

In "Proceedings of the Royal Society," 1878, Captain Abney, F. R. S., publishes the results of experiments on the Gramme machine, in which he shows that the electromotive force increases directly as the number of revolutions of the armature, and that the current for any given number of revolutions varies inversely as the resistance in circuit; or, in other words, that the electromotive force for a given number of revolutions is constant. The dynamics of electric lighting by the use of the dynamo-electric machine is discussed by Mr. Robert Briggs in *Engineering*, xxvi., 316, and by Mr. Silvanus P. Thompson in the same journal, xxvi., 341. The former writer points out that the Franklin Institute experiments above detailed gave as a result but 380 candles of light as proceeding from 1 horse-power. Starting from this, he analyzes the theoretic expenditures of heat (or force) in producing both gas and electric lights, and comes to the conclusion that the relative expenditures of heat and fuel practically of the electric system by the dynamo-electric machines and steam-engine, as compared to that of coal-gas for equal quantities of light, is at present 1 to 2.2; while in the processes there will have been burned as fuel 1 lb. of coal under a steam-boiler, against  $5\frac{1}{4}$  lbs. of coal treated in the retort for the manufacture of coal-gas.

No subject is more prominently before inventors (1879) than the adaptation of the dynamo-electric machine to the economical production of the divided electric light; and the reader is therefore specially referred to the files of *Engineering*, *Scientific American*, *Journal of the Franklin Institute*, and other periodicals of later date than this work, for possibly important advances and discoveries.

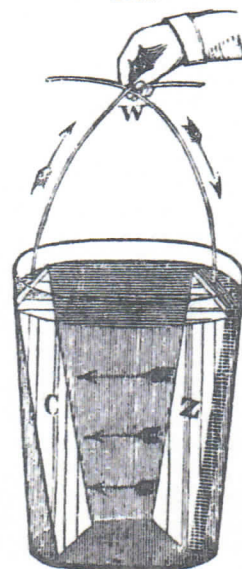
Art. from 1879 Appellton's Cyclopedia . . .

**ELECTRO-GALVANIC AND THERMIC BATTERIES. I. GALVANIC BATTERIES.**—When a piece of zinc is dropped into a vessel containing acidulated water, bubbles of gas are seen to issue from the metal, and the electro-dynamic impulses are propagated therefrom in every direction. By these counterbalanced opposite directions, the impulses neutralize each other's actions and reactions; consequently, no decided electro-dynamic action is perceptible. This experience was repeated thousands of times before the discovery of the galvanic battery arrangement, without developing electric excitation. But if a plate of copper or platinum, as at *C*, Fig. 1221, be placed opposite to the zinc *Z*, the impulses are determined through the water to the atoms of the copper plate, in one common specific direction. When the zinc is dissolving it gives off hydrogen and heat, while forming the more satisfied compound sulphate of zinc (the water being acidulated with sulphuric acid). The energy set free by the zinc entering into new combinations takes that form which we call electricity, instead of the other form which we call heat, and is capable of manifesting itself by its magnetic, chemical, or calorific effects (Sprague).

When the two free ends of the wire are brought in contact as shown, a current of positive electricity is generated, which, as indicated by the arrows, passes from the zinc through the liquid to the copper, and, traversing the copper plate from it, through the wires toward the zinc. At the same time a current of negative electricity is supposed to start from the immersed part of the copper plate, traveling in the opposite direction through the liquid to the zinc plate, and out of the cell from the zinc by the wire connected with it toward the copper. The particles (molecules) of the liquid through which the current passes are supposed to undergo polarization, i. e., the separation of the electricity of the respective molecules, so that one half of each molecule becomes positively and the other negatively charged (Angell), by which their invisible transfer is effected.

**Definitions.**—The combination of parts above described constitutes a *couple*. Many couples connected form a *battery*; couples of certain forms are called *cells*. The two metals or their equivalents are called *elements*, the one most acted upon being always the *positive* substance, and the other the *negative*. The supposed positive electric fluid will, however, always come out from the negative. The liquid employed is commonly called the *exciting liquid*. That metal which has the strongest affinity for oxygen is usually the most electro-positive, and one metal may therefore bear an electro-positive relation to a second, while it is electro-negative when compared to a third. Potassium is the most electro-positive of all bodies, but its attraction for oxygen is so violent as to make it practically useless as an element in the galvanic circuit. Among those which can be usefully employed as electro-positive elements, zinc ranks first, while platinum is the most highly electro-negative metal. But the relative electrical condition of several of the metals changes when immersed in different liquids; thus, if an iron and a copper plate be connected with the electrodes of a galvanometer and immersed in dilute sulphuric acid, the needle will be deflected in one direction; while if the plates are immersed in a solution of sulphide of potassium, the deflection will be in

1221.



the opposite direction. The following table shows a few of the results obtained by Faraday :

*Comparison of Different Metals in the Presence of Different Liquids.*

Dilute sulph. acid.	Hydrochloric acid.	Sol. of potash.	Sol. sulphide of potash.
Silver.	Antimony.	Silver.	Iron.
Copper.	Silver.	Nickel.	Nickel.
Antimony.	Nickel.	Copper.	Bismuth.
Bismuth.	Bismuth.	Iron.	Lead.
Nickel.	Copper.	Bismuth.	Silver.
Iron.	Iron.	Lead.	Antimony.
Lead.	Lead.	Antimony.	Tin.
Tin.	Tin.	Cadmium.	Copper.
Cadmium.	Cadmium.	Tin.	Zinc.
Zinc.	Zinc.	Zinc.	Cadmium.

The order in each column places the most positive metal in regard to the fluid at the bottom, and the most electro-negative at the top. It has been demonstrated by Poggendorff that the electromotive force between any two metals is equal to the sum of the electromotive forces between all the intervening metals.

The *conductive circuit* comprises the wires, instruments, etc., forming the path for the passage of the current (Prescott). *Resistance* is the opposition presented by the circuit to the development of the current; it is an inherent property of every substance, varying in degree in each substance, from silver, the best conductor, up to gutta-serena and other so-called non-conductors. The force of a battery, sometimes called the *tension* of the current, is the power which it has to transmit a current against resistance, such as that offered by a bad, long, or thin conductor, and is designated as its electromotive force. The unit of electromotive force is called a *volt*. The unit of resistance to the passage of an electric current is the *ohm*, and is about equal to that of a cylindrical wire of pure copper, .05 inch in diameter and 250 feet in length (No. 18 Birmingham wire gauge), or of 330 feet of No. 9 iron wire (.155 inch in diameter) of the average quality. The unit of the current is called a *farad*, and is equivalent to the quantity of electricity flowing per second in a circuit having an electromotive force of one volt and a resistance of one ohm. The quantity of electricity passing in a circuit, or the strength of the current, is estimated by the power of the current to deflect the magnetic needle, by the chemical decomposition it effects, or by the temperature to which it raises a wire of given thickness and material. The strength of the current must not be confounded with the strength of the element or battery which produces it. A battery of 100 cells has 100 times the electromotive force of a single cell of the same kind, yet in certain circumstances the one cell will produce as strong a current as the 100. The greatest quantity of current which a given galvanic element can produce is proportional to its surface. By doubling the size of the plates, the amount of current is doubled, provided the connecting-wire offers no appreciable resistance, and the quantity is not increased by increasing the number of cells. The electromotive force of a battery, on the contrary, is not affected by the size of plates, but by the number of cells in combination.

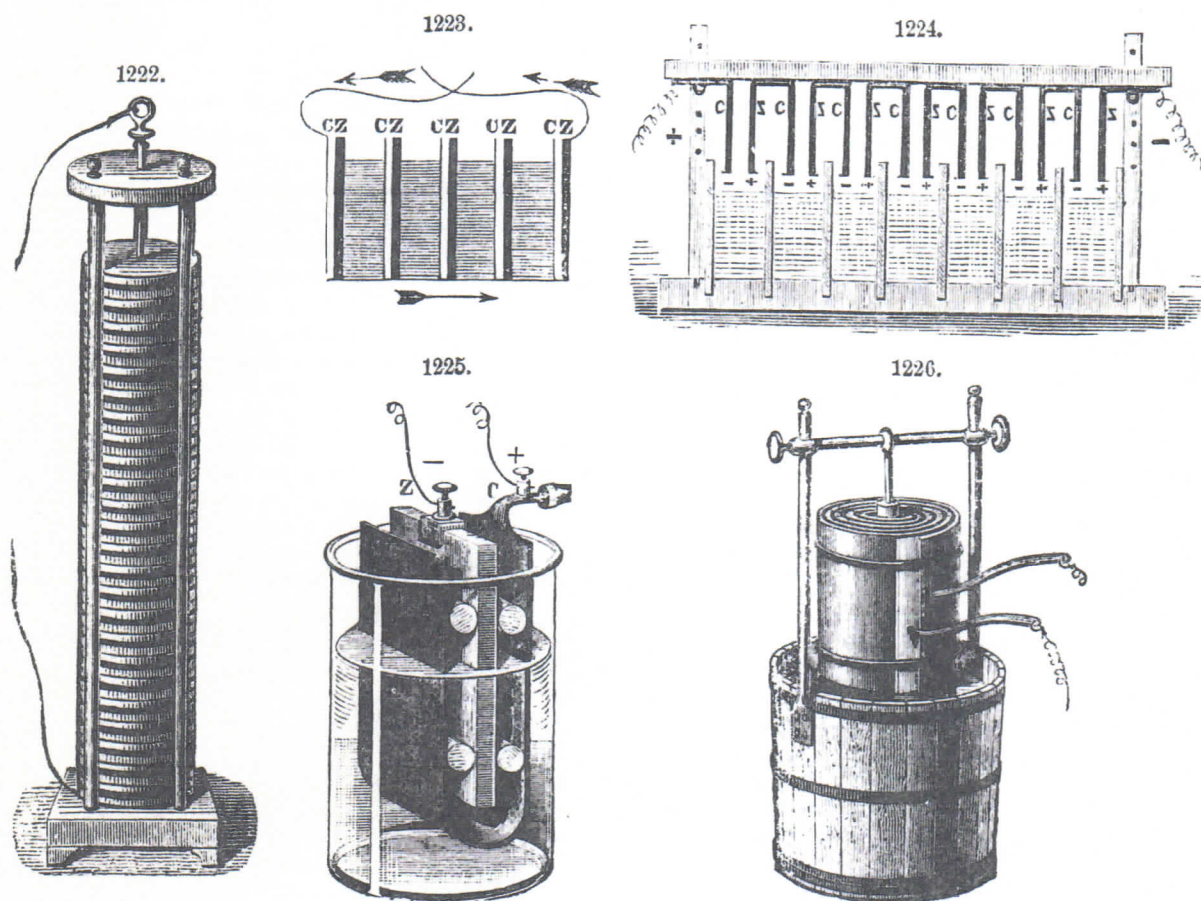
*Electrodes* is the term applied by Faraday to the poles or plates leading the current into and out of a cell. *Electrolysis* is the act of decomposition by an electric current. *Electrolytes* are bodies capable of being so decomposed (Sprague). *Ohm's laws* are formulas devised by Ohm for calculating unknown electrical magnitudes from certain given data. The symbols should represent fixed units to obtain definite results. They are as follows: 1. Current equals electromotive force divided by resistance. 2. Resistance equals electromotive force divided by current. 3. Electromotive force equals current multiplied by resistance. The chief *difference between frictional and voltaic electricity* consists in the fact that the latter is generated in very large quantities, but its electromotive force is so feeble as to render it incapable of overcoming a comparatively slight resistance; while the former, on the contrary, is generated in very minute quantities, but its electromotive force is so great as to enable it readily to overcome a resistance many million times as great as that which would entirely stop the passage of a current of voltaic electricity. The quantity of electricity which is denoted by unity in calculations based on electro-magnetic phenomena is nearly thirty thousand million times as great as the quantity denoted by unity when electro-static phenomena are taken as the basis of measurement.

*The Voltaic Pile.*—The voltaic pile of Volta, Fig. 1222, is constructed by placing upon a bottom piece of wood a disk of copper, and upon this a disk of zinc, repeating the order indefinitely, one end of the pile terminating in a copper, the other in a zinc disk. In Cruikshank's battery, Fig. 1223, plates of zinc and copper are placed together in pairs and held in vertical grooves, all the zinc plates facing in one and all the copper plates in the other direction; the connection between the plates should be impervious to the fluid of the trough. This arrangement is really a horizontal voltaic pile.

*The Dry Galvanic Pile of De Luc* is constructed of sheets of paper, coated on one side with gold or silver leaf, and alternated with thin leaves of zinc. By means of a circular steel punch, about an inch in diameter, disks may be cut out of sheets of this paper foil, all of one exact size, adapted to be packed neatly together in a long glass tube. The atoms of the leaves of zinc very slowly

become united with the atoms of oxygen of the air, recoiling to their natural polarized condition of groupings of an oxide, whereby a feeble propagation of electro-dynamic action is sustained during surprisingly long periods of time. Mr. Singer constructed a dry pile of 20,000 series of disks of silver, zinc, and writing paper, which propagated an intense electro-dynamic action, like that produced by frictional electrical machines, causing a pair of pith balls of an electro-scope to become divergent. A pith ball suspended by a silk thread between two metallic knobs, one connected by a wire with the top cap of the pile, and the other with the lower cap of the pile, continued to vibrate unceasingly between the two knobs during several years. A thin glass jar containing 50 square inches of coated surface, charged by 10 minutes' contact with the column, was found by Mr. Singer to propagate sufficient electro-dynamic action to fuse one inch in length of platinum wire of the diameter of  $\frac{1}{5000}$ th part of an inch. He states that an efficient pile may be made of one kind of metal only, as of zinc foil, if one side be made bright, and thus rendered more readily oxidizable than the opposite surface.

The black oxide of manganese contains an extraordinary excess of oxygen, capable of freely uniting with zinc and other metals. Zamboni improved De Luc's pile by coating one side of the paper

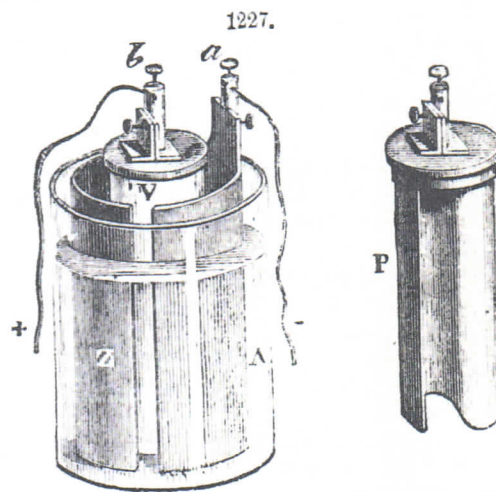


disks with this substance, mixed with sulphate of zinc, and the other side with tin foil. These piles are capable of developing sparks across a space of air of one-sixteenth of an inch, and also of producing chemical decompositions.

A common form of battery, which is merely a modification of Cruikshank's, is represented in Fig. 1224. It consists of a wooden trough divided into separate compartments containing the exciting fluid, into each of which are suspended a zinc and a copper or a zinc and a platinum plate, from a horizontal wooden beam, the opposite elements in each compartment being connected together. The beam slides in vertical grooves in posts at the end of the trough, by which means the plates may be raised out of or lowered into the liquid. They may also be easily removed from the beam and cleaned or amalgamated with mercury, an operation which it is essential to perform with zinc plates which are not of pure metal; and, it not being practical to procure this, the operation of amalgamation is therefore universal. It consists in applying metallic mercury to the cleared surface of the zinc plates, by which the pure zinc becomes dissolved and brought to the surface, where the action of the acid is confined. In impure unamalgamated zinc local polarization takes place, forming local currents which greatly diminish or annul the electromotive force. A modification devised by Wollaston consisted in having a sheet of copper brought around one end of a zinc plate and separated from it by pieces of cork. Any number of couples can be united by using a trough divided into compartments, or by employing a number of glass or earthen cups such as are represented in Fig. 1225.

*Hare's Deflagrator*, Fig. 1226.—A powerful form of battery for heating purposes, in consequence of the immense quantity of electricity it generates, was constructed by Prof. Hare of Philadelphia, and consists of one or only a few simple couples, having a great metallic surface. A large sheet of zinc of several hundred square feet of surface, and a similar one of copper, are separated by a piece of felt or cloth saturated with acidulated water and then rolled together in the form of a cylinder.

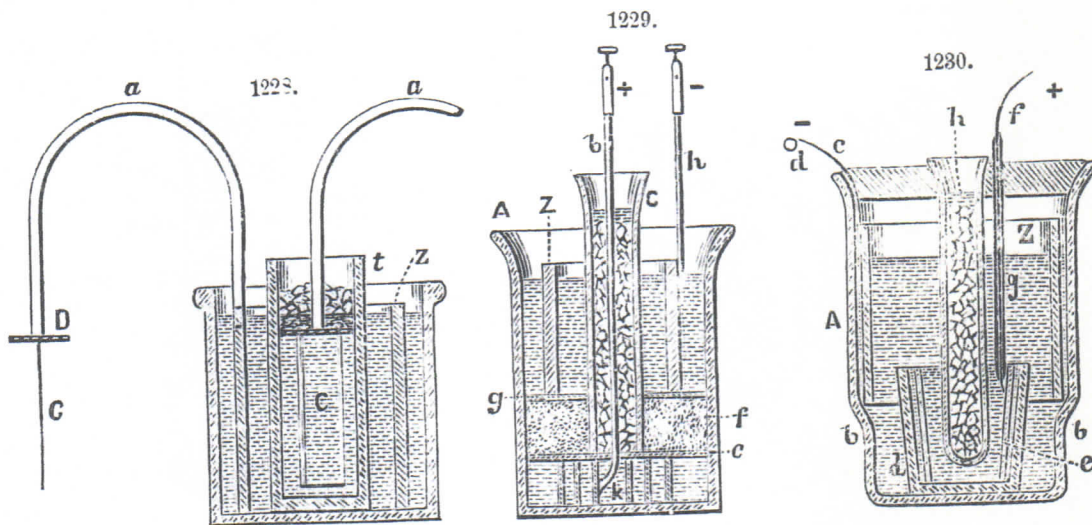
*Grove's Element*, Fig. 1227.—A glass or earthen vessel *A*, containing dilute sulphuric acid, receives a cylinder of zinc, within which is a porous earthenware cup *V* containing strong nitric acid, and in which there is immersed a platinum plate *P*. A cover attached to it confines the fumes of hyponitric acid, which are liberated by the decomposing nitric acid. The electromotive force is 1.956 volt.



The *Sesquioxide of Iron Element* of Messrs. Clamond and Gaiffe is composed of a prism of charcoal which contains sesquioxide of iron in its pores, and a small rod of amalgamated zinc. The latter passes through the stopper, in the under surface of which is fixed the charcoal. A solution of ammonium chloride is used as the exciting liquid. The reactions are the same as in Leclanché's couple, where oxide of manganese is used.

Its electromotive power is as 12 to 10 of the sulphate-of-copper battery, and it is thus well adapted for industrial purposes.

The *Daniell Improved Element*, Fig. 1228.—A porous-clay cylinder *t* is surrounded by a zinc cylinder *z*. Within the former is suspended a thin sheet of copper, which is attached to the copper wire *a*, connected to the zinc cylinder of the next cell. At the upper part of the copper sheet *C* a sieve-like perforated copper plate is attached, which serves to hold the sulphate-of-copper crystals. The glass vessel and porous cup of each cell is filled with water, and the crystals of sulphate of

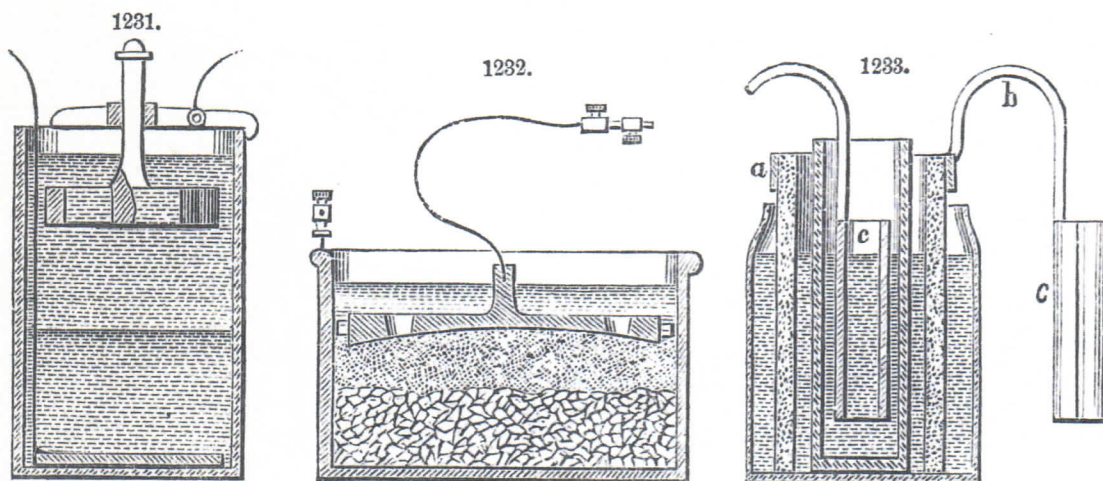


copper are placed as stated. Adapted for electro-deposition, gilding, silvering, electro-magnets, and large telegraphs; scentless, develops no poisonous vapors; electromotive force in volts, 1.08.

*The Siemens-Halske Element*, Fig. 1229.—*A*, glass vessel; *c*, glass tube; *k*, perpendicular copper plate bent in spirals; *b*, wire attached to it; *e*, thin pasteboard disk; *f*, diaphragm in place of porous cell in Daniell's battery, formed of a peculiarly-prepared mass of paper *z*; *h*, zinc ring, with clamp. Inner glass cylinder filled with crystals of sulphate of copper and water poured on. Ring-shaped intermediate space filled with water, to which on first filling is added acid or common salt. Quite constant, cheap, owing to prevention of chemical consumption of zinc and copper. Adapted for working long telegraph-lines; electromotive force same as Daniell's.

*The Meidinger Element*, Fig. 1230.—*A*, glass vessel, in which is placed cemented small glass vessel *d*, surrounded by zinc disk *Z*. Inside wall of *d* covered by copper sheet *e*, to which insulated copper wire *g* is riveted. Mouth of vessel closed by wooden plate, which receives glass cylinder *h*, having an opening below. This is filled with sulphate-of-copper crystals. Large vessel filled with diluted solution of Epsom salts. Valuable where long duration and a current of moderate but constant strength is required, and especially so for operating Morse telegraph, electrical clocks, hotel telegraphs, and electric bells. Electromotive force same as Daniell's.

*Gravity Element*, Fig. 1231.—A cylinder of zinc is suspended near the top of a glass jar, and a copper plate is placed at bottom. Jar filled with saturated solution of sulphate of copper and a



dilute solution of sulphate of zinc. The difference in the specific gravity of the two solutions causes them to separate at once and become superposed in the jar, the sulphate of copper occupying the lower and the sulphate of zinc the upper portions. Does not have the inconvenience experienced in use of Daniell battery from deposit of copper on porous cell. Electromotive force same as Daniell's.

An improvement on this form of battery has been devised by Edison, and is extensively used on telegraphs in this country. The modification consists in preventing the diffusion of the two liquids through each other by placing the copper element on top of a large quantity of the crystals of sulphate of copper, the tendency to diffusion being checked by the decomposition of the sulphate of copper.

*Callaud's Element* is constructed on the gravity principle, and works constantly for some months if care is taken to replace water lost by evaporation. It consists of a glass or earthenware vessel in which is a copper plate soldered to a wire insulated by gutta-percha. On the plate is a layer of crystals of sulphate of copper. The whole is then filled with water, and the zinc cylinder immersed in it. The lower part of the liquid becomes saturated with sulphate of copper. The action of the battery is that of a Daniell, and the sulphate of zinc which gradually forms floats on the solution of the sulphate of copper owing to its lower density.

*Sir William Thomson's Element*, Fig. 1232, consists of a containing vessel of sheet lead, in the bottom of which is placed 5 or 6 lbs. of sulphate of copper. This is covered with a layer of clean pine sawdust from 1 to 2 inches thick, upon which the zinc plate rests. The vessel is then nearly filled with soft water, or for quick action with a solution of sulphate of zinc. Remains constant, giving strong current for from three months to a year. Internal resistance low. Adapted for working circuits of small resistance, where comparatively strong and continuous currents are required.

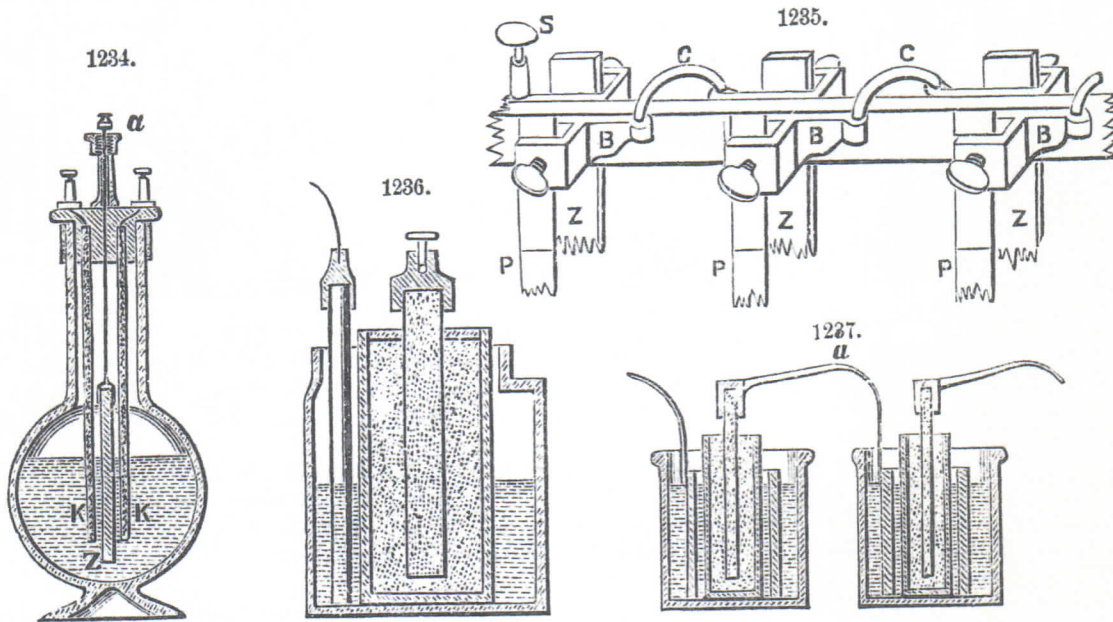
*The Bunsen Element*, Fig. 1233.—This consists of a carbon cylinder, open at the bottom, placed in a narrow-mouthed glass vessel. In the hollow of the carbon cylinder is inserted a hollow porous-clay cylinder closed at the bottom. A ring *a* is closely laid around the upper part of the carbon cylinder, and is attached to a hollow cylinder *c*, of rolled zinc. The porous-clay cup is filled with sulphuric acid, and the glass vessel with concentrated nitric acid. The zinc cylinder *c*, belonging to the next element of the battery, hangs in the porous cup filled with sulphuric acid. The positive current in this battery passes in the closing wire, outside the fluid, from carbon to zinc. The Bunsen element, like the Grove, develops a very powerful current, but it evolves a heavy deleterious gas. The carbons are sawn from the carbon deposited in gas retorts. A modification of the Bunsen battery is in use, in which a solution of bichromate of potash and sulphuric acid takes the place of the nitric acid. Electromotive force, nitric acid, 1.964; chromic acid, 2.028.

*The Grenet Element*, Fig. 1234.—This has a bottle-shaped cell, containing a mixture of 2 parts bichromate of potash, dissolved in 20 parts of hot water, and 1 part of sulphuric acid. To the wooden cover, which is inclosed in a brass frame, are attached two carbon plates, which permanently dip into the fluid; and between the carbon plates a zinc plate is suspended, which may be plunged into the fluid or withdrawn at pleasure. This element is not suitable for continuous use; but in all cases where a powerful current is required for a brief period, it may be economically employed. Electromotive force, 1.095.

*The Smee Battery*, Fig. 1235, consists of a strip of platinum, 1 inch wide by 10 in length, fastened to a beam of wood, upon the opposite side of which is a plate of zinc covered with mercury. Both are plunged into the glass vessel. *A* is the wooden bar, *B* brass clamps, *Z* zinc plate, *P* platinized silver plate or strips of platinum. Electromotive force when not in action, 1.090; in action, 0.482.

*The Leclanché Element*, Fig. 1236.—The + pole consists of a carbon plate, which on its upper end is coated with rosin and provided with a binding-screw; it stands in a porous cup, which is

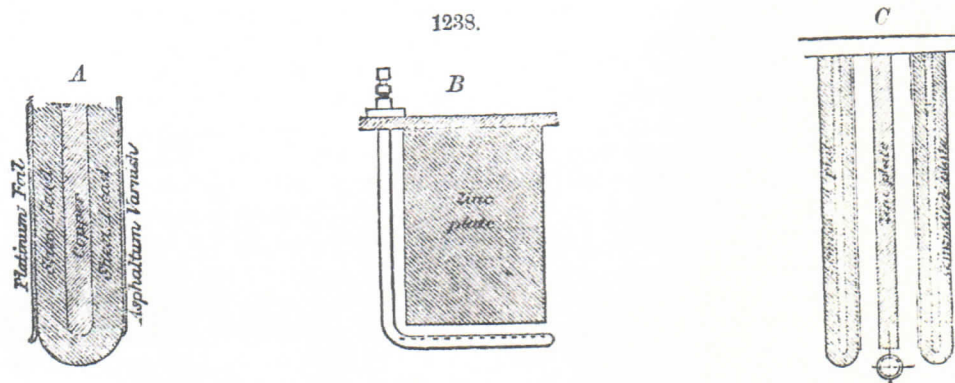
filled with a coarse-grained mixture of the needle form of peroxide of manganese and carbon from gas retorts. The — pole consists of an amalgamated zinc rod. Both poles stand in a diluted solution of sal-ammoniac, which is poured into the outside glass vessel. There is no waste of material when the battery is not in action, so that, if the evaporation of the liquid is prevented, it may be allowed to remain untouched for months without losing power. It is well suited for a telegraph-wire not in



constant use, and worked upon the open circuit plan or for electric bells. It is not suitable for permanent currents or local circuits, because when placed in short circuit it polarizes very rapidly and loses power. Electromotive force, 1.481.

*The Marié-Davy Element, Fig. 1237.*—The zinc stands in pure water, and the carbon in a paste of moistened protosulphate of mercury in a porous cup. While this makes a powerful battery which produces excellent effects, its maintenance is expensive, and it is not adapted for continuous work, owing to the slow solubility of the salt. Electromotive force, 1.524.

*The Byrne Compound-Plate Battery.*—The special feature of this battery consists in the negative plate, which, instead of being of one material, is constructed of three different metals soldered together. The surface exposed to the exciting solution and opposed to the positive or zinc plate is platinum; this platinum is backed by and soldered to a plate of sheet lead; behind this again is a plate of copper backed by a fold of the first lead plate doubled on to the back of the copper. The back surface of this second layer of lead is coated with asphaltum varnish. The arrangement will be understood from Fig. 1238, in which *A* represents a vertical cross-section of the compound negative plate, the thickness of its laminae being greatly exaggerated in order to show its construction. Each cell consists of a central zinc plate placed between two of the compound plates, as shown at *C*. The exciting solution consists of 5 ounces of potassium bichromate dissolved in 5 pints of boiling water, to which is slowly added when cold 1 pint of strong sulphuric acid. In the pneumatic form of the compound-plate battery the exciting solution is kept in a state of mechanical agitation by air being pumped into the cells through a perforated tube leading from each cell-cover to the bottom of the cell, where it turns at right angles, so as to lie in a horizontal position underneath and in a line with the central zinc plate and between the compound plates. Jets of air are thus injected into the cell, which, rising in the form of bubbles between the plates, keep the solution in violent agitation, washing off from the plates bubbles of hydrogen which otherwise would collect,



and insuring fresh fluid being continually brought into contact with the plates. The position of the air-tube is shown at *B* and *C*, leading to a small hand-syringe or bellows. A battery of 10 cells has heated to incandescence no less than 36 inches of stout platinum wire (No. 14 B. W. G.), and has decomposed acidulated water at the rate of producing 16 cubic inches of gas per minute. This battery has been tried with Mr. Spottiswoode's 18-inch induction coil, which it was capable of charging to its fullest extent, giving sparks in air 18 inches in length while the air was being pumped in, but which fell to 8 inches when the air supply was cut off. Mr. W. H. Preece, C. E., has determined that the greatly increased current is due partly to the diminution of resistance in the compound plate, partly to a second diminution of resistance in the liquid itself caused by the passing of the air through it, and partly to the production of heat, which, by modifying the chemical affinity between the molecules of the solution, reduces its resistance. Mr. Preece's experiments lead him to the belief that the action of the air is principally and directly mechanical, and indirectly chemical; for by mechanical agitation it removes adherent hydrogen from the negative plate, as well as the chrome alum which is formed there, and, by causing a circulation in the liquid, brings fresh acid into contact with the zinc, thereby assisting its consumption, and by the generation of heat reduces the resistance of the solution, and again aids the acid in dissolving the zinc. (See *Engineering*, xxv., 417-421.)

*Trouvé's Portable Battery*.—M. Trouvé has devised a simple and cheap form of portable battery suitable for military telegraphing, etc., which contains from 40 to 80 elements. Each of the elements is composed thus: Between two disks, one of copper, the other of zinc, are placed a number of round pieces of blotting-paper. One half of the rouleau is saturated with sulphate of copper, the other half with sulphate of zinc. The elements are arranged for tension in a case of hardened caoutchouc, and about a commutator and galvanometer, the whole being inclosed in a mahogany box. When the apparatus is to be used, the elements are immersed in water, which, absorbed by the paper, dissolves the sulphate of copper and sulphate of zinc, producing the chemical action necessary to a current. The paper remains moist for a long time. To recharge the pile, it is sufficient to immerse it one half in sulphate-of-copper solution, since the sulphate of zinc is continually being produced. (See *Les Mondes*, xxxiii., 3; *Scientific American*, xxxvii., No. 21.)

*The Maynooth Battery* is essentially the same as the Grove battery, except that it has a plate of iron instead of platinum, and is therefore much cheaper.

*Earth Batteries*.—These are simply voltaic couples in which the layers of acidulated cloth, etc., are replaced by a layer of moist earth. Large plates of copper and zinc have been buried several miles apart, and a powerful electric current has been found in a wire connecting them. The construction of such earth batteries, easy and simple as it appears to be, has never become a settled practice, by reason of the laborious digging required, it being much easier to plunge plates into cups and renew them after a while, than to dig up the oxidized zinc plates in order to replace them by new ones. However, when a brook or river is at hand, the use of earth batteries may be recommended, as in that case the zinc plate has only to be sunk at a convenient and safe spot. Then at any time, if the current becomes weak, the plate may be easily replaced by a fresh one, while in place of the copper a quantity of coke may be buried in the moist earth. The great objection to this form of battery is, however, the unavoidable total lack of intensity; as the latter quality depends upon the number of cups, and the earth or water acts as but one single cup, and thus the burial of several plates is equivalent only to the immersion of them in a single cup. If the plates are connected for quantity (that is, all the zincs together and all the coppers or cokes together), the series will act like a single pair, of which the surface is equal to the sum of the individual plates, and thus as one pair of large surface. If, on the other hand, the plates are connected for intensity (that is, every alternate zinc to the next copper), only the two plates at the extremes of the series will be of use, because the several intermediate pairs discharge mutually all the electricity generated into the moist earth through their metallic connections.

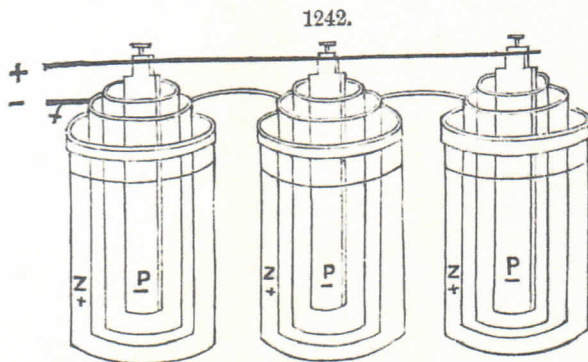
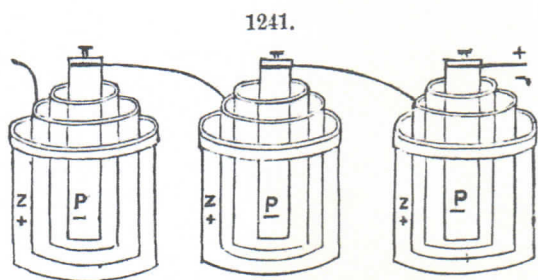
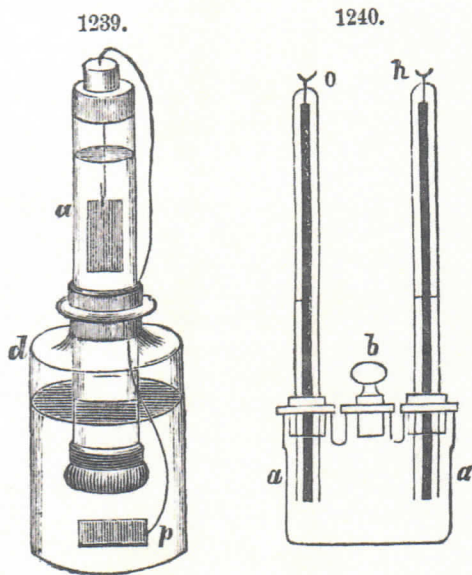
*Carbon-consuming Elements*.—It has been stated as probable that when the discovery shall have been made of how to oxidize carbon in the galvanic battery, the cheapest source of electricity will have been attained. Crookes's battery, in which carbon is claimed to be oxidized, consists of an iron ladle, which serves both as a containing vessel and as the non-attackable electrode. In this is melted nitrate of potash, and into the liquid thus produced carbon is plunged. The oxygen in the nitrate with the carbon produces carbonic acid, which unites with the remaining potash, forming carbonate of potash, and by the chemical action a current of electricity, which "affects the galvanometer," is liberated. A better current is obtained by a plate of platinum placed with the carbon in the fused salt. M. Jablochhoff has devised another form of carbon battery essentially the same as the foregoing. He rejects the platinum in favor of iron alone, and suspends his carbon in a wire basket in the liquid; but he says that by adding different metallic salts he is enabled to vary the power of the battery and the rapidity of expenditure of carbon, and with these salts there is received a galvanoplastic deposit of the metals on the non-attackable electrode. The electromotive force of the battery is stated to vary between 2 and 3 units, according to the nature of the metallic salts used.

*Becquerel's Two-Liquid Element*.—Fig. 1239 represents a galvanic couple composed of two liquids and one metal, devised by Becquerel, and called an oxygen circuit. A bottle, *d*, contains nitric acid, and into its mouth is inserted a tube containing a solution of caustic potash, and having a cork in the top through which passes a wire. The bottom of the tube is stopped by a piece of linen cloth,

which is covered with clay, and this with cotton wool, to prevent the clay from mixing with the liquid. The wire connects two plates of platinum, *a* and *p*, and the connection may be made through the coil of a galvanometer if it is desired to measure the strength of the current. The two liquids meet each other in the clay, and a current of considerable strength is generated, which passes through the wire from the acid to the potash solution, and through the clay from the potash solution to the acid; the latter answering to the copper plate of an ordinary couple, and the potash solution to the zinc. The water in the potash solution is decomposed, its oxygen escaping in bubbles, and its hydrogen going to the nitric acid, which it reduces to nitrous acid. The current which is generated is of constant strength, and the plates do not become polarized. The power is increased by making the plate in the potash solution of amalgamated zinc, which being attacked by the nascent oxygen produces polarization in the direction of the current. A simple couple of this kind is sufficient to effect the electrolysis of water, and several couples form a powerful battery.

**Gas and Secondary Batteries.**—In the electrolysis of water or any body which causes oxygen to be evolved at one electrode and hydrogen at the other, a thin film of gas becomes attached to each plate, having sufficient electromotive force to send a current in the contrary direction when the battery is removed and a connecting-wire introduced. Such currents, produced by polarized plates, are called secondary currents; and upon this principle Prof. Grove constructed a gas battery which is capable of producing a continuous current. Two glass tubes, Fig. 1240, closed at the top, each contain a strip of platinum, which is suspended by a platinum wire passing through the top of the tube. The surfaces of the strips present the metal in a finely divided state. The tubes at their upper extremities are closely sealed and filled with dilute sulphuric acid, and their lower ends, which are open, are placed in the same liquid in the vessel *a a*. The platinum strips are then connected with the poles of a battery, and by electrolysis hydrogen is collected in one tube and oxygen in the other. Upon removing the battery and connecting the platinum strips either through a galvanometer or an easily decomposed electrolyte, as iodide of potassium, a current will flow from the oxygen to the hydrogen tube, and in the opposite direction to that produced by the battery used in evolving the gases, while during the action the gases in the tubes will gradually disappear, the hydrogen twice as fast as the oxygen. Ritter's secondary pile is constructed upon the same principle. A number of disks of the same metal are separated by pieces of moistened cloth. After passing for a time a galvanic current through the system, on removing the battery and connecting the ends of the pile a current will be found passing in the opposite direction to the battery current.

M. Gaston Planté has devised a secondary element, which consists of a tall vessel of glass, gutta-percha, or ebonite, in which are placed two sheets of lead, rolled spirally, and parallel one to the other, and kept from touching by two cords of India-rubber rolled up with them; they are immersed in a solution of 1 part of sulphuric acid to 9 parts of water. The vessel is closed by a sealed cover pierced with a small hole, through which the liquid can be poured in or extracted, and which also allows the escape of any gas which may be generated during the charging of the battery. The



apparatus is surmounted by a disk of ebonite, upon which are fixed two contact pieces in connection with the two electrodes; two clips are also provided for the purpose of holding metallic wires to be made red-hot or melted by the secondary current. Two Bunsen cells, or in their stead three Daniell cells, are required to charge this secondary element. During the operation of charging, one of the electrodes oxidizes, a brown coating of peroxide of lead soon shows itself, and the metallic appearance disappears entirely; the other electrode also changes in appearance, its surface becoming covered with a powdery gray coating. When the charge has attained its maximum—that is to say,



when oxygen begins to be given off by the brown electrode—the secondary element is disconnected from the charging battery, for any further expenditure of the polarizing current is entirely wasted. The secondary element, once charged in this manner and left to itself, will retain a portion of its charge for several days; and even at the end of a week it is still far from being exhausted. The secondary element, when fully charged, has an electromotive force once and a half greater than that of Bunsen; it will redden a platinum wire of a greater or lesser diameter according to its size, or rather according to the size of the electrodes. Secondary elements can be joined together either for intensity or quantity, and form batteries capable of producing very powerful effects for short periods of time. (See *Scientific American Supplement*, i., 65. As to effects of large numbers of these elements when coupled together producing the electro-silicic light, see *Scientific American*, xxxviii., 313.)

*Connection of Elements in Batteries.*—The coupling of elements to overcome external resistance is represented in Fig. 1241. This is termed coupling for intensity or in series, and is the arrangement adopted in telegraph batteries and in galvanoplastic operations. Coupling for quantity is represented in Fig. 1242, where plates of the same metal are grouped together. It has the same effect as the employment of one pair of plates having an equal area of surface.

*Discharges from Great Numbers of Cells.*—Some remarkable experiments showing the effects of discharges of great numbers of cells have been made by Messrs. Warren de la Rue, Spottiswoode, and Muller. (See *Proceedings of the Royal Society*, No. 160, 1875, and No. 166, 1876.) The element consisted of a flattened wire of silver and a rod of zinc. At one end of the silver a cylinder of chloride of silver was cast. In order to prevent contact between the rods of zinc and chloride of silver, the latter was surrounded with a cylinder open at top and bottom, and made of vegetable parchment. The cell was a glass tube, the stopper a cork saturated with paraffine, and through which a rod of non-amalgamated zinc was inserted. The exciting liquid was a solution of 23 grammes of chloride of ammonium to 1 litre of water. On examining the length of discharge from various numbers of these elements, its length was found to be in the direct ratio of the square of their number, as follows:

No. of cells.	Striking distance.		No. of cells.	Striking distance.
600	.0033 inch.		1,800	.0345 inch.
1,200	.0130 “		2,400	.0535 “

These are very nearly the squares of the number of cells. As the experiments were carried further, it was found that the striking distance probably increases in far greater ratio. Taking as a basis the spark with 600 cells = .0033 inch, the investigators point out that a unit of 1,000 such cells would give a spark of  $\frac{.0033 \times 1000^2}{600^2} = 0.009166$  inch; one hundred units (100,000), a spark of 91.66 inches; and a thousand units (1,000,000), a spark of 9,166 inches, or 764 feet—nearly a true flash of lightning, not only in distance but in quantity. With 5,640 cells sparks were obtained over .139 and .140 inch; and other phenomena were noted, which will be found described in detail in the references above given.

An excellent series of lectures on the voltaic battery by Dr. Gladstone, F. R. S., appears in the *Telegraphic Journal*, iii., 14. See also the list of works for reference given under the general heading of ELECTRICITY.