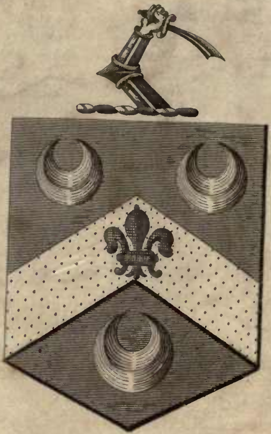
Society of Apothecaries.

PRESENTED BY



Fortnum.

AN ACCOUNT OF THE HISTORY AND PRESENT STATE OF GALVANISM.

BY

JOHN BOSTOCK, M.D. F.R.S.

MEMBER OF THE GEOLOGICAL SOCIETY; MEMBER AND LATE PRESIDENT OF THE EDINBURGH MEDICAL SOCIETY; MEMBER OF THE LONDON MEDICAL AND CHIRURGICAL SOCIETY; HONORARY MEMBER OF THE NEW-YORK HISTORICAL SOCIETY, &c.

LONDON:

PRINTED FOR BALDWIN, CRADOCK, AND JOY, PATERNOSTER ROW.

1818.

C. Baldwin, Printer,
New Bridge-street, London.

ADVERTISEMENT.

THE basis of the following Essay is an article that was published in the tenth volume of Dr. Brewster's Encyclopædia. The commendations which it received, while under that form, from those whom I supposed competent to decide upon its merits, have induced me to reprint it, although with considerable additions and corrections, which will, I hope, render it more deserving of the public favour. My present residence in the metropolis has given me the opportunity of examining several works on galvanism, which I had not before been able to procure, and I have also endeavoured to profit by the remarks of my scientific friends, so as to rectify the inaccuracies into which I had fallen, and to render those parts more perspicuous, which were thought to be obscure.

Great Coram Street,
June 24, 1818.

For a Description of the Plates, see Page 156.

ERRATA.

Page 27,	line 11,	for *cocks*	read *corks.*
Page 28,	line 9,	for *dissolved*	read *decomposed.*
Page 69,	side note,	for *d*	read *and.*
Page 127,	line 10,	for *effected*	read *affected.*

ON GALVANISM.

GALVANISM is a branch of natural philosophy, entirely of modern origin, which derives its name from Galvani, Professor of Anatomy at Bologna. He had the good fortune to make some observations on the electricity of the muscles of frogs, that appeared to him to depend upon a new power in the animal body; and although it is now generally admitted that he drew an erroneous inference from his observations, yet they led to a train of experiments, which have associated his name with some of the most brilliant discoveries of modern science. To the supposed new power he gave the name of *animal electricity*, conceiving it to depend upon something inherent in the animal body itself; but we now regard these effects as produced by minute quantities of the electric fluid, set at liberty by a certain agency of substances upon each other.

Galvanism may be defined, a series of electrical phenomena, in which the electricity is developed Definition without the aid of friction, and where we perceive a chemical action to take place between some of the bodies employed.

Plan of the essay.

In treating upon this science, it will be found convenient to arrange the subject into two divisions: in the first I shall give an historical detail of the discoveries that have been successively made from the time of Galvani's first observation to the present period; and, in the second place, I shall examine the principal theories and hypotheses that have been formed to explain the phenomena of galvanism.

PART I.

SECTION I.

Experiments before the Discovery of the Pile.

In reviewing the history of galvanism there are two great eras, which especially arrest our notice, the formation of the pile of Volta in the year 1800, and the decompositions of the alkalies and earths by Sir H. Davy in 1806; these discoveries naturally divide the narrative into three periods, during each of which a particular train of phenomena was pursued, and the attention was occupied by a different kind of investigation. **Galvani's experiments, 1791.**

The original discovery, to which I have already alluded, took place from a singular accident. The wife of Galvani, being in a declining state of health, employed as a restorative, according to the custom of the country, a soup made of frogs. A number of these animals, ready skinned for the purpose of cookery, chanced to lie in his laboratory, on a table near an electrical machine. While the machine was in action, an attendant happened to touch, with the point of a scalpel, the crural nerve of one of the frogs that was not far from the prime conductor, when it was observed, that the muscles of the limb were instantly thrown into strong convulsions. This experiment was performed in the absence of the Professor, but it was noticed by his lady, who was much struck with the appearance, and communicated it to her husband. He repeated the experiment, varied it in different ways, and perceived that the convulsions only took place when a spark was drawn from the prime conductor, while the nerve of the frog was, at the same time, touched with a substance which was a conductor of electricity. At the time that this accidental discovery was made, Galvani was engaged in a set of experiments, the object of which was to prove that muscular motion depends upon electricity; and it appeared, in a very remarkable manner, to confirm his hypothesis; so that he was induced to prosecute the inquiry with redoubled diligence.*

Prepared frog a very delicate electrometer.

When a frog was so placed as to form part of the electric circuit, it was found that an extremely minute quantity of electricity produced contractions in the muscles. If the hind legs were dissected from the body, the connexion being kept up by the crural nerves only, and the electric fluid was passed through it in this state, a still more minute quantity was rendered visible; so that a frog, prepared in this manner, was capable of exhibiting

* Eloge de Galvani, par Alibert.

very decisive marks of electricity, where none could be detected by Bennet's gold-leaf electrometer.

Discovery of proper galvanism.

After employing the electric fluid, as disengaged from the common machine, Galvani next tried the atmospherical electricity; and it was in pursuance of this object, that he was first led to observe the effects of galvanism properly so called. Having suspended a number of frogs by metallic hooks to an iron railing, he found that the limbs were frequently thrown into convulsions, when it did not appear that there was any electricity in the atmosphere. Having duly considered this phenomenon, he discovered that it did not originate from an extraneous electricity, but that it depended upon the position of the animal, with respect to certain metallic bodies.

Action of two metals.

It appeared, that when the muscle and nerve of a frog were each in contact with metallic bodies, and these were also connected by a metal, the contractions were always produced. The effect was considerably increased by *arming* the nerve with a metallic coating, by which means a larger portion of it was brought into contact with the metal. But the most important of Galvani's discoveries was the effect produced by the combination of two metals. Of these combinations the most powerful was that of zinc and silver; and the most violent convulsions ensued when the nerve was coated with one of these metals, the muscle placed in contact with the other, and the

Plate I. Fig. 9.

two metals connected by a conductor of electricity.

General conclusion.

Galvani's general conclusion from his experiments was, that the animal body possesses an inherent electricity of a specific kind, which is connected with the nervous system, and conveyed by means of the metals into the muscles, so as to throw them into convulsions. He deduced a theory of muscular motion from his discoveries, according to which the body contains an apparatus analogous to the Leyden phial, its different parts being in different states of electricity, and the metals forming a connexion between them, by which the electricity is equalized. In this application of the new phenomena, Galvani went beyond the limits of correct deduction; yet he deserves much commendation for the perseverance and ingenuity which he exhibited in prosecuting the inquiry. Although the discovery originated, in a considerable degree, from accident, still it must be remembered, that it is only men of ability who take advantage of such accidents.*

Valli's letters, 1792.

Galvani had no sooner published an account of his discovery, than the philosophers, in different parts of Europe, entered with eagerness upon the examination of the new phenomena. Among the earliest writers on the subject were Valli, Fowler, and Volta. The principal object of Valli's letters †

* A. Galvani de Viribus Electricitatis in Motu musculari Commentarius.

† Journal de Physique, xli. and xlii.

was to examine how far the opinion of Galvani was correct, respecting the dependence of the new influence upon the nervous fluid, and its identity with electricity. Although much of his reasoning must now be regarded as erroneous, yet still he manifests ingenuity and address in the contrivance of his experiments, and in the inferences which he deduced from them.

Fowler's Essay on Animal Electricity, 1793.

In the following year, Fowler published his Essay on Animal Electricity, which displays considerable acuteness, and by which he may be considered as having prepared the way for many of the discoveries of his successors. At the time when he wrote, the question was warmly agitated, whether the phenomena of galvanism could be referred to the electric fluid, or whether they do not rather depend upon some specific agent peculiar to the animal body. He accordingly commences by the inquiry, "Are the phenomena exhibited by the application of certain different metals to animals referable to electricity?" Although he conducts his train of reasoning with much ability, yet he drew the conclusion which we are now enabled to say is not correct. After examining minutely the circumstances which are necessary for the production of the galvanic influence, he finds that it is requisite that there should be two different metals, which are to communicate with each other and with the animal. He conceives it necessary that they should be in contact, one with the nerves, and the other with the

Are galvanism and electricity identical?

muscles; and points out an error into which Valli had fallen in his experiments, where he thought that the contact of the nerve only is sufficient to cause the contractions: he shows that, in this case, the moisture on the surface of the nerve acted as a conductor of the influence of one of the metals to the fibres of the muscle.

Supposed to be different.

Fowler concludes that the galvanic influence is not referable to electricity, because for the production of the former the presence of two different metals appears to be necessary, while electricity, as proceeding from the electrical machine, is excited by the action of an electric upon a conductor; an inference which was correct, according to the state of the science at the time when he wrote. He also endeavours to show that electricity and galvanism are not, in all cases, conducted by the same substances, and particularly adduces charcoal, which, although a conductor of electricity, is impervious to the galvanic influence. He afterwards made some curious observations upon the effect of galvanism on animals not furnished with distinct limbs, such as worms of various kinds. These animals could not be made to contract; yet by the nature of their motions, they seemed to be sensible to the impression of the two metals, when they were placed, partly on one, and partly on the other. From these experiments he inferred that animals of this description were furnished with a nervous system, and that the peculiar effect of the metals upon them depended upon the mechanism of their organs of motion.

Fowler afterwards enters upon an interesting inquiry respecting the effect of galvanism on the different parts of the body. "What are the relations which subsist between the influence discovered by Galvani, and the muscles, the nervous, and the vascular systems of animals?" He found that the contractions were very readily excited in all the muscles which are subservient to the will, but that they were with great difficulty produced in the heart, while he was not able to produce any effect upon the stomach and intestines. He observed, that when a part is in a state of inflammation it acquires an additional sensibility to the galvanic stimulus, and he made the curious discovery of the flash of light, which is produced by placing the two metals in contact with the ball of the eye, and then causing them to communicate with each other. Sultzer, a German metaphysical writer, had mentioned several years before, the effect produced on the organ of taste, by applying two metals, one above and the other below the tongue, and then bringing them into contact; but the sensation was ascribed to a peculiar vibration excited by the metals, and conveyed to the tongue. The experiments with the two metals, upon the eye and the tongue, were varied in different ways by Professor Robison, an account of which is published at the end of Fowler's Essay. Professor Robison also mentions the sensation of taste which is excited, when the tongue is applied to the edges of a number of plates of zinc and

Effect on the voluntary and involuntary muscles.

Effect on the eye and tongue.

Robison's experiments.

silver, placed alternately upon each other; a construction which may be regarded as an approximation to the apparatus afterwards discovered by Volta.

Volta's letters, 1793.

In the same year in which Fowler's Essay was published, a very valuable communication appeared in the Philosophical Transactions of London, from the pen of Professor Volta, of Pavia, in the form of letters to Cavallo. He gives a luminous account of Galvani's discovery, and adds many curious experiments and observations of his own. He attempted, and with complete success, to overthrow Galvani's opinion, that the animal body bears an analogy to the Leyden phial, its different parts being in opposite states of electricity. He supposed, that for the production of the effect it was essential to have two different metals; and hence he arrived at the important conclusion, which may be regarded as leading to all his future discoveries, that the muscular contractions are produced by small portions of electricity, that are liberated by the action of the metals upon each other. Another point which Volta established was, that the nerve is the organ on which the galvanic influence immediately acts; but he found that if a part of a muscle be laid upon two different metals, and these be made to communicate, a contraction is produced. This probably depends upon the nervous matter that is dispersed through the muscles, and also upon the moisture that is always present, and which serves to conduct the electricity to all parts of the body. Volta performed many experiments, in order to discover what circumstances are favourable to the excitation of the contractions, and what parts of the body are the most easily called into action. His observations agree, in almost all respects, with Fowler's, although it is certain that their experiments must have been made without concert or communication. He found that snails and worms could not be made to contract; but that many of the insects, as butterflies and beetles, were subject to the influence of the metals. It appeared from his numerous trials, that those animals alone were sensible to galvanism who are furnished with distinct limbs, having flexor and extensor muscles. In the animals of this description, he supposed that it was the voluntary muscles alone which are capable of being made to contract. Although the heart is a muscle which is easily thrown into powerful action, by chemical or mechanical stimuli, yet he could never produce any effect upon it by the action of the two metals. Volta made some of the same observations upon the effect of the two metals on the organs of sense as have been mentioned in the account of Fowler's Essay.

Volta's theory.

In these letters Volta lays down the basis of the theory of galvanism, which, with certain modifications, he has since so zealously defended, and which may be regarded as the one that has been most generally received. He argues against the doctrine of Galvani, that the animal body has any share in the production of the electricity; this is thought to be entirely owing to the action of the two metals upon each other; by this action a small quantity of the fluid is liberated, which, by passing through the nerve, causes the muscular fibres connected with it to contract. This action of the metals upon each other is described as one by which their electrical equilibrium is destroyed; and by establishing a communication between them, their equilibrium is restored. This destruction of equilibrium he speaks of as a new law of electricity discovered by himself; and the animal is supposed to have no further concern in it, than as being a peculiarly sensible electrometer, and affording a very delicate test of the presence of this disengaged electricity in its passage from one metal to the other.*

Wells's paper, 1795.

Dr. Wells wrote an interesting paper on galvanism, which was also published in the Philosophical Transactions of London. He proposed three distinct objects of inquiry, which, at the time when he wrote, embraced the points that were the most general subjects of discussion. He first inquires, whether the influence discovered by Galvani depends upon any property inherent in the animal body, or peculiar to it: in the second place, he inquires into the conditions that are necessary for its excitement: and, lastly, he examines how far

* Phil. Trans. for 1793, p. 20, et alibi.

it ought to be considered as identical with electricity. Dr. Wells coincides in opinion with Volta, that the contractions of the muscles depend upon electricity liberated by some cause, independent of the animal body, and that the moisture which is present in all parts is the immediate cause of the facility with which the effect is produced. He discovered the important fact, that charcoal may be employed, together with one of the metals, for exciting the influence; and also that the influence, when excited, may be conducted by charcoal. He argues at length against the hypothesis of Volta, respecting the production of the electricity by the contact of the two metals, and urges as a decisive objection to it, that the moisture which is attached to the animal ought to serve as a conductor, and equalize their electrical condition, without their being absolutely brought into contact.

Dr. Wells made some curious experiments upon the effects that were produced on the power of the metals and on charcoal by friction; after this operation he found that one of the substances alone was sufficient to produce the contractions. As it appeared that the friction did not immediately communicate electricity to the body that was rubbed, it must be supposed that some change was brought about in its nature, by which its different parts were enabled to act upon each other in the same manner with two distinct substances. He is decidedly of opinion, that galvanism is identical with electricity, because every substance which is a conductor of one of these principles is also a conductor of the other.*

Humboldt's experiments, 1795.

An interesting set of experiments was performed about this time by Humboldt, on the irritability of the muscular fibre; the object of which was to prove that this property depends immediately upon a specific proportion of the chemical elements which enter into the composition of the muscle. When certain agents were applied to a muscle, he conceived that its contractile power was increased, in consequence of some change that had been effected in its chemical composition, or even that the contractility might be restored after it had been destroyed, while, on the contrary, there were other agents which seemed to be equally powerful in depriving the muscles of their irritability, in consequence of an opposite change in their chemical constitution. He employed the galvanic influence as a test of the presence of the irritability of the muscle; and he was led, in the course of his experiments, to inquire into the nature of this influence, and to make many curious observations concerning it, which were derived from a very elaborate train of experimental research. He was induced to form some conclusions very different from those that had been adopted by Galvani, Volta, and the authors that had preceded him, some of which were important additions to our

* Phil. Trans. for 1795.

knowledge; but with respect to others, we can have no hesitation in pronouncing them to be erroneous.*

Remarks upon them.

One of his doctrines, to which this remark applies, is the opinion that the galvanic influence is not electrical, an opinion which he embraced after long deliberation, and, as he supposed, after duly considering all the phenomena, and carefully weighing the arguments on both sides of the question. As at this period the whole that was known of the effects of galvanism was their action upon the organs of the living body, Humboldt was led to suppose that it was entirely a vital action, or that it depended upon something essentially connected with the living body; he however differed from Galvani and Valli, who regarded it as a proper electrical phenomenon, depending upon electricity evolved from the different parts of the body itself, without the addition of any extraneous substance. Humboldt's experiments were brought forward in such a manner, as to impress upon his readers the idea that they were performed with the most scrupulous regard to accuracy; yet owing to the novelty of the subject, and no doubt also, in a considerable degree, to the extremely delicate nature of the substances on which he operated, it appears that many of them

* Ann. de Chim. xxii. 51; Journ. de Phys. xlvi. 465, and xlvii. 65; Experiences sur le Galvanisme, Traduction par Jadelot, 1799.

have not been found to succeed in the hands of other experimentalists. One important fact, however, he may be considered as having established, that contractions can be excited in an animal by placing the nerves and the muscles in certain situations with respect to each other, without employing any metallic substance; a fact which was afterwards brought forward in a very striking manner by Aldini, but which appears still to be involved in a degree of mystery, both as to the nature of the operation itself, and as to the class of physical phenomena to which it ought to be referred.

Volta's additional theory.

Volta continued to be actively engaged in prosecuting his inquiry into the nature of galvanism, and in perfecting the hypothesis that he had formed, to explain the operation by which it is excited. He now introduced a new principle into his theory, and found it necessary to alter the terms in which he had announced it, particularly with respect to the circumstances requisite for the extrication of the electric influence. He had before stated that two metals were essential to this purpose; but he now informs us that, provided the substances differ in their power of conducting electricity, their metallic nature may be dispensed with. He divides conductors into the two classes of the dry and the moist; the first including metals and charcoal; the latter essentially consisting of water, holding various substances in solution. In order to form a galvanic circuit, it is necessary that a body from one of these classes be placed between two bodies from the other class; by this means the equilibrium is destroyed, and it is again restored when the two are united by a conductor. The same effects proceed from this arrangement as when the equilibrium is destroyed by the contact of the two metals; but two conductors of the same class, whatever be their difference, are not sufficient to form a circuit without the intervention of one of the other class. For the purpose of illustrating his theory, he brings forward what he calls an *experimentum crucis;* he applies the ends of two metallic rods, one formed of silver and the other of tin, to the two disks of Nicholson's doubler, and unites their other ends by a moist conductor; after they have remained for some time in this situation, he finds that the disk in contact with the silver rod indicates the positive electricity, and that in contact with the tin the negative. As was the case in his former paper, he does not attempt to explain the cause of this change in the electric state of the substances, but is satisfied with pointing it out as a matter of fact which he had discovered, and as constituting a well-established, although empirical law of electricity.*

Committee of the French Institute, 1798.

A very ample and elaborate memoir on the subject of animal electricity was drawn up by a committee of the French Institute, which, besides

* Ann. de Chim. xxiii. 276.

examining all the opinions and controversies that existed on the subject, contained an account of a great variety of original experiments. The committee was composed of some of the most celebrated chemists and natural philosophers of France; Morveau, Fourcroy, Vauquelin, Hallé, Coulomb, Sabbatier, Pelletan, and Charles. They arrange the materials of their report under six heads: 1st, They examine the different circumstances which influence the nature of what they call the animal arc, by which they mean, that part of the galvanic circle which consists of the parts of the animal. They conceive that the animal arc may consist of nerve only; they found that cutting a nerve across did not prevent the passage of the influence, provided the cut ends were laid close together, and also that it was transmitted through different parts of the same animal, or even through parts of different animals, provided they were in perfect contact. They observe, that when a nerve is made part of the circle, those muscles are thrown into contractions to which the extremities of the nerve are distributed, not those which are contiguous to the trunk of the nerve. In the 2d place, they examine the nature and disposition of what is called the excitatory arc, or the metallic part of the circle. 3d, They inquire into the circumstances extrinsic to the composition of both parts of the galvanic circle, but which in any way affect its action, or influence its effects. The 4th head consists of the means which may be employed for varying, diminishing, or restoring the sensibility of the animal to the galvanic influence. In this part, they mention the effects of immersing the animal in a fluid, or in an unrespirable gas, so as to produce suffocation, when the susceptibility to the galvanic influence was either destroyed or much impaired; but the effects were very various, and difficult to account for in many cases. The 5th head consists of a comparison between electricity and galvanism; and the 6th contains a detail of some experiments which were performed by Humboldt, and subjected to the inspection of the committee. These appear to have been substantially the same experiments of which I have already given an account.*

An ingenious paper was about this time published by Fabroni, of Florence, in which he discusses the question, whether the galvanic phenomena are immediately referable to electricity, or whether they ought not rather to be attributed to chemical affinity? He relates many observations, that he made upon the chemical action of different metals on each other, when placed in contact, and shows, that they were then disposed to oxidate under the same circumstances, except that of being in contact, where, if separate, no effect would have been produced. He argues, that the facts stated by Galvani, Volta, and others, which were con- **Fabroni's paper, 1799.**

* Journal de Physique, xlvii. 392, 441.

ceived by them to prove the electrical nature of the phenomena in question, only went so far as to show, that electricity was concerned in the operation, but did not prove it to be the cause of them; and he is inclined to regard it rather as the effect.

Fabroni mentions, among other facts, that mercury and tin when pure, and kept distinct from other metals, will remain a long time without tarnishing; but when alloyed, or placed in contact with other metals, they soon begin to exhibit signs of oxidation. He remarked, that coins composed of a pure metal were more durable than such as were composed of a mixture of metals. He mentions the corrosion which takes place, when copper roofs are soldered with another metal, and in the copper sheathing of ships when fastened with iron nails. These phenomena are supposed to depend upon a chemical affinity between the metals, by which their particles are individually attracted towards each other, while the separation of the particles of the solid metal, which is caused by their tendency to unite, permits the oxygen to act upon them. "These facts," he says, "as well as many others of the same nature, no less common than well known, ought to have proved to philosophers, that the metals, by exercising their mutual attractive force, must by the same energy diminish their respective powers of aggregation; that though neither of them separately may be able to attract oxygen from the atmosphere, or from water, they may acquire that power by simple mechanical touch, as they pass to new combinations."

He then relates some experiments which he performed, in order to observe the comparative effect produced, by placing metals first in separate vessels of water, then in the same vessels, but not in contact; and lastly, in the same vessels, and also in contact. In the two former cases there was no change produced, while in the latter there was a considerable degree of oxidation. He afterwards entered upon some speculations on the source of the oxygen, and he found that, by covering the water with a stratum of oil, and thus excluding the atmosphere, the process of oxidation was retarded. This fact he adduces as a powerful argument in favour of the chemical hypothesis. He concludes, that the oxygen in these cases cannot be derived from the water, because, were the water decomposed, there would be a liberation of hydrogen. The effect that is produced on the senses of vision and of taste, he attributes to the formation of new chemical compounds, which act in a peculiar manner upon the organs; an opinion which may be true, to a certain extent, so far as respects the tongue; but it is not easy to conceive how it could cause the flash of light which is excited in the eye by the contact of the metals.*

Fabroni's paper did not appear to excite much

* Journal de Physique, xlix. 348.

attention at the time when it was published, as it directly opposed the current of popular opinion. But many of the statements have been since verified by succeeding philosophers; and when we consider that it was written before the discovery of the pile, it must be regarded as displaying much sagacity and nice observation.

In this state the science of galvanism remained until the year 1800. It was generally admitted, that the immediate agent in producing the phenomena was the electric fluid, and that the actions exhibited by the animal body depended merely upon its extreme sensibility to small quantities of this fluid. The experiments principally consisted in different combinations of conducting substances with parts of the animal body, composing what was called the galvanic arc or circle. The chemical effects had been little attended to, except by Fabroni; and his remarks, although truly ingenious, must be regarded rather as the first glance of a series of important facts, than as constituting their complete development.

SECTION II.

Experiments from the Discovery of the Pile to the Decomposition of the Alkalies.

Discovery of the pile by Volta, 1800.

THE second period of the history of galvanism commences with the important discovery made by Volta, of the instrument which has been called the *galvanic* or *voltaic pile*. Volta, as has been remarked above, adopted the idea, that the action excited by the two metals depended upon an alteration in their respective states of electricity, or in a destruction of its equilibrium. The effect produced by one pair of plates could only be comparatively small; but he supposed that by interposing a conductor between several pairs of plates, it might be multiplied and concentrated in an indefinite degree. He accordingly provided a number of silver coins, and pieces of zinc of similar dimensions; these were disposed in pairs, and between each pair was placed a piece of card soaked in water; and thus a pile or column was formed, in which the three substances silver, zinc, and water, existed in regular rotation. The effect of the combination fully justified the expectations of the discoverer. All the phenomena that had been excited by a single pair of metals were far exceeded by those of the pile, while by touching the two ends of it at the same time, it was found

Description.

PLATE I. Fig. 1 & 2.

Effects.

that a distinct shock was felt in the arms. This fully established the opinion that had been formed, and was generally adopted, of the identity of electricity and galvanism; although there were still some circumstances connected with the latter, which appeared not to be completely analogous to the usual operations of the electric fluid.

Galvanic shock.

He found that forty pairs of the metallic disks, with the proper number of pieces of moistened card interposed, were sufficient to produce a shock, which was very distinctly felt in the hands and arms, and that by increasing the number of pairs, the power of the pile was proportionally augmented. In order to produce the full effect, it was found necessary that two pieces of metal, either composing the extremities of the instrument, or in contact with them, should be firmly grasped by the two hands; and the shock might, in this case, be repeated for any number of times, as long as the pasteboard between the two metals remained sufficiently moist. Volta conceived that the newly invented apparatus was analogous in its action to the electrical organ of the torpedo.

Couronne des tasses, Fig. 3.

He afterwards constructed another apparatus, or rather arranged the component parts of the pile in a different form. It consists of a set of small glasses, placed side by side, and containing water or some saline solution. A number of metallic arcs are then procured, having one end composed of zinc, and the other of silver or copper; these arcs are inserted into the glasses in a uniform order, each glass having the zinc leg of one arc, and the copper or silver leg of another arc, immersed in the fluid. The zinc and copper legs are not in contact, and they are always to be disposed in the same situation with respect to each other, *i. e.* one is to be always at the right hand, and the other at the left. Volta named this apparatus, the *couronne des tasses.* The operation of both these instruments is precisely the same, and is referred by the author to the new principle, which he conceives he had discovered, by which different metals, when placed in contact, destroy the electric equilibrium, or, as he expresses it, become movers of electricity, producing that electric motion which is supposed to be the primary and essential cause of the galvanic action.

The experiments which Volta performed with the pile were almost exclusively confined to the animal body; and he seems to have entertained no idea of the important use to which it might be applied, as an instrument of chemical analysis. His attention appears indeed to have been so totally absorbed in the electrical action of the apparatus, that he overlooked its other effects, and only noticed, in a very cursory manner, the changes which it induced upon the fluid. It is indeed a little remarkable, that after making so curious a discovery, he should have rested there, and not have proceeded with the further prosecution of the subject. It would be unjust not to acknowledge, in the warmest terms, the obligation under which the scientific world was laid by the discovery of Volta; but, at the same time, it must be admitted, on the other hand, that the benefit of the discovery has been obtained by others.*

No sooner was the discovery of the galvanic pile announced, than the English experimentalists began their operations with it, and almost at the first trial of its effects made some important and interesting observations. Sir Joseph Banks, on the receipt of the information, having communicated an account of it to his scientific friends, a pile was formed by Messrs. Nicholson and Carlisle, with which they began to repeat the experiments of Volta. They arranged the substances in the order of silver, zinc, fluid; silver, zinc, fluid, &c.: an arrangement which it is necessary to attend to, in speaking of what have been called the silver and zinc ends of the apparatus. Volta, it appears, had satisfied himself that the action of the pile was electrical, because it produced the shock; but Messrs. Nicholson and Carlise applied to it the instrument called the revolving doubler, † and by this means decidedly proved it to be the case: they found, that the silver end was in the negative and the zinc end in the positive state of electricity.

Nicholson's and Carlisle's experiments.

Discovered the + and − states.

In the course of the experiments, a part of the circuit between the upper and lower ends of the pile was formed by water, and it was observed that there was a disengagement of gas at the part

Decomposition of water in the interrupted circuit.

* Phil. Trans. for 1800. † Phil. Trans. for 1788.

where the wire came in contact with the fluid. This gas was thought to have the odour of hydrogen; and it led them to notice, with more attention, the effect produced by causing the electricity to pass through a tube of water, into the two ends of which wires were inserted, which communicated with the extremities of the pile. I shall relate this very important experiment in Mr. Nicholson's own words. "On the 2d of May we inserted a brass wire through each of two cocks, inserted in a glass tube of half an inch internal diameter. The tube was filled with New River water, and the distance between the points of the wires in the water was one inch and three quarters. This compound discharger was applied, so that the external ends of its wire were in contact with the two extreme plates of a pile of thirty-six half-crowns, with the correspondent pieces of zinc and pasteboard. A fine stream of minute bubbles immediately began to flow from the point of the lower wire in the tube, which communicated with the silver, and the opposite point of the upper wire became tarnished, first deep orange, and then black. On reversing the tube, the gas came from the other point, which was now lowest, while the upper, in its turn, became tarnished and black."—"The product of gas, during two hours and a half, was two-thirtieths of a cubic inch. It was then mixed with an equal quantity of common air, and exploded by the application of a lighted waxed thread."

In the body of the pile.

Mr. Nicholson observed, that the same process of the decomposition of water is carried on in the body of the pile, as between the two ends of the wire in the interrupted circuit; the side of the zinc next to the fluid being covered with oxide in two or three days, and the apparatus then ceasing to act. It was also observed, that the common salt which had been dissolved in the water was dissolved, for that there was an efflorescence of soda round the margin of the plates. Mr. Nicholson afterwards found that, by using metallic plates of considerably more extensive surface, no greater effect was produced in the decomposition of water, or in the violence of the shock; so that he concludes, " the repetition of the series is of more consequence to this action than the enlargement of the surface." As he proceeded in his experiments it was more decidedly ascertained, that the electricity of the silver end was negative, that of the zinc end positive. Although it appeared evident that there had been a decomposition of water effected by the copper wire, yet Mr. Nicholson determined to render the operation more decisive, by employing a metal which was not oxidable. Platina was therefore substituted for the copper, and now gas was disengaged from both sides, and neither of the wires were tarnished. In a subsequent experiment, the wires were so managed, that the gases extricated from each side were kept distinct; and it was found that they consisted, the one of oxygen, and the other of hy-

Platina wires produced both hydrogen and oxygen.

drogen, and that they were generated in the proportion necessary to produce water. In some of these experiments the spark was visible.* Every one will be sensible of the important views that were disclosed by the experiments related in this paper, in connexion with those performed by Mr. Cruickshanks of Woolwich, of which an account will be given below. They must be regarded as leading directly to the wonderful discoveries that have been made by means of the galvanic apparatus, as well as the theoretical deductions to which it has given rise, and which have produced almost a complete revolution in our ideas of the action of bodies upon each other.

Cruickshanks's experiments.

Cruickshanks confirmed the observations of Nicholson, respecting the actual appearance of sparks and the decomposition of water. This last process he varied in different ways. By employing the interrupted circuit with silver wires, and passing the influence through water tinged with litmus, he found, that the wire connected with the zinc end of the pile communicated a red tinge to the fluid contiguous to it; and afterwards, by employing water tinged with Brazil wood, he found that the wire connected with the silver end of the pile produced a deeper shade of colour in the surrounding fluid. Hence it appeared, that an acid was formed in the former, and an alkali in the latter case. The galvanic influence was passed

Acid and alkali produced in the water.

* Nicholson's Journ. 4to. iv. 179.

through the interrupted circuit, in which the tube was filled with the solution of acetate of lead, when it was observed that the lead was separated in the metallic state, and deposited at the end of the *silver wire*, or the wire connected with the silver end of the pile, in the form of fine needles. Experiments were afterwards made upon the solutions of sulphate of copper and nitrate of silver: in this last case, he observes, "the metal shot into fine needles, like crystals articulated or jointed to each other, as in the *arbor Dianæ*." He also succeeded in decomposing some of the neutral salts.*

Metals revived from metallic solutions.

In a second memoir, Cruickshanks paid more particular attention to the nature of the gases emitted in the interrupted circuit—to the effects of different kinds of wires—and to the influence of the fluid medium upon the decomposition of the water. Some of his most important conclusions are, that from the wire connected with the silver or copper end of the pile, whatever be its composition, if it terminate in water, the gas emitted is chiefly hydrogen; if it terminate in a metallic solution, the metal is reduced, and is deposited at the end of the wire. When the wire connected with the zinc end is formed of a perfect metal, nearly pure oxygen is disengaged: when of an oxidable metal, it is partly oxidated and partly dissolved, and only a small quantity of oxygen is

Concludes that hydrogen is always emitted from one wire, from the other oxygen, or the wire oxidated.

* Nicholson's Journ. 4to. iv. 187.

liberated. When fluids contain no oxygen, they appear to be incapable of transmitting the galvanic influence; while, on the contrary, it would seem that it may be transmitted by every one which contains this element.* These views of Cruickshanks respecting the action of the pile were confirmed by some experiments that were performed, about the same time, by Colonel Haldane. He found that the apparatus ceased to act when it was immersed in water, or if it was placed in the vacuum of an air-pump. He found, on the contrary, that it acted more powerfully in oxygen gas, than when confined in an equal bulk of atmospheric air, while azote had the same effect as a vacuum. These circumstances led him to conceive that its action depended essentially upon the combination of oxygen, which it derives from the atmosphere.† He also made some experiments on the series of metals which are the best adapted for producing the galvanic effects, and the relative power which they possess in this respect.

Fluids without oxygen will not act.

Haldane's experiments.

Pile will not act without oxygen.

In the early part of his experiments, Cruickshanks invented a new manner of disposing the apparatus, which has proved scarcely less important to the interests of science, than its original discovery by Volta. I allude to the method of placing the metals horizontally in a frame or trough, with proper intervals for containing the fluid which is intended to act upon them.

Trough apparatus. Fig. 5.

* Nicholson's Journ. 4to. iv. 254. † Ibid. 241, 313.

The power of the pile in decomposing chemical substances being now established, by the experiments of Nicholson and Cruickshanks, a new field of investigation was opened, which was ardently entered upon by some of the most distinguished among the English chemists. Dr. Henry was among the first who employed the galvanic influence for the purpose of analysis; he decomposed the sulphuric and nitric acids, and ammonia, and he reduced the oxymuriatic to the state of muriatic acid; but as gases do not conduct the galvanic influence, its decomposing power could not be applied to this last body.

Henry's experiments.

Decomposes acids and ammonia.

Sir H. Davy, at an early period of the science, commenced the career of discovery which he afterwards brought to so brilliant a termination. He proposed, as a subject of experimental research, whether the ends of the wire, in the interrupted circuit, would discharge the two gases, if they were made to terminate in different portions of water. They were therefore placed in separate glasses, while the glasses were made to communicate by means of the fingers, or a moist substance, and it was found that the oxygen and hydrogen were evolved as usual. He next inquired whether it was necessary for the effect that the wires should be in contact with the ends of the pile; and in order to prove this point, slips of muscular fibre were interposed between the wires and the ends of the pile. The result of this disposition was that the gases were disengaged,

Davy's experiments. Disengages the gases from two portions of water.

but in a reverse order; the hydrogen now proceeding from the wire connected with the zinc end of the pile, and the oxygen from the silver or copper wire.

New combinations.

These experiments, which at the time when they were performed seemed most extraordinary, and almost inexplicable, were succeeded by others equally curious, in which Sir H. Davy produced the galvanic effect, by a new combination of substances. He found that charcoal was capable of conducting the influence and of decomposing water, the copper end giving out hydrogen, holding a little carbon in solution; the zinc end did not produce any considerable quantity of gas, as the carbonic acid which was produced was absorbed by the water in which the charcoal was immersed. He formed a pile of zinc and charcoal, which acted with considerable energy; and he afterwards discovered that a pile may be constructed of only one metal, with different fluids applied to its two surfaces, one of them capable of oxidating the metal, the other of preventing the effect of oxidation, the two fluids being separated from each other by water. The series which he employed was metal, diluted nitric acid, water, sulphuret of potash, and then again metal. In a subsequent train of experiments, he proceeded still farther, and composed a pile without any metal, but consisting solely of pieces of charcoal, having their opposite surfaces exposed to the ac-

Pile of one metal.

Pile of charcoal without metal.

tion of two fluids that bore a different chemical relation to them.

Pile will not act with pure water.

Sir H. Davy also made some very important observations on the nature of the fluid interposed between the plates of the pile, and the nature of the changes which it experiences. If the water that is employed be perfectly pure, containing no acid, salt, or gas, the apparatus is incapable of acting. He found that its energy was in proportion to the rapidity with which the oxidation of the metal advances, and consequently was most energetic when nitric acid was made use of. Strong sulphuric acid, on the contrary, had little effect, because zinc has not the power of decomposing it; but if the acid be diluted, the metal was oxidated, and the electricity was evolved. Upon the same principle it appeared, that the sulphurets, which cannot act upon the metallic surface, had not the power of exciting the energy of the pile. In pursuance of this opinion, he discovered, that the pile can act *in vacuo*, if an acid be interposed between the plates.*

Remarks upon Davy's experiments.

Sir H. Davy's very curious discovery, that the two constituents of water might be obtained separate from two portions of the fluid contained in different glasses, seemed at variance with all former opinions of chemical composition, and gave rise to a number of speculations, which although

* Nicholson's Journ. 4to. iv. 275, 326, 337, 380, 394; v. 78, 341; and 8vo. i. 144.

many of them sufficiently ingenious and interesting at the time when they were proposed, it is not necessary to relate, as they have been entirely superseded by his subsequent discoveries. I may observe, that one of two consequences seemed necessarily to result from it; either that water, by some kind of combination with the two states of electricity, is convertible into oxygen and hydrogen; or that one of these bodies has the power of uniting to other bodies, without apparently affecting their form, and passing silently through them. The earlier discoveries of Sir H. Davy seemed to afford a very powerful support to the chemical hypothesis of Fabroni, and to be equally irreconcileable to that of Volta; and they appear, when they were first announced, to have been viewed in this light by the discoverer himself, and by the most scientific of his countrymen.

With respect to the nature of the galvanic influence, or the primary cause of its operation, the English philosophers seem at this time to have been nearly unanimous in ascribing it to electricity. On the Continent, however, where the late discoveries that had been made in this country were little known or imperfectly understood, a considerable difference of opinion still existed on this subject. Of these discussions, which have now entirely lost their interest, it will not be necessary to give any account, but I shall briefly notice an hypothesis which was brought forwards about this time by Brugnatelli, of Pavia, Theoretical discussions.

Brugnatelli on electric acid.

which, although at present known to be erroneous, seemed, in the first instance, to be supported by a considerable body of direct evidence. He supposed that the galvanic influence was identical with electricity, but that when it is extricated in contact with water, so as to decompose this fluid, it unites with a portion of its oxygen, and forms a new acid, which he called the electric acid. Like other acids, he conceived that it had the property of combining with bodies and forming various compounds, the properties of which he describes. It might be difficult and little important to trace out, in every instance, the source of Brugnatelli's errors. There can be no doubt that he operated upon impure substances; it is probable that the acid which he obtained was derived either from small portions of nitric acid which were generated, or of muriatic acid which were liberated in the course of the experiment.

Wollaston's experiments, 1801.

Soon after the discovery of the pile, Dr. Wollaston turned his attention to the subject of galvanism, and displayed his accustomed sagacity and penetration in a paper which he presented to the Royal Society. He observes that the energy of the apparatus seems to be in proportion to the tendency which one of the metals has to be acted upon by the interposed fluid. An experiment is related, not very unlike some of those which had been previously performed by Fabroni. If a plate of zinc and a plate of silver be immersed in diluted sulphuric acid, and kept asunder, the silver is not affected, but the zinc begins to decompose the water, and to evolve hydrogen. If the plates be now placed in contact, the silver discharges hydrogen, and the zinc continues, as before, to be dissolved. From these, and other analogous facts, he concludes, that whenever a metal is dissolved by an acid, electricity is disengaged. He extends this principle to the action of the electrical machine, which he conceives has its power increased by applying an amalgam to the cushion, into the composition of which a metal enters which is readily oxidated. As a further illustration of the same principle, he found the machine will not act when immersed in carbonic acid gas.

Electricity disengaged by metals dissolved in acid.

Nicholson had already suggested the opinion, that the electricity of the pile differs from that of the machine, in consequence of the latter being in a state of higher intensity, but in less quantity; the former of course being in greater quantity, but of low intensity. Dr. Wollaston coincided in this idea, and supposed that it might explain the difference between the operation of the two instruments. It had been long known that water might be decomposed by the electric shock, but the effect differs from that of the pile, the two gases being separated promiscuously from both ends of the wire, not, as when the pile is employed, the oxygen from one end, and the hydrogen from the other. But Dr. Wollaston succeeded in producing the galvanic effect on water by common electricity, so as to keep the gases separate This

Electricity of the pile in large quantity, and of little intensity.

he accomplished by coating two silver wires, the ends of them only being left exposed. He then connected these wires with the two conductors of the electrical machine, and passed the spark, from one to the other, through a solution of a salt of copper; the negative wire was found to be covered with a metallic coating, as if it had been connected with the copper or silver end of the pile.*

Remarks on Wollaston's experiments.

The experiments of Dr. Wollaston, and the reasoning which he employed concerning them, must be considered as both affording a very important addition to our knowledge of galvanism, and as giving a greater precision to our ideas on the theory of its production, and on the nature of the relation which it bears to common electricity. In the experiment in which the plates of zinc and silver are separately immersed in a diluted acid, we find that the decomposition of the water is effected solely by the zinc; but that when the metals are connected, the hydrogen is disengaged from the silver. In this case it does not appear that the silver in any way tends to promote the decomposition of the water, but that it merely influences the manner in which its constituent parts are liberated, which, there is every reason to suppose, depends essentially upon the electrical condition of the different parts of the metallic surface. Although Nicholson, by applying his doubler to the two extremities of the pile, may be

* Phil. Trans. for 1801, p. 427.

considered as having shown that the galvanic influence depends upon some modification of electricity, yet the complete identity of the two agents could scarcely be considered as fully proved, until the most remarkable effects of the pile had been imitated by the action of the machine. Dr. Wollaston's view of the subject has been considered as combining, to a certain extent, the theory of Volta with that of Fabroni; according to the literal acceptation of the terms, however, it must be regarded as favouring the chemical hypothesis, because it contemplates a chemical change as the primary step in the operation, from which all the subsequent effects are ultimately derived.

Desormes' experiments. A set of experiments was performed about this period by Desormes, the object of which was to ascertain the source of the oxygen which combines with the plates; this he conceives did not depend upon the actual decomposition of the water, but upon some change which the water experiences by the union of the negative and positive electricity. The same reasoning was of course applied to the hydrogen, and a similar opinion has been since adopted by other philosophers, but it has generally been regarded as a less simple method for accounting for the facts, and as involving more gratuitous suppositions.*

Trommsdorff burns metallic leaves. Professor Trommsdorff discovered that the pile possesses a very powerful effect in burning me-

* Ann. de Chim. xxxvii. 284.

tallic leaves. He formed an instrument of large plates of zinc and copper, and fixed gold leaf to the zinc end; then by bringing it in contact with the silver end, the leaf was rapidly consumed, the process being attended by a beautiful emission of coloured light. Silver, tin, and copper leaves were burned in the same manner, each giving out a brilliant flame tinged by its appropriate colour.* In a subsequent set of experiments he even succeeded in burning the metals in the different gases which contained no oxygen, but we are not fully informed what was the exact nature of the products obtained in this case. Experiments on the combustion of metals were performed about the same time by Fourcroy, Thenard, and Vauquelin, when they observed, that the energy of the shock and the power of decomposition were not increased by the size of the plates, but by the number of the repetitions; while the same extent of surface, arranged in the form of a few large plates, readily consumed the metallic leaves, but had only a comparatively small effect on the sensations.† Fourcroy, at this period of the investigation, supposed that the galvanic phenomenona could not be referred to the action of electricity; but this opinion he was afterwards induced to retract. Indeed this point was shortly afterwards established beyond dispute by Mr. Cruickshanks actually charging the

The effect of large plates.

* Nicholson's Journ. 4to. v. 238.

† Ann. de Chim. xxxix. 103.

Leyden phial from the pile; and in this way he was able to demonstrate still more clearly than it had been before done, that the extremity of the apparatus which gives out oxygen is in the positive, and that which gives out hydrogen is in the negative state.

As the opinion of philosophers was generally agreed in respect to the identity of the galvanic and electric influences, many speculations were formed as to what constituted the essential difference between the electric fluid, as generated by the pile, and as disengaged by the common machine. In order to elucidate this point, Van Marum, in conjunction with Professor Pfaff, of Keil, entered upon a series of experiments, in which the action of the pile was compared with that of the great Teylerian machine at Haarlem. He succeeded in charging, not only single jars, but whole batteries, by the pile; and it appeared that they were always charged to the same degree of intensity with that which the pile itself indicated to an electrometer placed upon it. He found that the zinc end of the pile communicated positive electricity to the side of the jar or battery with which it was in contact, and the copper end the reverse. No perceptible difference could be experienced between shocks of the same intensity given by a jar or by the battery; whether they were charged by the pile or by the machine. He observed that the intensity of the pile was always the same from the same number of plates, whatever was their size;

Van Marum compares electricity and galvanism.

but he perceived Fourcroy's observation to be correct, that it was necessary to employ large plates to burn the metals. He formed a pile of large plates of zinc and copper, and succeeded in fusing iron wires of considerable thickness; he at last even fused a wire of platina. He found that a battery, consisting of 137½ square feet of coated glass, was charged by a galvanic apparatus to an intensity equal to itself, in 1-20th of a second; a circumstance which proves the amazing velocity of the fluid. He conceived that the energy of the pile was much augmented when it was kept in an insulated state, and likewise when a solution of the muriate of ammonia was interposed between the copper and zinc plates.*

Fuses iron and platina wires.

Action of the pile deoxidates the air.

We have already noticed the discovery of Cruickshanks, that the pile acted more powerfully in oxygen gas than in the air of the atmosphere; and an observation the converse of this, was made by Biot and Cuvier, which confirmed the relation between the action of the apparatus and the chemical state of the fluid in which it is immersed. When the pile was enclosed in a limited quantity of air, they found that, after some time, the air was sensibly deoxidated.†

State of opinions in 1801.

The discoveries that were made with the galvanic pile, especially by the English chemists, completely established some of the most important points which had previously been subjects of doubt

* Ann. de Chim. xl. 289. † Ibid. xxxix. 242.

or controversy. Animal electricity, as produced in the original experiments of Galvani, and afterwards in those of Valli, Fowler, Volta, and others, was now admitted to depend upon nothing adherent in, or attached to, the animal body, but upon an agent, called into action by external causes, and manifesting itself in consequence of the delicate sensibility of the nervous and muscular systems. This agent was now generally recognized as being identical with electricity, conducted by the same substances, possessing the same properties, and, in short, subject to the same physical laws. It was conjectured, that the apparent difference between electricity, as excited by the machine and by the pile, depended upon the different states of intensity in which they exist; the electricity of the machine being in a much higher state than that of the pile, although this latter is generally disengaged in greater quantity. This may be regarded as the state of the science in 1801; from this time, until the grand discovery of Sir H. Davy, which I have marked out as the third era, the attention of the different experimentalists, who devoted themselves to this department of natural philosophy, was partly directed to improving or modifying the apparatus, and partly to hypothetical discussions, respecting the nature of the action, and its connexion with chemical affinity.

Biot's observations on the size of the plates.

The effect of the size of the plates in the galvanic pile had been already observed by Fourcroy and others, and was now more particularly noticed by Biot, who wrote a memoir, the principal object of which was to illustrate the relative action of the different kinds of apparatus, and to discover the cause on which this difference depends. Electricity is known to be discharged by points, and to be retained by extensive surfaces; and from this circumstance he conceives, that the smaller the plates are, the more rapid will be the circulation of the fluid; large plates furnish a greater quantity of the fluid, but it is less rapid in its motion; smaller plates, on the contrary, furnish less fluid, but it passes with more rapidity through the different parts of the apparatus. Hence what was spoken of by Nicholson and others, as constituting the intensity of the fluid, is resolved by Biot into the velocity of its motion. The different operations of the pile are differently affected by these two properties. The taste, the flash, and the shock, exist nearly in the same degree, and all depend principally upon the velocity; while the combustion of the metals is more influenced by the quantity of the electricity. The electrical attractions also depend upon the quantity of fluid, and are therefore more perceptible when large plates are used. It is observed that a pile composed of small plates affords very pungent shocks, but is more quickly exhausted. It was before stated, that Biot had perceived the pile to deoxidate a portion of the air in which it was confined; and he now informs us, that the effect was produced more rapidly when the ends of the pile were

Different velocity of the electricity.

made to communicate by intervening wires. The general conclusions with which he sums up this interesting paper, are, that the galvanic fluid resembles the electric in the repulsive property of its particles, and that the different phenomena depend upon variations in the quantity and velocity of the fluid.*

Lehot's observations on the direction of the current.

An elaborate set of experiments was published about this period by Lehot, on the direction of the galvanic current. This subject had also occupied the attention of Biot, and it was generally admitted that its course was from the zinc plate, across the fluid, to the silver or copper plate.†

Erman's remark on the names of the extremities.

A circumstance of some importance in our view of the action of the pile, was pointed out by Erman of Berlin; he remarks, that the action takes place, not between the metals, but between the metal and the fluid; therefore, in designating the end of the pile, we should say that the zinc end is the negative, and the copper the positive. Nicholson and Cruickshanks supposed the apparatus to be constructed of copper, zinc, fluid; but it would be more correct to say, zinc, fluid, copper, as in this arrangement we have the complete circle.‡ A similar remark was made by Priestley, who was at this time performing experiments on galvanism in America. He says, that no alteration is produced in the apparatus by whatever metal is

Priestley's.

* Journ. de Phys. liii. 264. † Ibid. lii. 135.
‡ Ibid. liii. 121.

placed at the ends beyond the reach of the fluid. Most of the phenomena of common electricity had been imitated by the electricity of the pile, except that of attraction; and Gautherot at length succeeded in contriving an apparatus for producing this effect. It consisted of two delicate wires, which hung loose from the extremities of the pile; when they were brought near together, a sensible approximation was perceived, and they were found to adhere with a sensible degree of force.*

Gautherot on galvanic attraction.

Volta defends the electrical hypothesis.

It does not appear that Volta himself participated, in any degree, in the various discoveries that were made by means of his apparatus, or that he employed any means for improving or altering its original form. He seems to have interested himself solely in defending the hypothesis, which he had proposed to account for its operation, and which indeed may be considered as having led to its construction. His opinion, that the primary action was electrical, and that it depended entirely or essentially upon a change in the distribution of the electric fluid, had been called in question by Mr. Nicholson, Dr. Wollaston, and other English chemists, who were more disposed to refer the effects to the chemical action of the fluid interposed between the plates in oxidating the metals. Volta, however, still adhered to his first opinion; and, in a paper written about this time, he lays it down

* Ann. de Chim. xxxix. 203.

as his decided conviction, that the action of one of the metals upon the other is the sole cause of the excitation of the electricity, and that the only use of the interposed fluid is to convey the excited electricity from one pair of plates to the other.*

Cuthbertson's experiments.

Many papers were written on the subject of this controversy, some of them containing illustrations or modifications of the electric hypothesis, while others proceeded entirely upon the opposite opinion, endeavouring to prove, either that the phenomena could not be explained on this principle, or that the data on which it was attempted to be founded were incorrect. Of this latter description is an examination of the experiments which Volta had himself brought forwards as the basis of his reasoning, by Mr. Cuthbertson, an able practical electrician, who, after repeating the experiments with every precaution, could not obtain the results which had been announced; a circumstance which he attributes to a defect in Volta's apparatus.† It was about that time that I published the outline of a chemical theory of galvanism, which was afterwards given more in detail,‡ the further consideration of which will be deferred to the second part of the essay.

Professor Simon, of Berlin, repeated on a large

* Nicholson's Journ. 8vo. i. 135. † Ibid. ii. 281.

‡ Ibid. iii. 69; and Thomson's Ann. iii. 32.

scale the experiments of Trommsdorff, on the combustion of metals by galvanism, and gave a minute account of the different phenomena which were produced during the process.*

Pepys's galvanometer.

By an ingenious alteration in Bennet's electrometer, Mr. Pepys endeavoured to convert it into a galvanometer, and it may be so far entitled to this appellation as it is calculated to measure extremely minute quantities of electricity, which perhaps could not be made sensible by any other means. He also confirmed the facts which I have already alluded to, that oxygen is absorbed by the pile, that it will not act in azote or in hydrogen, and that it may be excited *in vacuo*, provided an acid be interposed between the plates.† About this time, Ritter of Jena entered upon his investigation of the galvanic phenomena, and both performed many new experiments, and entered very zealously into theoretical discussions. He conceived that he had observed a connexion between galvanism and magnetism: he says, that if an iron wire be placed in the magnetic meridian, the north pole of the wire is more disposed to become oxidated than the south pole; when the magnetized wire is placed in water, the south pole, on the contrary, is most affected. If similar wires be employed, but not placed in the magnetic meridian, no difference is to be observed in

PLATE II. Fig. 9, 10, 11.

Ritter's experiments.

Supposed connexion with magnetism.

* Ann. de Chim. xlii. 1.
† Tilloch's Phil. Mag. x. 38.

the oxidation of the two extremities.* It does not, however, appear that these experiments of Ritter have been confirmed by any subsequent observations.

Experiments on animals with warm blood.

In the experiments that had been performed on animals, those with cold blood were generally employed, both on account of their being more convenient for the operation, and from the greater tenacity with which they retain their vitality. It was, however, ascertained, that animals with warm blood were equally susceptible of the influence; and Creve, of Wurtzburg, produced strong contractions in a human leg after amputation. **By Vassali.** Vassali-Eandi, in conjunction with his friends Giulio and Rossi, performed a more ample set of experiments upon the bodies of some criminals that were beheaded at Turin.† They paid particular attention to the effect of the galvanic electricity upon the heart and the other involuntary muscles, a point which had been the subject of much controversy. Volta supposed that the involuntary muscles could not be made to contract; Fowler however asserts, that contractions were excited in the heart, although with difficulty: Vassali confirmed the observations of Fowler, and extended them to the stomach and intestines; **Nysten.** the same opinion was also maintained by Nysten,‡ who afterwards published an elaborate treatise on

* Journ. de Phys. lv. 235. † Ibid. lv. 286.
‡ Ibid. lv. 465.

Aldini.

the subject.* On the other hand, Aldini, the nephew of Galvani, who now came into notice as an assiduous experimentalist, asserted that he was unable to act upon the heart. In order to complete our view of the experiments that relate to the action of galvanism on the different parts of the nervous system, I may mention, that Bichat, in his treatise on life and death, informs us that he found the nerves which are connected with the great sympathetic, and with the ganglia, those which are distributed to the organs of what he calls the organic functions, to be very little acted upon by this stimulus, so as indeed to be almost insensible to it, when compared with its effects upon the nerves which go to the voluntary muscles.†

Circaud's experiments on fibrine.

Circaud announced a discovery, which, if it were fully confirmed, would prove of great importance in physiology, that the fibrine of the blood, immediately after it leaves the vessels, may be made to contract by the galvanic apparatus. Delametherie confirms the statement of Circaud, from his own observations; but the experiment has not succeeded in this country, even although repeated in the most careful manner; and when we consider the difficulty and delicacy of the process, we may be allowed, without impeaching the veracity of the narrators, to entertain some doubts on the subject. ‡

* Nouvelles Experiences Galvaniques, 1803.

† P. 336, et alibi. ‡ Journ. de Phys. lv. 402.

In the year 1803, Aldini, professor of natural philosophy at Bologna, published his Treatise on Galvanism, a work which contains many curious experiments, and also some new theoretical opinions. The experiments which were the most calculated to produce an impression upon the spectators, were performed on the body of a criminal, who was hanged at Newgate, and also on the head and limbs of some of the larger warm-blooded animals. A powerful battery being applied, very strong contractions were excited, the limbs were violently agitated, the eyes opened and shut, the mouth and jaws worked about, and the whole face was thrown into frightful convulsions. These experiments, however, were principally remarkable from the subjects made use of, and the magnitude of the effect: there were others performed, really more curious, in which very considerable muscular contractions were excited, without the intervention of any metal, or other substance which could be supposed capable of disengaging the electric fluid. In some cases the effect was produced by bringing into contact the nerve of one animal with the muscle of another, and at other times by employing the nerves and muscles of the same animal. In some of the experiments, there appears to have been the most powerful contractions excited, by bringing the parts of a warm and a cold blooded animal into contact with each other. It does not appear, from any expressions in this treatise, whether Aldini considered the

Aldini's experiments.

Contractions in the human body by the pile, 1803.

Contractions produced without metals.

animal electricity, as he calls it, to be of a specifically different kind from that excited by the pile, or whether he supposes that the different parts of the animal body have the power of generating the same kind of electricity, without the aid of any external agent. He, however, deduces from his experiments an inference in favour of Galvani's hypothesis, of a proper animal electricity inherent in the body, and not requiring the assistance of any external agent for its development.

Remarks on Aldini's experiments.

There are some points respecting these experiments that require farther explanation. The most obvious conclusion that we should draw from them, would be that which was formed by Aldini himself, in favour of a proper animal electricity. But if this be the case, they must be regarded as essentially different from those of Galvani, where an electricity of the usual kind was certainly excited. Perhaps the most probable supposition is, that the parts of the body, in these experiments, acted in a manner analogous to the pile which was constructed by Sir H. Davy, in which electricity was developed by the action of two different fluids upon carbon. There are, however, many circumstances wanting to render this analogy complete.

Lagrave's animal pile.

An important experiment was announced by Lagrave: he stated, that by placing upon each other alternate layers of muscular fibre and of brain, separated by a porous body, soaked in salt water, a pile was formed which produced the usual effects of the galvanic apparatus.* The experiment must be of difficult execution, and I believe no one has since attempted to repeat it. Should it be confirmed, it might throw some light upon the experiments of Aldini, and assist in the explanation of those facts where animal electricity seemed to be developed, without the intervention of metallic bodies.

Galvanism employed in medicine.

About this time galvanic electricity began to be extensively employed in medicine, especially in those diseases where common electricity had been previously found useful. It might have been expected that much benefit would have been derived from so powerful an agent, and one which is so easy of application to any part of the body. Our expectations of advantage have, however, been generally disappointed. Flattering accounts of success were indeed published, in different nervous disorders, in paralytic affections, in deafness, in some kinds of blindness, in the recovery of persons apparently drowned or suffocated, and even in hydrophobia and insanity. But subsequent trials did not support the credit which the remedy acquired in the first instance; it gradually fell into disuse, and for several years it was very little employed as a medical agent, until it was again brought into notice by Dr. Philip, of Worcester. From some pathological opinions which he adopted on the nature of spasmodic asthma, he was in-

* Journ. de Phys. vol. lvi. p. 235.

duced to make trial of it in this complaint, and from the report of his first experiments, we have reason to hope that it will prove a powerful remedy for this untractable disorder.*

Ritter's secondary pile.

Ritter published an account of a curious appendage to Volta's pile, which he called the secondary pile, and which has been since named the pile of Ritter. It is a kind of electric apparatus, which may be charged by the voltaic pile, or may be made to retain the electricity that is perpetually flying off from this instrument. He perceived that a body, which had formed part of the galvanic circle in the pile of Volta, when the pile was removed, became itself electrical; but it exhibited an electricity opposite to that which it had previously possessed. Thus, if two wires terminating in water, and connected with the pile, were discharging one oxygen and the other hydrogen, when they were removed from it, they would still continue to discharge the gases, but the operation would be reversed. These wires, in this state, may be considered as charged, and if a greater number of similar wires be placed between the ends of the pile, they will all become charged. The nature of the experiment will not be affected, if, instead of wires terminating in water, plates of a single metal be substituted, with

Described.

wet cards interposed. An instrument will thus be formed, which of itself cannot produce any signs

* Phil. Trans. for 1817.

of electricity, but which may be rendered electrical, by being placed in contact with the primary pile. When the two piles are connected, the action of the ends of each are reversed to each other, and as when they are separated, the ends of the secondary pile are again reversed, consequently the ends of both the piles will now act in the same manner. It is necessary for the pile of Ritter to remain for some time in contact with the pile of Volta, in order that it may be sufficiently charged. It is stated that the chemical effect of Ritter's pile, that is, its effect in decomposing water, does not bear a regular ratio to its physiological effect, that is, its effect in giving shocks. The author observes, with respect to the voltaic pile, that its tension is the greatest, and it produces the strongest effects on the sensations, immediately after it is constructed, but that its chemical effects are the most powerful after it has been acting for some hours.*

Effects.

Shortly after the publication of the account of the secondary pile, Ritter made a number of experiments with the pile of Volta, which are original and curious. He observed that when a communication was formed between the positive end of the voltaic pile and the earth, the whole instrument became negatively electrified, and when the communication was made with the negative end, the instrument became positive. These changes do

Farther experiments of Ritter on the voltaic pile.

* Journ. de Phys. lvii. 345.

not, however, destroy the chemical action of the pile, which goes on in the same manner as be fore the communication was formed. He supposes that the decomposition of water is effected in con sequence of the positive end disengaging oxygen, and the negative end hydrogen, and that the two ends have also a tendency to dispose metals to unite with oxygen and hydrogen respectively. He says, if the positive end be armed with gold leaf, and the negative with charcoal, and these substances be then brought into contact, the gold will be burned; but if the position of the substances be reversed, the charcoal will be burned. When the extremities of a pile do not communicate, it is said that the action exercised between the different plates is very unequal; the zinc, which is nearest the positive end, is the most oxidated. It is also asserted, that if a pile be broken into separate parts, by a number of wires inserted between every fifth pair of plates, those wires nearest the positive end will be the most oxidated; while, on the contrary, those wires near the negative end will be less oxidated than if they had been simply plunged in water. Hence he infers, that at the negative end an action has taken place, or a state has been induced, the reverse of oxidation. He goes so far as to say, that different sensations are excited by the two ends of the pile, the one expanding, and the other contracting, the muscular fibre; the positive end

Different effects in different parts of the pile.

strengthens the pulse, and produces heat, the negative weakens it, and produces cold *.

Remarks on Ritter's experiments.

So far as I have been able to learn, few, if any, of the experiments of Ritter have been repeated, either in England or in France; a circumstance which is not a little remarkable, when we consider that many of them are quite original, and would lead to important theoretical deductions. His language and manner of writing are, however, unfortunately obscure; and he abounds so much in hypothesis, that he has not obtained that degree of attention to which he would seem to be entitled, from his industry and ingenuity. It is scarcely to be supposed that he could have been mistaken respecting the effect of the secondary pile, or that he would have invented a series of facts, the fallacy of which might be so easily detected. With respect to the experiments on the voltaic pile, their authority is more doubtful; they seem to have been performed with a manifest view to a particular hypothesis; some of them are of an indeterminate nature, and we may imagine that many are exaggerated, or even inaccurately stated.

Biot's opinions respecting the nature of the galvanic action.

The attention of the different experimentalists was still very much occupied with the comparative merits of the two hypotheses, the electrical and chemical; generally speaking, the English seemed to incline to the latter, and the continental writers

* Journ de Phys. lvii. 401.

to the former. Biot drew up a candid and judicious memoir, in which he compares the merits of the two opinions, and endeavours to show how far either of them is supported by acknowledged facts. Electricity, he observes, is certainly excited, but it is not certain whether we ought to regard it as cause or effect. He proceeds to inquire whether the action of the pile depends upon the oxidation of one of the metals, upon their electric operation, or upon the two causes in conjunction. The first supposition, he says, is certainly not true, because Volta has proved that metals produce electricity by mere contact, without any oxidation taking place, and his experiments likewise tend to show that the fluid merely performs the part of a conductor, because the electrometer is equally affected whether water or acid be employed; but M. Biot doubts the accuracy of this experiment. It is admitted that the increase of electricity is in proportion to the oxidation of one of the metals; but this circumstance does not prove that these actions stand to each other in the relation of cause and effect, it only shows that electricity renders bodies more oxidable. He performed a set of comparative experiments on the effect of different fluids being interposed between the metals, and by employing the electrical balance as a measure of the quantity of electricity that was liberated, he finds that it is much influenced by the nature of the fluid. The following is supposed to be the order in which the fluids have the power of exciting the action of the pile, beginning with those which are the least powerful: water, muriate of soda, muriate of ammonia, hyperoxymuriate of potash, sulphate of alumine, and sulphate of iron. It is remarked, that if the fluids differed in their action merely in consequence of a difference in their conducting power, the same effects should be produced by suffering them to remain for a sufficient length of time in contact, but on account of the changes which take place in the state of the pile in other respects it is difficult to ascertain this point. Substances generally have their electrical condition altered when they undergo any change in their state, and therefore the chemical action of the pile will probably develop electricity, as well as the action of the metals upon each other; but the author is disposed to conclude that the effect of the chemical change in the fluids is considerably less than the electrical effect excited by the contact of the metals.*

Hisinger and Berzelius on the transfer of substances, 1804.

In the year 1804, a very valuable memoir was written by Hisinger and Berzelius, which must be regarded as containing the germ of those doctrines, which have since been so extensively developed by Sir Humphry Davy. By passing the galvanic influence through solutions of the different neutral salts, they found that there was a transfer of the acid and alkali to different parts of the apparatus. They formed the general con-

* Ann. de Chim. xlvii. 1.

clusion, that whenever electricity is sent across a fluid, it disposes its constituents to separate and pass to the two sides respectively; combustible substances, alkalies, and earths, are attracted to the negative; acids, oxides, &c. to the positive extremity of the pile. The force of the decomposition they suppose is in the ratio of the quantity of electricity, and that the electricity is in proportion to the surface of metal which is in contact with a moist conductor. The decomposition is also influenced by the affinity of the components of the substance, its power of conducting electricity, and other circumstances.*

Supposed production of muriatic acid. 1805.

Mr. Cruickshanks, among his earliest discoveries, had observed, that an acid and an alkali were generated at the two ends of the wires in the interrupted circuit, and this fact had been confirmed by Pfaff,† Brugnatelli,‡ and other experimentalists. The substances produced were supposed to be nitric acid and ammonia; the first originating from the union of oxygen with the azote of air dissolved in the water, the latter from hydrogen combining with the same element. Desormes also had obtained an acid and an alkali during the decomposition of water; but he thought the acid was the muriatic; and the same result

* Ann. de Chim. li. 167.

† Nicholson's Journ. xvii. 362.

‡ Journ. de Phys. lxii. 298; lxiv. 78.

was obtained by Simon.* In these experiments we may conceive that there was a minute portion of common salt contained in the water upon which they operated. It was now, however, announced that muriatic acid and soda were generated by passing the electric current through pure water, where the muriate of soda could not be suspected to be present in any part of the apparatus, or in any of the materials employed. In the spring of 1805, the following letter was published, purporting to be written by Mr. Peel of Cambridge: "I took about a pint of distilled water, and decomposed about one half of it by means of galvanism; the other half I evaporated, and found to remain at the bottom of the glass a small quantity of salt, which, upon examination, proved to be muriate of soda. The salt could not have been contained in the water before I made the experiment, because I used every precaution to have it free from impurities. I even took the trouble to repeat the same experiment, though a tedious one, and I again obtained the same, result. A friend of mine has just informed me that he has tried my experiment, and has succeeded in procuring the salt."†

Peel's experiments.

Almost at the same time that this notice was published in London, Pacchioni, professor at Pisa, gave an account of some experiments upon the

Pacchioni's experiments.

* Ann. de Chim. xxxvii. 284; xli. 109.

† Tilloch's Phil. Mag. x. 221, 279.

action of galvanism on water, in which he obtained results analogous to those stated above. He informs us that when water had been for a long time subjected to the galvanic influence, and had been parting with its oxygen from the extremity of a gold wire, the fluid was found to contain a quantity of oxymuriatic acid. From this experiment he drew the following conclusions: oxymuriatic acid is an oxide of hydrogen; it consists of water deprived of part of its oxygen; muriatic acid is water in a still lower degree of oxidation; and, of course, hydrogen is susceptible of different degrees of oxidation.*

Not confirmed.

A great degree of attention was excited by these experiments, to which the more credit was attached, because they proceeded from sources entirely independent of each other. They were repeated by different experimentalists in this country, and, in some cases, with apparent success. Mr. Sylvester, in particular, obtained traces both of muriatic acid and soda, where proper precautions were supposed to have been taken, to exclude the muriate of soda from every part of the apparatus. But from facts which have been subsequently discovered we may conclude, that the substances obtained in these cases were not derived from the decomposition of the water. Pacchioni's experiments are now universally admitted to have been incorrect; and it appears that no such indi-

* Edin. Med. Journ. i. 393.

vidual as Mr. Peel could be found in Cambridge, so that the letter bearing his name is a complete fabrication. It was not, however, entirely without its use: for the minute examination of the effects of galvanic electricity upon water to which it gave rise, may probably be regarded, in some measure, as the immediate cause of Sir H. Davy's most brilliant discoveries.

An elaborate memoir was written by Erman of Berlin, on the conducting power of different bodies, which obtained the prize from the French Institute. His object was to remove some anomalies, which appeared to exist in the relation of the galvanic electricity to the different conducting substances. **Erman's experiments. 1806.**

He divides all bodies into five classes: 1st, Perfect non-conductors; 2d, Perfect conductors; 3d, Imperfect conductors; 4th, Positive conductors; and 5th, Negative conductors. The nature of the three first classes requires no explanation; the fourth and fifth class of bodies act as perfect conductors, when applied to either of the two poles separately, but when placed between them, insulate either the positive or negative pole respectively, and do not form a communication between them. The flame of a spirit lamp is described as a positive conductor; if it be applied to each pole separately it conducts the electricity; but if it be placed between the two poles, it will not form a communication between them, in consequence of its insulating **Five species of bodies.** **Flame a positive conductor.**

the negative electricity. Although flame is a conductor of galvanism, it does not conduct it so perfectly as metals. No effect is produced when flame is interposed between the extremities of the pile. Flame is, however, a very different substance according to the body from which it is procured: the above observation refers to the flame of a hydro-carbonous body. The flame of sulphur insulates both the poles; and that of phosphorus insulates the positive, and conducts the negative influence. Phosphorus must therefore be placed in the fifth class of bodies; and perfectly dry soap is also a negative conductor.

Soap a negative conductor.

The author gives an account of a number of experiments that he performed on this latter substance, many of which are curious and original. Hard soap, when perfectly dry, if applied to either end of the galvanic pile, conducts all the electricity from that extremity into the ground, and there appears to be no perceptible difference in its action upon the two extremities. If wires be connected with each end, and be made to terminate in a prism of hard dry soap, which is kept insulated, the circuit will not be completed; but if this soap be uninsulated, by establishing a communication with the ground, an electrometer connected with the positive pole manifests a great degree of divergence, while one on the negative pole loses all signs of it. "Consequently," M. Erman observes, "the soap which insulates the positive effect, is a perfect conductor for the negative." As a proof and illustration of this property, the author informs us, that "if one finger be applied to the wire of the positive pole, and another finger wetted to the soap, no shock is felt, and the electrometers do not show the least change in their respective divergencies. But if the experiment be repeated, by establishing a communication between the positive pole and the soap, with both fingers wetted, a very perceptible shock will be felt, and the two electrometers will arrive at an equal, and a very weak degree of intensity." He proposes the following nomenclature for these five classes of bodies: 1st, Insulators; 2d, Perfect conductors; 3d, Bipolar imperfect conductors; 4th, Positive unipolar; and 5th, Negative unipolar bodies.* Although, as we shall afterwards find, Mr. Brande explains the facts upon rather a different principle, yet they are highly important, and Erman is entitled to much commendation for the skill with which he conducted his experiments.

Erman's nomenclature.

Morveau suggested an idea, which appears sufficiently plausible, that the action of galvanism may affect the formation of metallic oxides, and even cause them to assume the particular forms which they occasionally exhibit.† Bucholtz detailed a series of experiments which he performed, where a metallic oxide, held in solution by an acid, was precipitated in the metallic state by the

Morveau's observations on metallic oxides.

Bucholtz on reducing metallic oxides.

* Journ. de Phys. lxiv. 121. † Ann. de Chim. lxiii. 113.

metal itself. The metallic solution was placed in the bottom of a cylindrical jar, and a stratum of water was carefully spread over it. A slip of the same kind of metal that formed the solution was then placed perpendicularly in both the fluids. The upper part of the metal which was in the water was oxidated, while the lower part in the metallic solution had particles of the reduced metal deposited upon it. The reduction of the oxide was always expedited by whatever promoted the oxidation of the upper part of the metal.* Experiments of an analogous nature were performed by Grotthus, on what he calls the arborization of metals, which, like the circle of actions described by Bucholtz, he attributes to a galvanic operation. In these processes, however, there are two metals concerned; and he shows that the tree is formed by successive portions of the dissolved oxide being reduced and attached to the solid metal, which, in its turn, becomes oxidated.† I have a little anticipated the chronological order in the relation of these last two sets of experiments, in order that the account of the decomposition of the alkalies and earths, which composes the third period of the history of galvanism, might not be interrupted.

Grotthus's experiments on arborization.

* Ann. de Chim. lxvi. 266. † Ibid. lxiii. 5.

SECTION III.

Decomposition of the Alkalies and Earths.

ABOUT the conclusion of the year 1806, Sir H. Davy read to the Royal Society of London the first of his series of papers on what has been styled the electro-chemical action of bodies, which have been so justly celebrated, no less for the brilliant discoveries of which they give an account, than for the acuteness and sagacity which the author displays in his researches into the most hidden operations of nature. He commences by some remarks on the action of galvanic electricity upon water. He notices the experiments in which acids and alkalies appear to have been formed in water subjected to the galvanic current; and he states, that when he employed separate portions of water, connected together by slips of bladder, and united by gold wires to the voltaic battery, he obtained nitro-muriatic acid at the positive, and soda at the negative wire. It was, however, conjectured, that the animal matter placed between the two portions of water might contain muriate of soda, and thus afford the substances procured in the experiment; he therefore, at the suggestion of Dr. Wollaston, substituted asbestos for the slips of bladder. It was also con-

Davy's electro-chemical researches, 1806.

Action of galvanic electricity upon water.

PLATE I. Fig. 11.

ceived, that when glass vessels were used, the alkali might proceed from a partial decomposition of the glass; and after trying various other substances, at length conical vessels of gold were employed. With these precautions, and when the water was very carefully prepared, neither acid nor alkali were obtained; and consequently the author concludes that in all those experiments, which were attended with contrary results, the acid and alkali must have proceeded from some extraneous source, not having been generated, but evolved, either from something held in solution by the water, or from some of the materials employed in the apparatus. Perfectly pure water, when subjected to the action of electricity, affords nothing except oxygen and hydrogen.

Neither acid nor alkali generated.

Decomposition of earthy and neutral salts.

The very powerful action of the galvanic electricity, in the decomposition of various earthy and saline compounds, as experienced by Sir H. Davy in the researches above-mentioned, offered an extensive field for farther investigation. Hisinger and Berzelius, in the valuable memoir to which I have already referred, noticed the tendency which different bodies possess, to attach themselves to one of the wires exclusively; acids and analogous bodies being attracted to the positive, while alkalies, metals, and all inflammables, were attracted to the negative wire. Our author had observed similar phenomena in his own experiments, and was induced to make them the more immediate subject of his examination. Acids and alkalies were found uniformly to observe this order; and it was perceived, that when substances, not supposed to be soluble in water, formed part of the circuit, they were also decomposed, and their components carried to the positive and negative wires respectively. In this way was effected the decomposition of sulphate of lime, sulphate of strontites, fluate of lime, and sulphate of barytes. It was also perceived, that where small portions of acid and alkaline bodies entered into the composition of solid earths, they might be detected by the galvanic influence, and would be transmitted to their respective wires. In this way, lime and soda were obtained from basalt and from zeolite, potash from lepidolite, &c. In proportion to the solubility of a salt, its decomposition was the more readily accomplished; and when neutral salts were employed, the separation of the component parts seems to have been quite complete.

Transfer of the constituents of compounds.

The tendency which different substances possess to attach themselves to their appropriate wires, causes them to be transferred across a medium which may be interposed. Thus, if muriate of lime be at the positive wire, the lime will pass, for a considerable space, to gain the negative wire, and may be conveyed from one vessel to another along the conducting fibres of the asbestos. In the same manner, when nitrate of silver was on the positive side, and distilled water on the negative, the silver passed along the trans-

PLATE II. Fig. 13, d

PLATE I. Fig. 6.

mitting amianthus, so as to cover it with a thin metallic film. When a neutral salt was placed in a vessel between two other vessels of water connected by asbestos, the alkali passed to the negative, and the acid to the positive side: the decompostion in this case is complete, and the substances produced quite pure. A small vessel of the infusion of litmus was interposed between pure water and the solution of sulphate of potash, and the latter was negatively electrified. The acid passed across to the positive wire, and reddened the litmus, but the change of colour did not extend beyond the centre; so that the negative side, although it was transmitting the acid, was not affected by it. An experiment of precisely an opposite kind was performed with the infusion of turmeric, with a similar result; and afterwards the two operations were combined in the same experiment, so that soda passed through turmeric, and muriatic acid through litmus, each without changing their colour.

Passage of acids and alkalies through different media.

As it appeared that acids and alkalies could be conveyed through water, without affecting colouring substances dissolved in it, Sir H. Davy next tried whether this power might not extend to other bodies. He accordingly found, that acids could be transmitted through alkalies, and alkalies through acids, to their respective wires, without neutralizing each other; and, in short, that the electrical state which was induced upon a substance, by the contact of the galvanic apparatus, had the power of counteracting, or even changing, the effects of chemical affinity. The general principle was thus completely established, that hydrogen, alkalies, and metals, are attracted by the negative, and repelled by the positive end of the pile; while acids and oxygen are attracted by the positive, and repelled by the negative end. For the production of this effect, it is necessary that there be a conducting chain of particles through the transmitting fluids; the transfer cannot take place where insoluble compounds are formed, because in this case the new compound is carried out of the sphere of action.

General principle.

The establishment of the general principle mentioned above, suggested some views of the nature of the change produced by electricity, which led to a new train of experiments. Sir H. Davy observes, that many bodies, after being brought into contact, exhibit opposite states when they are separated. When a galvanic combination is formed from an acid, an alkali, and a metal, the alkali appears to acquire, and the acid to part with, a quantity of electricity; the alkali is therefore rendered positive, and the acid negative, and they will of course have an attraction for each other. He found that when such acids as were capable of being employed in the dry state were touched by metals, and then separated, the acids were rendered negative, and the metals positive; but when the metals were touched by the alkaline earths, the metals became negative.

Effect of electricity in producing chemical changes.

Hence it may be concluded that acids and alkalies not only exhibit opposite electricities, when they have been in contact with metals, but also when they have been in contact with each other. The attraction of oxygen and acid for the positive, and of hydrogen and alkalies for the negative electricity, is so powerful, as to counteract their usual chemical affinities.

Relation between the electricity and affinity of bodies.

These considerations induced the author to enter into some farther speculations respecting the relation between the electricity of bodies and their chemical affinities. We have seen that chemical affinity is destroyed by giving a body an electricity different from its natural one, and is, on the contrary, increased by giving it a greater share of its natural electricity. It would farther appear, that all those bodies which possess a chemical affinity for each other are naturally in opposite states of electricity; and hence we conclude, that by inducing a state of electricity upon any body, contrary to its natural one, its chemical relations may be changed, and that thus we have in our possession an agent of indefinite power for affecting the decomposition of substances which had hitherto withstood all our attempts.

Action of the voltaic pile.

With respect to the action of the voltaic pile, Sir H. Davy conceives, that the first step in the process is the destruction of the electrical equilibrium, and that the chemical changes tend to restore it to its original state. The saline solution, which is interposed between each pair of plates, is decomposed, the acid is transferred to the zinc, and the alkali to the copper surface. This tends to restore the equilibrium which is destroyed by the contact of the metallic elements of the pile; but the solution of the zinc, which then takes place, again alters the electrical condition of the bodies, and maintains the energy of the apparatus. Upon the whole, although it may be supposed that the chemical changes are an essential part of the process, they are considered by the author as only of secondary importance; the first step in the process, and that which immediately gives rise to all the rest, being an electrical effect arising from the action of bodies placed in contact.*

Primary effects electrical.

The uncommon merit of this paper will be a sufficient reason for this copious abstract of its contents. It may be regarded, not only as giving rise to some of the most important experiments and discoveries that have occurred in the history of modern science; but as leading to the establishment of a new train of reasoning, and to a new theory, respecting the action of bodies upon each other, and the connexion which subsists between the different branches of natural philosophy. The general principle being clearly established, the consequences were comparatively obvious, and the skill and ingenuity which Sir H. Davy afterwards manifested in the contrivance and execution of the experiments, which are next to be related,

Importance of this paper.

* Phil. Trans. for 1807, p. 1.

although attended by such brilliant results, are really less meritorious than that profound insight into the operations of nature by which they were suggested. Highly, however, as we must appreciate the merit of Sir H. Davy, it is proper to remark, that the views suggested by Hisinger and Berzelius must be regarded as leading to the theory that was so amply detailed and so firmly established by our illustrious countryman.

Decomposition of the fixed alkalies, 1807.

About a year after the reading of the above paper, Sir H. Davy presented a second to the Royal Society, in which he most happily applied his hypothesis to practice, and succeeded in solving the problem, which had so long remained involved in obscurity, respecting the composition of the fixed alkalies. After encountering some difficulties in the arrangements of the operation, the grand object was at length accomplished in the following manner, "A small piece of pure potash, which had been exposed for a few seconds to the atmosphere, so as to give conducting power to the surface, was placed upon an insulated disk of platina, connected with the negative side of the battery, of the power of 250 of 6 and 4, in a state of intense activity; and a platina wire, communicating with the positive side, was brought into contact with the upper surface of the alkali. The whole apparatus was in the open atmosphere. Under these circumstances, a vivid action was soon observed to take place. The potash began to fuse at both its points of electrization. There was a

Relation of the experiment.

violent effervescence at the upper surface; at the lower, or negative surface, there was no liberation of elastic fluid; but small globules, having a high metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burst with explosion and bright flame, as soon as they were formed, and others remained, and were merely tarnished, and finally covered by a white film, which formed on their surfaces."

Base of potash and soda. These globules proved to be the substance of which the author was in search, and were found to be a peculiar inflammable body, possessed of very singular properties, which constituted the base of potash. By employing a similar kind of process, a substance was procured from soda, which exhibited properties of an analogous nature, and which was the basis of the mineral, as the former was that of the vegetable alkali.

Proved to be metallic. The author then proceeded to examine the properties of these bodies, and by a masterly train of experiments, simple yet conclusive, he demonstrated that they are metals; that they have every quality which is deemed essential to characterize this class of substances, and that the alkalies are oxides of these metals. **Theory of the process.** The theory of the decomposition of the alkalies, by means of the galvanic apparatus, is sufficiently obvious, and follows as the direct consequence of the facts that had been previously established. In all the decompositions that had been effected by the electrical influence, combustible substances were developed at the negative wire, while oxygen was produced or evolved by the positive termination. That this was the case with the alkalies, was not only rendered probable by the result of the process, but was afterwards proved by subsequent experiments. "When solid potash or soda, in its conducting state, was included in glass tubes, furnished with electrified platina wires, the new substances were generated at the negative surfaces; the gas given out at the other surface, proved by the most delicate examination, to be pure oxygen; and unless an excess of water was present, no gas was evolved from the negative surface."

Recomposition of the alkalies.

The experiments by synthesis confirmed the results of those by analysis. The new metallic bodies were converted into potash, by exposure to the air, and it was found that this depended upon the oxygenous part of it. When the globules were placed in contact with oxygen, they combined with it, and were covered with an alkaline crust. Sir H. Davy observes very justly, "that in these facts there is the same evidence for the decomposition of potash and soda into oxygen and two peculiar substances, as there is for the decomposition of sulphuric and phosphoric acids and the metallic oxides into oxygen and their respective combustible bases." The two components of the alkalies obey the general law which was laid down in the former paper; the metallic or combustible base is attracted by the negative extremity of the apparatus, and perhaps repelled by the positive; while the oxygen, which reduces it to the state of an oxide, follows the contrary order. In the recomposition of the alkalies, the substances exert their natural affinities; according to circumstances, either simple oxidation is produced, or a more rapid combination, attended with the extrication of heat and light.

Properties of new metals.

Sir H. Davy next proceeded, in an elaborate train of experiments, to ascertain the physical properties of these metals, to which he gave the names of potassium and sodium, and their chemical relations to other bodies. He examined their fusibility, the power which they possess of conducting electricity and caloric, and their specific gravity. He afterwards observed their action on water, the acids, sulphur, phosphorus, the metals, oils, and metallic oxides. It is scarcely necessary to remark, that the examination was conducted with the address and dexterity which characterizes all the operations of this distinguished experimentalist. A minute detail of the particulars would be foreign to the object of this work, and strictly belongs to the science of chemistry; galvanism being no farther connected with these bodies, than as the instrument by which they are produced. On this account it will not fall under my province to notice the discussions which ensued respecting the nature of these new metals; for although it was generally admitted that the substances were the bases of the fixed alkalies, and were metallic, yet there were some circumstances in the mode of their formation, which led to the supposition that they were a compound of a metal and hydrogen; but this opinion is now abandoned.

Attempts to decompose ammonia.

The analogy which exists between the properties of the fixed and the volatile alkalies, led Sir H. Davy to apply his powerful means of decomposition to ammonia. The analogy of properties, however, which causes them to be placed in the same class of bodies, seemed to be counteracted by the experiments of Berthollet, who, as is well known, had resolved this latter substance entirely into hydrogen and azote. Accordingly the metallic nature of ammonia has not yet been proved; and although Sir H. Davy, in his earlier experiments, conceived that he had procured oxygen from it, and Berzelius obtained a species of amalgam, by exposing it in contact with mercury to the galvanic influence, yet subsequent experiments by Dr. Henry, and MM. Gay-Lussac and Thenard, appear to explain these appearances on other principles, and to restore the original conclusion, that ammonia is a compound of azote and hydrogen alone.*

Decomposition of the earths.

Sir H. Davy next turned his attention to the earths. He found them more difficult to decompose than the alkalies, and many arrangements were employed without success. The object was,

* Phil. Trans. for 1808, p. 1.

however, at length, to a certain degree, accom plished by mixing the earth with a metallic oxide, and placing this in contact with a globule of mercury negatively electrified, when an amalgam was formed, consisting of the mercury and the metal of the earth employed. In this way it appeared, that a metallic basis had certainly been obtained from the four alkaline earths, to which the names of barium, calcium, strontium, and magnium, were respectively applied. The remaining earths, silex, alumine, zircon, and glucine, were still more refractory, probably in consequence of their more powerful affinity for oxygen. No decomposition could be effected by the same means which had been found successful with the alkaline earths; but it was at length partially accomplished, by keeping the earth in fusion with potash, inducing upon it positive electricity, and touching it with a negative wire. In this case an amalgam was produced, which probably consisted of the metal of the earth employed and potassium.*

Confirmation of Davy's experiments.

The brilliant discoveries of Sir H. Davy, and still more the new and powerful agent which he had introduced into chemistry, could not fail to engage the attention of all those who were interested in the progress of the science. Among these, Gay-Lussac and Thenard in France, and Berzelius in Sweden, immediately commenced

* Phil. Trans. for 1808, p. 333.

their operations in the application of galvanic electricity to the decomposition of bodies, made many important experiments, and brought to light many new facts. The general result was, to afford an ample confirmation of the statements of our illustrious countryman in their most important parts, although in some particulars they regarded the subject in a different point of view, both as to the mode of accounting for the effects, and the consequences which they deduced from them. These discussions, as well as the many new and interesting experiments connected with them, which have completely changed the aspect of many branches of chemistry, and have enlarged our knowledge of the nature of bodies far beyond its former limits, it does not belong to my present subject to detail. It will be proper, however, to notice some of the observations that were made by Gay-Lussac and Thenard, on what strictly belongs to galvanism, reserving the consideration of the hypothetical opinions to the second division of the essay.

Gay-Lussac and Thenard's researches, 1811. Difference between the electrical and chemical action.

These sagacious experimentalists point out a distinction, which had not been sufficiently attended to, between the electrical and the chemical energy of the pile; actions which are essentially dissimilar, and which do not exist in the same ratio. They state, that a comparatively few plates, with acid interposed between them, will decompose the alkalies; while a greater number, with water instead of acid, will not produce this effect, and will yet exhibit a higher electrical tension. The power of the apparatus was found to be nearly in proportion to the strength of the acid employed; and some comparative experiments were instituted, for the purpose of comparing the effects of acids, alkalies, and neutral salts. The test which they employed to judge of the quantity of effect produced by the pile, was the amount of gas evolved from a fluid, subjected to the action of the wires connected with its two extremities: this they conceived was a more exact measure of its energy than the different lengths of wire which it was capable of consuming. The general conclusion which they formed respecting the action of the pile was, that its chemical energy depends upon its tension, upon the conducting power of the fluids with which it is charged, and upon the facility of their decomposition.

When they employed a very powerful battery, it was observed that considerable shocks were given by it to an individual; but that in a chain of four or five persons, it was not felt in the centre; and in the extremities of the chain, that part of the body received the greatest impression which was nearest to the apparatus. This fact is supposed to prove, that the electric fluid cannot circulate through the whole circuit, according to the Franklinean hypothesis. When the battery is put into strong action, its chemical effect, *i. e.* its power of decomposing water, soon declines, or al-

Shock produced by a large battery.

together ceases, while its electrical tension remains for some time longer unimpaired.

An interesting train of experiments is next detailed, in which mercury was interposed between the wires, and formed an amalgam with the substance which was intended to be decomposed: an arrangement which we have already pointed out, as having been employed by Sir H. Davy in his decomposition of the proper earths. They repeated the experiments of this philosopher on ammonia, and they formed the amalgam with mercury, which he conceived was composed of this substance with the metallic basis of ammonia; but they differ from him in their idea of its constitution, and suppose that there is no evidence of the existence of the metal of the volatile alkali, although the analogy of the fixed alkalies offers so powerful an argument in its favour. But it does not belong to my present subject to give any farther account of the chemical effects produced by the apparatus.

De Luc's analysis of the pile, 1809.

While Sir H. Davy was pursuing, with so much success, his interesting researches into the electro-chemical action of bodies upon each other, De Luc undertook to investigate the nature of the galvanic pile, and to examine the mode of its operation. After some animadversions upon the hypothesis of the inherent electric energies of bodies, which constitute the origin of the train of phenomena that are connected with the pile, he proceeds to dissect this instrument into three parts. He divides it into three separate groups, corresponding to what he regards as the three elements of the pile. These elements are the two metals and a fluid. They were first placed with the fluid between the two metals; then with the fluid in contact with one, and afterwards in contact with the other metal, the different groups being kept distinct from each other by small wire stands, so as to confine the action to that part alone. When the piles were fitted up in these three different ways, a delicate electrometer was attached to each extremity, and they were also connected by the interrupted wire passing through water. His first set of experiments were made upon the pile in which the groups were arranged with the fluid between the two metals. By means of the electrometer, he observed which ends of the apparatus were in the positive and negative states respectively; and he likewise made some new observations on the direction which the electric current takes in its passage across the water—in the interrupted circuit—and in the body of the pile itself. His observations agreed with those originally made by Nicholson, that the extremity of the pile, which is connected with the wire emitting oxygen, is positive, and that the current is directed from this to the wire which emits the hydrogen. He informs us, however, that although electrometers placed at the extremities, when they are affected, indicate the electricity to be in the state mentioned above; yet they are not always both of

Dissection of the pile.

PLATE II. Fig. 1, 2, 3, 4.

PLATE II. Fig. 12.

First dissection of the pile.

Observations on the direction of the current, and on the positive and negative states.

them affected, sometimes only the positive electricity is visible, sometimes only the negative, while at other times both of them are perceptible. He conceives that, from various causes, the electric fluid passes through the apparatus with different velocity at different times, or through its different parts at the same time, so as to produce a partial accumulation or deficiency: it seems to be always retarded when it passes from the point of the wire into water. He observes, that the expressions positive and negative, as applied to the ends of the pile, or to the wires in the interrupted circuit, can only be regarded as comparative terms, because the chemical action of the pile goes on as usual in the decomposition of water, although the whole instrument be rendered positive or negative, by attaching it to the prime conductor, or to the rubber of the electrical machine. This experiment is adduced to prove, that the action of the pile is not necessarily connected with the electric energy of the substances that enter into its composition. The pile, when dissected in the first way, with the fluid interposed between the two metals, acts in the same manner as if the parts were continuous, except that the effect is rather less powerful.

Second dissection. De Luc then examined the action of the pile, when dissected according to the second arrangement, where the metals were placed together, and the wet cloth in contact with the zinc, or the most oxidable of the metals; the ternary groups being separated from each other by the wire frames.

The extremities of the pile indicated to the electrometer the same states of positive and negative, as in the former instance, but no shock was experienced; when the wires of the interrupted circuit were placed in water, although it appeared that there was a communication established through the fluid, yet no decomposition took place, nor did there appear to be the retardation of the electric current upon its entering the fluid, as in the former case. Hence the author concludes, that the electrical and chemical effects originate from different causes, because in this state of the instrument the electrical effects continue, although the chemical effects are suspended. The third dissection of the pile was now made, *i. e.* it was divided into ternary groups, consisting of the metals contiguous to each other, and the wet cloths in contact with the silver; the groups being separated as before, by wire supports. Here there was no effect perceptible, either electrical or chemical.

Third dissection.

In the above experiments, the cloths which were employed to retain the fluid were moistened with water: a second set of experiments was now performed, in which a strong solution of muriate of soda was employed. The pile, whether moistened with water or the saline solution, had the same effect upon the electrometers, both as to quality and quantity; but when the salt was used, there was a more powerful effect upon the sensations. He observed, that a new shock was experienced every time either of the hands was brought into contact

Muriate of soda employed between the plates.

with the apparatus, or removed from it; but that no effect took place as long as they remained in contact. When the interrupted circuit was applied between the extremities of the pile, the shock might be felt, but it was rendered less violent; and the chemical effects were diminished, but not suspended, while the contact of the body was preserved: hence it may be inferred, that the body is about an equally good conductor with water. The retardation of the current appeared to be rather greater in this case, than where the apparatus was supplied with pure water.

The pile was now dissected in the same three ways as before, muriate of soda in solution being employed instead of water. In the first dissection, *i. e.* with the moistened cloths between the plates, the same electric effects were exhibited by the electrometers, the same shock was felt, and the same chemical effects were produced, only in rather a less degree than in the continuous pile, with muriate of soda. The second and third dissections of the pile produced exactly the same effect, as when the same dissections were employed with pure water.

Hypothesis of the different cause of the electrical and chemical effects.

The author afterwards enters upon a number of speculations respecting the manner in which the electric fluid circulates through the apparatus, and upon the immediate cause of the electrical and chemical phenomena. He conceives, that when no cause of retardation exists, the electric fluid circulates so rapidly through the pile, as not to exhibit any of its effects, or indeed not to indicate its presence; and that when these are manifested, it always depends upon some retarding cause. The electrical and chemical effects are supposed to originate from different parts of the pile, or from different groups, considered in their relation to the parts contiguous to them. The electrical effects consist simply in the combination of the two metals, each pair being separated by a non-metallic conductor; while for the chemical effects, ternary groups are necessary, the two metals with a fluid between them. This distinction between the two sets of properties, or the two modes of action, is supposed to be proved by the different effects which are produced by the pile in its three states of dissection. In the pile dissected in the first manner, which indeed may be regarded as equivalent to the instrument in the continuous state, both the electrical and chemical action takes place: for here are the two metals, either in contact, or connected by the wire frames, for the electrical effects; and for the chemical effects, there are the two metals with the wet cloth interposed. In the pile as dissected in the second manner, there are the binary groups, *i. e.* the metals in contact, and accordingly they produce the electrical effects; but we have no chemical effects, because they have no fluid between them. In the third dissection, no effects are produced; we have not the chemical effects, because the metals have not the wet cloth between them, and we have no electrical effects, because the zinc has the copper plate on one side, and the wire frame on the other, which have the same electrical relation to the zinc, and therefore counteract each other.

Pile of silver and pewter.

The different effects which seemed to ensue, between the pile when furnished with pure water, and with the solution of a neutral salt, induced De Luc to examine what connexion existed between the oxidation of the zinc, and the chemical action of the instrument. For this purpose he formed a pile of silver and pewter, the pewter being selected for the experiment, because it has an electrical relation with silver, and is oxidable by muriatic acid, at the same time that it is not much affected by pure water. In the first instance, water was interposed between the plates; the extremities of the pile, as indicated by the electrometer, became electric, the pewter side negative, and the silver positive; but there was no shock, nor any decomposition of the water in the interrupted circuit. A pile was then formed of such a number of zinc and silver plates, that its electrical energy might be the same with the pewter pile; but here there was both the shock produced, and the decomposition of water. The pile of pewter and silver was then fitted up with muriatic acid; and in this case, when the pewter plates became oxidated, the shock and the decomposition of water were both produced. From these experiments, the author deduces the following conclusions. When the metal is not oxidated, no

General conclusions.

chemical effect is produced on the water in the interrupted circuit. When the oxidation is produced by means of pure water, there is no shock, although the chemical effects take place; and lastly, when either of these effects are produced, the current of electricity is retarded in its passage across the water in the interrupted circuit.*

Discovery of the electric column.

It was in the prosecution of these experiments, while he was examining the effect of different conducting substances placed between the plates, that De Luc was led to the discovery of the curious instrument, which he named the electric column. It is a pile consisting of a number of disks of zinc and Dutch gilt paper, placed alternately upon each other, and included in a glass tube. In order to produce any considerable effect, it is necessary that the instrument should contain several hundred pairs of plates; when the number amounts to 800 or 1000 it will always affect the electrometer. They are made about two-thirds of an inch in diameter, and are kept in their proper position by rods of glass, coated with sealing wax. The end of the column which is bounded by the zinc plate is found to be in the state of positive electricity; that bounded by the copper plate, of negative electricity.†

Remarks on it.

Different opinions have been entertained respecting the nature of this apparatus, whether it should be regarded as a galvanic, or simply as an

* Nicholson's Journal, xxvi. 116, 241. † Ibid. xxvi. 246.

electrical instrument; in other words, whether its primary operation is to produce any chemical change in the metals of which it is composed, or whether it depends merely on the electric action of the bodies upon each other. It has been supposed by some that the phenomena of the electric column originate from a small quantity of moisture, which is still adherent to the paper interposed between the metallic plates; and experiments have been adduced to prove, that in proportion as the paper is carefully dried, the electric effects are diminished. These observations have not, however, been confirmed, while there are, on the other hand, some circumstances which seem to favour the contrary supposition. The instrument has been known to remain in action for months or even for years, and yet no visible alteration could be perceived on the surface of the metals; which could scarcely have been the case had any chemical action existed between the metal and the moisture in the paper. Another circumstance which seems in favour of its being essentially an electrical, rather than a chemical instrument, is the connexion which there appears to be between its action and the electric state of the atmosphere. This connexion was perceived by De Luc soon after he had constructed the apparatus, and he made a number of accurate observations upon the subject. Mr. Forster, by a mechanical contrivance, has adapted a bell to it, which continues to ring with a regular motion in the ordinary electric condition of the atmosphere, but ceases or proceeds irregularly when any considerable change occurs in this respect. If the action of the instrument were galvanic, or essentially connected with any chemical change in the state of its component parts, it is not probable that the atmospheric electricity would have affected it in so great a degree and in so uniform a manner.

Zamboni's pile, 1812.

I shall anticipate a little the chronological order of discovery by giving an account in this place of an instrument, supposed to be analogous to De Luc's, which has been constructed by Professor Zamboni, of Verona. Zamboni's pile, as it was first announced, consisted of disks of silvered paper, to the plain side of which was applied a layer of the black oxide of manganese mixed with honey. In this state it could not literally be entitled to the appellation of *a dry pile,* but it is said that it has been since constructed upon a less exceptionable principle. The most curious property of Zamboni's pile is the degree in which it exhibits the electrical attractions and repulsions. If two of these piles be placed at the distance of four or five inches from each other, and a metallic needle be properly suspended between them, it will be alternately attracted by the two piles, so to move between them like a pendulum. This action, we may presume, is certainly electrical; but the pile of Zamboni appears likewise to have a proper chemical action; for when it has been confined for some time in a limited portion of air, the air becomes deoxidated, and the action of the pile ceases. We are not informed whether, in this case, any visible change is produced on the surface of the metals, or whether all access of moisture was very scrupulously prevented in the instrument upon which these experiments were made.*

Hachette and Desormes's pile.

The account of De Luc's pile had been published for some time, when a claim of priority of invention was made by Hachette, in favour of himself and Desormes, stating that they had formed a dry pile so long back as the year 1803. It is difficult to decide upon the merit of such claims; but as a general principle it is always proper, in these cases, to adhere to the date of publication, unless they can be substantiated by written documents of unexceptionable authority. In the present instance, however, it would appear, that the original pile, as formed by Hachette and Desormes, is by no means entitled to the appellation of dry, and indeed does not appear to be analogous to De Luc's instrument, for it is described as having been constructed with paste or size between the plates; and we are expressly told that, in proportion as the moisture was evaporated, the action of the apparatus was diminished.†

Children's large battery, 1809.

While Sir H. Davy and De Luc were thus enlarging our knowledge of the powers of galvanism as a chemical agent, and of the means by which

* Journ. of Science and the Arts, ii. 161.

† Ann. de Chim. et Phys. ii. 76; see also Biot in Ann. de Chim. xlvii. 15.

its wonderful effects are accomplished, Mr. Children was advantageously employing himself in improving the apparatus. He formed a battery, constructed upon the principle employed by Volta, in the couronne des tasses, according to which the plates are not in contact through the whole of their extent, but are connected only at the top by a metallic conductor, and are then immersed in the cells of a trough. He employed 20 pair of plates, of four feet by two, making in all a surface of 92,160 square inches. The fluid that he used was a diluted mixture of nitric and sulphuric acids, the whole quantity being no less than 120 gallons. The effect of these large plates was to fuse entirely, in about 20 seconds, 18 inches of platina wire, of one-thirtieth of an inch in diameter, and to render three feet of the same wire red-hot. Charcoal burned with intense brilliancy. It seemed not a little remarkable, considering the powerful effect on platina wires, that the action of this battery on iron wires was comparatively trifling. Of iron wire, one-seventieth of an inch in diameter, it barely fused ten inches, and was not able to ignite three feet. It had not the power of decomposing barytes and other similar substances; it did not affect Bennet's electrometer; and it scarcely produced a perceptible shock.

Plate I. Fig. 4.

nb

Mr. Children next formed a battery of 200 pairs of plates of two inches square, affording a surface of 3,200 inches. With this the alkalies and alkaline earths were readily decomposed, and a con-

Comparative effects of smaller plates.

siderable divergence was produced in the gold leaves of the electrometer. From this comparison of the effects of the two batteries, we are led to the conclusion which has been already referred to, that the *intensity* of the electricity is increased with the number, and the *quantity* of it with the extent of the metallic plates. Upon this principle, we may explain why the platina wire was acted upon more readily than the iron wire, the more perfect conducting quality of the former presenting no obstacle to the passage of the electricity through it; while the tendency of the iron to oxidation required a greater intensity of the fluid to effect its transmission through the wire. In this paper, the author states, that he has removed one of the objections that have been urged against the identity of the galvanic and the common electricity, that the former has no striking distance; by employing a proper apparatus, he ascertained that the galvanic spark was capable of passing through a certain space between the extremities of two platina wires.

Striking distance of galvanic electricity.

General conclusion.

Mr. Children's general conclusion is, that "the absolute effect of a voltaic apparatus is in the compound ratio of the number and size of the plates; the intensity of the electricity being as the former, the quantity given out as the latter; consequently, regard must be had in its construction, to the purposes for which it is designed. For experiments on perfect conductors, very large plates are to be preferred, a small number of which will probably be sufficient; but where the resistance of imperfect conductors is to be overcome, the combination must be great, but the size of the plates must be small. But if quantity and intensity be both required, then a great number of large plates will be necessary. For general purposes, four inches square will be found to be the most convenient size.*

Mr. Children has since constructed a still larger and more powerful battery, consisting of 20 pairs of copper and zinc plates, each plate being six feet by two feet eight inches. It ignited six feet of thick platina wire, and melted platina with great facility; it also melted iridium and osmium. At the suggestion of Dr. Wollaston, a singular fact was ascertained, that a greater length of thick platina wire was ignited, than of platina wire of a much smaller size.† More powerful battery, 1813.

About this time a battery of very great power was constructed at the Royal Institution. It consisted of 200 separate parts, each part composed of 10 double plates, and each plate containing 32 square inches, the whole of the double plates being 2,000, and the whole surface 128,000 square inches. When the whole series was put into action, platina, quartz, sapphire, magnesia, and lime, were all rapidly fused; while diamond, Battery at the Royal Institution.

* Phil. Trans. for 1809. p. 32.
† Annals of Philosophy, ii. 147.

charcoal, and plumbago, in small portions, disappeared, and seemed completely evaporated. A singularly beautiful effect was produced by placing pieces of charcoal at the two ends of the wires in the interrupted circuit; when they were brought within the thirtieth or fortieth part of an inch of each other, a bright spark was produced, above half the volume of the charcoal, which was rather more than an inch long, became ignited to whiteness; and by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal to at least four inches, producing a most brilliant arch of light; this light constituted the sphere of activity of the instrument. When the communication between the two wires was made in air so far rarefied as to support only one quarter of an inch of mercury in the barometric gauge of the air-pump, the spark passed through a space of nearly half an inch; and by withdrawing the points from each other, the electric fluid was discharged through six or seven inches, producing a most beautiful coruscation of purple light, while the charcoal itself became intensely ignited, and some platina wire attached to it fused with brilliant scintillations, and fell down in large globules. All the effects of chemical decomposition were rapidly and powerfully produced; various substances submitted to the action of the apparatus were instantly resolved into their elementary gases; and so intense was the action, that

Plate II. Fig. 14.

sparks were produced even in the nitric and sulphuric acids.*

I have given above some account of a paper of Erman's, in which he endeavours to show, that certain bodies are what he calls Unipolar, that is, that they are conductors of one kind of electricity only. Mr. Brande conceived, that the facts brought forward by Erman might admit of a better explanation upon a different principle, viz. that some chemical bodies being naturally positive, and others naturally negative, they would be attracted to the surface of the pile in a contrary state to their own, the positive to the negative, and the negative to the positive surface. **Brande's remarks on Erman, 1814.**

In order to submit his opinion to the test of experiment, Mr. Brande procured two insulated metallic balls, one connected with the prime conductor, and the other with the rubber of an electrical machine; and placing between them the different substances under examination, he observed to which of the balls they were attracted. He found that the flame of a candle, which principally consists of carbon and hydrogen, was attracted to the negative ball; while the flame of phosphorus, which would contain a quantity of phosphoric acid, was attracted to the positive side. Here the bodies seemed to follow the known laws of electrochemical attraction, according to the idea of their inherent electrical states; and the other experi- **Experiments.**

* Davy's Elements of Chemical Philosophy, p. 152.

ments which he performed of a similar nature generally tended to the same conclusion. The facts stated in this paper are conceived to be favourable to the hypothesis of Sir H. Davy, respecting the natural electricities of bodies, and also, when viewed in connexion with Erman's observations, to afford an additional proof of the identity of electricity and galvanism.*

Mr. Brande's method of viewing these experiments is, I conceive, preferable to that of the author himself, as being more simple, and as involving no principle in addition to those which are deduced from other phenomena. In most cases at least it offers a satisfactory explanation of the facts; and it does not appear, in any instance, to be directly at variance with them.

Wollaston's elementary battery, 1815.

Dr. Wollaston constructed a very curious apparatus, which he calls an elementary galvanic battery, the object of which is to exhibit the most minute arrangement of electrical substances, by which visible ignition can be produced. The smallest that he has constructed consists of a thimble, without its top, flattened until its sides were about one-fifth of an inch asunder; a small plate of zinc was then contrived to be fixed within the thimble, but without touching it; and a proper appendage of platina wires was added. The zinc plate was less than three-fourths of an inch square, and even when water was employed that

* Phil. Trans. for 1814.

contained only $\frac{1}{30}$ part of sulphuric acid, a platina wire of $\frac{1}{3000}$ of an inch in diameter, and from $\frac{1}{30}$ to $\frac{1}{50}$ of an inch in length was readily fused.* In the formation of his minute apparatus, this sagacious experimentalist made an observation of great importance in enabling us to produce as much effect as possible from the smallest quantity of materials. He remarks that the zinc plate should have a counterpart of copper opposed to each side of it; for in the usual arrangement, although both sides of the zinc are oxidated, that side only is efficient which has a copper surface opposed to it.

This principle, which Dr. Wollaston had used with so much success in his elementary battery, was applied by Mr. Children with proportionate success, to the formation of the most powerful galvanic instrument which has hitherto been constructed. The plates were six feet long by two feet eight inches, so as to present 32 square feet of surface; each zinç plate was supended between two copper plates, and they were connected together by lead. Each of these sets or triads of plates was immersed in the separate cell of a trough, which was filled with a properly diluted mixture of the sulphuric and nitric acids, and the plates were all attached to a beam, and so adapted to a counterpoise as that they could be readily lifted up out of the trough and again immersed in it at

Children's new battery.

* Ann. of Philosophy, vi. 209.

pleasure. The following was the order in which metallic wires were raised to the red heat; platinum, iron, gold, copper, zinc, and silver, an order which was conceived to be exactly the reverse of their conducting power; the places of tin and lead could not be ascertained, because they melted before they became red hot.

Its effects. Among the effects of this powerful apparatus in generating heat, the following are some of the most remarkable. Five feet and a half of platinum wire, ·11 inch in diameter, was raised to a red heat visible in day-light; the same effect was produced upon $8\frac{1}{2}$ inches of platinum wire, ·44 inch in diameter, and upon a bar of platinum $\frac{1}{6}$ inch square, and $2\frac{1}{4}$ inches long. The chemical effects of the apparatus were no less remarkable than its power of extricating caloric. The oxide of molybdenum was easily fused and reduced; the oxide of tungsten was fused and partly reduced; the oxides of uranium, titanium, and cerium were fused, but not reduced; and the oxide of tantalum was partially fused. The compound ore of iridium and osmium was fused into a globule, and iridium was formed into a globule containing cavities. Box-wood charcoal was intensely heated in chlorine and in azote, but in neither case produced any effect. By heating iron in contact with diamond powder, the diamond was consumed; and the iron was converted into steel. Blue spinell and gadolinite were fused, and zircon from Norway imperfectly so; magnesia was agglutinated; while ruby, sapphire, quartz, and silex, were not affected.*

Since the experiments of Mr. Children, the only addition which the science of galvanism has acquired is from Dessaignes, who some time before had made a series of observations on the effects of temperature upon the action of the pile, which he now repeated and extended. He informs us, that the instrument ceases to act if the whole of it be heated to 212°: but that, on the contrary, its action is doubled, if one half of it be heated, while the other is cooled. He farther informs us, that two pieces of metal of the same kind will act, if one of them be heated, while the other is cooled; and even that the same effect will follow if different parts of the same piece of metal be kept at different temperatures. The result of these experiments is probably what we should not previously have expected; yet they may be explained either upon electrical or chemical principles; as both the electrical condition of bodies, and the effect of chemical re-agents, is materially affected by the degree of temperature to which they are exposed.* Dessaignes' experiments, 1816.

These experiments will conclude the first part of this essay, containing the history of galvanism. Although it may be somewhat hazardous to form predictions respecting the progress of science, I Concluding remarks.

* Phil. Trans. for 1815, p. 363.

† Journ. de Phys. lxxiii. 230, 417; lxxxii. 360; lxxxiii. 194.

may remark, that the impulse which was given, in the first instance, by Galvani's original experiments, was revived by Volta's discovery of the pile, and was carried to the highest pitch by Sir H. Davy's application of it to chemical decomposition, seems to have, in a great measure, subsided. It may be conjectured that we have carried the power of the instrument to the utmost extent of which it admits; and it does not appear that we are at present in the way of making any important additions to our knowledge of its effects, or of obtaining any new light upon the theory of its action.

PART II.

THEORY OF GALVANISM.

ACCORDING to the plan which was laid down, I must now proceed to give an account of the theories and hypotheses that have been formed to explain the phenomena of galvanism. I have had occasion to allude to many of these in the course of the historical sketch; and the reader will, in some degree, have anticipated my opinion respecting them. The subject divides itself into several branches, partly corresponding with the progress of our knowledge of the facts that were gradually developed, and partly depending upon the supposed relation of galvanism to the other departments of natural philosophy. General remarks.

In this concise view of the science, I shall not think it necessary to enter into the merits of the earlier speculations that have been superseded by later discoveries. Of this nature is the original hypothesis of Galvani himself, that the convulsions which he observed in the muscles of frogs were produced by a new and peculiar agent, residing in the body, to which he gave the name of animal electricity. Although there are some few cases which seem to militate against the supposi- Galvani's hypothesis.

tion, it must, upon the whole, be regarded as being decisively proved, that all the phenomena which we style galvanic depend merely upon the action of electricity, modified by the manner in which it is produced or excited.

What is galvanism?

Hence arises an interesting question, and one which lies at the very foundation of all our future inquiries, How does galvanism differ from common electricity? This question may refer both to the nature of the phenomena themselves, and to the means employed for their production. We may define galvanism, either by enumerating the specific characteristics of those events which we class together under this title; or we may show how they have all a reference to each other, from the similarity of the processes that are employed for their development. The definition that was given at the commencement of the essay, may be regarded as sufficiently correct and comprehensive, without exceeding the limits to which a definition ought to be restricted. It appears to include every action of bodies upon each other which is usually considered as belonging to this particular branch of natural philosophy; while it excludes those that are, by common consent, referred to a different department. It is, however, in some cases, difficult to draw the exact line of distinction between electricity and galvanism; and indeed we may doubt whether any precise distinction actually exists. For as it is conceived that they both depend upon the same agent, having merely experienced some

Remarks on the definition.

modification in its nature, or mode of action, we must conclude, that there may be some intermediate or indeterminate state, which might be referred to one or the other with almost equal propriety.

Definition.

To recur then to the former definition: "Galvanism is a series of electrical phenomena, in which the electricity is developed without the aid of friction, and where we perceive a chemical action to take place between some of the bodies employed." This definition may perhaps be thought to limit the science too much, and to remove from it many facts which have always been regarded as galvanic. For example, a great number of the original experiments of Galvani himself, and his contemporaries, where contractions were excited in the muscles of animals, by the application of the two metals, many of those of Fowler, and the first set of Volta's experiments, would, according to this definition, be reduced to the effects of common electricity. To this objection we may reply, that wherever moisture comes in contact with the zinc, or more oxidable metal, it is not improbable that some chemical action is produced, but that it is very slight, and has therefore not been noticed. If, however, upon a strict examination, it is found not to be the case, and that there is actually no change in the chemical condition of any part of the apparatus, it must be admitted that, according to our present ideas, the phenomena are not to be referred to galvanism. The first unequivocal experiments where the chemical effects

First proper galvanic experiments.

were observed, and were connected with the electrical condition of the substances, are those of Fabroni's; and it was not until Volta's discovery of the pile, that we were put in possession of a method by which we were enabled to examine, with any degree of accuracy, the relation between these two actions. Even if we find it necessary to conclude that Galvani, although he had the good fortune to have his name associated with a new department of science, did not witness any of the facts to which we now apply the term, the contradiction will be more apparent than real; and we must not permit the mere circumstance of *names* to influence our opinion respecting the essential nature of *things*. The present state of our knowledge seems, however, to warrant the conjecture, that the action of the two metals on the parts of animals is strictly galvanic, *i. e.* accompanied by a chemical action on the metals and the fluids, so as to reduce it within the limits of the proposed definition.

Difference between electricity and galvanism.

Waving, however, the farther discussion of this point, which indeed can only be decided by experiment, we must recur to the question already stated, respecting the essential difference between galvanism and common electricity; and, conceiving it to be ascertained, that in the production of the former, a chemical action takes place, which is not necessary in the latter, we must next inquire, in what way this chemical change of the substances imparts to the electricity that particular state or modification which we style galvanic. With respect to the nature of this chemical change, experimentalists are generally agreed: as to the metals, it consists in the oxidation of that metal which possesses the strongest attraction for oxygen; and with respect to the fluid interposed between the metals, it consists in its decomposition, the oxygenous part being attracted to the most oxidable metal, and the alkaline to that which is the least oxidable. Although, as I have already had occasion to remark, there are various galvanic combinations into which only one metal enters, or even some entirely without metals, yet, as the most powerful and complete circle is that which consists of two metals with a fluid interposed, I shall confine my illustrations to this form of the apparatus.

Galvanic electricity of low intensity.

We may consider it as proved by a number of experiments, which have been stated in the first part of this article, that the electricity, as it is evolved by the different galvanic combinations, always exists in what has been styled a state of low intensity; and that, to whatever extent we increase the apparatus, and however powerfully it acts, still the intensity is but little augmented. Unfortunately it is still a doubtful point of theory, upon what the intensity of electricity depends, or in what it precisely consists. Some writers have ascribed it to a greater or less concentration of the fluid; some to a difference in the velocity of its motion, or in the strength of its affinity for the

Remarks on electrical intensity.

surrounding bodies; and others to its containing a greater or less portion of caloric. For the present, we must rest satisfied with admitting the fact of the low intensity, as manifested by the phenomena, without being able to explain its cause; and we may next proceed to inquire, whether there be any circumstances in the different methods of exciting or producing electricity, by the machine or the pile respectively, which should cause the first to develop the fluid in a higher, and the latter in a lower state of intensity.

Electricity as excited by the machine.

And here, it must be confessed, we have little to direct our inquiries but conjecture and uncertain analogy. Of these, however, as being our only guides, we must make the best use that lies in our power. It is generally agreed, that all bodies possess a certain quantity of electricity, which is said to be natural to them, and which, while it remains undisturbed, manifests no indications of its existence. There are many processes which alter the state of this natural electricity, by which it is extricated from one body, and may be transferred to others in the neighbourhood. But this additional portion, being more than their natural share, seems to be retained by them with difficulty, and is ready to fly off in all directions, in order to restore the equilibrium. This may be considered as descriptive of what occurs in the operation of the common electrical machine, where, by the friction of the rubber against the cylinder, a portion of the electric fluid is carried off from one or both of them, and is transferred to the conductor. From the conductor it may be communicated to a variety of other bodies that are placed within the sphere of its influence; but, in all these cases, it is retained by them for a certain space of time only, and is continually passing off, more or less rapidly to all the surrounding bodies.

Electricity of the pile.

But besides this temporary transfer from one body to another, without their undergoing any farther alteration, they occasionally experience a more permanent change in their electrical state, when, in consequence of their acquiring different physical and chemical properties, their capacity for electricity is entirely altered. When their capacity is diminished, a more gradual, but more continued discharge of the electric fluid takes place; and in this appears to consist the essential action of the pile, as contrasted with that of the machine. In the action of the machine, by which the electric fluid is set at liberty, and transferred from one body to another, no change appears to take place in the substances employed, except the alteration in their respective quantities of electricity. Their attraction for it is neither increased nor diminished; and, consequently, they have a tendency, the one to lose, and the other to acquire, the electricity which has been thus, as it were, forced into the one, and out of the other. According to the nature of the action by which the electricity is evolved, whether the substances experience any permanent change in their capacity, or whether their equilibrium is merely disturbed in a temporary manner, the state of the fluid appears to be affected, so as to cause a difference in its intensity.

The two electricities compared.

When we employ the machine, the electricity that we procure appears to be in a highly elastic state, its particles are strongly repulsive of each other, and at the same time not disposed to enter into a permanent union with other bodies. The galvanic electricity which we procure from the pile is more readily united to other bodies, and has a tendency to form new combinations with them, which is so powerful as to counteract some of the strongest chemical affinities. At the same time, it exhibits less of what may be called mechanical action: its particles are less repulsive of each other; its motions appear less rapid; it causes less commotion in its passage from one body to another; and although its ultimate effects are more powerful, it seems to act with less violence. The one may be compared to a small quantity of an agent highly concentrated; the other to a larger quantity, but in a state of greater dilution. The phenomena of electricity, as excited by the common machine, depend upon the attraction and repulsion of the electric fluid, and its passage from one body to another; while the most important actions of galvanic electricity result from the chemical changes that it produces in the composition of bodies. The excitation of common electricity is not necessarily attended with any permanent alteration in the state of the substances that are employed in producing it. It is usually developed by the mechanical aid of friction; and the same apparatus may continue to be employed for an indefinite length of time. Friction, on the contrary, has no effect in the production of galvanic electricity; it requires a chemical change in some part of the apparatus; and the individual parts which have been employed in generating it acquire new properties, and are incapable of any farther galvanic action. In the above remarks I have proceeded upon the hypothesis which is the most generally received in this country, and which I am disposed to consider as the most plausible, that the two electricities differ from each other merely in the relation of quantity. But if the contrary opinion be adopted, which is more current in France, and which has been so elaborately detailed by Biot in his late treatise, and we regard them as differing in their nature, still it will not essentially affect the reasoning that I have employed, although it may require to be expressed in somewhat different terms. According to this view of the subject, when we employ the common electrical machine, we forcibly alter the proportion in which the vitreous and the resinous electricities naturally exist in the different parts of the apparatus, which have a constant tendency to resume their former condition. In the action of the pile, on the contrary, we alter the capacity of some part of the instrument for one or other of the electricities, and produce a state in which their balance is permanently changed.

Action of the pile.

After these general observations, which, scanty and inconclusive as they are, appear to be all that our present knowledge upon the subject will warrant, we must proceed to examine more minutely into the nature of the action that is exercised by the galvanic apparatus. From the remarks that have been already made, it will be obvious, that in the operation of the pile there are both electrical and chemical phenomena produced; and it has been a point very warmly contended, which of these is the most essential, or rather which of them is the primary effect, and, consequently, is to be considered as the cause of the other, and of the whole train of actions. Volta, and most of the continental philosophers, support the electrical hypothesis; while there are several distinguished experimentalists in this country who maintain, that the chemical action is the one which gives rise to all the changes that are produced, and therefore constitutes the primary action of the instrument.

Volta supports the electric hypothesis.

In all the experiments that were performed with the two metals, previous to the discovery of the pile, with the exception of those of Fabroni, which seem to have been but little attended to, the only point in discussion was, whether the effects were to be referred to the electric fluid, or to a new agent inherent in the animal body. Volta strenuously adopted the opinion, that they depended simply upon common electricity; and accounted for them by supposing, that the contact of the two metals had the power of altering the quantity of electricity which was natural to them, adding a portion of it to the one, and subtracting it from the other respectively. To this power he gave the title of *electro-motion;* and he spoke of it as a new property, which had not been before noticed, and distinctly claimed to himself the merit of its discovery. He conceived that he might increase the power of the instrument, or rather concentrate the effect of a number of separate pairs of metal, by interposing between each pair a conducting substance, which, without altering the electric state of the metals, might increase the effect by transmitting it through a number of successive stages. Whatever we may think of the hypothesis, the experiment to which it gave rise was most fortunate; for it led to the construction of the pile; an apparatus by means of which the most curious and important discoveries have been made in the different departments of natural philosophy.

Forms the pile.

Although Volta completed the discovery of the pile, and fully ascertained its action on the animal body, yet it is not a little remarkable, that he limited his inquiries to this object, and seems to have been totally ignorant of the farther powers of the instrument of which he was possessed. This circumstance must appear the more remarkable, when we recollect that upon the very first employment of it by Nicholson and Carlisle, they perceived its chemical action, and became aware of its importance as an agent in the decomposition of bodies. Cruickshanks, Davy, Wollaston, Henry, and the other English philosophers, farther developed

Did not notice its chemical effects.

its powers in this respect, which had so completely escaped the notice of Volta, and they were consequently led to form a different idea of the mode of its operation. Dr. Wollaston seems to have been the first who decidedly adopted the opinion, that the chemical action of the pile is the primary origin of all the changes which it experiences, and is the cause of the electrical effects; and the same idea was embraced by Sir H. Davy, although he has since abandoned it for the hypothesis of electric energies.

An account of the electric hypothesis of the pile.

I must now proceed to examine the two leading theories of the galvanic action, as exhibited in the pile, with more minuteness; and I shall begin with that of Volta, or the one which supposes a change in the electrical condition of the metals to be the primary cause of its operation. This philosopher has given a statement of his opinions on the subject, in several letters which he wrote to his friends, and which have been published in different scientific journals. His first communication was in a letter to Cavallo; the second to Gren;* both written before his discovery of the pile. His original account of this apparatus is contained in a letter to Sir Joseph Banks, in which he explains his ideas respecting its action; and he afterwards farther developed them in letters to Delametherie and to Van Marum.† In

* Phil. Trans. for 1793; Ann. de Chim. xxiii. 276.

† Phil. Trans. for 1800; Nicholson's Journal, 8vo. i. 135; Ann. de Chim. 40, 225.

some of these papers Volta details his hypothesis at considerable length; yet, after an attentive examination of them, it appears to me that they are not altogether consistent with each other; and that, without any intimation of the circumstance, he has, in fact, presented to the world two distinct hypotheses.

The letter written to Cavallo, of which I have already given some account, is Volta's first essay on the subject of galvanism, and contains an account of Galvani's original discovery, and of the additional experiments which he had himself performed by the combination of the two metals. He accounts for all the facts on the principle, that when metals are placed in certain circumstances with respect to each other, there is "a destruction of the equilibrium" of the electricity. This action is stated to consist essentially in two metals, when placed in contact, giving the one to the other a portion of its natural electricity, so that the one becomes positive and the other negative. Some combinations of metals possess this electro-motive faculty much more powerfully than others; those that Galvani and Volta originally employed were zinc and silver; and in this case the zinc acquired the electricity and became positive, while the silver lost electricity or became negative. In this paper no other principle is referred to; and the action is not spoken of as belonging to any class of bodies except the metals. Volta speaks of the principle as a new law of electricity, which had not been before noticed, and decidedly claims to himself the discovery of it.

In the letter to Delametherie, written after the discovery of the pile, Volta still farther develops his hypothesis, but without altering the ground on which it rests. He describes each pair of metals as the efficient part of the apparatus, and speaks of the fluid that is interposed between them as merely carrying the electricity from one pair to another, without producing any change in it. In his letter to Van Marum, he relates the following fundamental experiment, as it is called: a plate of copper and a plate of zinc are placed in contact with each other, but so that a part of each plate projects beyond the other; and he finds, that of the parts which thus project, one becomes positive and the other negative. So far all these opinions appear to be consistent with each other; but in the letter written to Gren, an idea is brought forward, which is not noticed in the other essays, and which seems to be essentially different from them. All conductors of electricity are divided into two classes, the dry and the moist; and electricity is supposed to be always excited, when two conductors of either of these classes are placed in contact with one conductor of the other class. In this way one metal only would appear to be sufficient for a galvanic combination, provided there be two moist conductors in contact with it. How the fluids act in this case, or what relation they bear to each other and to the metal, we are not exactly informed; but we may conclude, that it is not from any chemical operation, because in the letter to Delametherie, written four years after that to Gren, it is expressly said, that the fluids have no effect but in transferring the electricity from one metal to another.

General view of the electric hypothesis.

Upon the whole we may conclude, that Volta conceives the electricity to be excited by the metals producing a degree of electro-motion, or by destroying the natural equilibrium of the electricity; one metal thus becoming positive and the other negative, they each of them exhibit signs of electricity to an electrometer or other similar instrument. The only use of the fluid is to tranfer the electricity which is excited by one pair of metals to the next pair; and although a chemical action may take place between the fluid and the metal, this action is merely incidental, and is not essential to the production of the galvanic effects.

Objections to it.

The objections to Volta's hypothesis are very forcible: in the first place, I am disposed to think that the fundamental position, on which the whole rests, is objectionable.

Volta's fundamental experiments doubtful.

Volta supposes that two metals, as for example, a plate of zinc and one of copper, when placed in extensive contact with each other, may become respectively positive and negative. This he endeavours to prove by direct experiment; but it will be found that in none of the cases is the experiment precisely in point. He adduces some facts, where metals were found respectively positive and negative, that *had been* in contact, but were afterwards separated: in one of his experiments the metals never actually touched, but were connected by a moist conductor; and in the experiment which we have related above, it was only the projecting parts of the plates that could be made to exhibit the opposite electric states. And it appears that a very general misconception has prevailed on the subject, and that almost all writers have confounded the state of approximation with that of contact. The experiments of Bennet and Cavallo have been adduced as analogous to those of Volta, and Sir H. Davy expressly designates Volta's hypothesis as an extension or generalization of these experiments, remarking that Bennet had proved, that bodies brought into contact, and again separated, exhibited different states of electricity.* Volta himself has clearly fallen into the same error; for in the experiments which are related in his letter to Delametherie, he examined the metals separately, after they had been in contact, and draws his inference from this examination.† Yet these experiments do not apply to the circumstances of the pile, where the metals have an extensive communication with each other, and where, from this circumstance, it is probable that, while they remain in

* Phil. Trans. for 1807, p. 32.

† Nicholson's Journ. 8vo. i. 136, &c.; Henry's Elements, i. 248; Murray's Chemistry, i. 581. See also Haüy, Traité de Physique, ii. 15, &c.; Biot, Traité de Physique, ii. 471; and Ann. de Chim. xlvii. 8.

contact, or this communication is preserved, they must be in the same state of electricity. An electrified body may communicate electricity either by contact or by approximation; in the first case the electricity is the same with that of the communicating body; in the second, the communicated electricity is of the opposite kind, but it is destroyed as soon as the bodies actually come into contact. The experiment of Volta, which comes the most near to the circumstances of the galvanic apparatus, is that mentioned above, where the projecting parts of two metallic disks were found to be in opposite electric states. But this is an experiment of a most delicate nature, and Mr. Cuthbertson, who attempted to repeat it, obtained results contrary to those stated by Volta.*

Chemical effects not accidental.

But, waving this objection, and admitting that the two metals, while they are in extensive contact, may be in opposite electrical states, it may be objected to Volta's hypothesis, in the second place, that the chemical effects of the pile are not, as he supposes, merely accidental. They seem, on the contrary, to be absolutely essential to its action, for when perfectly pure water is interposed between the metals, or when the apparatus is placed in any situation where it is excluded from obtaining a supply of oxygen, it ceases to act. The same thing happens when the acid, or other oxidating fluid, is all expended; and in short it may

* Nicholson's Journ. 8vo. ii. 281.

be stated, as a general principle, that whatever promotes the action of the fluid upon one of the metals increases the energy of the instrument, and whatever tends to prevent or destroy this action suspends the energy. When considered in this point of view, the experiments of De Luc, on the dissection of the pile, seem to be strongly adverse to the electric hypothesis. In the second distribution of the ternary groups, the two metals are in contact, and therefore any electrical effect might be produced, which would arise from this circumstance; there was also the fluid between them, which would serve as a conductor of electricity; yet because the apparatus was so arranged that this fluid could not act upon the zinc and oxidate it, no proper galvanic effect ensued.

It is a little remarkable, that notwithstanding the weight of authority to prove that the action of the pile is suspended in vacuo, or in any gas which does not contain oxygen, unless the fluid between the plates contain some saline matter,* Volta, even in a comparatively late period of the inquiry, still continued to deny the fact.† And the same remark may apply to what this philosopher says respecting the superior efficacy of saline fluids, which, notwithstanding the experiments of Davy and others, he still perseveres in ascribing simply to their superior conducting power.‡ And, indeed,

* Davy, Biot, Van Marum, Pepys, Haldane, &c.

† Ann. de Chim. xlii. 281.

‡ Nicholson's Journ. 8vo. i. 239.

independently of any experiments performed expressly for the purpose, when we consider how readily pure water transmits the electric fluid, we can scarcely attribute to a deficiency in its conducting power the comparatively small effect which it produces in the pile, nor to a mere increase of this conducting power, the vastly greater activity of diluted acids or neutral salts. And if we refer to the principle of the hypothesis, the more we increase the conducting power of the fluids, the less should be the action of the pile. The contact of the metals is supposed to destroy the electrical equilibrium, and the operation of the fluid is to counteract this disturbance and restore the equilibrium. It must then follow, that the more perfect the conductor, the more completely will the equilibrium be restored, and the less effect will be produced by its destruction.

It may be urged as an objection to Volta's hypothesis, that it does not provide for any absolute increase of the electric power. The two metals, by their contact, become one positive and the other negative; and this is equally the case with each pair; but the fluid that is interposed between the metals is conceived to restore the equilibrium of the electricity, which has been disturbed by the metals. This is the whole effect of the apparatus; and we are not informed how any electricity can be actually produced or generated, as it would appear that the nature of the instrument is to cause an electric action in one part, which must be immediately counteracted by another part.

Whatever deficiency of electricity there was in any copper-plate would be instantly supplied by the water communicating the superabundant electricity of the opposite zinc plate, so that the effect of the whole would be reduced simply to the difference between the two extreme plates of copper and zinc.

The hypothesis may be thus illustrated. C 1 and Z 1, by their contact, produce a change in their natural state of electricity; part of what belonged to C 1 is transferred to Z 1, so that C 1 becomes negative and Z 1 becomes positive; and supposing that their natural share of electricity is represented by 100°, and that the copper gives $\frac{1}{10}$ to the zinc, C 1 and Z 1 will be brought to the states of 90° and 110° repectively. The same alteration in their electrical states will, at the same time, take place in the second pair of plates, C 2 and Z 2. The water, which is in contact with C 1 and Z 2 will, however, from its conducting power, have the effect of equalizing the electrical states of these bodies, and will therefore reduce the electricity of Z 1 to 100°, and raise that of C 2 to the same degree. The electrical state of the four plates will therefore be 90°, 100°, 100°, and 110°. The third, and every succeeding pair of plates will be acted upon exactly in the same manner with the second; the electricity of the copper, which was reduced to 90° by the action of the zinc in contact with it, will be brought to 100° by sharing a part of the excess which the former zinc plate had acquired. This appears to be all the change which can be produced upon the original hypothesis of Volta; the only fundamental positions of which are, that the electrical equilibrium of the two metals is destroyed by placing them in contact, and that the water, when interposed between the plates, conducts the electricity so as to destroy the equilibrium. In this state of things the apparatus will be nearly inert, at least it will have no more power than that produced by a single pair of plates; for all the intermediate ones, being in contact with water, will be brought to a state of equilibrium.

Dr. Wollaston, as I have already remarked, was the first who decidedly pronounced the chemical action of the pile to be the primary cause of its effects; but in establishing this point, he did not proceed to explain the nature of the operation, or show what was the train of events which contributed to the final result. This was attempted by Mr. Cuthbertson, who, in the essay to which I referred above, after pointing out the inaccuracy of the experiments that were brought forward by Volta in favour of the electric hypothesis, offers some observations in support of the contrary opinion. He conceives that the chemical action of the interposed fluid upon the zinc alters the electric properties of the metal, and disposes it to part with electricity; that this evolved electricity cannot enter into the remainder of the zinc which has not been acted upon, because it retains its former electric state, but that it is "propelled forwards

Chemical hypothesis.

Cuthbertson's opinion.

from the zinc, through the menstruum, to the next adjoining copper in the pile or trough." This effect, however, can only happen in a progressive manner, because the fluid is but an imperfect conductor; and to this he ascribes many of the peculiar phenomena of the apparatus. Dr. Henry, in a judicious essay, "*On the Theories of the Excitement of Galvanic Electricity*,"* observes, that, "the explanation of Mr. Cuthbertson is unequivocally a valuable supplement to the theory of Volta, inasmuch as it takes into account the efficiency of chemical menstrua." But, as he farther remarks, it is defective, because it does not explain why "the action of the menstruum is chiefly, if not entirely, exerted in oxidizing and dissolving the zinc plates, and why the evolution of hydrogen gas, or of nitrous gas, occurs chiefly at the copper surface."

The author's hypothesis. The first attempt which I made to explain the chemical action of the pile, was written about the same time with the above remarks of Mr. Cuthbertson, and may be considered, in some degree, as supplying the deficiency of his hypothesis which is noticed by Dr. Henry. I proceeded upon the principle which was laid down by Dr. Wollaston, that electricity is evolved by the oxidation of metals; and generalized it so far as to conclude, that the electric fluid is always liberated when an oxidable substance is united to oxygen. In addition to this principle, I proposed

* Manchester Mem. 2d series, ii. 293.

to admit the two following postulates, that the electric fluid has a strong attraction for hydrogen, and that when in passing through a chain of conductors, it leaves the oxidable substance to be conveyed through water, it combines with the hydrogen, and is again disengaged from it, whenever it again enters into an oxidable substance. I shall again quote from the essay of the same candid and judicious writer, as his account of the hypothesis, although concise, is, at the same time, perfectly correct.

"To the efficiency of the pile, two circumstances are essential; that the electric fluid should be disengaged, and that it be confined and carried forward in one direction, so as to be concentrated at the end of the apparatus. The first object is fulfilled by the oxidizement of the zinc; the second, as Dr. Bostock supposes, is effected by the union of the evolved electricity with nascent hydrogen, and by the attraction of the next copper-plate for electricity. At the surface of this plate, the hydrogen and electricity are supposed to separate; the hydrogen to be disengaged in the state of gas, and the electricity to be conveyed onwards to the next zinc plate. Here, being in some degree accumulated, it is extricated in larger quantity, and in a more concentrated form, than before. By a repetition of the same train of operations, the electric fluid continues to accumulate in each successive pair; until, by a sufficient extension of the arrangement, it may be made to exist at the zinc

Henry's account of it.

PLATE II. Fig. 5.

end of the pile, in any assignable degree of force." After an interval of fifteen years, and notwithstanding the succession of brilliant discoveries that have been made during this period, I am not aware of any fact which is adverse to the above hypothesis, or any phenomenon which it does not explain. It must, however, be confessed that it entirely depends upon the assumption of two postulates, for which we have no other proof except the facility with which they explain the phenomena; yet they are positions which are not in themselves improbable, and which do not seem incompatible with our ordinary conceptions on the subject.

The pile both an electrical and galvanic instrument.

A considerable part of the difficulty which has occurred in forming a theory of the pile, has, I think, arisen from our not clearly discriminating between its effects in exciting common electricity, and that modification of it which is called galvanism. I have endeavoured to point out in what respect these two actions differ from each other; and, imperfect as our knowledge is concerning the cause, I conceive that there is an obvious difference in the effect. Now it will appear that the pile, as it is usually constructed, is both an electrical and a galvanic instrument; and that when we attempt to form a theory of its action, we have two distinct sets of phenomena to explain. The power of producing muscular contraction is an electrical effect, that of decomposing chemical bodies a galvanic effect; while that of burning metallic leaves, or igniting wires, probably partakes of both these actions. That the electric and galvanic effects of the pile bear no proportion to each other, that one may exist in a great degree while the other is scarcely apparent, is rendered evident from the experiments of the late Mr. Singer. In examining the power of different kinds of fluids interposed between the plates, he observed, that although some of the effects were rendered more powerful by employing a solution of salt, yet the electrometer was not more effected than with simple water. He even asserts, that in many trials on a very extensive scale, for example, with 1000 pairs of metals, he has "found the electrical effects greatest when the chemical effects have been least." He relates other facts of a similar kind, which appear to place this matter beyond all doubt, and to establish a decisive difference between these two operations of the instrument.*

Singer's experiments.

De Luc's experiments confirm and illustrate this view of the subject; for they not only show this want of proportion between the two effects, but they enable us to separate them from each other. In his second dissection of the pile, we have a powerful electrical instrument, but one which does not produce galvanic effects; and the same may be said of his electric column, which exhibits none of the phenomena that we exclusively refer to galvanism. On the contrary, some of those combinations which have been made by Mr. Children,

De Luc's experiments.

* Singer's Elem. p. 330.

and other experimentalists, where a few large plates were employed, and where a diluted acid was interposed between them, may be considered as precisely the reverse of De Luc's column. Here very slight marks of common electricity were manifested, while the most powerful galvanic effects were produced.

Proper electrical action of the pile.

The general conclusion that I should form on the subject is, that part of the effects usually proceeding from the pile are purely electrical, and do not, in any degree, depend upon a chemical change in the state of the metals. I conceive it to be a doubtful point in what way this electrical action is induced, because, for the reasons which have been already given, I do not think that the experiments of Volta, and the others that have been supposed to coincide with them, are applicable to the state of things as they exist in the pile; nor, if we were to admit them, would they account for the continued evolution of fresh portions of electricity;* or explain, why the disturbance of the electric fluid, or the electro-motion, as it is styled, is not counteracted by the conductors that are connected with the metals.

Galvanic effects.

As to the proper galvanic effects of the pile, I conside rthem to be always immediately caused by the chemical action of the fluid upon the metals; and that, in proportion to the extent of this action, as depending upon the quantity of surface exposed, or the nature of the fluid

* Davy's Elements of Chemical Philosophy, p. 174.

employed, we obtain the evolution of electricity in greater or less quantity, and in a more or less intense state.

Davy's hypothesis.

The great discoveries that have been made by Sir H. Davy, in his application of galvanism to chemical decomposition, and the importance which must attach to all his opinions upon the subject, will make us anxious to inquire, what view he takes of the question that has now been discussed. I have already related the experiments which he performed on the chemical action of the pile; and it appears that he formerly considered it as the primary cause of the phenomena. This opinion, however, he afterwards retracted, and adopted an hypothesis which he conceived might reconcile the doctrine of Volta with the experiments of the English chemists. He supposes, that both electrical and chemical actions are necessarily concerned in the production of the effect; that the former are the first in order of time, and that their tendency is to disturb the electric equilibrium of the different parts of the apparatus, while the chemical changes operate in restoring this equilibrium. In the farther detail of the hypothesis I shall employ the author's own words. "In the voltaic pile of zinc, copper, and solution of muriate of soda, in what has been called its condition of electrical tension, the communicating plates of copper and zinc are in opposite electrical states. And with regard to electricities of such very low intensity, water is an insulating body; every copper plate, consequently, produces by induction an increase of positive electricity upon the opposite zinc plate, and every zinc plate an increase of negative electricity on the opposite copper plate; and the intensity increases with the number, and the quantity with the extent of the series.

"When a communication is made between the two extreme points, the opposite electricities tend to annihilate each other; and if the fluid medium could be a substance incapable of decomposition, the equilibrium, there is every reason to believe, would be restored, and the motion of the electricity cease. But solution of muriate of soda being composed of two series of elements, possessing opposite electrical energies, the oxygen and acid are attracted by the zinc, and the hydrogen and alkali by the copper. The balance of power is momentary only; for solution of zinc is formed, and the hydrogen is disengaged. The negative energy of the copper, and the positive energy of the zinc, are consequently again exerted, enfeebled only by the opposing energy of the soda in contact with the copper; and the process of electro-motion continues as long as the chemical changes are capable of being carried on."*

This hypothesis agrees with that of Volta, in ascribing the train of actions to the electric condition of the metals, yet it differs from it in many

* Phil. Trans. for 1807, p. 45: and Elements of Chemical Philosophy, p. 168, et alibi.

essential points. It supposes the chemical decomposition of the interposed fluid to be a necessary, although not the first step in the process. The conducting power of the fluid is, in both cases, taken into account, yet it is regarded in precisely an opposite point of view. According to Volta, the better is the conducting fluid, the more energetic is the action of the pile; while the hypothesis of Sir H. Davy seems to require the fluid to possess almost a non-conducting property.

Electric energies. Some of the late speculations of this illustrious chemist have led him to deviate still farther from the ordinary hypothesis, not only as it respects galvanism, but electricity in general. Those effects which were formerly attributed to a material agent, capable of being added to, or subtracted from a body at pleasure, are now conceived, like gravitation, to be inherent qualities of matter. To these, which are called electric energies, all chemical decompositions are to be ultimately referred; for it is supposed, that chemical attraction, in all cases, results from the circumstance of two bodies possessing opposite electric energies, and consequently having a strong tendency to unite. By means of the galvanic combinations, we have it in our power to excite the electric state of a body to an indefinite degree, and to induce an electricity contrary to that which is natural to it.

At the same time, however, that Sir H. Davy conceives this intimate relation to exist between the natural electricity of bodies and their electric attractions, he decidedly states his opinion that they are not absolutely identical. He regards them, on the contrary, as distinct phenomena, produced indeed by the same power, but acting in one case on masses, and in the other on particles. He illustrates his opinion by observing, "that the primary cause of both may be the same, and that the same arrangements of matter, or the same attractive powers, which place bodies in the relation of positive and negative, *i. e.* which render them attractive of each other electrically, and capable of communicating attractive powers to other matter, may likewise render their particles attractive, and enable them to combine, when they have full freedom of motion."*

But the farther consideration of the merits of this theory belong rather to electricity than to galvanism strictly so called. To whatever cause we ascribe the electric state of bodies, whether to a material agent distributed through them in different quantities, or to some affection of their primary qualities, the states of positive and negative electricity actually exist, and our present business is merely to inquire what relation they bear to the phenomena of the galvanic pile.

De Luc's objections. De Luc advances an argument, which he conceives to be quite decisive, against the hypothesis of the natural electric energies of bodies producing the phenomena of the pile, that the whole in-

* Davy's Elements of Chemical Philosophy, p. 164.

strument may be rendered either positive or negative, by connecting it with the conductor or rubber of the electrical machine; and yet its operation is not in any degree affected. He also contrived an apparatus, in which there were three wires placed between the extremities of the pile, two of them connected with the ends of the pile, and the third in the centre; the wires having water interposed between them, and electrometers so situated, as to ascertain the electric condition of the wires. In the ordinary state of the apparatus, the terminating wires were one positive and the other negative, corresponding to the ends of the pile to which they were attached, while the central wire was neutral; yet the ends of this neutral wire produced opposite electrical effects, one separating oxygen, and the other hydrogen. By altering the apparatus, the electrical state of the wires was altered; the central wire was rendered at one time positive, and afterwards negative, and the state of the terminating wires was reversed; yet no change took place in the chemical action of the wires, each of them continuing to evolve oxygen and hydrogen as at first, and the two ends of the central wire separating oxygen and hydrogen respectively at its extremities, in the same manner whether the wire itself was positive, negative, or neutral.*

Singer's objections.

Mr. Singer has proposed an objection to Sir H. Davy's hypothesis, very similar to this of De Luc.

* Nicholson's Journal, xxvi. 124, et alibi.

Plate II. Fig. 6.

If a number of metallic wires are placed in a line, with their extremities immersed in a fluid, and the whole connected with the pile, each wire will evolve oxygen at one end, and hydrogen at the other. Now, he conceives it impossible that every wire can have an opposite electricity at its two extremities, when it is surrounded by a conducting fluid; for no metallic body can be made polar, *i. e.* one end positive and the other negative, but by the temporary disturbance of the equilibrium of its natural electricity; an event which can only happen when they are separated by a non-conducting substance. But he observes, "No one can maintain, that water, or any saline fluid or acid mixture, is a non-conductor, either of the chemical or electrical effects of the voltaic apparatus; yet the usual chemical changes produced by voltaic electricity occur at every interruption of the metallic circuit in such fluids." *

Chemical hypothesis.

As I am disposed to think that the electric hypothesis, under any of its modifications, is inadequate to explain the action of the pile, we must substitute in its place the chemical hypothesis, which supposes that the first step of the process consists in the action of the fluid upon one of the metals, and that the electrical, or rather the galvanic phenomena, depend upon this action. This action essentially consists in the oxidation of the surface of one of the metals, while the opposite sur-

* Elements, p. 376.

face of the other metal is not affected. The positions upon which the chemical hypothesis rests are the following:—1. One of the metals, the zinc for example, is oxidated, the oxidated part has its capacity of electricity diminished, and electricity is consequently evolved: 2. This electricity is received by the contiguous fluid, and is transmitted by it to the surface of the other metal, the copper, which is not oxidated, and is therefore disposed to receive it, and the whole of the copper plate hence becomes positive: 3. The remaining part of the zinc which is not oxidated remains in its natural state, and therefore, as it relates to the copper, is negative: 4. The elements of the pile, which, according to the electrical hypothesis, are supposed to be in the order of copper, zinc, fluid, are, according to the electric hypothesis, zinc, fluid, copper; the electricity passing from the zinc plate, across the fluid to the copper plate: 5. The action takes place, not between the metals, but between the oxidated surface and the fluid; no change would therefore be produced by placing a copper plate beyond the first zinc plate, or a zinc plate beyond the last copper plate.* Strictly speaking, it is the zinc end of the apparatus which is negative, and the copper positive.

Its fundamental positions.

The following are the circumstances in which the chemical appears to explain the phenomena of the pile more easily than the electrical hypothesis. It shows why the action of the pile is always in

Superiority of the chemical hypothesis.

* See Lehot, Priestley, Erman, De Luc, &c.

proportion to the oxidation of the metallic surface. It satisfactorily explains the progressive increase in the energy of the different parts of the instrument. The first copper plate, in consequence of the electricity which it has acquired from the oxidated part of the zinc, becomes positive, or, to use the numerical illustration, is brought to the state of 110°. This state it communicates to the contiguous, or second zinc plate, which also becomes 110°. The fluid oxidates the surface of the metal here, as in the former case, but a larger quantity of electricity is liberated to the second copper plate, which raises it to 120°. According to the chemical hypothesis, although one end of the pile becomes highly positive, and is therefore disposed to communicate a portion of its redundant electricity to the other end, yet this end may be considered as only relatively negative, and there is no part of the apparatus in a neutral state. There is no tendency in any part of the apparatus to restore the equilibrium of the electric fluid which is destroyed by the oxidation of the metal. The essential effect is to increase the electricity of one end of the apparatus, and therefore the more powerful is the action of the fluid either in oxidating the metals, or in conveying the electricity to the opposite surface, the more powerful will be the effect of the apparatus. This effect does not necessarily depend upon the ends of the pile being united, because the essence of the operation consists in the oxidation of one of the metals. It is, however, to

PLATE II. Fig. 5.

be expected that the effect will be increased when the extremities of the pile are united; for in this case the electricity will be powerfully attracted towards one end of the apparatus, in order to produce an equilibrium with the other end, which is relatively negative. The chemical hypothesis is not encumbered with the necessity of a current of electricity from one end of the pile to the other; it only supposes the passage of the electricity across the interposed fluid in each individual pair of metals. The chemical differs from the electrical hypothesis in the material circumstance of the former pointing out a source for the liberation or evolution of electricity, in consequence of a change in the nature of one of these substances, which diminishes its capacity for it, and therefore renders it less disposed than before to retain it. The electrical hypothesis only contemplates an interchange of electricity between the different parts of the apparatus, one part merely acquiring what it attracts from the other part, a process by which there can be no *absolute production* of it.

Relative state of the metals.

The chemical differs very essentially from the electrical hypothesis with respect to the supposed state of the contiguous metals; the electrical supposes that they can have different states of electricity while they are in contact; the chemical takes it for granted, that, while they are in contact, their electrical states must be similar. The chemical hypothesis satisfactorily explains all the facts that have been observed, respecting the necessity of oxygen for the action of the apparatus; it explains the reason why the metals must differ in their degree of oxidability, and why the fluid must be one that will act differently upon the two metals. The facts that have been noticed respecting the different effects of the interposed fluids may be explained by referring to three circumstances, which all coincide with the chemical hypothesis, but which seem to have no relation to any electrical action: 1. That the fluid acts only upon one of the metals: 2. That the surface of one of the metals is oxidated with a certain degree of rapidity: 3. That the oxide is removed so as to present a fresh surface to the fluid. If acids be employed, those are the best that dissolve the oxide; or if neutral salts, those which form triple compounds with the oxide which is produced. The chemical hypothesis affords a plausible method of accounting for the different effects of the apparatus, whether we use large or small plates; for it is not unreasonable to suppose that the electricity will become more intense or concentrated at every successive transmission through a new oxidating surface, while its absolute quantity will depend upon the amount of oxide that is formed.

Nature of the fluid.

Size of the plates.

With respect to the experiments of Bennet, and others of a similar kind, which have been adduced in favour of the electrical hypothesis, it is probable that Volta has been mistaken in his application of them, and of the principle to which they should be referred. Instead of supposing, as he does, that

Nature of Bennet's experiments.

all metals are naturally in the same state of electricity, and that, by being placed in contact, a portion is attracted from one to the other, the facts would seem to indicate that the reverse takes place: and that although the electricity of each individual metal is in equilibrio with the atmosphere, yet that it is unequal with respect to each other; that zinc, for example, is negative with respect to copper. When they are placed in contact, their electricity is equalized; but when they are again separated, the zinc, having acquired a portion of electricity from the copper, becomes positive with relation to the atmosphere; and the copper, for the same reason, negative.

Relation of electricity to chemical affinity.

The electric hypothesis of galvanism being, in some measure, connected with the views which have been lately taken by Sir H. Davy, respecting the connexion between electricity and chemical affinity, it may be proper to consider the grounds upon which these opinions rest, and also to inquire how far they affect the present question. Hisinger and Berzelius seem to have been the first who distinctly pointed out the property which the two extremities of the pile possess of attracting to themselves different kinds of substances; and Sir H. Davy, by a masterly train of experiments, afterwards showed that this action was so powerful, as apparently to counteract the usual effects of chemical affinity. Not only was a solution of a neutral salt, in which the two wires terminated, decomposed, and the acid attracted to the positive, and the alkali or metal to the negative wire; but the wires seemed even to possess the power of attaching to themselves the acid and the alkali, when other substances intervened to which they each had a strong affinity. These effects were attributed to the attraction of the positive wire for substances containing oxygen, and of the negative wire for those that contained hydrogen, or any other inflammable ingredient, and Sir H. Davy was induced to infer, that the former class of bodies were naturally in a negative state of electricity, and the latter in a positive state. This conclusion respecting the natural electrical condition of these two classes of bodies he afterwards attempted to substantiate by more direct experiments, in which the electrometer indicated the negative electricity, after being in contact with acids, and the positive after being in contact with alkalies.*

Proofs of this relation.

Two distant sets of facts and experiments have been brought into view, those respecting the decomposition and transfer of acids and alkalies by the two extremities of the pile, and those to which the electrometer was applied; it is to the former of these only that the present question has any reference. Before we can form a correct judgment concerning them, it will be necessary to attend a little more minutely than has hitherto

* Phil. Trans. ubi supra; and Elements of Chemical Phil. p. 158, et seq.

been done to the electrical state of the water in the interrupted circuit. When water, or any other conductor, is interposed between two substances that are in different states of electricity, its first effect is to form a communication between them, by means of which their electricities are equalized, the water itself, as well as the two electrified bodies, all tending to acquire the same electrical condition. When the two extremities of the pile are connected by the intervention of water, there is, in the first instance, an attempt to produce this equilibrium; but the equilibrium is no sooner formed than it is again destroyed by the continual generation or evolution of electricity which goes on in the body of the pile. On this account the wire which was originally positive is kept in that state, and the same with respect to the negative wire. But the two wires being immersed in water must have a constant tendency to bring the water into the same electrical state with themselves, and will, to a certain degree, accomplish it; we may therefore conclude, that the water contiguous to the positive wire is itself positive, and that contiguous to the negative wire negative. These two portions of water must, however, be continually tending to equalize their electrical states with that of the remaining part of the water, and the result will be, that contiguous to the two wires there are two portions of water, in the same, or nearly the same, electrical states with the wires themselves, and that the electricity

Condition of the water in the interrupted circuit.

diminishes in the successive portions of water, until at length, in the middle of the vessel, the fluid is in a neutral state.

Decomposition of salts.

Now if we dissolve a quantity of a neutral salt in this water, we find that the acid particles diffuse themselves through the water which is positively electrified, and the alkaline particles through that which is negatively electrified. This is well illustrated in the experiments of Sir H. Davy, where the water was tinged with litmus and turmeric; for it was found that the intensity of the effect produced on the colours, and consequently the quantity of acid and alkali contained in the water, was greatest near the wires, and diminished until it arrived at the centre, where the effect ceased. The transfer of the acid to the neighbourhood of the positive wire may, therefore, with greater probability, be ascribed to its being attracted by the positively electrified water, than to the positive wire itself; for it does not attach itself immediately to the wire, but it diffuses itself through the water, in proportion to the electrical state of its different parts. If we go farther, and inquire why acids are disposed to be transferred to water which is in a state of positive electricity, we may, I think, conjecture, according to Sir H. Davy's hypothesis, that it is owing to the attraction which subsists between oxygenated substances and positive electricity, as the acquisition of this electricity seems to be the only change which the water has experienced.

The opinion which is entertained by Dr. Young on this much agitated question, whether the primary effect of the pile be chemical or electrical, although not given in a very decided manner, is, I apprehend, favourable to the hypothesis which I have endeavoured to defend, at least so far as relates to the connexion between the two operations. He observes, that the phenomena of galvanism are principally derived from an inequality in the distribution of the electric fluid, but that it originates from chemical changes. He supposes that this inequality is continued in consequence of the resistance which the electric fluid experiences to its motion depending upon the alteration of substances of different kinds, which is conceived to afford a greater resistance to its transmission than would have arisen from any one of the substances singly. He does not venture to determine in what degree the different conducting powers of the elements of the pile contribute to its action; but he conjectures that the oxidation of metals may produce positive electricity, and that, on the contrary, negative electricity is produced by their combination with sulphur, and that these electric states, when generated, may be communicated to the best conductors that are contiguous to them.* Young's opinion.

In tracing the progress of opinions, it is necessary to notice the abstruse speculations of Professor Berzelius, which are indeed not essentially Berzelius's hypothesis.

* Lectures on Nat. Phil. i. 674.

different from those of Sir H. Davy, although, as being more fully developed, and carried to a greater length, they are perhaps, on this very account, more open to animadversion. He conceives that the atoms of which bodies are composed always possess, what he styles, electric polarity—a term which is intended to express that two of their opposite sides possess different states of electricity. Upon the intensity of these opposite electricities the force of chemical affinity depends, which consequently becomes resolved into, or identified with, electric polarity. Each of the poles of bodies possesses an appropriate and specific electrical condition; it may be so precisely balanced as to leave the atom in a neutral state; but in most cases, the electricity of one pole is greater than that of the other, and thus gives the body, what he terms, a unipolar state, which may be either electro-positive, or electro-negative, according to the predominancy of the positive or negative extremities. It is supposed, however, that bodies may combine together in consequence of their general electrical intensity, as well as from the attraction of the different kinds of electricity, for we find that a very powerful affinity may be exercised between bodies that possess the same kind of unipolarity; and in this case the electro-chemical properties of the compound become the most intense, because all the energy is conceived to be exercised in one direction, whereas in other cases a kind of neutralization takes place, in which the opposite forces destroy each other. The essential effect of the galvanic pile is conceived to be that of restoring the particles that are combined together, and in consequence of this combination, have their electric energy partially neutralized, to their original state of intensity, or, as the author expresses it, to re-polarize them.*

If we proceed upon the supposition that electricity is the general cause of chemical affinity, we must admit literally, that the primary action of the pile is electrical, and that the chemical changes which its component parts experience, are to be regarded as an effect, and not as a cause. But this reasoning applies rather to the explanation of chemical affinity in general, than to what respects the galvanic apparatus in particular. It would not be inconsistent to regard a chemical change as the immediate cause of the action of the pile, although we might be induced to consider this chemical change, as well as all other chemical changes, to be dependent upon electricity. The question still remains, what is the first step in the process which constitutes the essential operation of the pile? Does the oxidation of the zinc depend upon any previous disturbance of the electrical condition of the two metals, or does the oxidation of the metal produce a change in its electrical condition? This view of the subject will reduce Remarks.

* Journ. de Phys. lxxiii. 251; Stockholm Mem. for 1812, xxxiii. 166, 223.

it to the same state in which it has already been considered, and will therefore render it unnecessary to recur to the arguments which have been previously adduced.

Oersted's hypothesis.

An hypothesis, which in its leading features seems very similar to that of Professor Berzelius, has been more lately proposed by M. Oersted of Berlin. M. Oersted, in the same manner with Professor Berzelius, resolves chemical affinity into the operation of two forces which are supposed to be identical with the positive and negative electricities, and which are also the immediate agents in the production of the phenomena of heat and light. Like Sir H. Davy, he proceeds upon the general principle that chemical substances may be divided into two great classes, according as they possess the positive aud negative electricities; that they are attracted to the end of the pile which is in the contrary state to that which they naturally exhibit, and that the force with which they are attracted is in proportion to the intensity of their positive and negative energy. Upon this hypothesis M. Oersted builds a complete system of chemical arrangement, classing the various substances according to their supposed positive and negative power, and to the intensity with which they exhibit their respective energies.* Into the merits of this part of the system it is not my business to inquire, as it has no immediate re-

* Journ. de Phys. lxxviii. 338.

lation to galvanism. As far as respects this particular department of science, it will stand upon the same general grounds with the hypothesis of Davy and Berzelius, although, for the same reason which induced me to prefer the view of the subject which has been taken by the former of these philosophers, I conceive that of M. Oersted to be still more objectionable, as by descending into a greater variety of minute details, it becomes more involved in difficulties and inconsistencies.

Biot's opinion.

I have already had occasion to detail the observations of M. Biot on the two leading theories of galvanism, in which he estimates their respective merits, and appears almost in doubt to which he ought to give the preference; but in his late learned treatise on natural philosophy he decidedly adopts the electric hypothesis. He defines galvanism to be electricity by simple contact, and he conceives that electricity is capable of being excited by simple contact in metals and many other substances, and probably indeed in all bodies in nature.* As a proof of this position he refers to Volta's experiment of the zinc and copper disks; and adapting it to the hypothesis of the two electric fluids, which he assumes in all his speculations, he supposes that the zinc acquires the vitreous, and the copper the resinous electricity as a consequence of their contact; and, like Volta, he conceives that this difference in their electric

* Traité de Physique, ii. 467.

states may exist while they actually remain in contact. He speaks of the pile under the title of an electro-motive apparatus, which derives its power entirely from the electric action of the two metals; the interposed fluid serving merely as a conducting body, and its chemical action being only incidental. In describing the effect of this instrument, the oxygen is stated to proceed from the vitreous and the hydrogen from the resinous pole; and he proceeds entirely upon the supposition that the effect depends upon the action of the metals on each other, and not upon that of the fluid upon either of the metals. His arguments against the chemical action of the pile may be considered as summed up in the following paragraph, which I give the reader in the author's own words. "The connexion which we observe between the oxidation and the electrical state has induced some distinguished philosophers to suppose that the second was an effect of the first; and the increase of action which is produced by chemical decompositions have furnished them with very powerful arguments in favour of this opinion. But it appears to me that the experiments of Volta on the development of electricity which takes place from the contact of insulated metals, can leave no doubt as to the principle; and the less so, because if we join to this the phenomena of the transfer, there is no circumstance in the experiments which is not perfectly explained by differences in the conducting power. If the chemical decompositions acted in any way but as conductors, if they gave electricity to the disks, we ought to perceive this electricity when we insulate the pile, and establish a communication for some time between the poles; but this is not found to be the case. Besides, if chemical affinity were the principle of the action, it ought to be exercised in the same manner whether the communication was established or not between the two poles of the pile, since this circumstance has no influence but upon the circulation of the electricity. But we find, on the contrary, that the decompositions are not carried on with any degree of energy in the pile, except the communication be established; and when it is not so, if we only employ simple saline solutions, which are of themselves incapable of attacking the metal, we find that there is either no oxidation at all produced, or only a partial and extremely feeble one, such as is capable of being produced by the imperfect communication which is established between the two poles of the pile by the mere contact of the molecules of air, which slowly remove the electricity which is developed at its summit." *

How far the remarks of M. Biot ought to be regarded as containing any valid objections against the chemical hypothesis, or how far the statements upon which he founds his opinions are agreeable to the facts that are the best established, and that

* Traité de Physique, ii. 537.

rest upon the best authority, those who have attended to the subject of galvanism will be able to judge. I shall not think it necessary to enter into any formal refutation of his hypothesis, or of the reasoning by which it is supported, as I do not perceive that he has advanced any thing which has not been already noticed, or that he has adduced any new arguments, in addition to those that had been brought forward by Volta himself.

Haüy and Thenard's opinion.

The opinions which are entertained by M. Haüy and by M. Thenard, respecting the immediate cause of the galvanic action, do not materially differ from each other, or from that of M. Biot. Like him, they believe in the existence of the two electric fluids, and suppose that when the relative proportion of the two fluids in one body is destroyed by the contact or approximation of the metallic plates, the phenomena of galvanism may be produced, so as to refer the whole to an unequal distribution of the vitreous and resinous electricity. The greater energy of the apparatus when acids or saline solutions are employed instead of water, Thenard, like Volta, ascribes merely to their superior conducting power, and agrees with him also in regarding the chemical changes which take place as not essential to its operation.*

Donovan's hypothesis.

The last publication on the subject of galvanism which I shall have to notice, is the essay of Mr. Donovan of Dublin, in which, besides many

* Haüy, Traité de Physique, ii. 1 to 58; Thenard, Traité de Chimie, i. 19.

ingenious experiments and much valuable information, we are presented with a new hypothesis, not only of the action of the pile, but even of the nature of the principle which produces the action. Mr. Donovan examines at considerable length the opinion of Volta, offering very much the same kind of objections against it which I had previously urged;* and he likewise regards the hypothesis of electric energies to be equally inapplicable to the phenomena. He states the following fact, which is assumed as the basis of his hypothesis. "If a piece of zinc and a piece of copper be immersed in dilute nitric acid, but not in contact, they effervesce and dissolve rapidly; and oxides of zinc and copper are found in the solution. Hence these two metals have an affinity for the oxygen of nitrous acid. If the zinc and copper be brought in contact, and immersed in the dilute acid, both appear to effervesce, but the zinc alone dissolves." †

The conclusion which the author draws from this fact is, that the copper has lost an affinity for nitric acid which it before possessed, which affinity appears to be gained by the zinc; for it must be observed that the zinc dissolves more rapidly than it did in the first instance, and therefore seems to have acquired what the copper has lost. This transfer of affinity from one metal to the other by

* Ann. of Phil. iii. 32.

† Essay on Galvanism, p. 274.

their contact forms the foundation of the theory; it is supposed that all bodies have specific affinities, which are transferable under certain circumstances, and that this interchange depends upon the nature of affinity itself, and is entirely unconnected with any electrical action. He brings forward many experiments to prove that electricity is not in any case the agent which produces the phenomena of galvanism, but that they may all be referred to the principle of transfer.

A number of experiments are detailed on various combinations of metals, to prove that the same effect which takes place with respect to zinc and copper may be observed in all similar cases, and hence is deduced the conclusion, that "the principle of transferred electricity is general; and whatever may be the attraction of any metal to oxygen, that it is always either diminished or increased by the contact of another metal; the more oxydable metal acquiring the increase, and the less oxydable suffering the diminution." * This hypothesis is then applied to all the operations which are usually styled galvanic, such as metallic arborizations, the chemical effects of the pile, the effect upon the muscle and nervous fibre, and other phenomena which are more related to common electricity. It must, I think, be admitted that there is much ingenuity in many parts of Mr. Donovan's reasoning, and that he has adduced many valuable

Remarks on Donovan's hypothesis.

* Essay on Galvanism, p. 285.

facts in its support, but still the fundamental position on which the whole rests, the transfer of chemical affinity, considered as a primary cause, is not easy to comprehend, unless we ascribe it to the agency of some principle that must possess different qualities from those that we usually ascribe to chemical affinity. I apprehend that it must be regarded as a verbal, rather than as an actual explanation of the fact, and that, at all events, we ought not to apply it as a means of explaining phenomena, until we have established its existence by some independent evidence.

Concluding observations. With these remarks I shall conclude my account of the theory of galvanism. It will be perceived, that much discordance of opinion still exists upon the subject, and that some strong objections attach to every hypothesis which has yet been proposed. The most important points to ascertain are, the difference between electricity, as excited by the friction of the common machine, and that modification of it which is strictly called galvanism. For this purpose, the nature of electric intensity should be further investigated; for it would appear that if we were able to attach a more precise idea to this term, a considerable insight would be gained into the cause of this difference. Experiments somewhat similar to those of De Luc should be prosecuted, in which the electrical and chemical effects of the pile are separated from each other, and a more accurate measure of the proper galvanic power should, if possible, be obtained, than any of which we are now possessed. The conducting power of the fluids concerned in the galvanic apparatus should be carefully examined, and the relation of their chemical action to their conducting power should be ascertained. But it is unnecessary to enlarge upon these topics: the rapid succession of discoveries which have been made in this department of science, and the very general attention which it has obtained from the first philosophers of the age, afford every reason to expect, that the farther investigation of it will be followed by no less success than that which has hitherto attended its progress.

BESIDES the references which have been made in the course of the essay, the following works and papers deserve to be noticed, either as presenting a correct view of the gradual progress of the science, or as containing an abstract of the hypotheses that have been brought forwards at different times.

Pfaff's *Dissertation on Animal Electricity*, 1793.

Monro *on Animal Electricity*, 1793.

Aldini *on Animal Electricity*, 1794.

Cavallo *on Electricity*, vol. iii. 1795.

Cuvier's *Report*, Journn. de Phys. lii. 1801.

Hachette's *Report*, Journn. Polytech. iv. 1801.

Biot's *Report*, Ann. de Chim. xli.*
Reports made by Delametherie, in several volumes of his journal, xli. xlvi. xlviii. l. liv.
Sue's *History of Galvanism*, 1802.
Cuthbertson's *Practical Electricity*, 1807.
Carpue's *Introduction to Electricity and Galvanism*, 1807.
Conversations on Chemistry, 5th conversation.
Article "*Voltaism*," in Rees's Cyclopædia.
Article "*Galvanisme*," in the Dict. des Scien. Med. by Hallé and Nysten.

* This was the report of a commission composed of Laplace, Coulomb, Hallé, Monge, Fourcroy, Vauquelin, Pelletan, Charles, Brisson, Sabbatier, Mourveau, and Biot.

DESCRIPTION OF THE FIGURES.

PLATE I.

Fig. 1. The galvanic pile, as originally constructed by Volta, where the letters C, Z, and F denote the plates of copper and zinc, and the pieces of cloth or pasteboard soaked in fluid. The pile has four rods placed round it, to keep it in the perpendicular direction. The lower end was called the *copper* and the upper the *zinc end*.

Fig. 2. When the number of plates is very considerable, Volta divides it into two or more parts, each being connected by slips of metal. In this case, it is essential that the same order of parts be observed from one end to the other, up the first pile, down the second, up the third, and, lastly, down the fourth.

Fig. 3. This was a modification of the galvanic apparatus, that was formed by Volta, which he called *couronne des tasses*, where the zinc plates Z and copper plates C are not in contact, but are connected by metallic rods, and then immersed in a fluid.

Fig. 4. Represents the battery of Mr. Children, which is a combination of the *couronne des tasses* of Volta and the trough of Cruickshanks. The plates are not in contact, but each pair is connected by slips of metal, and the whole is attached to a beam, so as to be lifted out of the cells at pleasure. The trough and partitions may be formed of either wood or earthenware, and contain the fluid that is to act on the zinc plates.

Fig. 5. Represents the trough apparatus invented by Mr. Cruickshanks; the plates of zinc and copper are soldered together, and are then cemented into a wooden frame, leaving intervals between the double plates, to receive the fluid which is intended to act upon the zinc. It is provided with wires at each end, which are in opposite states of electricity, and may be applied to any substance which it is proposed to subject to its influence.

Fig. 6. Represents the apparatus, which was employed by Sir H. Davy to exhibit the decomposition of salts, and the

transfer of their constituents, consisting of the three vessels connected by amianthus.

Fig. 7. Is one of the wire-stands employed by M. De Luc in his dissection of the galvanic pile.

Fig. 8. Is the apparatus for receiving in separate vessels the gases which are evolved by the action of galvanism upon water. The two small jars have metallic wires inserted at their upper end, one of which is connected with the positive, and the other with the negative extremity of the pile. They are filled with water and inverted in the same fluid; and the ends of the wires are so situated, that the gas disengaged from them rises to the top of the jar.

Fig. 9. Represents the lower limbs of a frog, lying on a plate of metal, while another kind of metal is placed in contact with the spinal marrow; these two metals are then connected by a conducting body, and the muscles of the legs are thrown into convulsions.

Fig. 10. Are the agate cups, connected by amianthus, employed by Sir H. Davy in the decomposition of water; and Fig. 11, are the gold cones in the same set of experiments.

Fig. 12. Represents the apparatus in which the gases disengaged from water may be reconverted into water by the electric spark.

PLATE II.

Figs. 1, 2, 3, 4. The dissected pile employed by De Luc, to illustrate the mode of its action. The shaded part represents the moistened cloths, and the letters C and Z the copper and zinc plates respectively. In Fig. 1, the pile is continuous, in its usual form; Fig. 2, is the first dissection; Fig. 3, the second; and Fig. 4, the third.

Fig. 5. Is the author's numerical illustration of the effect of the pile; the letters point out the nature of the substances, and the figures indicate the increase of power which the electricity acquires by passing along the instrument.

Fig. 6. Is an experiment of Mr. Singer's, which is supposed to disprove the hypothesis of electric energies. In this apparatus each wire will have its ends in the opposite states of electricity, one positive and the other negative.

Fig. 7. Represents the apparatus for taking the galvanic spark in gases: it consists of a graduated glass tube, into which two wires are introduced, the one which enters at the side being moveable, and capable of being approached to the other; according to circumstances, they may be tipped with pieces of charcoal, or the wires may be bare.

Fig. 8. Is a variation in the form, which may be employed over mercury. These instruments were invented by Sir H. Davy.

Figs. 9, 10, and 11. Consist of a representation of Mr. Pepys's galvanometer; Fig. 9, is the apparatus in its complete state, except that the lid is elevated a little above the mouth of the glass cylinder, in order to render the description more perspicuous. The lid is composed of two circular plates of brass, attached to a cork, that fits into the cylinder; a thin slip of silver is fixed to the lid, the end of which hangs down in the body of the cylinder and has a pair of gold leaves attached to it, and the whole is so contrived as to be capable of being moved nearer to, or farther from, the pieces of zinc, which stand up from the bottom of the cylinder. In Fig. 10, the under side of the cover is seen, and also a section of it, with the slip of silver adapted to it. The pieces of zinc are so contrived that the parts of them which project upwards from the bottom of the cylinder may be fixed at different distances from each other, by means of a slide and screw, as is represented in Fig. 11.

Fig. 12. Represents the apparatus employed by M. De Luc to illustrate his theory of the galvanic pile: it consists of two piles connected by a metallic rod at the bottom; between the upper ends is interposed the interrupted wires terminating in water, and to each extremity one of Bennet's electrometers is applied.

Fig. 13. Represents the apparatus which Sir H. Davy employed for the decomposition of salts, and the transfer of their constituents.

Fig. 14. Represents the luminous arch of light produced by passing the galvanic influence between two portions of charcoal.

INDEX.

THE END.

C Baldwin, Printer,
New Bridge-street, London.

Fig 1.

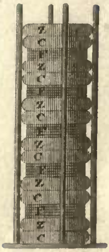


Fig 2.

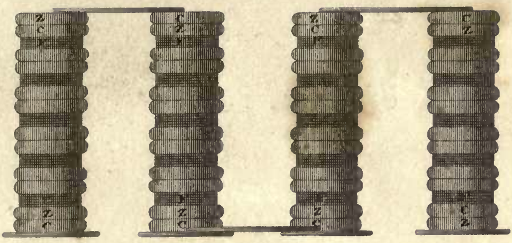


Fig 3.

Fig 4.

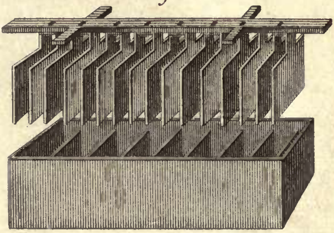


Fig 5.

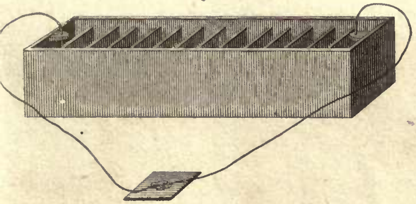


Fig 6.

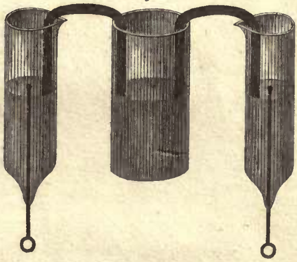


Fig 7.

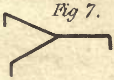


Fig 8.

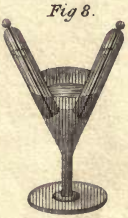


Fig 9.

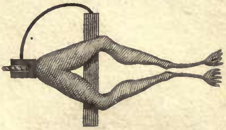


Fig 10.

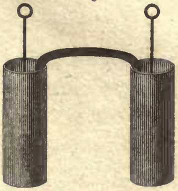


Fig 11.

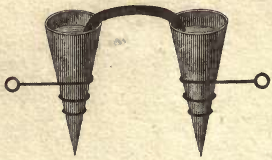
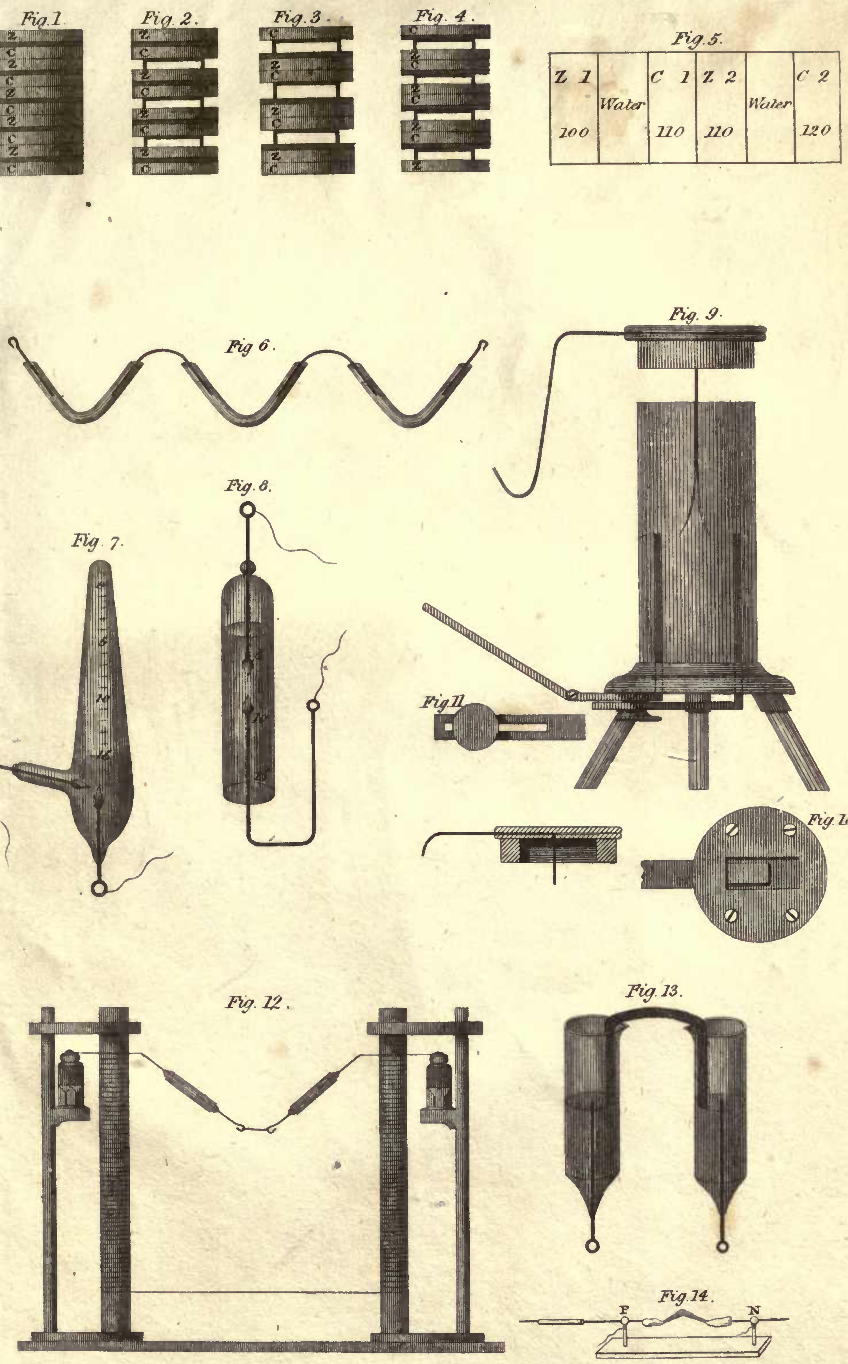


Fig 12.

Engrav'd by J. Shury, for Dr. Bostock's History of Galvanism.



Engrav'd by J. Shury for Dr. Bostock's History of Galvanism.