THERMO-ELECTRICITY

(THE EDINBURGH ENCYCLOPÆDIA; CONDUCTED BY DAVID BREWSTER, LL. D. VOL XVIII. P. 573—89. EDINBURGH 1830)[1]

THERMO-ELECTRICITY is a term introduced a few years ago into natural philosophy, to signify the electrical current, excited in a circuit of conductors, when the equilibrium of its heat is disturbed in such a manner as to cause therein a circulation of caloric. Thermo-Electricity.

Thermo-electricity being a particular branch of *Electromagnetism*, which has been discovered since the publication of the volume of this work in which it ought to have been treated, it will be necessary to comprehend the whole doctrine of electromagnetism in the present article.

HISTORY

In the earliest period of the history of magnetism and electricity, the minds of philosophers were more struck by the resemblances of these two agencies than by their disparities. The first philosopher who undertook a regular series of comparative experiments upon magnetism and electricity, was the celebrated Dr. *William Gilbert*, who first published his inquiries in the year 1600. He was aware of so many disparities between them, that he declared their resemblance to be merely accidental. He had indeed strong reasons to think so at that time, for the magnetical polarity was well known to him, and principally by his own experiments, but the discovery of the electrical polarity was reserved for a philosopher of the following century *(du Fay)*. This discovery, and particularly the fundamental law of electrical polarity, brought forward by *Franklin*, again countenanced the opinion of the resemblance of electrical and magnetical powers; and the sagacity of *Æpinus* gave great credit to it. But immediately after this acknowledgment of their resemblance, another excellent philosopher, *Van Swinden*, was struck with the disparities which remained still unexplained, and his ingenious inquiries obtained much approbation. The discoveries of *Galvani* and *Volta*, by which the electrical powers were exhibited in forms very different from those formerly History.

[1] [According to the editor's statement this article was written by *H. C. Ørsted.*]

History. known, gave the opinions upon this subject a new turn. The German philosopher, *Joh. Will. Ritter*, was thought during some time to have produced magnetical effects by the Voltaic pile, but his experiment having been repeated without success, the subject remained as it was. Thus the balance inclined alternately sometimes to the one and sometimes to the other side; but at no time have either of these opinions met with general reception. A certain turn of mind has here, as in most other controversial doctrines, exercised a considerable influence. One class of natural philosophers have always a tendency to combine the phenomena and to discover their analogies, another class, on the contrary, employ all their efforts in showing the disparities of things. Both tendencies are necessary for the perfection of science, the one for its progress, the other for its correctness. The philosophers of the first of these classes are guided by the sense of unity throughout nature; the philosophers of the second have their minds more directed towards the certainty of our knowledge. The one is absorbed in search of principles, and neglect often the peculiarities, and not seldom the strictness of demonstrations; the other considers the science only as the investigation of facts, but in their laudable zeal they often lose sight of the harmony of the whole, which is the character of truth. Those who look for the stamp of divinity on every thing around them, consider the opposite pursuits as ignoble and even as irreligious; while those who are engaged in the search after truth, look upon the others as unphilosophical enthusiasts, and perhaps as phantastical contemners of truth. Happily these two tendencies are in most natural philosophers so well tempered with good sense, that their controversies seldom exhibit any of the exaggerations which have disgraced so many theological and metaphysical controversies; but they always exercise their influence, which is generally a salutary one, in forming an opposition of sentiment in the republic of letters by which stagnation is prevented. This conflict of opinions keeps science alive, and promotes it by an oscillatory progress, though it seems to the common eye a mere fluctuation, without any definite purpose.

Analogy between electricity and magnetism.

The reasons for and against an essential resemblance between magnetism and electricity might, before the discovery of electromagnetism seem to be nearly balanced. The most striking analogies were, that each of them consists of two powers, or directions

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of powers, of an opposite nature, submitted to the same laws of attraction and repulsion; that the magnetical action on bodies, fit to receive it, has much analogy with the electrical action; that the distribution of the powers in a body, which has an electrical charge, and still more a series of bodies charged by cascade, differs very little from the distribution of the powers in a magnet; if we imagine a Voltaic pile, and principally the modification denominated after *Zamboni,* composed of minute and molecular elements, it would have the most perfect analogy with a magnet; and lastly, that the tourmaline differs but little from such an electrical magnet.

We shall not here consider that most of these analogies are overturned by the discovery of electromagnetism; but still confining ourselves to the period before this discovery, it may be objected that the magnetical and electrical powers do not act on each other, which should be the case, if they were of the same nature; that all bodies transmit with ease the magnetical action, but not the electrical; that neither the tourmaline nor any system of charged glass-plates, or of galvanical arrangements, has the effects of the magnet. Although it might be answered that the galvanical circuit, in its first period, seemed no less different from any electrical apparatus than the Voltaic pile from a magnet, these objections did not cease to have considerable weight, but we have hitherto deliberately omitted one of the arguments, viz. the observation of magnetism in bodies struck by lightning, and the experiments made to imitate this effect. It had often been observed, that the magnetical needles in a ship struck by lightning have suffered a change in their polarity.

Magnetical effects of lightning.

A very remarkable case of this kind, mentioned in the Philosophical Transactions, Vol. xi. No. 127, p. 647, seems to be the earliest on record. It is there related that a vessel, whose mast was struck by lightning, had the poles of the needles in all its compasses inverted, yet the compasses themselves were not struck. Some other observations of a similar nature are recorded in *Domsdorph's*[1] *Treatise upon Electricity, Magnetism, Fire, and Ether,* (über Electricität, Magnetismus, Feuer und Ether, 1783.) An accident of this kind, which happened in the year 1751, caused *Franklin* to try the effect of artificial electricity upon needles of steel. The result was, that when the needles were in a position in which the earth could

[1] [ɔ: Donndorph]

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produce in them some magnetism, this effect was much increased by any electrical stroke; but when the position gave no such advantage, he found that the extremity of the needle, in which the electricity entered (which received the positive electricity) was directed towards the north, when the needle was conveniently suspended. *Wilcke*, who repeated these experiments, obtained the same results, only with the difference, that in the case when the direction of the electrical stroke seemed to decide the polarity, this was the inverse of that observed by *Franklin*. (Transactions of the Royal Academy at Stockholm, 1766.)

Experiments of *Van Marum* and *Van Swinden*.

The experiments made in the year 1785, upon the same subject by *van Marum* and *van Swinden* have been considered as decisive against the magnetical effects of electricity, nevertheless the ninth of their experiments was precisely an electromagnetical one, for they led the electrical discharge transversely through a steel needle, and obtained a strong magnetical polarity in a direction perpendicular to the magnetical meridian; but they considered this as a singularity not to be explained, and hence it has been out of the sight of philosophers from the year 1785 until 1820, when electromagnetism was discovered (See *Van Marum description d'une très grande machine électrique.*)

Electromagnetic experiment by *Cavallo*.

One of the earlier experiments, which probably belongs to electromagnetism, is that of *Cavallo,* by which he proved that iron has more efficacy on the magnetical needle, when an acid, particularly diluted sulphuric acid, acts upon it.

Experiments of *Ritter*.

Joh. Will. Ritter, already mentioned, pursued a great number of researches upon the analogy of magnetism and electricity. He had in the year 1801 made a series of very delicate experiments upon the galvanical difference between the two magnetical poles of a steel needle. The result deduced from his experiments was, that the southern extremity of the needle was more oxidable than the northern, and that the galvanical effect of two magnetical needles upon a frog was such, that the south pole acted as the more oxidable, the north pole as the less oxidable metal. It is now acknowledged, that he has been led into error by the difference which a small disparity in the polish of the metal can produce, and which he employed insufficient means to avoid. The same philosopher stated likewise erroneously, that a platina wire, which has been employed to make a liquid communicate with a powerful galvanic circuit, assumes some magnetical direction, and that a needle, of

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which one half is zinc and the other silver, takes, when conveniently suspended, the same direction as the magnetical needle. The precipitation with which *Ritter* published these and some other erroneous statements, has thrown a shade over the name of this unhappy but ingenious philosopher, who has enriched science with several discoveries of great importance, and whose profound yet obscure ideas in many cases have anticipated the discoveries of future times. We are far from patronizing a vain exhibition of new ideas, by which it is possible for a very ordinary mind to make pretensions to every new discovery; but when works are marked with the true stamp of genius, it is but justice to acknowledge the merits of their speculations. Some writers have thought that this act of justice would deprive experimental philosophers of a part of the honour due to their exertions; but this honour is quite unimpaired, if the author, who has anticipated their discoveries, has only had a vague and obscure notion of them; while it must be avowed, that when the author has clearly announced the discovery, has derived it from good data and conceived its connections with other truths, the merit of the experimental philosopher is only that of having confirmed it by experiment, which still in many cases can be a work of no smaller claim to glory than the primitive conception itself.

Electrical experiment of Professor *Mojon* of Genoa.

Among the electromagnetical experiments which preceded the discovery of electromagnetism, ought to be mentioned an experiment of Professor *Mojon* at Genoa, who found that a steel needle having been 22 days in communication with a galvanical apparatus of 100 elements, had become magnetical, — an experiment which would have been of no historical interest, if its author had not founded upon it, 18 years later, a pretension to the discovery of electromagnetism. He seems not to have been aware that his pretended discovery, were it true, should be considered as new even now; for the magnetical effect, hitherto proved by experiments, is not in the direction of the electrical current, but perpendicular to it. The experiment of *Mojon* is described in *Aldini's, Essai Théorique et Expérimental sur le Galvanisme.* Paris, 1804, tom. i. pag. 339 and 340. *Aldini* mentions, at the same place, that a certain Mr. *Romanesi*[1] at Trent had confirmed the experiment of *Mojon*, and at the same time observed that galvanism makes the magnetical needle deviate. Professor *Aldini*, whose work upon galvanism com-

[1] [ɔ: Romagnosi.]

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prehends two volumes, does not say a word more upon this subject.

It is, therefore, not surprising, that neither the French institute, nor the other learned societiès, nor the numerous natural philosophers, to which the work was presented in the year 1804, took any notice of this observation, which would have accelerated the discovery of electromagnetism by sixteen years. *Romanesi* seems likewise to have forgot his observation, until electromagnetism was discovered.

Observation of Professor *Maschmann.*

Two or three years before the discovery of electromagnetism, Professor *Maschmann* at Christiania, in Norway, observed that the silver tree, formed in a solution of nitrate of silver, when put in contact with mercury, (the *arbor Dianæ,*) takes a direction towards the north; and the celebrated Professor *Hansteen* found that this direction can likewise be determined by a great magnet. As the metallic precipitation is also of galvanical nature, this observation may be considered as one of the precursors of electromagnetism.

Electromagnetism discovered by Professor *Oersted.*

Electromagnetism itself, was discovered in the year 1820, by Professor *Hans Christian Oersted,* of the university of Copenhagen. Throughout his literary career, he adhered to the opinion, that the magnetical effects are produced by the same powers as the electrical. He was not so much led to this, by the reasons commonly alleged for this opinion, as by the philosophical principle, that all phenomena are produced by the same original power. In a treatise upon the chemical law of nature, published in Germany in 1812, under the title *Ansichten der chemischen Naturgesetze,*[1] and translated into French, under the title of *Recherches sur l'identité des forces électriques et chymiques,* 1813, he endeavoured to establish a general chemical theory, in harmony with this principle. In this work, he proved that not only chemical affinities, but also heat and light are produced by the same two powers, which probably might be only two different forms of one primordial power. He stated also, that the magnetical effects were produced by the same powers; but he was well aware, that nothing in the whole work was less satisfactory, than the reasons he alleged for this. His researches upon this subject, were still fruitless, until the year 1820. In the winter of 1819—20, he delivered a course of lectures upon electricity, galvanism, and magnetism, before an audience that had been previously acquainted with the principles of natural philosophy.

[1] [This vol. p. 35.]

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Discoveries of Professor *Oersted.*

In composing the lecture, in which he was to treat of the analogy between magnetism and electricity, he conjectured, that if it were possible to produce any magnetical effect by electricity, this could not be in the direction of the current, since this had been so often tried in vain, but that it must be produced by a lateral action. This was strictly connected with his other ideas; for he did not consider the transmission of electricity through a conductor as an uniform stream, but as a succession of interruptions and re-establishments of equilibrium, in such a manner, that the electrical powers in the current were not in quiet equilibrium, but in a state of continual conflict. As the luminous and heating effect of the electrical current, goes out in all directions from a conductor, which transmits a great quantity of electricity; so he thought it possible that the magnetical effect could likewise eradiate. The observations above recorded, of magnetical effects produced by lightning, in steel-needles not immediately struck, confirmed him in his opinion. He was nevertheless far from expecting a great magnetical effect of the galvanical pile; and still he supposed that a power, sufficient to make the conducting wire glowing, might be required. The plan of the first experiment was, to make the current of a little galvanic trough apparatus, commonly used in his lectures, pass through a very thin platina wire, which was placed over a compass covered with glass. The preparations for the experiments were made, but some accident having hindered him from trying it before the lecture, he intended to defer it to another opportunity; yet during the lecture, the probability of its success appeared stronger, so that he made the first experiment in the presence of the audience. The magnetical needle, though included in a box, was disturbed; but as the effect was very feeble, and must, before its law was discovered, seem very irregular, the experiment made no strong impression on the audience. It may appear strange, that the discoverer made no further experiments upon the subject during three months; he himself finds it difficult enough to conceive it; but the extreme feebleness and seeming confusion of the phenomena in the first experiment, the remembrance of the numerous errors committed upon this subject by earlier philosophers, and particularly by his friend *Ritter,* the claim such a matter has to be treated with earnest attention, may have determined him to delay his researches to a more convenient time. In the month of July 1820, he again resum-

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ed the experiment, making use of a much more considerable galvanical apparatus. The success was now evident, yet the effects were still feeble in the first repetitions of the experiment, because he employed only very thin wires, supposing that the magnetical effect would not take place, when heat and light were not produced by the galvanical current; but he soon found that conductors of a greater diameter give much more effect; and he then discovered, by continued experiments during a few days, the fundamental law of electromagnetism, viz. *that the magnetical effect of the electrical current has a circular motion round it.*

When he had discovered this fundamental law, he thought it proper to publish the discovery, in order that it might be as soon as possible perfected by the co-operation of other philosophers. Apprehending that others might lay claim to this discovery, he sent a short Latin description[1] of his experiments to the most distinguished philosophers and learned bodies; and though, by this means, he has not avoided the pretensions which have been made to his discovery by others, still he has rendered them ineffectual. It deserves, perhaps, to be noticed, that the above-mentioned Latin description, consisting of four pages in 4to., of which the first gives the introduction and the description of the apparatus, the last the conclusions, contains upon the two intermediate pages, the results of more than 60 distinct experiments. From this brevity, it has happened, that some philosophers have thought that he had treated his subject in a superficial manner.

As the details of this discovery, and of all those which have originated from it, will be exhibited in this article, we shall in the remainder of this historical sketch, in order to avoid repetitions, confine ourselves to the most striking and leading facts, and insert the other historical notices in the doctrinal part.

Ampères discovery of the mutual action of conductors.

The first discovery to which that of Professor *Oersted* gave occasion, was that of Mr. *Ampère*, member of the French institute. He found that a conductor, conveniently suspended, is attracted by another, when both are transmitting an electrical current in the same direction; but that they repel each other, when the two currents have opposite directions. Professor *Schweigger* at Halle invented, at the same time, an electromagnetical multiplicator, which is of very extensive use. Mr. *Arago* found that steel can be magnetized by the electrical current. Mr. *Gay Lussac* at Paris, and Pro-

[1] [This vol. p. 214.]

fessor *Erman* at Berlin, discovered, that when the current has passed perpendicularly through the plane of a steel ring, or through a steel plate, it shows no magnetical effect, before the circumference was interrupted. History.

The most remarkable of all the discoveries, to which that of *Oersted* has given occasion, is no doubt the thermo-electricity, discovered in 1822 by Dr. *Seebeck,* member of the Royal Academy at Berlin.

In the same year, the rotation of a magnetical needle around an electrical current, and of a body, which transmits an electrical current around a magnet, first imagined by Dr. *Wollaston,* was exhibited in a series of ingenious experiments by Mr. *Faraday*.

EFFECT OF THE ELECTRICAL CURRENT UPON THE MAGNETIC NEEDLE

Effect of the electrical current upon the magnetic needle.

The galvanic battery was the first apparatus, by which the magnetic effects of electricity were demonstrated. In order to make it give its magnetic action, its two poles must be joined by a conductor, commonly a metallic wire, which, for brevity's sake, we shall call the *uniting conductor*, or the *uniting wire.*

When not closed, the galvanic circle produces no effect upon the needle of a compass.

When the uniting wire is approached, and placed parallel, or nearly so, to a properly suspended magnetical needle, it is caused to deviate from its ordinary direction.

The magnetical effect of the electrical current is not interrupted by the interposition of other bodies. Already the first experiment showed that it passes like the magnetism of a loadstone through metals, glass, resin, wood, stoneware, water, &c.; even when the magnetical needle was placed in water, it was affected by the electrical current.

When the conducting wire is placed parallel to a conveniently suspended magnetical needle, the direction of the needle is changed.

1. If the needle is above the wire, and the positive electricity passes from the right to the left hand of the observer, the north end of the needle will go from the observer.

2. When the needle is below the wire, the direction of the needle is changed in the opposite way; its north end approaches to the observer. It is not necessary, in this and the preceding experiment,

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that the needle is in the same perpendicular plane as the conducting wire; it is only required that the needle shall be sufficiently near the wire, and in the first experiment, in a plane above, in the last in a plane below it.

3. When the needle is in the same horizontal plane as the wire, and is placed between the observer and the wire, the north end is elevated.

4. If the needle is upon the opposite side, the north end is forced down. In these two experiments, the needle must be very near to the wire.

From these facts, Professor *Oersted* concludes, *that the magnetical action of the electrical current describes circles round the conductor.* It will perhaps not be out of place to quote here his own words, which have been overlooked by several authors, who have written the history of this discovery.

In the original publication he says, »ex observatis colligere licet, hunc conflictum (the electrical current,) gyros peragere; nam hoc esse videtur conditio, sine qua fieri nequit, ut eadem pars fili conjungentis (conducting wire,) quæ infra polum magneticum posita cum orientem versus ferat, supra posita eandem occidentum versus agat.« For the sake of brevity we shall, in the following pages, denominate the direction of the current after the system of *Franklin;* or, to speak according to the system of two electricities, after the direction of the positive electricity in the current. If we now suppose that the electricity of the current enters the conductor at the right hand of the observer, the austral magnetism (the same which predominates in the north-end of the needle,) will, upon the superior surface of the conductor go off from the observer; on the side most distant from the observer, the austral magnetism goes downwards; on the inferior surface it goes towards the observer; on the side nearest the observer it goes upwards. This is represented in Fig. 1. where *BA* is the conductor in which the direction of the current is *AB,* the circle *cdef* represents a plane perpendicular to the conductor, in which the magnetical circulation takes place. This plane is here and in the other figures represented as if it were material and opaque. The little arrows show the direction of the austral mag-

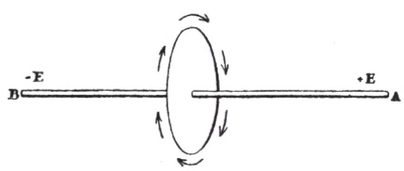

Fig. 1.

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netism. We can make the application of this law to experiments, in a very commodious manner. For this purpose take a piece of paper (Fig. 2,) upon which the arrows and letters, there represented, are drawn. This piece of paper is to be wrapt around a cylindrical body, for instance a pencil, in such a way that the arrows lie in a plane perpendicular to the axis of the cylinder. We have thus an electromagnetical index, which, put in the place of any part of the conductor, shows the direction of the magnetical powers in it. The sharp ends of the arrows indicate the direction in which the austral magnetism (and consequently the north-end of the needle,) is repelled, and the contrary attracted; the opposite ends of the arrows indicate also the direction in which the boreal magnetism (and consequently the south-end of the needle) is repelled, and the contrary attracted. The reader may understand without trouble the most complex facts we are here to explain, if he has at hand two such cylinders, during the experiment. The same thing may be expressed in different ways. Mr. *Hill,* lecturer of mathematics at the University of Lund, in Sweden, has proposed one of the best. Let us imagine, says he, that the observer swims upon the electrical current, with his face turned outwards, (with his back turned towards the axis of the current,) and his head towards the origin of the current, the direction of the austral magnetism of the current will always proceed from his left to his right hand.

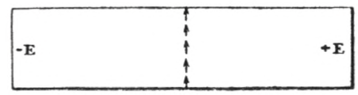

Fig. 2.

This law was confirmed by several other experiments.

When the uniting wire is placed in the same horizontal plane as the needle, but perpendicular to its direction, and near one of its poles, this pole will be elevated, if the current comes from the east, but depressed if it comes from the west. This will easily be understood by the inspection of Fig. 3. *BA* represents here the conductor, *NS* and *N′S′* two needles. All the parts of the drawing have the same signification as in Fig. 1, only that the dotted lines denote the inferior parts of the magnetical circles, but the uninterrupted lines the superior parts. It is evident that *N* (the north-end of one of the needles,) is here driven

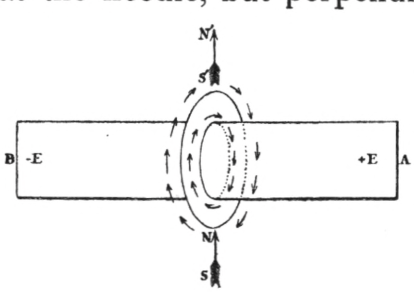

Fig. 3.

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upwards by the repelling action from below and the attracting one above it. In the same manner, *S'* (the south end of the other needle,) is both drawn and pushed upwards.

The effect is on both sides the same, because not only the magnetical poles, but likewise the opposite sides have contrary effects. If one of the needles were turned by means of a magnet, so that each side of the wire could act upon a pole of the same kind, one of them would be elevated, when the other was depressed.

When the uniting wire is perpendicular, and the current enters its superior part, a needle, of which one of the poles is very near to the wire, will be thrown westwards; but if the wire is placed over against a point of the needle, situated between one of the poles and the middle, the needle will be turned eastwards. By opposite currents the results are likewise opposite. Fig. 4. will make this easier understood. *AB* is the uniting wire, the notations the same as in the former figures. It is evident, by the inspection of the figure, that the north-end of the needle *a*, having predominant austral magnetism, must be repelled by the similar magnetism of the conductor; and be turned towards the west. The attraction of the opposite magnetism in the conductor tends to give the needle the same direction; but as this coincidence of motions, produced by opposite powers, is constant in electromagnetism, we shall always confine ourselves to mention but one of them. The south-end of *c*, having predominant boreal magnetism, is also repelled by the similar magnetism of the current, which here has the same direction as the austral on the opposite side of the conductor. Thus the north-end of the needle is on one side of the conductor turned the same way as the south-end on the other side. The north-end of *c* receives the strongest impulses from the west, and must, therefore, be pushed eastward; while the south-end of *d* receives the strongest impulses from the east, and must move towards the west, and in consequence of this its north end must also turn eastward like that of *c*. Were the wire placed exactly over against the middle of the needle, this would be solicited equally in opposite directions, and therefore rest at its place.

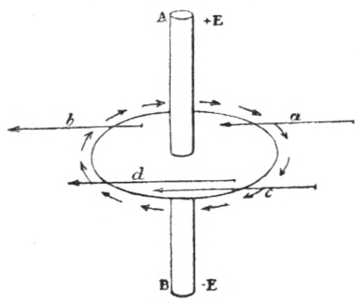

Fig. 4.

When the uniting wire is bent in such a manner, that the parts on each side of the flexure are parallel, the exterior surfaces of the two branches are similar, and also the interior ones. In Fig. 5, *ACDB* represents such a wire. As the current enters the superior branch at *C*, and in the inferior at *B*, it is obvious that the directions of the powers in the magnetical circles are the same at *e* and *f*, at *g* and *h*. Suppose that the two branches are in one perpendicular plane, and the north-end of the needle is placed in a plane, below the superior and above the inferior branch, the north end will be repelled, when placed on the west side, and attracted, when placed on the north[1] side of the wire. Above the superior branch, or below the inferior branch the effects are in the opposite direction. All the other cases, belonging to the effects of bent connecting wires upon magnetical needles, may be easily explained in a similar manner.

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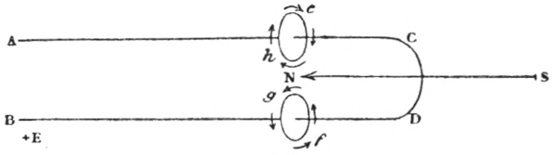

Fig. 5.

These are the principal experiments, by which Professor *Oersted* endeavoured to establish the fundamental law of electromagnetism. As they all belong to one class, it has been practicable for us here to maintain in our account the historical order, without impairing the systematical one. In order to have a short term, we shall call the magnetical action of the electrical current, the *revolving magnetism*.

The discoverer remarks, in his Latin publication, that the magnetical action of the current being necessarily propagated and not instantaneous, the association of a progressive and revolving motion, must give origin to a spiral motion; still, he adds, this seems not to be required for the explanation of the electromagnetical facts hitherto discovered. His words are, »Præterea motus per gyros cum motu progressivo, juxta longitudinem conductoris conjunctus, cochleam vel lineam spiralem formare videtur, quod tamen, nisi fallor, ad phænomena hucusque observata explicanda nihil confert.« Several writers upon the continent have considered it as an essential point in *Oersted's* theory, that the magnetical motions in the current, should be of a spiral form; but it is evident that he has well distinguished this theoretical but still necessary consequence from the fundamental law, deduced from the facts. Supposing here spirals in the place of parallel circles, their windings must be so

[1] [ɔ: east?]

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near to parallelism, that the deviations from it must be imperceptible. Thus the question belonging to the spirals may be left for farther research, in which, perhaps, the whole doctrine of vibrations might be considered.

In an appendix[1] published two months later (in *Schweigger's* Journal,) Professor *Oersted* explained the apparent difference observed between the effect of the galvanical battery, and that of a simple galvanical circuit. In the battery, which is a compound galvanical circuit, as well as in the simple one, the electrical current goes from the more oxidable metal (zinc), through the liquid conductor, to the less oxidable (copper): and when the water is taken away in one of the elements of the battery, and a wire put in its place, the direction of the current remains of course the same; but when we make use of a simple circuit, the water remains at its place, and the uniting wire connects the two pieces of metal in a place, where the direction of the current is the opposite to that of the water. Fig. 6 will make this more perspicuous;

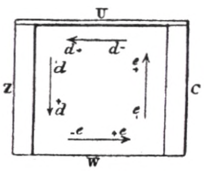

Fig. 6.

Z represents here the zinc, *C* the copper, *W* the water, *U* the uniting wire; the arrows marked with + *e* and − *e* [+ *d* and ÷ *d*] indicate the direction of the electrical current. It is visible that when in *W* the current goes from zinc through the water to the copper, it must in *U* go from the copper to the zinc.

In this appendix it is remarked that the magnetical efficacy of the electrical current depends not on its intensity, but on its quantity of electricity, and that the simple galvanical circuit is preferable for electromagnetical experiments. Some time after the discovery of electromagnetism, the great Swedish chemical philosopher *Berzelius* was of opinion that all the effects of the uniting wire could be explained in assuming four magnetical poles in its circumference. Fig. 7, where *A* indicates the austral, *B* the boreal poles, represents such a distribution. As the appearances in the first electromagnetical experiments may,

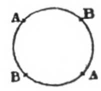

Fig. 7.

until a certain degree, be represented by this scheme, it had many adherents, even since *Berzelius* had abandoned it. In order to decide the question upon this subject, Professor *Oersted* made a direct experiment, which will be understood by Fig. 8. *AB* is a wooden pillar more than twelve feet high; *C* is a magnetical needle, protected with glass against motions in the air; *DE* a wire of brass;

[1] [This vol. p. 218.]

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K a galvanical apparatus; *HGF* and *OJL* brass wire; *M* and *N* small cups with mercury. The whole moveable part of this arrangement was supported by a wooden frame, not here represented. It appears that the apparatus *K* with its conductors, whose extremities are plunged in the mercury, can turn around nearly through the whole circle, without an interruption of the continuity of the conductors; thus the same point of the perpendicular wire, though immoveable itself, changes every moment its relative place in the circuit, when the moveable part *FGIL* is turned round. The experiment shows that the deviation remains the same, whatever the position of the moveable part may be, and that of consequence the polarity must be the same in all points of the circumference of the conductor. The great distance of the other parts of the circuit is the reason that *DE* is the only one which can have a sensible effect upon the direction of the needle.

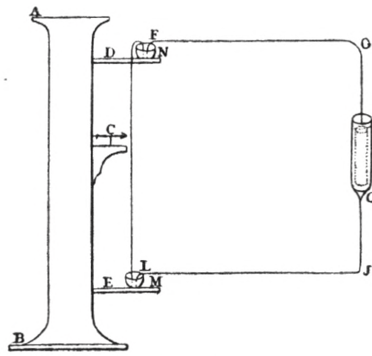

Fig. 8.

Schweigger's multiplier.

A most useful application of electromagnetism is the *electro-magnetic multiplier,* invented by Professor *Schweigger* at Halle, and improved by several other philosophers. We have already seen that when the uniting wire is bent so as to form two parallel branches each of them acts in the same direction upon one of the poles of a magnetical needle placed between them (Fig. 5.) On proceeding upon this principle it is clearly shown that when the uniting wire is bent several times, as *ABCDE,* Fig. 9, and a magnetic needle is suspended in the space, inclosed by the windings of the wire, each of its horizontal parts must produce upon the needle an equal effect; thus in the figure the effect is quadrupled. It is to be remarked that the windings should be as near each other as possible, in order to keep them all very near to the needle. At the same time the windings must be isolated from each other, which is effected by covering the wire with silk. As the windings can be repeated a great number of times, the multiplication of the effect may go very far. It should be nearly

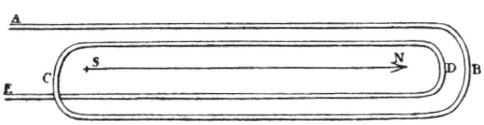

Fig. 9.

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without limits, were it not that the conducting power decreases when the length of the wire increases. In order to give the instrument the solidity necessary, the wire is wound upon a frame. As it is required that the needle should be as moveable as possible, it is suspended by a fibre of silk, such as is found in the cod of the silk-worm. The instrument may be made much more sensible by means of another magnet placed so as to diminish the directive power of the needle. Mr.

Fig. 10.

M. *Nobili's* improved multiplier.

Nobili has made a new improvement in this apparatus. In the place of one needle he introduces a compound index, consisting of two needles, *NS* and *S'N'*, Fig. 10, in opposite directions, and joined by a piece of wood or of stout wire, *GH*. When these two needles are of equal strength, the directive power of the index is reduced to nothing; so that the most feeble impulse will move it. But even when one of them has some preponderance, the force required for making the index deviate is still inconsiderable. At the same time this arrangement has the advantage, that both needles receive an impulsion, the needle *NS* from the inferior side of the conductor, and *S'N'* from the superior. The needles being in opposite situations, one will receive the same direction by the superior, as the other by the inferior side of the wire. When the needles approach as much to equality as is required for some nice experiments, the index is too easily moved in some others. In order to make the instrument proper for experiments with various degrees of force, though all of the feebler kind, Professor *Oersted* added a bent magnet, *JKL*, which can be placed so as to repel the nearest end of the index, or so as to attract it. The first of these positions is represented in Fig. 10. The magnet can also be approached to the index or removed from it. Fig. 11 represents the whole instrument of half its dimensions. *AB* is a stand of wood, having a screw on each corner for levelling it. *CCC*, *CCC* are two supporters likewise of wood, bearing the frame *defg*, upon which the multiplying wire is wound. This wire may be conveniently 50 to 60 feet long, and make 100 or more windings. From the windings each end of the wire passes through a little ring *h*, (the other is not to be seen in the figure) at *ii* the ends of the wire pass also through rings, which

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are here covered by the other parts of the figure; *KK, KKK* are two small pillars of ivory or wood, supporting the transverse piece *ll*, through which passes the cylindrical piece *mp*, having a head at *m*, and being moveable upwards and downwards. At the centre *r* of the inferior extremity, *p* is a little hole, communicating with a transverse hole, which here is represented as shut with a pin, seen immediately under the ring *o*. Through the hole at *r* is in-

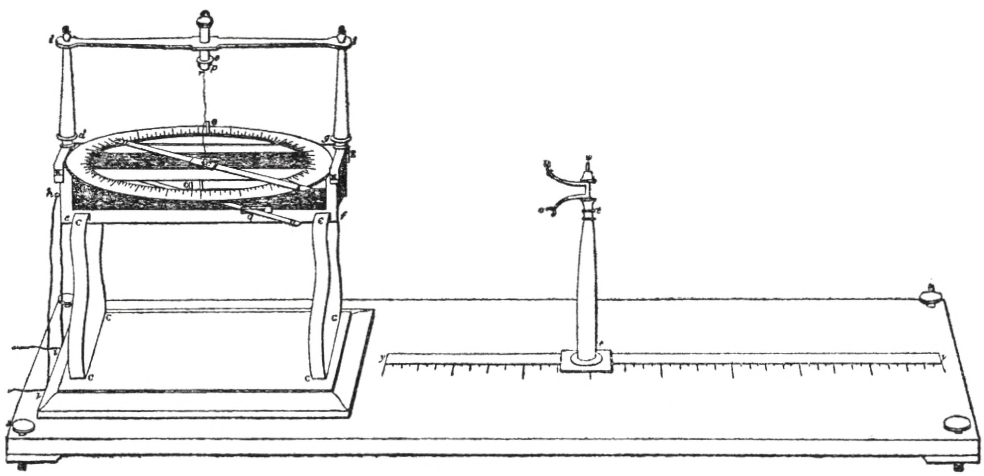

Fig. 11.

troduced one end of the silk *rx*, which is drawn out through one of the openings of the transverse hole, and fastened by means of the pin above-mentioned. By the silk *rx* is suspended the index, consisting of the superior magnetic needle *ns*, and the inferior one, of which the extremity *n* is here visible, the other being covered by other parts of the figure. The boreal pole of one of these needles is turned in the same way as the austral of the other, and both connected with a piece of wire. The circle at whose divisions the index points, is made of glass, preferable to brass, which often is magnetic. At *q* is a slit to receive the needle and keep it, when the instrument shall be transported, a similar one is on the other side of the instrument. The index is cleared from the slits when the instrument is to be employed. Having been thus cleared, it is still at rest until the piece *mp* is drawn upwards, the ring *o* stops it, so that it shall not be elevated too much. The index is sheltered from the air by means of a case of glass which covers the whole frame including the index, and has in the upper part a hole through which the head *m* of the piece *mp* passes; *tt* is a pile moveable in the slit

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y y, which has a scale, showing the distance from a point in the same plane, perpendicular below the centre of the index; *uv* is a bent magnet, which has two points, one of which is visible at *w*, the other is placed in a hole in the pile *tt*. This magnet can be taken out, and the point *w* introduced in the pillar, in order to augment or diminish the directive power of the index, as the purpose may require. When this instrument is to be used, the index must, as already mentioned, be taken out of the slits and the piece *mp* be elevated, so that the index can move freely. When it is made to oscillate too much it may be brought to rest by lowering the piece *mp* a moment. If the two needles of the index have exactly the same power, it will have the highest mobility; but if this is not obtained, the bent magnet *uv* is to be so placed upon the pillar *tt* that the two nearest poles of the index are repelled. By approaching or retiring the pillar, the magnet may be brought into such a position that the directive power of the index is scarcely sensible. When the instrument is in this state it can make sensible the difference between two pieces of metal, of which one differs only from the other by $^1/_{100}$ alloys, when a powerful liquid is applied. When a more considerable effect is to be tried, the bent magnet is put in such a position that it attracts the nearest poles of the index. When the magnet is near the index, and the current makes the index deviate very little, the deviation increases as the magnet is removed. The distance of the magnet being measured by the scale, this arrangement may contribute much to the determination of the powers. As the needles submitted to the effect of the current can never rest at an angle greater than 90^0, the needle is prevented from going farther by means of two small pins here marked with the Greek letter φ.

Application of the multiplier.

The use of the electromagnetical multiplier is very extensive. Before the invention of this instrument, a prepared frog was considered as the nicest test for galvanism; the multiplier surpasses it by far. Mr. *Poggendorff* has made a very extensive trial upon the galvanic series of metals and other conductors, by means of this instrument. Professor *Oersted* has made use of it, for confirming the discovery earlier made by *Zamboni*, upon electrical currents which two pieces of one metal makes with a liquid. He has also discovered, by means of this instrument, that two equal pieces of metal give galvanical effects, when one of the pieces is earlier introduced in the fluid than the other, a fact which Sir *Humphry Davy* has confirmed, as it appears, without knowing *Oersted's* experiments. Professor *Oersted* has also made use of this instrument for trying silver. With a powerful liquid conductor, solution of potash and muriatic acid for instance, silver pieces, whose alloy differs less than a hundredth, give a deviation of several degrees. As silver containing brass gives more effect than silver containing an equal quantity of copper, when muriatic acid is employed, but less when solution of potash is the liquid conductor, the presence of brass in silver is easily discovered by this instrument. It need scarcely be mentioned that gold and other metals may be tried in the same manner. Dr. *Seebeck*, at Berlin, has investigated, with much care, all the circumstances belonging to the construction of the multiplier. These researches are given in an excellent paper, read at the Royal Academy of Berlin, on the 14th December 1820, and the 8th February 1821, containing a valuable detail of experiments upon several points of electromagnetism. Dr. *Seebeck* has proved, by experiment, what might be presumed in theory, that the increase of the effects of the multiplier, with the number of the turns, is limited by the resistance against the transmission increasing with the length. The effects of the multiplier increase also with the breadth of the conductor, which he made of a long and thin lamina, in the place of a wire; still the advantage of broad conductors is only confined to experiments with considerable powers: In feeble currents the effects of broad and narrow conductors are equal.

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Several philosophers have given themselves much trouble to produce upon the needle, by means of common electricity, the same effects as those produced by galvanism. A simple electric spark transmitted through a conductor passes too speedily to move the needle. A current produced by the electrical machine does not seem to contain a sufficient quantity of electricity for acting upon the needle without the aid of the multiplier. Even by this instrument it was tried often, without decided success, until of late Mr. *Colladon*, at Geneva, repeated the experiment with a multiplier, in which the wire was covered with three folds of silk, and thus well isolated. Then he approached the two ends of the wire of this instrument to the two conductors of an electric battery of 4000 square inches, so as to make the discharge go a little distance through the air, before it enters in the wire. In this manner a current suffici-

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ently strong, and of some duration, is produced, whereby a considerable deviation is effected. The current produced by an electric machine caused also a deviation of several degrees in this instrument.

Professor *Oersted* proposed, in a paper[1] printed in *Schweigger's* Chemical Journal, 1821, to make use of magnetical needles, suspended in various directions for investigating the electrical currents in the atmosphere; but he has published nothing since that time. Mr. *Colladon* has, with full success, employed the multiplier, to prove the presence of electromagnetism in a thunder storm.

The idea of magnetical revolutions around the uniting wire experienced much opposition at its first publication. Professor *Schweigger* objected to it, that when such revolutions did exist, it would be possible to make a magnet circulate round the uniting wire. Dr. *Wollaston* drew the same conclusion, but with the contrary meaning; finding this result probable, he invented an instrument to prove it. The experiment having been stopped by an accident, Mr. *Faraday* took it up, and made an extensive series of experiments on the subject, conducted with the same skill which he has displayed in so many other investigations. He found that not only the magnet may be made to turn round the conductor, but that likewise a moveable conductor may be made to turn round the magnet. We shall have an opportunity to return to this subject; here we can only give an account of the experiments by which the motion was communicated to the magnet. Fig. 12, represents an apparatus proper for the experiment, *CCCC* represents a cup of glass, or some other non-conductor, through the bottom of which passes the conductor *EFG*. The cup is filled with mercury, in which a small magnet *AB* floats, being kept in a vertical position by a piece of platinum, fixed at its inferior extremity. It can also be kept in this position by fixing the inferior extremity to the bottom by means of a short thread of silk. *D* is a conductor whose lower end dips in the mercury. When a strong electrical current is now caused to pass through this arrangement, the magnet revolves about the conductor *D*. The directions of the rotations are in all cases such as the fundamental law of electromagnetism indicates that they should be. A magnet can also be made to turn round its own axis

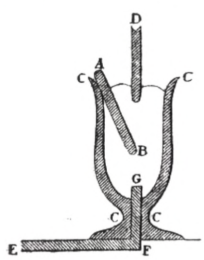

Fig. 12.

[1] [This vol. p. 245.]

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by an electrical current. Let *CCCC,* Fig. 13, be a cup of glass or wood, nearly filled with mercury; *A B* a magnet, having at its lower extremity a steel point, introduced into the agate *H. JK* is a slip of brass or ivory, having a hole through which the magnet passes freely, and by means of which it is kept perpendicular at the superior extremity; *A,* is a cavity for receiving mercury; *E F* is a wire, at whose extremity is also a cup for mercury; and at *D* is placed a similar one, from which proceeds a wire amalgamated on its lower extremity, in order to favour the electrical communication. When the electrical current is established by conductors plunged in the mercury at *D* and *F,* the magnet will turn, with great rapidity.

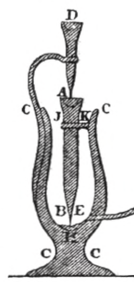

Fig. 13.

ON THE POWER OF THE ELECTRICAL CURRENT IN DEVELOPING MAGNETISM IN OTHER BODIES

The electrical current developing magnetism in other bodies.

In a paper read before the French Institute, the 25th September 1820, Mr. *Arago* showed that the electrical current possesses, in a very high degree, the power of developing magnetism in iron and steel. Sir *Humphry Davy* stated the same facts in a letter to Dr. *Wollaston* on the 12th November 1820. Dr. *Seebeck* communicated to the Royal Academy at Berlin, the 14th December, an excellent series of experiments upon the same subject. Thus treated in the space of three months by three so highly distinguished philosophers, the subject was nearly exhausted in the same year that the discovery was made. The uniting wire of a powerful galvanic apparatus attracts iron-filings often with such a power as to form a coating around the wire ten or twelve times bigger than itself. Mr. *Arago* found that this attraction did not take its origin from any previous magnetism in the iron-filings, which could touch iron without adhering to it; nor was the attraction to be considered as a common electrical one, since brass- and copper-filings were not attracted. He found also that the iron-filings began to move before they came in contact with the uniting wire. Hence it must be admitted that this attraction is operated by converting each little piece of iron into a temporary magnet. Greater pieces of soft iron were also converted into temporary magnets, and small steel-needles into permanent magnets. Sir *Humphry Davy* had, in his researches,

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obtained the same results, before he had got notice of the experiments of the French philosopher. Dr. *Seebeck* seems to have been in the same case, when he made his experiments; but he had received notice of *Arago's* experiments when he published his own. The direction of the magnetism produced is always according to the fundamental law. Let the circle in Fig. 14 represent a horizontal section of a perpendicular conductor, in which the current comes from above; let the little arrows indicate the direction of the revolving magnetism, and *BA, BA, BA, BA,* some steel needles; then these needles will obtain austral magnetism at *A*, and boreal magnetism at *B*.

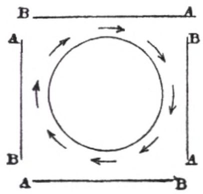

Fig. 14.

Dr. *Seebeck* found that a steel needle was strongly magnetized when it was drawn around the conductor. The direction of the magnetism was the same as it should be, if the needle had been laid closely around the conductor, and afterwards removed. He laid also an armour of soft iron on both sides of the conductor, which hereby was made able to bear a considerable weight of iron.

Mr. *Arago* and Mr. *Ampère*, employed in the development of magnetism the principle of the multiplier, without having notice of the discovery of *Schweigger*. A steel needle *AB* covered with paper, was surrounded by a winding of the uniting wire *EE*, as represented in Fig. 15. The steel-needle may also be included in a glass tube. The great galvanic apparatus of the London Institution is now found to develope magnetism in such an eminently high degree, that a little steel bar, by falling through a glass tube, around which the windings of the uniting wire passed, was magnetized to saturation.

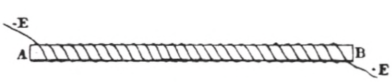

Fig. 15

The electricity produced by friction, when employed in sufficient quantity, developes likewise magnetism in steel. The discharge of an electric battery, and even of a single bottle, magnetizes a steel needle. All these magnetical effects are submitted to the same law as those of the galvano-electrical current, and hence they are also increased upon the principle of the multiplier. When the discharge passes through the air across the steel-needle, the magnetism developed is feebler than it is when the electricity passes across it through a metallic conductor.

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Mr. *Savary's* discoveries.

Mr. *Savary,* at Paris, has of late discovered that steel-needles placed at different, yet small distances from a wire, through which passes an electric discharge, do not all obtain magnetism in the same direction. In one of his experiments he caused to pass the discharge of a battery having twenty-two feet surface through a platina-wire of about three feet in length and one-hundredth of an inch in diameter. The needles in contact with the wire became magnetized in the direction commonly observed, which he calls the positive direction, but a needle placed at the distance of 1.1 millimetre, about $^1/_{24}$ inch, becomes magnetic in the opposite direction, which he calls the negative. At the distance of 2 millimetres a needle was not made magnetic by the discharge. At the distance of 3 to 8 millimetres the needles become magnetic in the positive direction, but most at the distance of 5.5 millimetres. From 8.6, to 21.4 millimetres, the magnetic direction was negative, with increasing intensity from 8.6, to 14.6, and with decreasing from this point until 21.4, where it was nearly at zero. From 23 millimetres distance the magnetic direction became again positive. As for different conducting wires, he found, that within certain limits the maximum of effect is the more distant from the wire, and the numbers of alternating directions the greater, in the same degree that the wire is shorter in comparison to its length. In a helix of narrow windings, needles placed parallel to its axis obtain all the same kind of magnetism, but by varying the electrical power, from that of one bottle of Leyden, to that of a battery of twenty-two feet surface, he obtained, in one experiment, six alternations, viz. three positive and three negative. When the needles are included in a metal coating, for instance, wrapt in a lamina of tin, the effect is changed. If the coating is thick, the effect is nothing, but by a coat sufficiently thin the effect may be increased. When the conducting wire is straight, a plate interposed between the wire and the needle, if thin, augments the effect, if thick, diminishes it; a certain thickness may also be found by which the plate is without effect. The needle is in all these experiments in contact with the plate. When the plate is not interposed, but the wire placed upon the plate, the effect of a very feeble discharge is increased by the plate, and still more the thicker it is. At a certain degree of discharge a thin plate diminishes the effect, a thick plate augments it. The effect of very considerable discharges is always reduced to

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nothing, or inverted by thick plates. By the galvanic arrangement the same effect is not produced, when the current is uninterrupted, but analogous effects to those mentioned may be produced by an apparatus which has intensity enough to give sparks at the moment of closing the circuit. The current must, for this purpose, only be established for a moment; a constant current destroys the alternations.

The analogy of these effects, with those alternations, which may be produced in bad conductors, by common electric experiments is obvious.

Experiments of Mr. *Hill.*

Mr. *Hill,* at Lund in Sweden, has found that when the discharge passes along a magnetical needle, exactly through its axis, all its magnetism is destroyed. He even considers this as the best means to take away the magnetism of a needle. At the same time he remarks that when the electric charge does not go through the axis, a feeble magnetism is developed on both sides of the line of passage, which probably has led preceding philosophers into an error respecting the magnetical effects of electricity. (*Schweigger's* Journal for the year 1822, No. 3.)

Professor *Erman's* experiments.

Professor *Erman* at Berlin found that when the electrical discharge passes perpendicularly through the center of a round plate of steel, it reveals no magnetism, but when a split is afterwards made in the plate, or a sector cut out of it, the opposite side of the gap shows the opposite magnetism. The celebrated *Gay Lussac* and Mr. *Welther*[1], without knowing the experiment of the Prussian philosopher, discovered the same fact in a steel ring. This experiment is very illustrative; it shows that the steel disc or steel ring, whose circumference has been in the same state as that of the uniting conductor, preserves after the cessation of the current a latent magnetism, resembling that of a magnetic circle, composed of small magnets, connected by their opposite poles. Such a circle is ineffectual, when the circumference is closed, but becomes a magnet when opened. This magnetism was, however, effectual during the time that the ring or disc was comprehended in the current, wherein its magnetism at every moment received a new impulse. Hence we may conclude that the circumference of the uniting conductor is not to be compared with a magnetic circle, wherein the powers are at rest, which is the theory brought forward by Mr. *Prechtel*[2], director of the polytechnic school at Vienna;

[1] [ɔ: Welter. [2] [ɔ: Prechtl.]

but our experiment confirms the original idea of the magnetical effect of the current, as produced by a revolving magnetism. Thermo-Electricity.

This view of the subject, that the magnetism of the electrical current, is a magnetism in motion, has been overlooked by a great number of authors, who have written upon electromagnetism; while it has been adopted by two highly distinguished philosophers, Dr. *Wollaston* and Mr. *Biot*. The difference between magnetism in motion and at rest being until our time unexemplified, this view appeared to many philosophers as a mere postulate, which they tried to avoid, by adopting some other theory, particularly the elaborate theory of *Ampère,* of which we shall afterwards speak. Now the theory of revolving magnetism has obtained a considerable support by the discovery of Mr. *Arago,* who, in his researches on the effect of metals upon the oscillations of the magnetic needle, found that it was much affected by a metallic plate, for instance a copperplate, when either the needle or the plate was put in motion. There is certainly but few philosophers, who have not repeated *Arago's* remarkable experiment by which a rotatory plate of copper, or some other metal puts a magnetic needle, conveniently suspended, into a revolving motion. We must pass in silence the numerous and skilfully conducted experiments of Mr. *Barlow* and Dr. *Seebeck;* and only quote for our purpose those of Messrs. *Herschel* and *Babbage*, by which it is proved that a rotating magnet causes a conveniently suspended metallic plate to turn round. Mr. *Poisson* has read before the French Institute an elaborate mathematical treatise upon the theory of moved magnetism. Thus the theory of revolving magnetism has obtained the only confirmation which could still be desired.

EFFECTS OF THE MAGNET UPON THE UNITING WIRE

Effects of the magnet upon the uniting wire.

Professor *Oersted*, in the prosecution of his experiments, was well aware that a moveable part of the electrical circuit must be attracted and repelled by a magnet after the same laws by which the uniting wire acts upon the magnet. He published, two months after his first electromagnetical paper, another paper[1] in which he gives an account of an experiment he made; he found that a little galvanical circuit, suspended by a thin metallic wire was put in motion by a magnet. He complains himself, in this paper, that he had not succeeded hitherto in getting an apparatus sufficiently

[1] [This vol. p. 218].

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moveable to be directed by the magnetism of the earth (*Schweigger's* Journal.) Professor *Schweigger* at Halle, and Professor *Erman* at Berlin, both invented, without knowing *Oersted's* experiment, apparatuses fit for the same purpose. It would be tedious to give an account of all the experiments made upon this subject; a short description of those which are considered as the best, will be sufficient. Fig. 16 represents, with some slight modifications, an apparatus invented by Mr. *Ampère*. *ABCDEFGH* is a bent wire, of which the two ascending parts at *B* and *G* are isolated from each other by some non-conductor and tied together. At *A*, and also at *H*, is soldered a steel point, which reposes on the bottom of a small iron cup filled with mercury, at *K* and *M*. *JK* and *LM* are brass wires, *NO* a piece of wood, in which they are inserted, and by means of which they can be fixed at a convenient place. It appears that when the current enters at the end of one of these wires, for instance at *J*, it is obliged to pass through the whole moveable conductor *ABCDEFGH*, and go out at the other end *L*. This conductor is put in motion with much promptitude by means of the magnet. In comparing this arrangement with Fig. 5, it is obvious that the part *DEFG* of the moveable conductor, in which the current enters at *D*, is quite analogous with *BDCA*, Fig. 5, and that therefore the austral magnetism on the interior side of both, is turned towards a spectator placed over against the place represented by the figure. It is also evident, that the magnetical direction is the same in the part *BCD*, which turns the same side to the space included by the moveable conductor. Thus a magnet whose austral pole is directed against this space, will repel the conductor, but placed near to a point of the exterior side it will attract it. On the opposite side of the plane *BCDEFG*, all the effects are opposite to those here mentioned.

Ampère's apparatus.

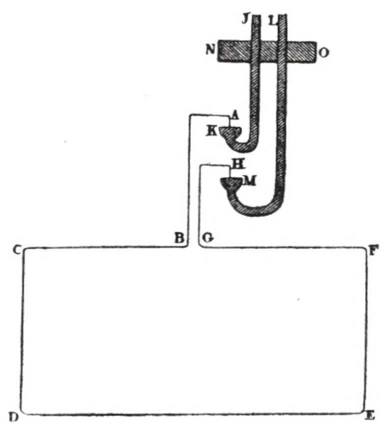

Fig. 16.

The magnetism of the earth is likewise able to give a direction to the suspended wire. This direction must, in the northern hemisphere, be the same which is produced by a magnet placed below the wire, with its austral pole above, and its magnetical axis put in

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the direction of the dipping needle; which direction is the same as that which a magnetical needle should tend to give the wire, if it were fixed below it, in the same position which the current gives it. Thus the plane *CDEF* must be directed perpendicularly to the magnetical direction; when the current enters at *A*, the perpendicular part *FE* will be placed towards the west, but towards the east, if the current enters at *H*.

The same reasoning may be employed in all other cases where a moveable uniting wire is exposed to the influence of terrestrial magnetism; for instance, when the wire is suspended in such a way as to permit the particles to move only in vertical planes. Fig. 17 represents an arrangement of this kind. *ABCD* is a wire, whose two extremities are wrapt round the ends of a thin axis of some non-conductor, and are terminated by two steel points, *a* and *b*, destined to be placed in two steel cups filled with mercury, and communicating with a galvanic apparatus. In order to give it the mobility necessary, it is nearly balanced by a counterweight at *E*. When the axis is placed perpendicularly to the direction of the magnetic needle, and the current enters at *a*, that is in the west, the plane *ABCD* will be driven out of its perpendicular position, and deviate towards north: but if the current enters at *b*, the deviation will be austral. If the axis *AB* is placed in the direction of the magnetic needle, the deviation will, in the first case, be towards the west, in the last towards the east. The boreal pole of a magnet, placed below *DC* produces the same phenomena; the deviation goes always to the left of the current.

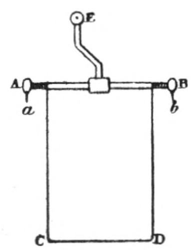

Fig. 17.

The principle of the multiplier has also been applied to the moveable uniting wire. Fig. 18 represents one of these contrivances, invented by Mr. *Ampère*, and somewhat modified by Professor *Van de Ross*. On the extremity *A* of the wire is a steel point, resting in a cup with mercury: *B* is a part of the wire, which forms spirals, fixed on a circular piece of pasteboard, through whose centre it passes at the last, and is prolonged to *C*, which dips in a cup of mercury. Another apparatus, likewise invented by Mr. *Ampère*, is represented in Fig. 19. The wire passes through a glass tube, from *A* to *B*, it is then wrapt around it, and, being

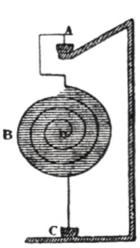

Fig. 18.

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returned to the extremity *A*, passes also around *C D,* and being arrived at *D* is drawn through the tube, and descends finally to the inferior cup.

Another apparatus of Mr. *Ampère,* improved by Mr. *Marsh*, destined to show the magnetical effect of the earth upon the uniting wire, is represented Fig. 20; *AB* is a cup of glass nearly filled with

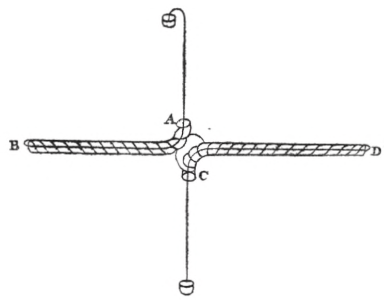

Fig. 19.

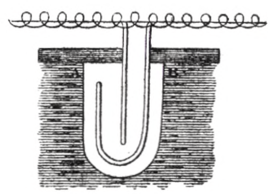

Fig. 20.

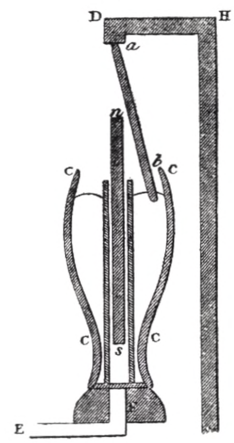

Fig. 21.

a convenient liquid, containing a galvanical arrangement, and kept swimming upon a liquid by a piece of cork; the uniting wire is like that of Fig. 19.

In the same manner as a magnet can be made to revolve round the uniting wire, so can a moveable uniting wire be made to revolve round a magnet. Fig. 21 shows the principal parts of an apparatus for this experiment, *CCCC* is a glass cup, having a hole through its foot, into which is inserted a copper tube, soldered to a copper disc, cemented to the foot of the glass. The wire *EF* is also soldered to another copper disc upon which the glass rests; *ns* is a magnet inserted in the copper tube. The cup is filled with mercury. At *a* there is a sort of ball and socket joint, by means of which a wire *ab* is put in communication with the arm *DH* of a brass pillar: both the socket and the ball are amalgamated, and a piece of silk fixed to the ball or head of the wire, passes through a hole drilled in the arm *DH*, and by which the wire *ab* is suspended, thereby

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preserving the contact, and leaving to the latter a perfect freedom of motion. When the current is established, the wire *ab* will revolve about the magnet. The directions of the rotations are such as the theory indicates.

We have seen that a magnet can be made to turn round its axis. An apparatus has likewise been contrived for producing the same phenomena in a moveable uniting wire. For shortness sake we shall here omit the description of it; while we give the description of a very simple turning apparatus invented by Mr. *Ampère*, and whereof a perpendicular section is exhibited in Fig. 22. *ABCD* and *abcd* are two cylinders of copper, soldered to a bottom of copper, in such a manner that the space between the two cylinders is able to contain a liquid, but the interior cylinder is left open at both its ends. To *a* and *b* is soldered a bent copper wire, having a cavity at *F*. *zz* is a light cylinder of zinc, to which is also soldered a bent wire, in the middle *E* of which is a steel point, resting in the cavity *F*, and consequently the cylinder *zz* will move upon its point of suspension. When the space between the two cylinders is filled with a convenient fluid conductor, an electrical current is established. Now, if a magnet *NS* is introduced into the cylindrical space of *abcd*, the cylinder *zz* will begin to turn. When the north end (the austral pole) is upwards, the motion is from left to right of the observer, and the contrary with the magnet reversed; all as it could be predicted from the fundamental law of electromagnetism.

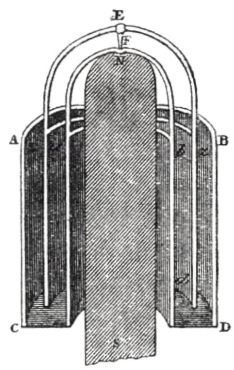

Fig. 22.

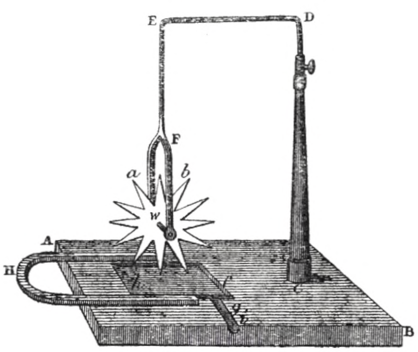

Fig. 23.

Mr. *Barlow's* apparatus.

Another ingenious contrivance, invented by Mr. *Barlow* is represented in Fig. 23, where *AB* is a rectangular piece of hard wood, *CD* a wooden pillar, *DEF* a piece of stout brass or copper wire, *ab* a somewhat smaller bent wire, soldered to it at *F*, through the legs of which passes the axis of a wheel *W*, of thin copper, *hf* is a small reservoir for mercury, and *gi* a narrow channel running into it. *H* is a strong horseshoe magnet. Mercury being now poured

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into the reservoir *hf*, till the tips of the wheel are slightly immersed in it, and the surface covered with weak dilute nitric acid, let the connection with the battery be made at *i* and *D*, and the wheel will immediately begin to rotate. If the current or the magnet be inverted, the motion of the wheel will also be reversed. In order to understand this experiment, it must be remarked, that each radius of the wheel, which touches the mercury, is a part of the uniting conductor, of which one side is repelled by the austral, the other by the boreal pole of the magnet; thus it must either tend to raise or depress each of these radii.

Sir *H. Davy's* experiments.

Sir *H. Davy* has exhibited the rotation of a conductor by means of mercury. When in a shallow non-conducting vessel containing mercury, the conductors of a powerful galvanical arrangement are plunged at some distance from the sides, and one of the poles of a strong magnet is brought from below to the bottom of the vessel, near one of the conductors, the mercury round this conductor will form a vortex about it. The directions of the motions are always according to the poles and conductors in action, such as the fundamental law indicates.

When a moveable part of the uniting wire is placed in the direction of the dipping needle, it cannot be put in motion by the magnetism of the earth; but when it is placed in another plane, though under the same inclination, it is put in motion. Professor *Pohl* at Berlin, has invented an apparatus, represented in Fig. 24 exhibiting this phenomenon. *AB* is af piece of board, supported by screws, by means of which it can be levelled. *CD* is a wooden pillar, whose superior part is moveable, and has on its top an agate, which serves to support a steel-point, whereupon rests a wire *EF*, balanced by a counter-weight *G*. At *E* is a cavity containing a drop of mercury, by means of which one of the conductors, whereof only a part *H*, here is represented, may be made to communicate with the moveable wire. *JKL* is a circular channel containing mercury, which can be put in communication with the galvanic apparatus, through a conductor at *M*. When a powerful electric current is transmitted through the apparatus, *EF* can only rest in the position of the

Professor *Pohl's* apparatus.

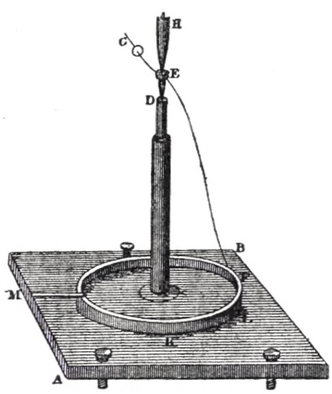

Fig. 24.

Thermo-Electricity.

dipping needle; in all others, it moves until it arrives at that position, which it nevertheless will leave by the motion already obtained. Hence it must still continue to turn, when it is not stopped, to the position in which it is possible for it to rest.

MUTUAL ACTION OF ELECTRICAL CURRENTS

Mutual action of electrical currents.

Mr. *Ampère* found, soon after the discovery of electro-magnetism, that *two conductors attract each other, when they are transmitting electrical currents of the same direction, but that they repel each other, when the currents have opposite directions.*

The moveable conductor, represented in Fig. 16, and already described, may be employed to prove this by experiment. As the current which passes through the moveable wire *ABCDEFGH,* has in *CD* the opposite direction of that in *FE,* the same uniting wire, which attracts one of these, will repel the other. This experiment may be exhibited in various shapes; but it does not appear that any experiment which could not be made by this simple apparatus, is necessary for confirming the law above-mentioned.

This law may easily be deduced from the fundamental law of electro-magnetism, as may be seen by Fig. 25, which represents two parallel currents of equal direction, and expressed by the same signs of which we have made use in the preceding pages of this article. It is here evident, that the boreal magnetism at *b* meets with the austral at *α,* and that the austral at *a*, meets with the boreal at *β*, thus the effect must be attraction. In Fig. 26, two currents of opposite direction are represented, where the boreal magnetism at *b*, meets with that at *β*, and the austral magnetism at *α,* with the similar at *a*: which must produce repulsion.

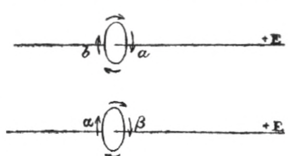

Fig. 25.

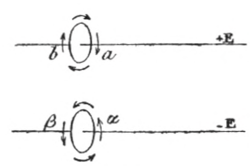

Fig. 26.

When the currents are not parallel, but form an angle, they attract each other when both are directed either towards the apex or in the contrary way, but they repel each other when one of the two currents is directed towards the apex, at the same time that the other goes off from it. Fig. 27 represents two currents which go off from the apex. The boreal magnetism being in one of these directed from b to a; the austral magnetism in the other from β to α, the result must be an attraction by which the conductors, if one of them is moveable, are brought to parallelism. The figure represents only one side of the conductors; but the opposite sides, having both their magnetical directions reversed, will likewise be attractive. It is also easily understood, that the opposite magnetical poles are directed against each other, and produce attraction when the current in both conductors goes towards the apex of the angle. Fig. 28 represents two currents having opposite directions,

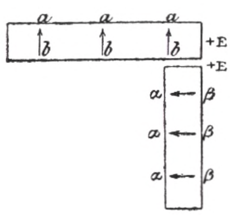

Fig. 27.

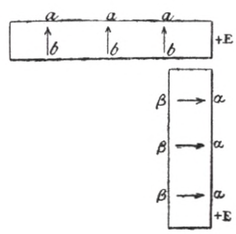

Fig. 28.

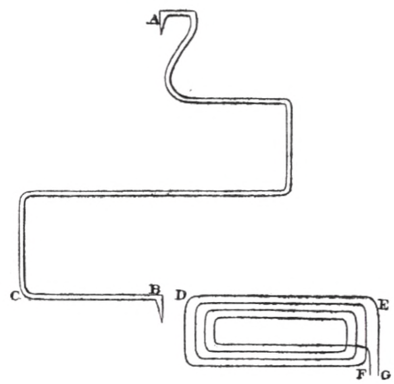

Fig. 29.

with respect to the apex of the angle. Here the similar poles in the magnetical rotations, are directed against each other, and therefore produce repulsion, such as to place both conductors in the opposite ends of one straight line, if one of them is moveable.

This may be confirmed by means of the apparatus represented in Fig. 29, consisting of two parts, viz. a moveable conductor, *ACB,* and a multiplying wire *DEFG.* The moveable wire is terminated by two steel points at *A* and *B*, which are to be placed in two small steel cups, filled with mercury, and communicating with a galvanic apparatus. The multiplying wire is preferred to a straight one, in order to increase the effect. The upper part *DE,* of the multiplying wire is placed at the same height as the branch *BC* of the moveable conductor; but in such a position that both conductors prolonged would form an angle. The extremities *F* and *G* of the multiplying wire, are to be put in communication with a galvanic apparatus.

Mr. *Ampère,* to whom we are indebted for the discovery of the mutual attractions and repulsions of the electrical currents, considers the law of this action as a fundamental one, at least so far as our present knowledge extends. He thus admits no rotative action in the electrical current, but he transports it to the magnet, in which he supposes electrical currents, revolving in planes perpendicular or nearly perpendicular to the axis of the magnet. At first he supposed that all the currents had their centres in the axis, and were situated in planes perpendicular to this axis, but as he soon found that this would not represent the phenomena, he supposed that each atom of the magnet was surrounded by electrical currents, still revolving in planes perpendicular to the axis of the magnet. When Mr. *Poisson,* however, showed, that in consequence of this view the greatest effect of a magnetical bar would be placed in its extremity, contrary to experiment, he changed this supposition, and at present he is of opinion that the currents are situated in a plane somewhat inclined to the axis of the magnet. Thermo-Electricity.

By these suppositions, and a considerable exertion of mathematical skill, he is enabled to make this view represent well enough the phenomena, though his theory is very complicated. It is not necessary here to enter into a discussion on all the points of this theory, as simple consideration of the fact upon which it is founded will be sufficient to decide the question.

Let us suppose that electromagnetism had not been discovered before the discovery of the mutual action of electrical currents, the application of the common philosophical rules should enable us to discover therein the rotative character of the action. The fact is, as above mentioned, that parallel currents attract each other, when they have the same direction, and repel each other, when they have opposite directions. Now it is to be remarked, that two parallel things of the same direction have their opposite sides placed against each other: the left of the one is nearest the right of the other; but two parallel things of contrary directions have their similar sides turned against each other: right against right, or left against left. Thus the fact reduced to the simplest philosophical expression is that *two points of electrical currents repel each other by their similar sides, and attract each other by their opposite sides.* The most direct enunciation of the experimental result cannot here be considered as at the same time the expression of the philosophical one; for it is evident that two parallel things cannot act upon each other immediately, but only

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by some transverse action, which here shows itself as consisting of attractions and repulsions in opposite directions, or in other terms, as having polarity. But such contrary powers forming a circle, should keep themselves in equilibrium, and produce no effect without their limits, were they not in motion. Thus the very experiment of Mr. *Ampère* should, in the absence of all other evidence, be sufficient to prove, *that the electric current contains a revolving action, exhibiting every appearance of polarity.* We do not mean to ascertain the nature of these attractions and repulsions; but it has been our object only to point out the more immediate consequences of the facts.

ELECTROMAGNETICAL CURRENTS PRODUCED BY HEAT

Electro-magnetical currents produced by heat.

Dr. *Seebeck,* in his researches upon electromagnetism, extended at the same time his investigations to the laws of galvanic action, and among these to the influence of heat in galvanic arrangements. Some phenomena here occurred to him, which led him to think that two metals, forming a circuit, might produce magnetism when the equilibrium of heat in it was disturbed. Experiment confirmed this opinion. Fig. 30 represents such a circuit; let ABC be a piece of bismuth, and ADC a piece of copper, and let one of the junctions, A for instance, be heated, an electrical current will be established, which here can only betray its existence by the magnetical needle; this indicates all the magnetical properties of an electrical current, and, in the instance here mentioned, the current goes into the heated junction from the bismuth to the copper. Dr. *Seebeck* is not inclined to consider the effect thus produced as a true electrical current, but an effect *sui generis;* and indeed we have not hitherto been able to discover in this circuit either any chemical effect, nor heat or light; still we can represent all the phenomena of Dr. *Seebeck's* circuit by the same terms as those of the common electrical current: and in the explanation of all the facts, it will appear highly probable that this current is truly a particular kind of electrical one. Professor *Oersted* has proposed to call the current discovered by Dr. *Seebeck* the *thermo-electrical* current, and in consequence of this to distinguish the action hitherto called Galvanism, by the name of the *Hydro-electrical current.* Hence we

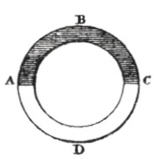

Fig. 30.

have now the names *thermo-electricity* and *hydro-electricity*, to which we could add the name *tribo-electricity* for the electricity produced by friction. Dr. *Seebeck* has made a very considerable number of experiments upon the thermo-electricity produced by the metals and other perfect conductors. In a circuit containing bismuth, together with one of the other metals, he finds that, in the heated junction, the current goes always from the bismuth to the other metal; of course the bismuth loses, at that point, positive electricity. This we shall, for shortness sake, express thus: bismuth becomes negative with all other metals in the thermo-electrical circuit. In the same sense tellurium may be said to become positive with all other metals. It appears already by these two examples, that the thermo-electrical order of the metals is not the same as the hydro-electrical; and indeed the experiments of Dr. *Seebeck* have proved that these two orders are discrepant throughout. Thermo-Electricity.

The order of the metals, beginning with that which becomes negative with all others, is,

1.	*Bismuth.*	
2.	*Nickel.*	
3.	*Cobalt.*	
4.	*Palladium.*	
5.	*Platinum.*	Several pieces of this metal gave very different results, even those which came from the same workshop. Three pieces from *Jeannetty's* platina manufacture were placed in the order of their effects very far from each other. The pieces which kept this place here between palladium and uranium were prepared by Dr. *Wollaston*, Mr. *Bergemann,* chemist at Berlin, Mr. *Trick,* chemist, appointed to the manufacture of china at Berlin, and Mr. *Jeannetty* at Paris. As one of these pieces was prepared by Dr. *Wollaston,* and the two Berlin chemists being men of much chemical skill, we may consider this place as that of the pure platinum, if Mr. *Becquerel* had not found that two parts of the same platinum wire give a considerable thermo-electric action, when one of them was drawn out so as to become much thinner. Hence it appears that the density of the platinum has a considerable influence upon its thermo-electrical effect. This might perhaps also be the case with other metals.
6.	Uranium.	
7.	Copper,	reduced from the oxide, by means of black flux, Comp. No. 12.
8.	Manganum.	
9.	Titanium.	
10.	Brass,	some specimens. (Comp. No. 13.)
11.	Gold,	of Hungarian ducat containing $^1/_{90}$ alloy of silver and copper.
12.	Copper,	occurring in the trade, and containing no silver, iron, lead or sulphur. (Comp. 21.)
13.	Brass,	some specimens. (Comp. No. 10.)
14.	Platinum,	a piece of unknown origin. (Comp. No. 5, 18, 29.)
15.	Mercury,	the purest occurring in trade.
16.	Lead,	specimens occurring in trade, and pure lead.

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17.	Tin,	English and Bohemian.
18.	Platinum,	a bar from *Jeannetty's* manufacture.
19.	Chromium.	
20.	Molybdænum.	
21.	Copper,	occurring in trade, and containing neither silver, iron, lead or sulphur. (Comp. 12.)
22.	Rhodium.	
23.	Iridium.	
24.	Gold,	*a,* purified by antimonium, *b* reduced from the oxide.
25.	Silver,	*a,* purified by cupellation, *b* reduced from the chloride of silver.
26.	Zinc,	*a,* occurring in trade, *b* pure zinc.
27.	Copper,	reduced from sulphate of copper, *a* by iron, *b* by zinc. (Comp. 12 and 21.)
28.	Wolfram.	
29.	Platina,	some specimens, (Comp. 5, 14, 18.)
30.	Cadmium.	
31.	Steel.	
32.	Iron,	*a,* occurring in trade, *b,* pure iron.
33.	Arsenic.	
34.	Antimony,	*a,* occurring in trade, *b,* pure.
35.	Tellurium.	

In this series, Dr. *Seebeck* found that though most of the metals placed here near each other give only a feeble effect, and the more distant a stronger effect, this rule is not constant; tellurium, for instance, gives with bismuth less effect than antimony. With most of the metals in the series tellurium produces a feebler effect than antimony; with silver it produces more effect than with most of the metals placed above it. Antimony produces more effect with cadmium than with mercury. Iron produces only a feeble effect with most of the other metals, and particularly with nickel and cobalt. Of such exceptions Dr. *Seebeck* has found a great many.

Dr. *Seebeck* also examined the thermo-electrical powers of several other bodies. Sulphuret of lead becomes negative even in contact with bismuth. Some other sulphurets, as sulphuret of iron, of arsenic, of cobalt and arsenic, of copper, all with a maximum of sulphur, stand in the thermo-electrical series very near to the bismuth. On the contrary, the sulphurets with a minimum of sulphur stand very near to antimony; that of copper stands even under antimony.

Dr. *Seebeck* found also that concentrated nitric and sulphuric acid are to be placed above the bismuth, but that a concentrated solution of potash or of soda, obtains a place below antimony and tellurium.

Dr. *Seebeck* constructed also circuits of two pieces of one metal; heating or melting one of the pieces, and putting one extremity of the other piece, which must be bent, in durable contact, while the

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opposite extremity was in temporary contact with the heated piece. A bent silver wire was, for instance, plunged first with one of its extremities and afterwards with the other in melted silver; the magnetic needle indicated that the current was directed from the melted metal to that extremity which had been the longest time in contact. The same effect, though feebler, was observed when the silver had ceased to be liquid. When a platina wire is tried with a heated piece of platina the direction of the current is opposite. The general result of *Seebeck's* experiments is, that in the metals of the superior part of the thermo-electric series the direction of the current is as in the platina going from the heated metal to that extremity of the bent piece, which is latest put in contact with it; but in the inferior part of this series the current goes, as in the silver, from the heated metal to that extremity of the other metal, which has been longer in contact with it.

As soon as the thermo-electrical current was discovered, it was obvious that a compound thermo-electrical circuit might be formed, in analogy with *Volta's* complex hydro-electrical circuit. This consequence did not escape Dr. *Seebeck,* but discovering some opposing circumstances, which we shall soon mention, he bestowed little labour upon this subject, to which he perhaps proposed to return another time. Baron *Fourier* and Professor *Oersted* undertook, without knowing this observation of Dr. *Seebeck's,* a similar research.[1] Their first complex thermo-electrical circuit was a hexagon formed of three pieces of bismuth and three of antimony soldered together. One of the sides was put in the magnetic direction, and a compass placed below it, when first one of the junctions was heated, then two, not adjacent junctions were heated, at last three, still leaving between two heated junctions one which was not heated. The compass needle changed its direction some degrees by the heating of one of the junctions, still more by the heating of two, and most when all the three junctions were heated. By cooling the three junctions by means of ice, and leaving the three others to the temperature of the atmosphere, similar and even more comparable effects were produced. By heating three alternating junctions, and cooling the other with ice, the effect rose to 60° of the compass used in the experiment. In another series of experiments a rectangular circuit of 22 bars of antimony and 22 of bis-

[1] [This vol. p. 272.]

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muth soldered together was employed. Here likewise as in the preceding experiment, the combined effect of heating and cooling was employed. Now the circuit was opened by dissolving one of the junctions, and, in order to establish the circuit, when required, a little cup of brass destined to contain mercury, was soldered to each of the two bars, whose conjunction was interrupted. A copper wire of about 4 inches in length, and $^1/_{25}$th inch in diameter re-established nearly the current; and by two parallel pieces of this wire the current was brought to the full effect. A wire of the same diameter, but a little more than three feet long, was found a tolerably good conductor, while a platina wire of $^1/_{50}$th inch and about 16 inches long scarcely transmitted a fortieth of the effect. Liquid acids and solutions of alkalis or other metallic oxides, which prove excellent conductors in the hydroelectrical current, were found quite isolating in the thermo-electrical circuit. Two discs of silver, separated only by a lamina of the thinnest blotting paper, moistened with sulphate of copper, isolated likewise the whole effect of the thermo-electrical current.

The thermo-electrical current, even the most intense that was tried, produced no visible chemical effect; nor was it capable of producing heat in thin metallic wires, probably because they are too feeble conductors of thermo-electricity.

The thermo-electrical circuit also produces no effect upon the electrical condensation.

It is very remarkable that, notwithstanding all that has been mentioned, the thermo-electric circuit makes a prepared frog palpitate, like the hydro-electrical circuit. The communication between the extremities of the circuit and the nerves of the frog were made by means of platina wire, in order to guard against the influence of unequally oxidated surfaces.

Among circuits differing only by their length, the shortest has the greatest effect. A circuit of double length has not much more than half the effect. Complex circuits do not seem, therefore, at first sight, more efficacious than simple ones; the length being as much increased by the increased number of elements, as the effect should be heightened by the greater number of acting junctions; but comparing circuits of equal length whereof one has only two junctions, the other more, we see the true influence of the increase of acting junctions. Fig. 31 represents a simple circuit of antimony

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aa, and bismuth *bb,* where only one of the junctions is to be heated or cooled. Fig. 32 represents a complex circuit of the same length, formed of two pieces *a a* of antimony, and two pieces *b b* of bismuth. Two of the junctions of the latter arrangement, situated on the extremities of one diagonal are here heated or cooled. Under the same changes of temperature, where the circuit, Fig. 31, made the needle to deviate about 22 degrees, that of Fig. 32 made it to deviate about 30 degrees. Fig. 33 and 34 represent two circuits of double the ex-

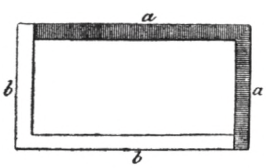

Fig. 31.

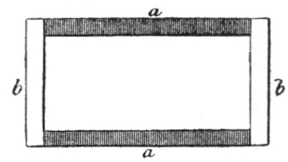

Fig. 32.

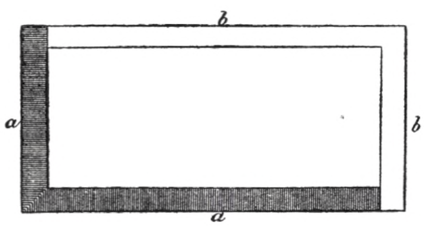

Fig. 33.

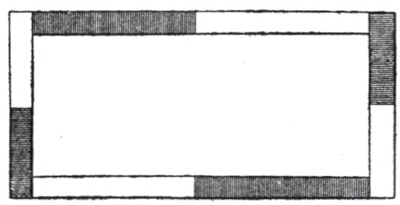

Fig. 34.

tent of the former, one simple, one having three alternations. By the same differences of temperature, by which the arrangement, Fig. 33, gave from 13 to 15 degrees, that of Fig. 34 gave nearly 32 degrees.

In several complex circuits, it is found that the heating or cooling of one junction only produces twice the angular deviations of that added by the addition of each active junction more. The effect of one active junction, when the others are at rest, is by experiment found to be twice the effect of all the arrangements, divided by the sum of the elements + one. The effect of each addition of a new active junction is only half this quantity, and seems even to be in a decreasing ratio, when the number of junctions is great.

The effect of thermo-electricity upon the multiplier is very instructive. Fig. 35 represents an arrangement formed by two pieces *b, b,* of bismuth, and one piece *a* of antimony. When the two free extremities of *b, b,* are put in communication with the extremities of the wire of the multiplier, and one of the junctions between *a*

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and *b* is heated or cooled, the needle of the multiplier is deviated, but very little; when one of the junctions is only cooled with ice, the effect is not so great as that of a disc of copper with one of silver, having common water as the liquid conductor.

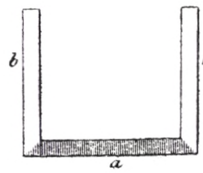

Fig. 53.

But when the extremities of *b, b*, are put in communication by means of a short piece of metal, the effect on the compass needle is considerable, whereas the effect of the hydro-electrical current of silver and copper, and even of silver and zinc, with common water as the liquid conductor, is scarcely sensible upon the same compass needle. This is a strong additional proof of the difficult transmission of thermo-electricity.

From all these observations we must conclude that the thermo-electric current produces an enormous quantity of electricity, but in a state of exceedingly small intensity. In order to conceive this well, it is to be remarked that the *intensity* of electricity is measured by the attractions and repulsions, whose force is in the inverse ratio of the squares of the distances, and that the *quantity* of electricity is measured by the number of equal surfaces which can be electrified by it to a certain degree of attraction and repulsion indicated by the electrometer. In the voltaic pile the intensity increases with the number of discs, the quantity with the surface of each of the discs. The greater the intensity the greater is the power of surmounting obstacles, or of penetrating through imperfect conductors; on the contrary, the greater the quantity the more perfect conductor is required to transmit it. The electricity produced by some thousand pairs of discs is able to penetrate a little lamina of air; that of some hundred pairs can at least penetrate through a considerable length of water; that of two pairs cannot easily be transmitted but by the solid conductors and some of the powerful liquid conductors.

The thermo-electrical current has a prodigious quantity of electricity in comparison with the hydro-electrical of silver, zinc, and water, but the intensity of the electricity is much greater in the latter; the electricity of the former is impaired by the resistance of the long multiplying wire, the electricity of the latter surmounting this resistance is on the contrary increased by the multiplying wire.

The complex thermo-electric circuit produces much more effect upon the multiplier, not only when the increased number of elements heightens the effect upon the compass needle, but still also when this increase does not augment the direct effect upon the needle. We must therefore conclude that the intensity increases with the number of the elements in the thermo-electrical as well as in the hydro-electrical current. It must therefore be possible to attain an intensity of the thermo-electrical current great enough for penetrating the liquid conductors, and producing the most considerable chemical effects. Still the construction of a thermo-electrical circuit of a great number of elements is very difficult, because the elements must be as short as possible in order to preserve the conducting faculty; but even the smallness of the distance between the heated and cooled parts must give way to a very speedy re-establishment of equilibrium. The best way seems to be, to produce the heating and cooling of the junctions by some continual current of hot and cold liquids.

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A very easy manner of constructing thermo-electric batteries deserves to be mentioned. Fig. 36 represents it. The parts indicated by the odd numbers 1, 3, 5, represent copper slips, and those indicated by the even numbers 2, 4, 6, small bars of bismuth. All the junctions situated on one side of the dotted line *cd*, are to be heated, those on the other side are to be cooled. The extremities *a* and *b* are to be connected by a conductor. The number of elements may here be tolerably great.

Thermo-electric batteries.

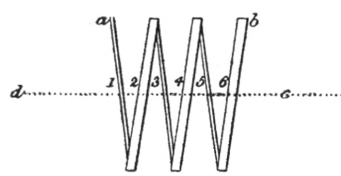

Fig. 36.

That the intensity of the electro-magnetic current must increase with the temperature was to be presumed; but this is not a general law. Dr. *Seebeck* had already found some exceptions, and also Professor *Cumming* at Cambridge, who made his experiments without knowing those of Dr. *Seebeck* upon this subject. We shall not stop here to detail these experiments, as another philosopher, Mr. *Becquerel*, availing himself of the imposed instruments of research, and making a very ingenious application of them, has given us exact measures of the quantities here occurring.

It was supposed that the declination of the needle, produced by the electrical current is in the ratio of the sine of the angle of deviation. Though this is a consequence of the resolution of powers, he thought that, in a matter so little known as the magnetical effects

Mr. *Becquerel's* experiments.

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of the electrical current, it might be advisable to examine the law of this measure by experiment, particularly with regard to the multiplier, where the current makes so many windings round the needle. In order to execute this plan, he formed his multiplier with four parallel and equal wires, covered with silk, and each making an equally great number of windings. Thus he had four multiplying windings about one frame. To the ends of each multiplying wire he soldered the ends of an iron wire, so that four thermo-electrical circuits, consisting of the copper wires of the multiplier and the iron wires were formed. When he wished to put one of these currents in activity, he cooled one of the junctions with ice, and heated the other in mercury. The junction was included in a thin bent glass tube, in order to guard it against the dissolving power of mercury. The mercury was heated by means of a lamp, somewhat above the temperature required, and when heated the lamp was taken away; thus the temperature remains for a short time stationary. In this manner he tried first the effect of one, then of two, three, or four of the multiplying circuits, and noted down the deviations produced, one of the junctions still being kept at the freezing point. Thus he found that one of the circuits gave, by 5° Centigrade or 9° Fahr. above the freezing point (41° Fahr.) a magnetic deviation of 0.65° French division, or 0.585° of common division of the arc. Two circuits gave by the same temperature twice 0.585°; three gave thrice, and four gave four times this quantity; whence he concluded, that when one circuit produces $4 \times 0^{\circ}.585$ it has four times the power of that producing only 0°.585. It is easily understood that the greater angles of deviation could not be in the same ratio as the action; but this does not hinder us from drawing analogous conclusions. Thus by a difference of 180° Fah. one circuit gave the deviation 10.71° of the circle; but two circuits gave nearly the same (10°.575) by a difference of 90° Fah. But it is not in all temperatures that this proportion of the effect and temperature takes place; in very high degrees of heat he found that the effect of circuits of copper and iron did not increase so fast as the temperature. From the freezing point (32° Fah.) up to 284° Fah. the magnetical effect increases with the temperature. From this degree to 572° the magnetic power, though increasing with the temperature, still proceeds in a decreasing progression; and exposed to the immediate action of a lamp, the current is inverted. When none of the junctions is at the freezing point, the effect of the circuit is equal to the difference of the effect, which each of the two temperatures applied to one of the junctions, the other being at the freezing point, should give; thus, for instance, a circuit of iron and copper, when one junction is heated to 392° F., the other being at 32° F., has an intensity expressed by 37; but when the heat is only at 212°, the intensity is expressed by 22. The difference of these two numbers is 15, which is found by experiment to be the effect of the circuit, in which one junction is heated to 392°, and the other to 212°. He found that a complex circuit of copper and iron produced an effect proportional to the number of elements, which is not the case, when the whole power of the circuit can be exerted, but is only so, when a very small part of the whole effect can be transmitted through a conductor, of such a length or feeble conducting faculty, that it requires much intensity of electricity, for being penetrated. Thus the observation of Mr. *Becquerel* proves, what had already been shown by less perfect experiments, *that the intensity of thermo-electricity increases as the number of the elements.* Thermo-Electricity.

Circuits of iron, with gold or silver, have likewise, as well as those which it forms with copper, a *minimum* of effect, by a certain elevated temperature, and in a still higher one their current changes its direction. In circuits of platina with gold, silver, lead, zinc, copper, and palladium, the differences of the intensities form an increasing arithmetical series.

Mr. *Becquerel* found that two pieces of platina form an active thermo-electrical current, when they are not of a perfectly equal nature. He cut through a piece of platina wire, and had one of the pieces drawn thinner; these two formed a thermo-electrical circuit. He maintains that the circuit is not efficacious unless a piece of some other metal is soldered to the one end of the wire, upon which statement we cannot but entertain some doubt, though Mr. *Becquerel's* authority is of no little weight. As Mr. *Becquerel* had found that the increments of the magnetic effect preserve the more their proportion to the increments of temperature, the more difficult the metal is in being melted [sic!]. He considers a circuit of two unequal pieces of platina as a pyrometer. By means of this, he has tried the temperature of the different parts of a spirit-flame, and estimated the temperature of the blue flame bordering the white,

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at 1350° Centigr., or 2462° Fahr.; in the white part he estimated it to be 1080° Cent. or 1976° Fahr., and in the darker part of the flame to be 780° Cent. or 1436° Fahr. The last he considers as too high, because the other parts of the flame contributed to heat the junction.

TERRESTRIAL ELECTRO-MAGNETISM

Terrestrial Electro-Magnetism.

We cannot pass by this subject entirely, though we must treat it very briefly. Mr. *Ampère,* who thinks that magnetism consists only in transverse electrical currents, must, in consequence of his hypothesis, suppose an electrical current round the earth, from east to west. He thinks that the numerous strata, of which our globe is composed, may form considerable galvanic arrangements; still he supposes that the rotation of the earth cannot but have an effect on the electric currents around it. Mr. *Ampère,* in consequence of his system, admits no other magnetism of the earth than these currents. The opinion, that the earth is surrounded by electrical currents, though not strictly proved, is very probable. As for the galvanic arrangements which the earth is supposed to contain, there can be no doubt that the strata of the earth may form such combinations; but it is not at all proved that they produce a current from east to west. As far as the different currents formed by the strata, do not destroy the effect of each other, it is probable that their resultant effect lies nearly in the perpendicular; for the most general situation of the strata, is that one is placed above the other, generally with some inclination; but as this inclination may have all possible directions, the effects of the galvanic arrangements, (in so far as their action should have a horizontal direction, and thus be founded upon the inclinations,) must destroy each other, even if the inclination towards one side should be somewhat predominant; for galvanic arrangements combined in variable directions of their currents, produce a total effect much feebler than the difference of their positive and negative effects. The most efficacious excitation of electricity upon the earth appears to be produced by the sun. Its light passes round the globe from sunrise to sunrise, and produces evaporation, deoxidation and heat. Evaporation in contact with oxidable matters, produces electricity, as has already been asserted, but first exactly elucidated by the ingenious experiments of Mr. *Pouillet.* That the deoxidation which the sun produces

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during the day not only of the surface of plants, but also upon the surface of many other bodies, particularly when moistened, excites electric currents, is a well-known galvanic fact. That the heat produced by the sunbeams, and also circulating from east to west must produce an electrical current can scarcely be doubted; for though the surface of the earth be not composed of perfect conductors, and this resistance should make a common current insensible, the celerity of the circulation may, on the other hand, augment the effect to a degree sufficient for producing some effect upon the magnetic needle. Now, if it be admitted that the sun produces an electric current round the earth, this current must form a zone of considerable breadth, whose most intense part is situated in the plane of the circle, in which the sun seems to make its daily motion. Thus the situation of the most intense part of the zone varies with every day of the year. If we suppose that the earth had no other magnetism than that of this zone, a steel needle made magnetic by an artificial current, and then freely suspended, should take a direction towards the north and the south. Even a steel needle laid across the great natural current should be made magnetic, and suspended, take its direction accordingly. But the great current must also produce magnetism in the body of the earth itself; and as the magnetic effects of the inferior side of the current are opposite to those of the superior one, the magnetic poles of the earth become the opposite to those of the needle directed by the current, and should therefore, if we for a moment suppose the electric zone destroyed, still give it the same direction. Thus the earth seems to have a constant magnetic polarity, produced, in the course of time, by the electrical currents which surround it, and a variable magnetism produced immediately by the same current. As the sun does not produce an equal effect upon water as upon solid bodies, the intensity of the current cannot be equal in all parts of a parallel circle, and therefore the direction of the needle cannot be perpendicular to the equator, nor can it form everywhere the same angle with the equator, for the lines of equal electromagnetic intensity must be twice bent by the influence of the two great masses of continent. The yearly and daily change of the electromagnetic zone must occasion yearly and daily variations. As to the variations comprehended in greater periods, we might perhaps attribute them to a motion of the coolest points in each continent, which it appears

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cannot remain the same for ever, because the currents of warmer air must principally be directed towards such points; but we shall leave this research to future times, which may discover causes concealed from us, for explaining the great and secret revolution, which is continually performing in our globe.

It would be to offend against a love of truth, if we proposed these views as ascertained facts. Our researches upon the magnetism of the earth have been, during too short a time, directed by the electromagnetic discoveries, to enable us to give a complete theory of this subject. The great series of profound mathematical and philosophical investigations by which Professor *Hansteen,* at Christiania, has confirmed and improved the theory established by Dr. *Halley,* shows how many difficulties are to be surmounted. The accordance of this theory with observation, seems even to exclude the possibility of a new theory; but it must be remarked that this theory is only a mathematical representation of the phenomena, and does not pretend to be a physical one. In the same way as the mathematical laws of the celestial motions were discovered by *Kepler,* long time before their physical laws were superficially guessed by *Hooke,* or profoundly recognised and demonstrated by *Newton,* so the physical laws of the magnetism of the earth may now, perhaps, be fairly conjectured, and in a future age be brought to the requisite degree of perfection. Still we hope that these views will recommend themselves to farther investigation, as they would, if proved, have the great advantage of showing an intimate connection between an extensive series of phenomena upon the earth and those of the universe.

SOME THEORETICAL CONSIDERATIONS

Some theoretical considerations.

The question has during late years been often proposed, *whether or not magnetism and electricity are identical.* There has been a good deal of misunderstanding in the discussions on this subject. Mr. *Ampère* pretends that the discoverer of electromagnetism, though he had earlier admitted the identity of these effects has, in his first paper upon electromagnetism, denied it. We must here remark that the words have two acceptations; in one of these Professor *Oersted* is perhaps the most earnest supporter of this identity, in the other he is a no less decided opponent of it. His opinion is, that all effects are produced by one

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fundamental power, operating in different forms of action. These different forms constitute all the dissimilarities. Thus, for instance, pressure upon the mercury of the barometer, wind and sound, are only different forms of action of the same powers. It is easy to see that this fundamental identity extends to all mechanical effects. All pressures are produced by the same powers as that of air; all communications of motion, and likewise all vibrations, owe their origin to the same expansive and attractive powers, by which each body fills its space, and has its parts confined within this space. This fundamental and universal identity of mechanical powers has for a long time been more or less clearly acknowledged; but the effects which have hitherto not been reduced to mechanical principles, seemed to be derived from powers so different, that the one could scarcely be deduced from the other. The discoveries which began with galvanism, and which have principally illustrated our century, led us to see the common principles in all these actions. Two or three years before the beginning of the century, *Ritter* had, by means of the simple galvanic arrangement, pointed out and distinctly stated the principle of the electro-chemical theory; still his ideas were not generally admitted before the discovery of the Voltaic pile had struck the mind of the experimental philosophers with more palpable facts. That heat and light are produced by the union of the opposite electrical powers, had been acknowledged by the Swedish philosopher *Wilcke,* a cotemporary of *Black*, but this view was far from being generally admitted. *Winterl* brought it forward in 1800, and was supported by *Ritter* and *Oersted*. The last investigated the subject farther, and developed some of the principal laws of the generation of heat by the electrical and chemical powers.[1] He proved that the electrical powers are present in all cases where heat and light are generated. That magnetical effects can be produced by the same powers need not here be mentioned. As the chemical powers give rise to expansion and contraction, it appears that their nature is not different. Thus acknowledging the fundamental and universal identity of powers, effects must be considered as different, when their form of action differs, and therefore magnetism, in this acceptation of the term, is far from being identical with electricity. It would likewise be erroneous to pretend that all chemical effects are produced by elec-

[1] Recherches sur l'identité des forces électriques et chimiques, p. 193-233. [This vol. p. 104-146.]

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tricity; but the truth seems to be, that the chemical effects are produced by the same powers which, in another form of action, produce electricity. The name of *electro-chemical* theory, given to the modern chemical system, seems therefore less admissible than the denomination of *dynamico-chemical* theory, proposed by *Oersted* so early as 1805. It is still true that the common electro-chemical theory deserves its name, as it does not go out of the limits of an electrical view of the subject. This theory stops throughout in generalities, and gives no account of the disparities of the effects. We will not pretend that a sufficient dynamico-chemical theory has hitherto been pointed out; we must even admit that our knowledge is not ripe enough for this purpose; but we think that some laws, accounting for the disparities, have been pointed out in the work above quoted, upon the identity of electrical and chemical powers (viz. fundamental powers), and that the ideas therein explained deserved attentive examination. The dynamico-chemical theory must still remain very imperfect, until it is decided if the powers acting in magnetism, electricity, heat, light, and chemical affinities are to be ascribed to vibratory, circulating, and other internal motions or not. That these effects do not pass without the most remarkable internal motions, appears from the experiments upon light and upon electro-magnetism. The electrical current is a system of rotative motions, upon whose directions, perhaps, all the disparity of positive and negative electricity depends. It is not improbable that even magnetism involves some rotations, and thus the opinion of Mr. *Ampère* comes to agree with ours, at least in this point. When the transmission of the electrical current through liquid bodies is accompanied with a chemical decomposition, it seems necessary to admit that the substances styled electro-positives and electro-negatives, must rotate in opposite directions, and we may suppose that their neutralizing powers are connected with the propensities to those opposite rotations. The new discoveries, in short, reveal to us the world of secret motions, whose laws are probably analogous to those of the universe, and which deserve to be the subject of our most earnest meditations.