by pieces of cork. With a battery of this kind, consisting of a few pairs of large plates, prodigious heating power is produced, though the intensity of the electricity is too feeble to communicate a shock.

Fig. 8.

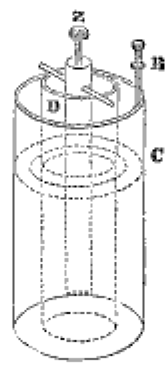


THE DANIELL VOLTAIC BATTERY.

The battery invented by Professor Daniell, is constructed on a different principle. It is found in the voltaic arrangements, that the zinc and copper plates immersed in the same cell are liable to have their action impeded, and ultimately altogether arrested, by the transfer of zinc to the copper surface. The action of the conducting plate is also greatly retarded by the accumulation of hydrogen gas; so much so, indeed, that very frequently, after the first minute the battery has been put in action, not more than one tenth of the original power is obtained. In Professor Daniell's battery the zinc and copper plates are kept apart by means of porous earthenware cells, or by pieces of animal membrane, which, though sufficient to prevent the passage of metallic particles, do not materially interrupt the voltaic action.

Fig. 9 shows an arrangement of a single cell of this kind: C is a copper cylindrical vessel, with a binding screw B, soldered to one edge for the purpose of holding a connecting wire. Into this copper cylinder a porous tube D, closed at the bottom, is introduced; and into the tube is placed a rod of amalgamated zinc Z, with a bending screw at the top. A solution of muriate of soda (common salt) is poured into the porous tube, and the outer copper vessel is nearly filled with a saturated solution of sulphate of copper to which a little sulphuric acid has been added.

Fig. 9.



When metallic connection is made between the rod of zinc and the copper cylinder, active excitement of voltaic electricity occurs. The oxygen of the acid combines with the zinc, and the liberated hydrogen passes through the porous cell to the copper. It does not, however, escape in the form of gas, but it enters into combination with the oxygen of the sulphate of copper, and the metal being thus deprived of its oxygen, becomes "revived," and is deposited in a metallic form on the inner surface of the cylinder. By the continued absorption of hydrogen by the sulphate, and the deposition of copper, a bright conducting surface is maintained; and this constant renewal of the conducting surface not only increases the intensity of the action, but maintains it with a steadiness that cannot be attained by any of the batteries previously described.

Fig. 10.

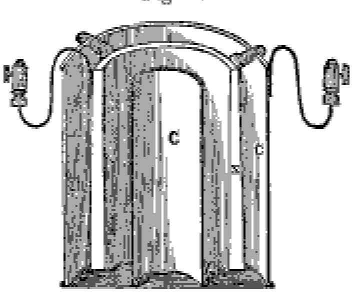


Fig. 10 represents a vertical section of the Daniell battery, used on some of the American telegraph lines, in the local circuits. It consists of a double cylinder of copper C C, with a bottom of the same metal, which answers the purpose both of a voltaic plate and of a vessel to contain the solution. The space between the two copper cylinders receives the solution. There is a moveable cylinder of zinc, marked Z, in the sectional view, which is let down into the solution whenever the battery is to be put in action. It hangs suspended in the solution, and presents its two opposite surfaces to the action of the liquid, and to the inner and outer cylinders respectively. The binding screw N is connected with the zinc, and the screw P with the copper cylinder.

Fig. 11.

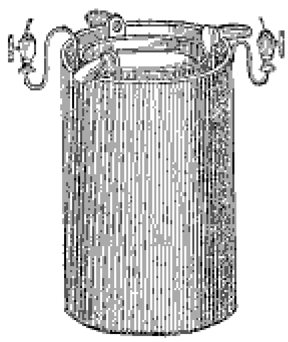


Fig. 11 is a perspective view of the same battery. The liquid employed to put this battery in action, is a solution of sulphate of copper, or common blue vitriol, in water. To prepare it, a saturated solution of the salt is first made, and to this solution is then added as much more water. A pint of water is capable of dissolving one fourth of a pound of blue vitrol, so that the half-saturated solution employed, will contain about two ounces of the salt to the pint. A small portion is sometimes added to increase the permanence of its action.

Fig. 12.

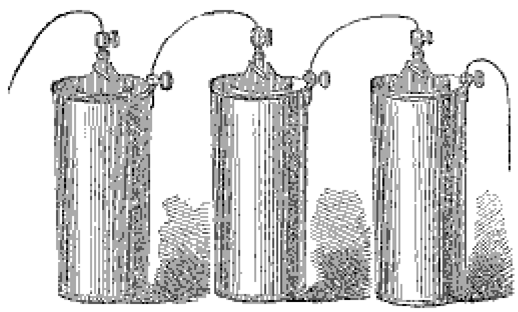


Fig. 12 represents the union of the cells of this battery, as in common use on some of the telegraph lines. Fig. 13 is a section of it, being the zinc and the porous cylinder. Fig. 14 is a covered cell and is called a protective battery.

Fig. 13.

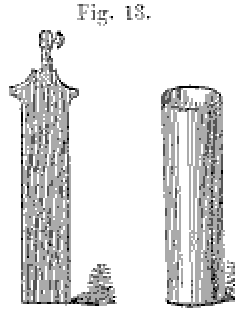
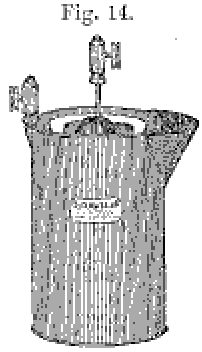


Fig. 14.

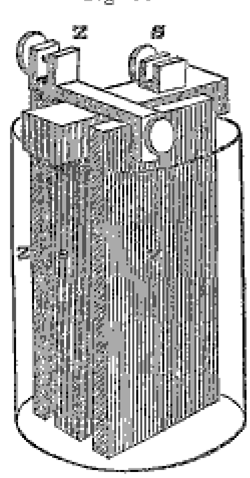


The Daniell battery, having thus been described in its especial arrangement, I will add a few explanations relative to its peculiar advantages. It is called a "constant" or "sustaining" battery, from the regularity and duration of its action. Mr. Smee denies the correctness of this name. He says, "It is often thought to signify long-continued action, whereas these properties are really different; for a battery may be constant, but only remain in action for a a short period; and, again, a battery might remain in action for years, and not be constant in its action." Among practical electricians, however, the Daniell battery is recognized as a "constant battery," and as such it has been used in the local circuits of many telegraph lines, with much economy and satisfaction.

THE SMEE VOLTAIC BATTERY.

The voltaic arrangement contrived by Mr. Smee deserves special notice from its general utility. The principal differences between it and a battery of Dr. Babington's arrangement consist in the material of the conducting plate and in the mode of placing it. The conducting plate is made of silver-foil platinized; that is, a thin coat of platinum is deposited on the silver by the electrotype process. The minutely-divided particles of platinum that thus cover and adhere to the silver, present a greatly-enlarged surface to liquid in which it is immersed, by which means a smaller-sized plate answers equally with a much larger one of smooth metal. Platinum also being a metal less readily oxydized than copper, the effect of the voltaic arrangement is heightened by the greater dissimilarity of the two metals. The platinized silver-foil is fixed in the centre of a wooden frame s, and two zinc plates, z z, well amalgamated, are attached to the upper rim of the frame by a brass clamp, which has a binding screw connected with it. By this arrangement the zinc plates can be very readily removed and cleaned. In this respect a Smee's battery is more convenient than any other; its action also approaches a Daniell's battery in constancy. These are important advantages, which render this form of voltaic battery the best that can be used for general purposes.

Fig. 15.



The substitution of graphite for the platinized silver plates promises to be a still further improvement. With graphite conducting plates there is no occasion for the wooden frame. A single zinc plate, with a binding-screw soldered to it, occupies the central place, instead of the platinized foil, and two flat pieces of graphite may be clamped on each side; care being taken to insulate the zinc from the graphite by small strips of varnished wood. It will be observed that in this disposition of the apparatus with the graphite, the position of the exciting zinc in reference to the conducting surfaces is transposed, as well as the proportions of each to the other being reversed; a single plate of zinc being placed between two conducting surfaces instead of the conducting surface being in the centre, with a zinc plate on each side.

Fig. 16 is another form of the Smee cell as practically applied by Mr. Hall of Boston, with great success as to its effi-

Fig. 16.

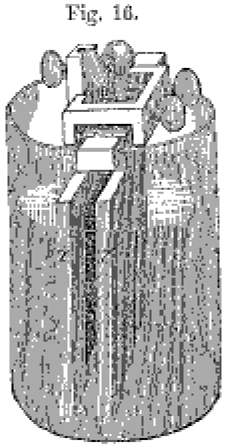
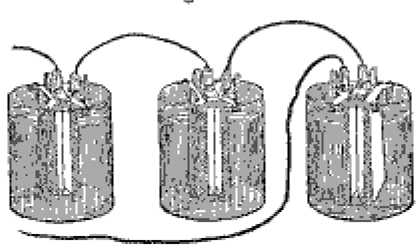


Fig. 17.



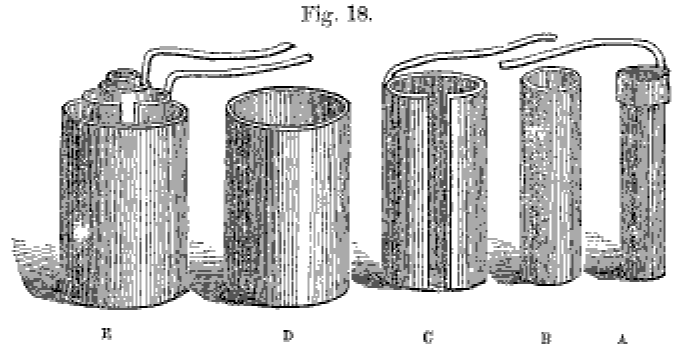
ciency and long service. The zinc plates are large, and the platinized sheet very thin. Fig. 17 is composed of three cells united by the wires, one connecting with the copper and the other with the zinc, the two poles of the battery.

The object in every case is to obtain from a given quantity of the exciting metal the greatest possible amount of current electricity, without allowing the power to be wasted in other ways. The consumption of a given weight of zinc cannot, by any possible combination, excite more electricity than will decompose a quantity of water equivalent to that which is decomposed by the chemical affinity of the metal for oxygen. Thus, supposing two grains of water to be decomposed in the generating cell, and eight grains of zinc to be oxydized, the electricity generated during the process cannot be more than sufficient to decompose another two grains of water. The power obtained, even by the best arrangements hitherto contrived, seldom amounts to so much. By increasing the chemical action of the liquid on the generating plates, the energy of the battery is increased, but most frequently not in proportion to the consumption of zinc. By bringing the plates in the generating cells nearer together, the energy of the battery is also increased, by diminishing the intervening fluid resistance; but this may be attended with waste of power if the plates be brought too close.

THE BUNSEN VOLTAIC BATTERY.

Professor Bunsen has substituted carbon for platinum, in nitric acid batteries, with good effect. To overcome the difficulty of shaping graphite into the required form, he made a composition of coke and coal in fine powder, which were heated together in iron moulds, and thus formed a solid mass of carbon of the required form. To give further solidity to the mass, it is plunged into a syrup of sugar, afterward dried, and then subjected to intense heat in covered vessels. The form which Professor Bunsen prefers for his carbon conducting surfaces is cylindrical, and the shape of his battery resembles that of Daniell's. To make a good connection between the carbon and the connecting wire, a ring of copper is fixed round the top of the carbon cylinder to which the wire is soldered. The accompanying diagram shows the several parts of one of the cells of a Bunsen's battery, A being the carbon cylinder, with its copper ring and attached wire, B the porous cell into which it is introduced, C the cylinder of amalgamated zinc that surrounds the porous cell, D is the external earthenware jar, and E represents the arrangements of the whole completed.

Fig. 18.



Bunsen's battery is extensively used on the Continent, and it is represented to be, when in good action, nearly equal to Grove's in power, and superior to it in constancy.

I noticed this battery on the German lines. Telegraphers expressed themselves highly in favor of it. Its intensity was highly commensurate with the wants of the telegraph.

Nitric acid, mixed with its own bulk of water, is poured into the vessel in contact with the carbon. A mixture of sulphuric acid 1 part, water 25 parts, by measure, is poured into the porous cup in contact with the zinc. This arrangement may be varied by using a solid cylinder of carbon in the porous earthen vessel in the centre, and a zinc cylinder outside next to the glass. This latter method, I noticed in the central office in Paris, from which place a battery of 40 such couples worked all the lines from Paris. The batteries are renewed every week. A current of great intensity is generated by this combination.

In Denmark, Prussia, Austria and other German states, I noticed the carbon batteries in very extensive use, but no nitric acid was employed; weak sulphuric acid, 1 of acid to 20 of water, by measure, is placed in contact with the zinc, which is well amalgamated, and acid of 1 part sulphuric, to 9 parts water, is used in contact with the carbon plate. All telegraphers with whom I discussed the relative merits of the carbon, with that of the platina, were of the opinion that for telegraphic service the former was the best, and that without the use of the nitric acid, a current of sufficient intensity could be generated.

THE GROVE VOLTAIC BATTERY.

The most powerful voltaic battery that has yet been brought before the public, is that of Professor Grove, invented about 1839. The *intensity* of its action depends on associating two metals the most dissimilar in their chemical characters, and exposing one of them separately to the strongest exciting acid. This can only be done by using a porous cell, which keeps the zinc from the distinctive action of the powerful acids employed, and to which platinum is exposed in a separate compartment.

This battery has been in use on nearly all the telegraph lines in America until some five years since, when many of them adopted a modification of the Smee battery, invented by Mr. C. T. Chester. The following is a description of the Grove battery as used on the American telegraphs.

Figure 19 represents the zinc cylinder about four inches high, and three pounds in weight. Fig. 20 is a cylinder with the platina strip soldered to the arm B at C. Between A A is D, an opening, to give free action to the chemicals.

The porous cup, fig. 21, is made of the same materials as stone-ware, and baked without being *glazed*. A represents the rim surrounding the top. From the under side of the rim to the bottom, it is three inches long, and one and one quarter

Fig. 19.

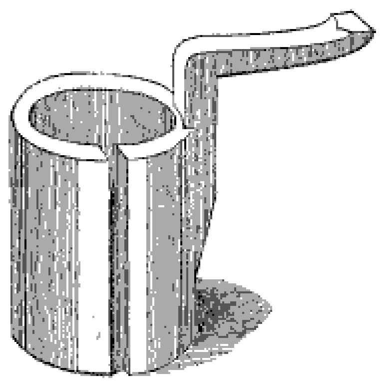


Fig. 20.

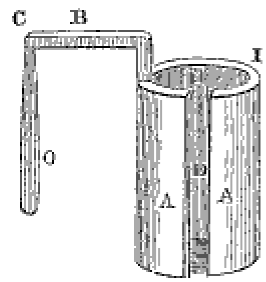


Fig. 21.

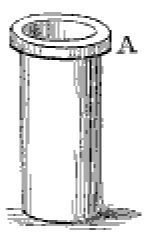
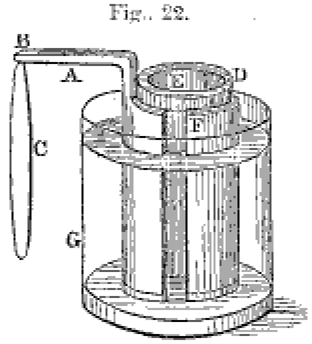


Fig. 22.



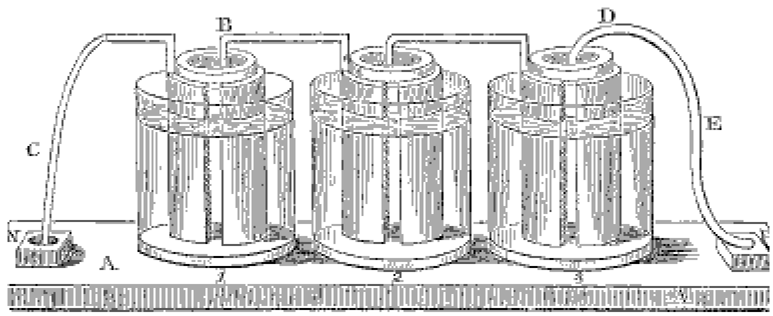
in diameter. The rim projects one quarter of an inch, and the shell of the cup is one eighth of an inch thick.

These several parts are placed together thus: The porous cup is set in the hollow of the zinc cylinder, represented by H, with the rim of the cup resting upon the top of the zinc at I. The zinc cylinder is then placed in the glass tumbler. The whole is represented in fig. 22.

D represents the porous cup, F the zinc cylinder, G the glass tumbler, A the projecting arm of the zinc, C the platinum plate, and B the overlapping of the platinum plate upon the zinc arm, where it is soldered to it.

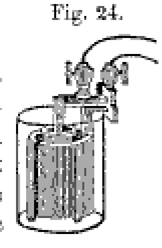
It is now in a condition to receive the acids, which are two: first, pure nitric acid, and second, sulphuric acid, diluted in the proportion of one part of sulphuric acid to twelve of water. First fill the porous cup with the nitric acid, to within one quarter of an inch of the top; then fill the glass with the diluted sulphuric acid, till it reaches to a level with the nitric acid in the porous cup. One cell of the battery is now ready for use; and as all the other members of the battery are similarly constructed, and are to be prepared and filled with their appropriate acids in the same manner, the above description will suffice. There remains, however, some further explanation in regard to the extremities of the series of glasses, that is, the mode of connecting the zinc of the first glass with the wire leading from it, and also the mode of connecting the platinum of the last glass with the wire leading from that end of the series of glasses. Figure 23 represents their arrangement.

Fig. 23.



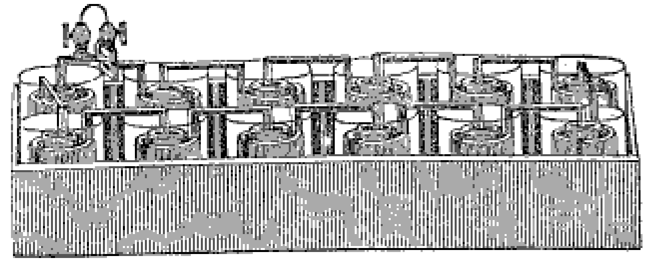
The glasses being all separately supplied with their acids, and otherwise prepared, they are put together upon a table, A A, perfectly dry, and made of hard wood. The first member of the series has soldered to its zinc arm a strip of copper, C, which, extending downward, has its end, previously brightened and amalgamated, immersed in a cup of mercury at N, the cup being permanently secured to the table. Then the second glass is taken, and the platinum, B, at the end of the zinc arm, is gently let fall into the porous cup, so that it shall be in the centre of the cup, and reaching down as far as its length, when the glass rests upon the table. The third glass is then taken and placed in the same manner, and so on to the last. The last glass has, in its porous cup, the platinum plate, D, soldered to a stripper, E, which is so constructed as to turn at the top, and admit of the easy introduction of the platinum into the porous cup, while the other end is fastened to the metallic connection with the line wire. The line wire is, also, connected with the mercury cup N. Sometimes the line wires are fastened with binding screws to the batteries as represented by fig. 24. When a large battery is required, the cells are placed in regular order as represented by fig. 25 excepting it is not uni-

Fig. 24.



versal to place the batteries in boxes. There are many contrivances having in view the insulation of the battery, to prevent local action, and cross currents from one cell to the other, generating various circuits of quantity electricity. I have seen the batteries, set upon tables covered with a sheet of gutta-percha, at other times I have seen the cells placed on the flat surface of glass, or on the edges of strips, cut an inch wide, and fastened in saw grooves. The glass strips were placed an inch apart. This

Fig. 25.



was quite an effective insulation. The best arrangement for insulating the cells, one from the other, has been gotten up by Mr. J. H. Wade, of the Western Union lines. The Wade insulator is squared flat at the top, and it is set on wooden pins, coated with gum lac, and fixed in the table. With this application there can be no cross currents, and the full voltaic force of intensity can be thrown over the lines for the uses of telegraphing.

Fig. 26.

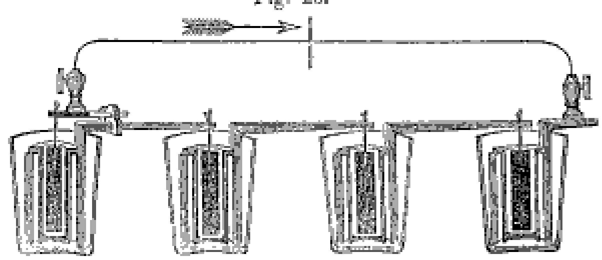


Fig. 26 represents a sectional view of the Grove battery, as practically employed on many lines, A is the platinum or positive pole of the battery, and B the zinc or negative pole. The chemicals act upon the zinc, and the platinum leads the electrical force generated in the cell, to the next in course and thence on. The current is indicated by the arrow, running from the platina end to the zinc or negative pole of the battery;

the circuit is thus completed. While the action proceeds, the zinc end is charged with *negative*, the copper with *positive* electricity. The current moves from the zinc to the copper or platina in the fluid, and from the latter by the intermediate wire to the zinc. Thus the wire attached to the copper or platina is positive, and that to the zinc is negative. If the circuit be several hundred miles the philosophy will be the same. On the telegraph lines, one end of the battery is connected with the earth, and the other with the line wire, thence to the terminal station, where that end of the wire is, also, connected with the earth. The opinion is entertained by some, and disputed by others, that the current flows over the line and returns through the earth. I have entertained the belief that the current does return to the source of its generation. It is a question, however, that no one is able to determine by the present known state of the science.

The Grove battery has proved its superiority for the greatest *intensity*. In getting this intensity—the power to overcome long distances—the telegraph incurs a very great expense. The zincs of a main line battery have to be renewed about every three months, and the consumption of nitric acid is very great.

Before using a zinc it should be well amalgamated with mercury, which penetrates the zinc if they are first immersed in water diluted with muriatic acid. It was my practice to use but $\frac{1}{30}$ part sulphuric acid in the water for the battery service, and every night the porous cups were emptied into a vessel and kept closed until morning. The zincs were removed from the tumblers and placed inverted in a trough of water acidulated with sulphuric acid. In the morning, the zincs were rubbed with a brush and the mercury caused to be diffused over the zinc. To every ten cups of nitric acid used in the battery, one additional cup of pure acid was mixed. By this process of mixing fresh acid every morning, the battery produced a steady and an even current on the line. The water, diluted with sulphuric acid, should be removed from the tumblers twice each week. Great care should be observed not to injure the connection between the zinc and the platina. On soldering platina to the zinc, the greater the surface of the platina applied to the zinc, the greater will be the power of the battery. The conductibility of the metals and fluids employed, should be commensurate, one with the other, in order to have the chemical and electrical action of the different elements uniform.

It is advisable for the telegrapher to make every connection of the different metals full, with the greatest amount of surface contact possible. The strength and efficiency of a battery of *intensity*, or of *quantity*, can always be determined by the fixed laws concerning the conductibility of the respective elements employed in the voltaic organization.

In the construction of the battery, care should be taken to insulate each cup or cell from the other. I have frequently seen a battery set upon a wet table, and the tumblers wet with moisture. When thus arranged, the chemical action of the battery will be more than ordinary, and several local circuits will be in electrical action. To prevent such hinderances to the efficiency of the battery, and to concentrate the greatest amount of electrical intensity, for purposes of the line, Mr. William M. Swain, the President of the Magnetic Telegraph Company, had constructed tumblers with feet, as represented by figs. 27 and 28.

Fig. 27.

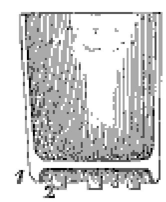


Fig. 28.

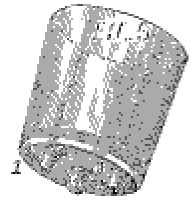


Fig. 29.

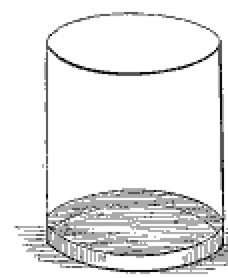


Fig. 27 is a sectional view of a tumbler. Beneath it is concave as seen by fig. 3, with the rim 1. The feet 2, project from the hollow below the rim 1. If moisture collects upon the glass it falls from the rim 1, or it remains upon the glass in globules. The arrangement is simple but of great importance to the efficiency of the voltaic organization, and no battery should be constructed without tumblers thus manufactured. The ordinary tumbler, fig. 29, sets upon the battery table, and the moisture gathered upon the glass soon forms a watery connection from one glass to the other, producing local action on many local circuits. The plan adopted by Mr. Swain economises the use of the battery, and attains a battery of intensity, so indispensable in the working of the line, and prevents the action of innumerable local circuits in the generation of quantity electricity.

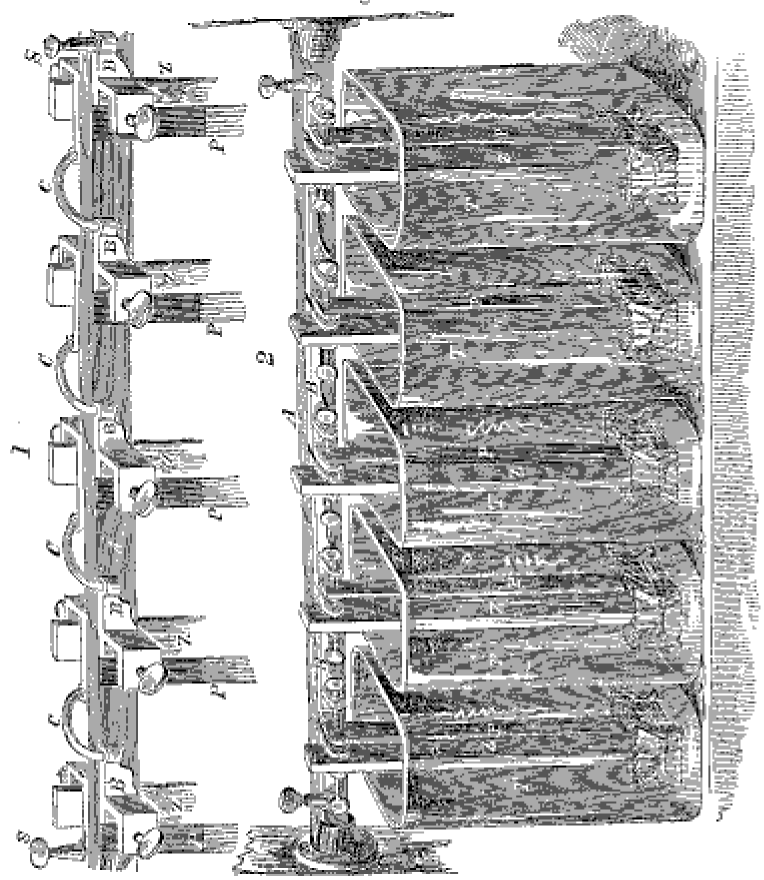
The local battery, generally composed of two or three cells, is more active, generating a *quantity* current for the working of the register. The circuit is confined to the station, the wire is larger in the register coils than in the relay, and the battery is more consuming than the main line series. The acids are renewed, sometimes every day, but generally whenever the register magnet requires an increased efficiency for the magnetization of the soft iron in the register spools.

THE CHESTER VOLTAIC BATTERY.

The next organization requiring especial notice is that generally known as the Chester battery, and extensively used on the American lines, both on the local and main circuits. The advantages in its use are, economy in the use of material, labor in taking care of it, and its uniform efficiency in generating a voltaic current suitable for practical telegraphing.

Fig. 30 is a representation of the Chester main battery, A A are insulated wooden bars, B B are brass clamps with the bind-

Fig. 30.



ing screw attached, Z Z are the zinc plates fastened by the clamp on the one side of the wooden bar; P P are platinized plates fastened by the clamps on the opposite side of the wooden bar from the zinc plates, T T are the elongated tumblers. In battery 1 the wooden bars rest upon the glasses, and in battery 2 they rest upon iron brackets fastened to supports. The wooden bar is covered with lac to prevent it from being destroyed by the acid. Gutta-percha and hard rubber bars have been used on some of the batteries, and they have served well. In the bottom of the tumblers are set small glass cups, in which are placed about two tablespoonfuls of mercury.

This battery has been widely extended over the American continent, to South America, Australia, and the Islands. Its cheapness, freedom from poisonous fumes, and long use without renewal, has gained for it many friends.

The battery is very cleanly, and can be placed on shelves or ornamented casings on the side of the wall in the operating room. Each zinc plate being supplied with a cup of mercury, the amalgamation continues, undisturbed by destroying acids. The zincs thus arranged continue in service about one year. The platinized plate with care in handling will not decay. The battery requires to be renewed or rebuilt about four times a year.

The following relative computations have been made in regard to the Grove, the Daniell, and the Chester batteries:

The Grove battery consumes 1½ pounds of nitric acid, 1¼ pounds of zinc, 1 pound of sulphuric acid.

The Daniell battery consumes 4 pounds of sulphate of copper, 1½ pounds of zinc, 1 pound of sulphuric acid.

The Chester battery consumes 1½ pounds of zinc, 3 pounds of sulphuric acid.

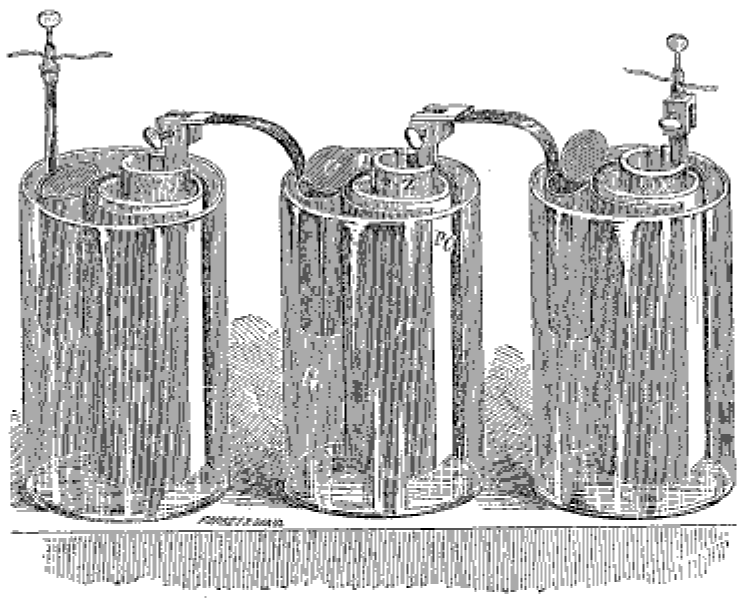
The only acid used in the Chester battery is sulphuric, in pure water and in very small quantities.

In a telegraph main-battery, the great object to be attained is the greatest degree of *intensity*, or *energy* of action or motion, to overcome distance; this intensity is obtained by increasing the number of the cells.

In a telegraph local battery, a *quantity* current is necessary. The circuit is short, and intensity current is not necessary. A quantity current depends upon the surface of the plates; and, to increase the *quantity* force, it is necessary to increase the size of the plates employed. These are the indispensable considerations to be regarded in the organization of any battery for telegraphic service.

Fig. 31 represents the Chester local battery, as practically empoyed on many of the American lines. Z is the zinc cylinders; P C the porous cup; C is the perforated copper chamber, attached, and G is the glass tumbler. It is arranged upon the

Fig. 31.



principles of the Daniell battery. A *quantity* current is generated by this combination fully equal to the requirements of the local circuit. The peculiar form of the metallic parts, present to the acidulated chemicals surface sufficient to produce the desired results. This form of battery has been very extensively used, and with advantages worthy of appreciation.

INTENSITY AND QUANTITY OF THE GROVE, DANIELL, AND SMEE BATTERIES.

The following facts have been determined relative to the comparative intensity and quantity powers of the Grove, Daniell and Smee batteries:

Intensity.		Quantity.	
Grove	87	Grove	44
Daniell	43½	Daniell	12
Smee, No. 1, open	27½	Smee, No. 1, open	42
Smee, approximated plates	32	Smee, approximated plates	49

Thus, it appears, that nearly equal quantities of electricity are excited by equal surfaces of Grove's and Smee's batteries, but that the intensity of the nitric acid battery, is rather more than three times that of Smee's. Daniell's arrangement holds an intermediate position with regard to intensity, but is deficient in quantity.