A manual of electricity, magnetism, and meteorology / By Dionysius Lardner.

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Publication/Creation

London : Printed for Longman, Brown, Green & Longmans, [1841-44]

Persistent URL

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LONDON:
Printed by A. SPOTTISWOODE,
New-Street-Square

A MANUAL of ELECTRICITY, MAGNETISM and METEOROLOGY,

by

Dionysius Lardner, D.C.L. F.R.S. &c. &c.

& CHARLES V. WALKER, SECRETARY TO THE ELECTRICAL SOCIETY.

In two Volumes

Vol. II.

Corbould del. *page 48, Vol. I.* *E. Finden sculp.*

London:

PRINTED FOR LONGMAN, BROWN, GREEN & LONGMANS, PATERNOSTER ROW;
AND JOHN TAYLOR, UPPER, GOWER STREET,
1844.

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THE

CABINET CYCLOPÆDIA.

CONDUCTED BY THE

REV. DIONYSIUS LARDNER, LL.D. F.R.S. L.&.E.
M.R.I.A. F.R.A.S. F.L.S. F.Z.S. Hon. F.C.P.S. &c. &c.

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Natural Philosophy.

A

MANUAL
OF
ELECTRICITY, MAGNETISM,
AND
METEOROLOGY.

BY DIONYSIUS LARDNER, D.C.L. F.R.S. &c.

VOL. II.

EDITED AND COMPLETED BY
CHARLES V. WALKER,
SECRETARY TO THE LONDON ELECTRICAL SOCIETY,
EDITOR OF "THE ELECTRICAL MAGAZINE," ETC.

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ADVERTISEMENT.

In presenting this volume to the public, it is only just to the publishers for me to state, that the long interval which has elapsed between the appearance of the first and the second volumes has arisen from causes over which they had no control. Circumstances having rendered it necessary for them to seek assistance to complete the volume, I was induced, at their request, to undertake it: and all that Dr. Lardner had contributed was forthwith placed in my hands.

It is unnecessary for me to state the difficulties which an author must encounter in attempting to complete a work commenced by another. I must, however, mention that, after a careful examination of the materials placed at my disposal, I have endeavoured to carry out Dr. Lardner's original design, as developed in the Introduction to Vol. I.; and shall now point out, as distinctly as I can, the nature and extent of my own contributions to the present volume.

In the early pages of the work, (a considerable portion of which was in type when I undertook its completion,) I have placed within brackets my own words, whether they be interpolations or condensed matter. I have also added extra chapters to this portion,— as Chap. XV. of Book I., On the

Electricity of Steam; Chap. VIII. and IX. of Book II., On Faraday's Researches, — and Memoranda which had not been included elsewhere; and throughout the volume I have appended many paragraphs, to supply deficiencies or to illustrate particular points. In order still further to mark the distinction between Dr. Lardner's contributions and my own, in the Table of Contents I have placed a star (*) at the head of every chapter and paragraph which are entirely his; the interpolations being, as before, indicated by brackets.

A few pages of Voltaic Electricity, comprising the first two paragraphs of Chap I., and Chap. II. to paragraph 310., are from the pen of Dr. Lardner. I used my own judgment in the continuation, adopting the arrangement and selecting the materials which were best suited to my limits; and my reason for quoting so frequently the words of other writers, instead of giving my own descriptions, is because that method allowed of my introducing smaller type, and including much matter for which I could not otherwise have found space. I have brought up the description of Voltaic Combinations to the latest improvements, including Grove's Gaseous Battery; and have done my best to collect the clearest illustrations of Electrolytic Action, and its applications. The chapter on Dry Piles is chiefly Dr. Lardner's. Magnetism is mine, and of necessity is only a sketch. I found a few wood-cuts prepared, and also the magnetic charts; and have therefore introduced them, with a view of keeping close to the original design. The commencing portion of Electro-magnetism was written; but it required so much revision and alteration to adapt it to my own views, and to the

circumstances before me, that it may almost be regarded as re-written. The latter portions of this branch, as also its kindred subjects, Magneto- and Thermo- electricity, are mine.

In conclusion, I would beg to remind the reader that this is professedly an Elementary Treatise, the chief design of which is to teach, as it were, the alphabet and the first principles of the science. When the student has made himself master of the contents of these volumes, he will find a rich store of electrical discoveries awaiting him: he will see that the science, which but a few years ago had no proper rank of itself, has now become of paramount interest; that, like the disregarded snow-flakes, it moved at first slowly and in obscurity; but now, like the mighty avalanche, it has advanced with a power and rapidity of which it originally gave no indication.

CHARLES V. WALKER.

London, Feb. 1st, 1844.

ANALYTICAL

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MANUAL

OF

ELECTRICITY, MAGNETISM,

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BOOK THE FIRST.

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CONDENSERS.

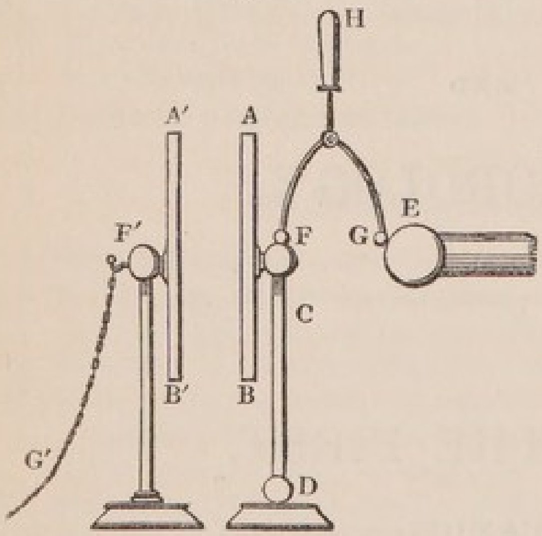
(221.) The principle of induction, in virtue of which a determinate quantity of free electricity of either kind, acting at a distance on conducting bodies, decomposes a proportionate amount of their natural electricities, and causes the fluids of the one kind and the other so decomposed to accumulate in particular directions, forms the foundation of several pieces of experimental apparatus of great importance in electrical researches, and which themselves afford striking illustrations of the play of the inductive principle, and supply further verifications of the theory which has been explained.

We shall now proceed to the description of the form, practical application, and the theoretical principles of some of the most important of these apparatus.

The Condenser.

(222.) Let A B (*fig.* 57.) be a metallic disc, supported on a glass pillar, C D, the disc being seen edgewise by an eye placed in its own plane. Let E be a conductor, feebly charged with electricity. If by the jointed discharger already described (220.) this conductor be put in metallic communication with the disc A B, the electricity of the conductor will be shared with the disc, the fluid imparted to the disc being diffused upon it in a stratum the depth of which will be determined by the conditions of electrical equilibrium. If the discharger H F G be removed, the depth of the electric fluid on the disc may be determined in the usual way by the proof plane and the electrometer; and if the discharger be restored to its position, the electrical state of the disc will remain unaltered, the fluid having previously attained a permanent state of equilibrium.

Fig. 57.



Let us suppose another disc, likewise insulated, such as A′ B′, to be placed face to face at some distance from the former. If the state of the disc A B be again examined by the proof plane, it will be found to be invested with a stratum of electricity of greater depth than before. Finally, let a metallic chain, F′ G′, form a communication between the disc A′ B′ and the ground.

If the state of the disc A B be once more examined, it will be found to be invested with a stratum of electricity of a depth still more augmented.

(223.) Such a series of phenomena is in conformity with, and might be anticipated by, a due consideration of the theoretical principles already explained. When the insulated disc A B was put in metallic communication with the conductor E in the absence of all other bodies which could produce an influence upon it, the electric fluid diffused itself over the disc in a stratum, the depth of which, at different parts of the surface of the disc, was determined solely by the conditions of equilibrium of the molecules of the free electric fluid acting on those of the natural electricities of the disc. But when the other insulated disc, A′ B′, was presented to the disc A B, the free electricity of A B decomposed a portion of the natural electricities of A′ B′, drawing the fluid of a contrary name to the face nearest to A B, and repelling the fluid of the same name to the remote face. The attraction of the fluid of a contrary name diffused upon the face of A′ B′, on the free electricity of the conductor being greater than the repulsion of the more distant fluid of the same name diffused upon the more remote face, an increased quantity of the electricity of the conductor was drawn towards the disc A B, and an increased depth of the fluid was accordingly indicated by the proof plane. But when, finally, a communication was supplied with the ground by the chain F′ G′, the electricity of the same name which was diffused on the remote side of the disc A′ B′ was allowed to escape to the earth, which it had a tendency to do in virtue of its expansive force; and the electricity of the same name diffused upon the nearer face of the disc A′ B′ exerted an undiminished force on the electricity of the conductor, and attracted an increased quantity of that fluid to the face of the disc A B. The augmented accumulation of fluid thus produced on A B causes a further decomposition of the natural electricities of A′ B′, the fluid of a contrary name being attracted to

the nearer face of the disc, and the fluid of the same name being driven away to the common reservoir, the earth; and this reciprocation of effects must continue until equilibrium is established between the fluids on the two discs. The effects, however, which have been here described as being produced in succession, are, in fact, accomplished in an instant; the time necessary to bring the fluids to a state of equilibrium being inappreciable.

(224.) Such being the principles on which these effects are explained, it will be apparent that the augmented accumulation of electricity caused by the presence of the disc A′ B′ must be dependent, other things being the same, on the proximity of that disc. If A′ B′ be brought nearer to A B, the effect of the decomposed electricity upon it, in drawing the electricity from the conductor to the disc A B, will be augmented, and a proportionately greater depth of fluid will be collected on that disc. This admits of easy experimental verification; for, if the test of the proof plane and the electrometer be applied to the disc A′ B′, at a gradually diminished distance from A B, the latter will be found to be charged with electricity of gradually increasing depth; and, in all cases, the depth of electricity upon it will be much greater than on the conductor E, from which the electricity is derived.

If the electricity thus accumulated on A B be relieved from the influence of the disc A′ B′ by removing the latter from its neighbourhood, being no longer under the attraction which brought it there, it will by virtue of its expansive power return by the rod of the discharger to the conductor E, and so much only will remain on the disc A B as that disc would have received from the conductor being put into metallic communication with it in the absence of the disc A′ B′.

(225.) But if it be desired to retain upon the disc A B the great accumulation of fluid brought upon it by the proximity of A′ B′, it is only necessary before removing A′ B′ to break the communication between the

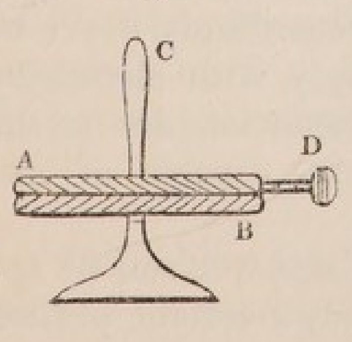
disc A B and the conductor E, by withdrawing the discharger. The removal of the disc A′ B′ will then produce no diminution of the absolute quantity of the electricity upon the disc A B, but will merely permit the fluid to be diffused upon it according to the conditions determined by its own form, independently of the influence of the other disc.

(226.) These effects have suggested the construction of the instrument called the CONDENSER, which, in the estimation of quantities of electricity, may be regarded as analogous to the microscope in the examination of visible objects. If, by approaching the disc A′ B′ to A B, the fluid can be collected on the latter in a stratum fifty times more deep than on the conductor from which that fluid is drawn, then an electroscope capable of determining the presence and quantity of the fluid accumulated on A B would, by inference, become an indicator of the presence of electricity fifty times more attenuated on the surface of the conductor E. By such means it is evident that the sensibility of the electroscope would be multiplied in the same proportion as the depth of the fluid on A B is greater than the depth of the fluid on E.

(227.) Such are the principles on which the condenser is formed; an instrument which stands in the same relation to the electroscope as the compound microscope holds to the micrometer screw and vernier in astronomical instruments.

(228.) The condenser consists of two metallic discs, A and B (*fig.* 58.), placed face to face, having their surfaces separated, not merely by a body of air, as in the preceding illustration, but by a thin coating of nonconducting resinous varnish applied to the faces of the discs. The superior disc A has an insulating handle of glass, C, by which it may be raised and removed from the inferior disc B. From its edge

Fig. 58.



there projects a short wire, terminated in a knob, D, by which it may be put into communication with an electrified conductor, such as E, *fig.* 57., or any other source of electricity. The inferior plate B is a similar metallic disc, supported on a strong metallic stand, E.

(229.) If by this instrument it be desired to ascertain the presence of electricity on any body, it is only necessary to put the knob D into contact with that body, or to carry a chain, or place the legs of a discharger, or, in short, to establish any metallic communication between D and the electrified body. The electricity will flow through D to the plate A, which is called the *collecting plate:* the inferior disc B, called the *condensing plate*, being in free communication with the ground, will, in this case, play the part of the disc A′ B′, *fig.* 57.; and, in consequence of its extreme proximity to the disc A, the depth of electricity accumulated on the latter will be proportionally great. The electricity of the collecting plate A cannot pass to the condensing plate B, being intercepted by the coating of nonconducting varnish with which both discs are covered. If, however, the depth of the fluid of one kind on A, and the nearly equal depth of fluid of the opposite kind on B, be so great as by their reciprocal attraction to overcome the resistance offered by the varnish, they will force their way through it, and their combination will take place, attended by an explosion. This effect would take place even at a greater distance, if the plates, instead of being separated by varnish, were only separated by the intervening stratum of air. As it is an effect which in any case defeats the object which the instrument is intended to attain, it should be avoided, and the condenser should accordingly never be applied to bodies charged so strongly with electricity that when it is multiplied in the proportion due to the power of the condenser it will be capable of explosion.

(230.) From what has been explained, it will be apparent, when a conductor is charged, a certain portion

of the electricity accumulated on the collecting plate is retained there solely by the influence of the decomposed electricity collected on the condensing plate. This portion, being thus retained there, would not be capable of passing away through any conductor which might be presented to it; but if the condensing plate were removed, and it were liberated from the attraction of the opposite electricity, then it would pass away by means of any conductor which might be presented to it. Electricity thus retained on a conductor by the attraction of electricity of the opposite kind in its neighbourhood, so that it cannot escape by conductors, is called *dissimulated* or *latent* electricity.

(231.) The whole charge of the collecting plate is, however, not thus dissimulated. That portion of fluid which it originally received by communication with the electrified conductor still remains free, and this portion may accordingly be drawn away by any conductor put in communication with the collecting plate. Since, however, no electricity is originally imparted to the condensing plate, and its whole charge is due to the attraction of the electricity of the collecting plate, this charge will be retained undiminished on the condensing plate by that attraction, and it will be therefore altogether dissimulated or latent electricity. These effects may be reduced to exact calculation, and may also be rendered manifest by experimental illustration.

Let the quantity of electricity which the disc A B (*fig.* 57.) receives from the conductor by the mere communication of the discharging rod, and in the absence of the disc A′ B′, be expressed by E; and let the additional fluid accumulated upon it by the influence of A′ B′, when brought within a given distance of it, be expressed by E′. If its entire charge be expressed by Z, we shall then have

$$Z = E + E' \ldots . [1.]$$

(232.) Now this quantity of fluid Z, by the attraction which it exerts, retains the whole of the opposite fluid on the

[other disc. Now, as this quantity bears some determinate numerical proportion to Z, let m express the ratio; and we have m Z for the quantity of disguised electricity on the *condensing* plate. As this quantity reacts on the electricity of A B, disguising it according to the same ratio, we have, for the disguised electricity of the *collecting* plate $m \text{Z} \times m$, i. e.

$$\text{E}' = m^2\text{Z} \ldots . [2.]$$

(233.) Whence the formula [1.], expressing the whole charge of A B, may be converted into

$$\text{Z} = \text{E} + m^2\text{Z} \ldots . [3.]$$

in which equation m must always be less than unity, because E is always a positive quantity.]

(234.) The POWER of the condenser is measured by the proportion which the total augmented charge of the collecting plate, under the influence of the condensing plate, bears to the charge which it would receive from the electrified conductor by mere communication without such influence; that is, by the proportion of Z to E in the preceding formulæ. This proportion may be derived directly from the equation [3.],

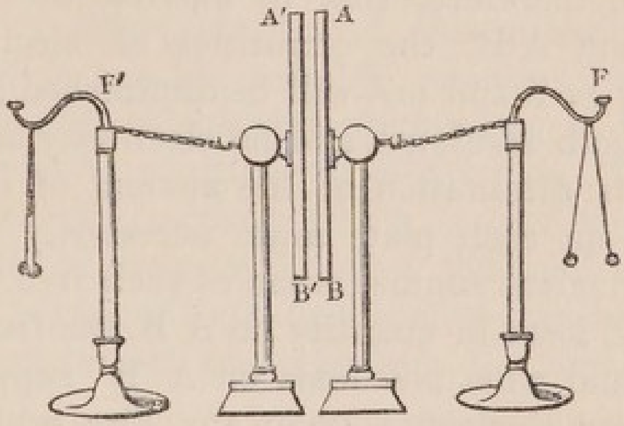
$$\frac{\text{Z}}{\text{E}} = \frac{1}{1 - m^2} \ldots . [4.];$$

which therefore expresses the condensing power of the instrument.

It is evident from the formula [4.] that the more nearly m is equal to 1, the greater will be the condensing power; and as m would become actually equal to 1 if no separating medium whatever were interposed between the plates, it follows that the thinner the varnish or other medium separating the plates is, the greater will be the power of the instrument. This result of the formula is therefore in accordance with what was previously inferred by other reasoning.

(235.) The circumstances attending the free and dissimulated portions of electricity in the condenser may be illustrated experimentally in the following manner:— Let A B (*fig.* 59.) be a metallic disc, on an insulating

Fig. 59.



stand, representing the collecting plate of a condenser; and let us suppose it to have received from an electrified conductor, under the influence of the disc A′ B′, the total augmented charge Z, as explained in the preceding observations; and let it be also supposed that when the disc A′ B′ has been charged by the attraction of Z with the quantity of the opposite electricity expressed by mZ, both discs are insulated, the disc A B having its communication with the electrified conductor removed, and the communication of the other disc, A′ B′, with the earth being withdrawn; we shall thus have the free and dissimulated electricities distributed on the two discs in the following manner:—

On AB - -	free - -	E,
	dissimulated	m^2Z.
On A′B′ - -	free - -	none,
	dissimulated	mZ.

Let F and F′ be two pairs of pith balls suspended by conducting threads and supported on insulating pillars, and let them be connected by chains or conducting wires with the discs A B and A′ B′ respectively. Any free electricity on either disc would pass to the pith

balls and be indicated by their divergence. It will be accordingly found that the pith balls F will diverge, while the pith balls F′ will exhibit no divergence.

(236.) It has been shown that the number expressed by m diminishes by the increased distance of the plates. It follows, therefore, that by moving the plate A′ B′ farther from A B, the quantities of electricities expressed by m^2Z and mZ will be diminished; but as the discs are both insulated, and no electricity can therefore escape, this diminution of the amount of dissimulated electricity on each plate must necessarily be attended by an equivalent augmentation of their free electricities. What m^2Z loses in quantity on A B, the free electricity E gains, and what mZ loses on A′ B′ supplies a portion of free electricity upon the disc which did not exist before. The results of experiment are in conformity with this. As A′ B′ is removed from A B, the increase of free electricity on the latter is indicated by the increased divergence of the pith balls F; and the production of free electricity on A′ B′, which did not previously exist upon it, is shown by the divergence of the pith balls F′.

(237.) Let us now suppose the disc A′ B′ to be restored to its primitive position: the balls F′ will collapse, showing that all the electricity on A′ B′ is again dissimulated; and the balls F will resume their primitive divergence, showing that the free electricity on A B is restored to its primitive amount. Let the disc A B communicate with the earth by a chain or other conducting body: the free electricity upon it will instantly pass away, and the pith balls F will collapse. The dissimulated electricity alone will remain upon it, being retained there by the attraction of the contrary electricity on A′ B′. But another effect will be produced which might not at first have been anticipated. The moment the communication between A B and the ground is made and the pith balls F collapse, a simultaneous divergence of the pith balls F′ will take place, indicating that some portion of the electricity of A′ B′,

previously dissimulated, has been set free. This effect is easily explained.

(238.) The moment that a conducting communication with the ground has been made, the free electricity E departs from the disc A B, and the dissimulated electricity m^2Z alone remains upon it. In conformity with what has been already explained, this quantity m^2Z of fluid on A B is capable only of retaining by its attraction a quantity of the opposite fluid on A′ B′, which would be found by multiplying m^2Z by m. The quantity, therefore, of electricity which is now dissimulated on A′ B′ can be only m^3Z. But the total electricity on that disc being still mZ (since none has escaped), a quantity must be set free equal to the excess of mZ above m^3Z.

[Hence there will be

On A B - -	free - -	none,
	dissimulated	m^2Z.
On A′ B′ - -	free - -	$mZ - m^3Z = mZ(1-m^2)$,
	dissimulated	m^3Z.

By continuing this process, throwing the discs alternately into communication with the ground, a portion of free electricity will escape to the earth from one disc, and a corresponding portion of dissimulated electricity will be set free upon the other disc. The portions of fluid thus dismissed to the earth and liberated upon the discs respectively in the successive stages of the process may then be expressed as follows: —

	Liberated on the discs.	Dismissed to the ground.
I. -	$mZ(1-m^2)$ - -	E
II. -	$m^2Z(1-m^2)$ - -	$mZ(1-m^2)$
III. -	$m^3Z(1-m^2)$ - -	$m^2Z(1-m^2)$
IV. -	$m^4Z(1-m^2)$ - -	$m^3Z(1-m^2)$
V. -	$m^5Z(1-m^2)$ - -	$m^4Z(1-m^2)$.

If the infinite series in the second column be summed up, we obtain, as the result, $E + m^2Z + mZ.$; of which] it will be remembered $E + m^2Z$ was the ori-

ginal charge of the plate A B, and m Z that of the plate A′ B′.

(239.) The value of m, on which the power of the condenser depends, must be determined by experiment in each particular case. To ascertain it, it is only necessary, after charging the condenser in the usual way, to insulate the plates and ascertain the depth of electricity upon them respectively by means of the proof plane and the electrometer. The angle of torsion corresponding to the collecting plate will represent Z, and that which corresponds to the condensing plate will represent mZ, and the latter divided by the former will give the value of m.

(240.) The absolute amount of electricity accumulated on a condenser depends not only on the value of m, but also on the value of E, which expresses the charge of electricity which the collecting plate would receive, independently of the influence of the condensing plate. Other things being the same, this quantity will increase with the magnitude of the plates. Condensers of great diameter, therefore, will collect a greater charge of electricity than smaller ones.

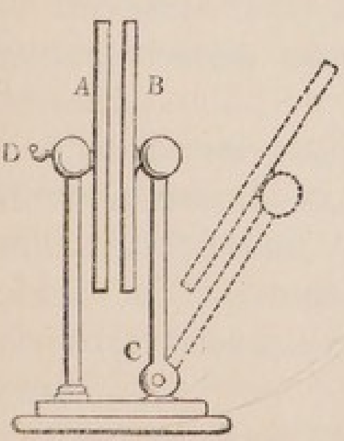
(241.) Instead of separating the discs of a condenser by a varnish of gum lac, a plate of glass is sometimes interposed between them. This is convenient when the instrument is applied to strong charges of electricity, which might force their way by explosion through the varnish; but an inconvenience attends the use of glass, inasmuch as a great portion of the electricity accumulated on the collecting plate attaches itself to the glass when the collecting plate is withdrawn. The plates of the condenser have therefore, under such circumstances, no other effect than to establish a free communication for the electricity between different points upon the surface of the glass, so that when discharged the whole fluid may escape at once. This is easily verified experimentally. After having charged such a condenser, raise the collecting plate from it; and then, taking the glass by the corner or edge, raise it from the inferior

plate. Let the two plates of the condenser be then examined, and they will be found to be charged with an inconsiderable portion of electricity. If the plate of glass be replaced between them, the condenser will be found to be charged almost as strongly as before. The electricity, therefore, remained upon the surface of the glass when removed from between thé plates; which may be further demonstrated by examining the glass in the absence of the plates with the proof plane and the electrometer.

(242.) Æpinus, to whom the invention of the condenser is due, constructed the first instrument of that kind with two large circular discs of wood coated with tin foil. He used no intervening nonconducting medium, except the air which filled the space between them. He put the superior disc in communication with the conductor of an electrical machine, and the inferior disc in communication with the ground. As the discs could not be brought very near each other, lest the electricity should pass from the one to the other through the air, the necessary condensing power was obtained by enlarging the discs. (Int. 81.)

(243.) Condensers have been constructed in various forms. A very convenient and useful form of this instrument is represented in *fig.* 60. Cuthbertson's condenser consists of the collecting plate A, which is a circular disc firmly supported on a glass pillar. The condensing plate B rests upon a pillar of brass or some other conductor, and is jointed at C so that it may fall back into the position represented by the dotted lines. If the collecting plate A be made to communicate by the hook D with any feeble source of electricity, the presence of the plate B, which communicates with the

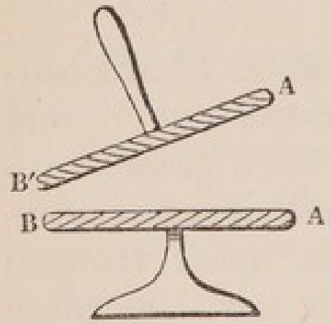
Fig. 60.



ground will have the usual effect of accumulating on A an increased quantity of electricity.

(244.) In the practical application of the condenser it is necessary, in separating the plates when charged, to move them at first parallel to themselves or nearly so, in order to avoid their assuming an oblique position to each other, such as that represented in *fig.* 61., for in that case the edges B′ and B being nearer to each other than A and A the electricity would accumulate in such increased depths at B and B′ that there would be a liability to its escaping by explosion, and the instrument being discharged; for this reason, the pillars which sustain the discs in the condenser, represented in *fig.* 60., should have such a height that when the jointed pillar is bent in turning it from the collecting plate A no effect of this kind shall be produced.

Fig. 61.



CHAP. XI.

ELECTROSCOPIC INSTRUMENTS.

(245.) In the investigation of the part which electricity plays on the theatre of nature, there is no inquiry which is more frequently presented to the experimental philosopher than the determination of the electric state of bodies when the free electricity with which they are charged, if they be so charged at all, is of extremely feeble tension. A class of instruments has been contrived, therefore, capable of detecting the presence and determining the species of electricity with which the different forms of matter may be charged.

Such instruments may be resolved into two classes: the *first* consisting of those by which the presence of electricity may be detected, but which are incapable of determining its quantity or energy with any useful degree of accuracy; the *second* consisting of those which are not only capable of indicating the presence of electricity, but by which its quantity or energy may be submitted to admeasurement with more or less accuracy, so that the electrical state of different electrified bodies, or of the same body at different times and under different circumstances, may be compared and numerically expressed.

The former class we shall call *electroscopes*, and the latter *electrometers*. These terms have been very generally confounded, being indifferently applied to both classes of instruments. There is, however, an evident propriety and convenience in the distinction here proposed.

Electroscopes in general consist of two light conducting bodies freely suspended, to which electricity is

imparted by the body whose electric state is under examination, and which, when thus electrified, will repel each other, the lines of suspension which were before parallel becoming divergent, the angle of their divergence being greater or less according to the intensity of the electricity imparted to them. These electroscopic bodies may be electrified either by direct communication with the electrified body, in which case their electricity will be of the same kind as that of the body under examination; or they may be acted upon inductively by the body under examination, in which case their electricity may be either similar to or different from that of the body, according to the relative position of the electroscopic bodies and the body to be examined. In some cases a single light body is suspended, to which electricity of a known species is imparted. The body to be examined, or a body electrified by it, being presented to this, attracts or repels it, according to the kind of electricity with which it is charged.

Such are in general the principles on which electroscopes are constructed. These instruments, however, vary in form, and in their mode of application, according to the purposes to which it is intended to apply them; and they possess various degrees of sensibility, according to the intensities of the electricities of which they are expected to detect the presence. In electroscopes, as in all other instruments, the most delicate and sensitive is not the most advantageous, except in cases where its delicacy and precision are required: the edge of a razor would be an ineffectual instrument for the felling of timber.

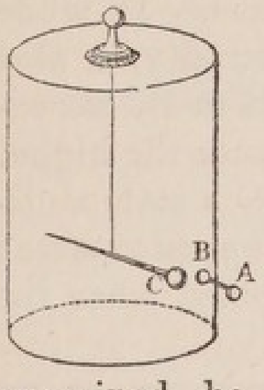
The most simple species of electroscope is the apparatus already described, consisting of a pith ball suspended by a silken thread, which may be designated the *pith-ball electroscope*. To give this instrument the greatest possible sensibility, the thread should be a single fibre of raw silk, as it is taken from the cocoon; the ball should be so small that its weight should not exceed a

small fraction of a grain, and should be accurately turned, in the spherical form, from the pith of elder.

Coulomb's Electroscope.

(246.) When Coulomb's electrometer is merely applied to the detection of the presence of electricity on bodies without reference to any very accurate measure of its intensity, it is usually constructed in form represented in *fig.* 62. A small disc of gilt paper, C, is attached to the end of the needle of gum lac, which is suspended in the manner explained in (56.). In the side of the cylindrical case of the instrument a wire is fixed, having gilt balls, A and B, attached to its extremities, the internal ball, B, corresponding in its position to the circle through which the disc C plays. If the disc C be brought into contact with B, and the body whose electricity is to be examined be placed in contact with A, the disc C being electrified similarly to B will be repelled, and the angle of torsion will indicate the force of repulsion.

Fig. 62.



Or if the disc be previously electrified with electricity of a known species, suppose for example with positive electricity, and be placed at a distance from B; then, on placing the body to be examined in contact with A, the disc C will be repelled if the electricity of the body be positive, and attracted if it be negative.

After each experiment the balls A and B and the disc C may be discharged, by bringing C into contact with B and touching A with the finger.

In the use of this instrument various effects are occasionally observed, which, unless attended to and rightly understood, might lead to erroneous inferences. Suppose that the disc being brought into contact with B, the body to be examined being charged with positive electricity is presented to A without touching it. Its

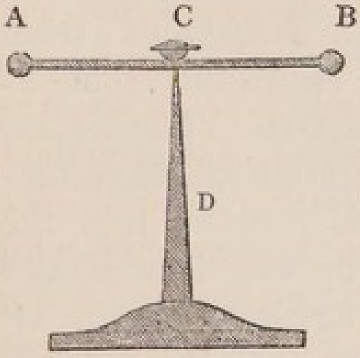
[inductive action will immediately produce in B a positive charge, although no actual charge passed; which will be shared with C, and repulsion will occur. If the exciting body be removed, the system A B, having lost that portion of its natural charge, which it imparted to C when under induction, being now negative, will attract C, which is positive; and on C and B again coming in contact, equilibrium will be restored. If the system A B, when under induction, be connected with the earth, the induced free electricity will escape; and on moving *first* the connection, and then the exciting cause, A B and C will be all negative, and repulsion will ensue. Thus can a charge of either kind of electricity be given by the same exciting means. If, while C has a *low* charge of one kind of electricity, a *high* charge of the same kind be communicated to B, *attraction* will occur, instead of *repulsion*, because the higher charge will induce in the *remote* side of C a state similar to its own, and in the *near* side the opposite state; and the two contiguous sides will be attracted when the *high* charge of B will be shared with C.]

[An extemporaneous Coulomb's Electroscope, as we see it on Dr. Faraday's lecture-table, is a very useful instrument of illustration. Two wooden stems, about two feet long, sustain a cross piece, from which, by a silk fibre, is suspended a thin rod of light wood varnished, being perhaps six or eight inches long, and having at one end a disc of gold-leaf. A *proof-plane*, that is, a piece of gilt paper is fixed on a rod of shell-lac, and is used to convey a charge to the gold-leaf; and then to take other charges from other bodies, in order to test their character by their attraction or repulsion of the previously electrized gold-leaf. A still more extemporaneous electroscope is a tobacco-pipe balanced on any body exposing a curved surface, as the case or glass of a watch; a stick of sealing-wax, rubbed on the coat sleeve, will drive the pipe entirely round.]

Gilbert's Needle Electroscope.

(247.) When great sensibility is not required, Gilbert's needle electroscope, one of the most simple and the oldest of this class of instruments, may be used. Pith balls, about $\frac{2}{10}$ths of an inch in diameter, are attached to the extremities of a fine metallic needle, A B (*fig.* 64.), supported at the centre, C, on an agate cap, which rests upon the point of a vertical rod, D, supported by a circular stand. The vertex of the hollow cone formed in the agate cap should be a little above the centre of gravity of the needle and cap, that it may have sufficient stability when resting on its support. A small slider on one of the arms of the needle may be added to the apparatus, by the adjustment of which the needle may be balanced on the point, so as to maintain its horizontal position. The agate cap, being a nonconductor of electricity, serves to insulate the needle; but this object may be further secured by placing the stand on a plate of gum lac, or other nonconducting material. There is a further provision against the escape of electricity; for if we suppose the cap to be made of metal instead of agate, and consider that the pointed metallic support, D, has a tendency to draw off the electricity, yet from the great length of the needle compared with its diameter the electricity upon it will have a tendency to accumulate at its extremities, and the inner part of the cap in contact with the point of the support D being a cavity within the general mass of the needle, the electricity diffused over the surface of the needle will not enter it in any sensible quantity.

Fig. 64.



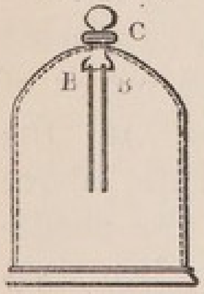
If an electrified body be presented to either of the balls A or B, an attraction will take place, and the free motion of the needle on its pivot will bring the ball into contact with it. The ball being thus electrified,

and the contact broken, will be repelled by any body similarly electrified, or attracted by any body charged with electricity of the contrary kind which may be presented to it.

Volta's Straw Electroscope.

(248.) This electroscope consists of two blades of straw (*fig.* 65.) of equal length suspended from two hooks B B, beside each other, and as nearly as possible in contact. The hooks, which are of wire, are attached to a metallic ball C, which is inserted into the top of a glass receiver, by which the straws are protected from the agitation of the air or any other cause which would derange them. If an electrified body be brought into contact with ball C, the electricity will pass by means of the wire hooks to the straws, which being thus similarly electrified will repel each other. The extent of their divergence will be more or less according to the quantity of electricity imparted to them.

Fig. 65.



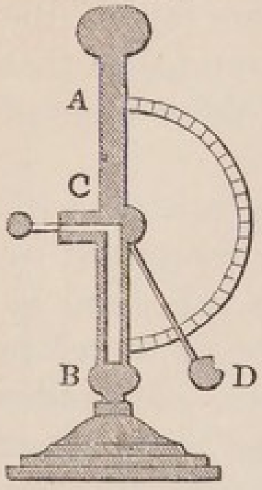
The straw electroscope, though much used by foreign electricians, has been but little adopted in England as a measure of the actual intensity of electricity: it is an extremely imperfect instrument, but as an electroscope merely in the proper sense of the term, it is susceptible of a high sensibility, and not so liable to derangement and injury as the gold leaf electroscopes.

Henley's Quadrant Electrometer.

(249.) This electrometer, which is generally used as an indicator on the conductors of electrical machines, consists of an upright rod A B (*fig.* 66.) of any conducting substance of about seven inches in length, terminated at the lower extremity by a ball B; another light rod about four inches long, terminated by a small

pith ball D, plays on a centre C, and moves round that centre in a vertical plane. Behind it is placed an ivory semicircle, the centre of which coincides with the centre on which the rod C D moves. This semicircle is graduated to show the angle formed by the rod C D with the vertical rod A B. When the instrument is not electrified, the rod C D hangs in the vertical position, the small pith ball D being in contact with the ball B. The moment the apparatus is electrified the ball D is repelled by the ball B, and rises along the semicircle, the angle formed by C D with the vertical rod being greater or less according to the force of repulsion.

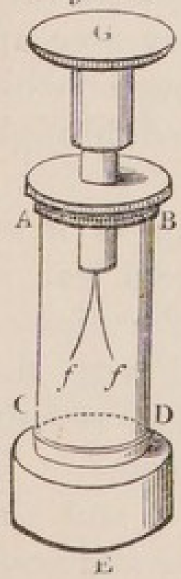
Fig. 66.



Bennett's Gold Leaf Electroscope.

(250.) This instrument, in the form in which it is now most generally used, is represented in *fig.* 67. This apparatus consists of a glass cylinder A B C D, cemented into a brass stand E, and closed at the top by a circular plate A B. The brass cap G of the instrument is attached at the bottom to a glass tube, which passes through the centre of the plate A B, into which it is cemented. To the centre of the lower surface of the cap G a wire is attached, which is carried through the glass tube, terminating in the upper part of the cylinder A B C D. To the lower end of this wire are fixed two small slips of gold leaf, half an inch in width, and from two to three inches in length. These hang from the wire in contact with each other. On the inside surface of the glass cylinder, and on opposite sides of it, two slips of tin foil are pasted, extending from the

Fig. 67.



upper surface of the brass stand E, which supports the cylinder, to a height a little above the lower extremities of the slips of gold leaf. The cap of the instrument G is capable of being turned round, so that the slips of gold leaf shall be parallel to these slips of tin foil.

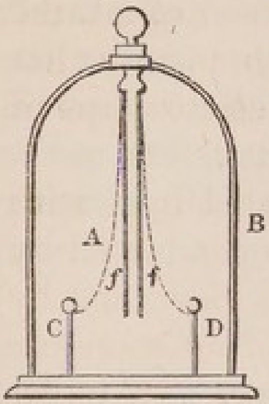
If an electrified body be brought into contact with the metallic cap G, its electricity will be conducted by the cap to the wire inclosed in the glass tube, and by the wire to the slips of gold leaf, which being therefore similarly electrified, will repel each other. If, under these circumstances, the slips of gold leaf, after their separation, touch the inner surface of the glass cylinder, they would deposit upon it a portion of the electricity with which they are charged; and this electricity, after repeated experiments, would be accumulated on the glass, where, by reason of the nonconducting property of the glass, it would remain, and, by its attraction or repulsion, would interfere with and disturb the indications of the instrument. This is prevented by the introduction of the two slips of tin foil above mentioned. When the slips of gold leaf repel each other and separate, their extremities respectively are brought into contact with the slips of tin foil, to which they give up their electricity; and the tin foil being in contact with the brass stand D, this electricity is transmitted through it to the earth.

When the electricity imparted to the cap G is so feeble that the divergence of the slips of gold leaf is insufficient to bring them into contact with the slips of tin foil, they would continue to be charged with the electricity thus imparted to them, and would remain divergent after the experiment has been completed. In such cases, the apparatus may be discharged, and the slips of gold leaf restored to their natural state and position, by touching with the finger the cap G, as by such means the electricity will be conducted by the finger to the body, and by the body to the earth.

The gold leaf electroscope is sometimes constructed

in the form represented in *fig.* 68., where G is a knob

Fig. 68.

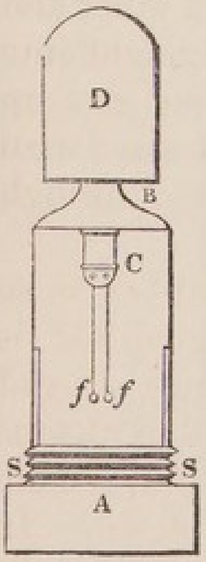


of metal inserted in the top of a glass receiver A B, having a wire proceeding from its lowest point by which the slips of gold leaf *f f* are supported. Instead of slips of tin foil, two small metallic balls C D, supported on the stand D by metallic rods, are so placed that when the slips of gold leaf diverge they shall touch them and be discharged. Mr. Nicholson proposed to substitute for the two slips of tin foil two thin plates of brass capable of being moved and adjusted by screws, so that they might be brought as near the two slips of gold leaf as might be desired.

Cavallo's Atmospheric Electroscope.

(251.) This instrument was intended to be employed

Fig. 69.



in meteorological inquiries, when the electricity of the atmosphere was to be examined. A wooden stand is represented at A (*fig.* 69.), to which a case covering and protecting the whole instrument when not in use may be fixed by a screw S. The glass cylinder, similar to that used in the gold leaf electroscope, is attached to the stand S S, and is provided with slips of tin foil, like those already described. The glass cylinder at the top is formed like the neck of a bottle, and terminates in a tube B. Into this tube B a smaller tube of glass is inserted, the lower part of which descends into the cylinder, and is seen at C.

Through this latter tube a wire passes, which supports a small metallic plate at C, which supports two fine silver wires, by which two small pith balls, *f f*, are suspended. These balls, when electrified, act in the

same manner as the slips of gold leaf in Bennett's electroscope. The central wire passing through the small glass tube B is attached above to the interior of a metal cap D, placed over the cylinder, which protects the upper part of the tube B when the electroscope is exposed to rain. The penetration of moisture to the interior of the apparatus is further prevented by coating the cylinder with wax or varnish.

Cavallo's Portable Electroscope.

(252.) This instrument, represented in *fig.* 71., consists of a small glass tube A B, $\frac{3}{8}$ths of an inch in diameter, and $3\frac{1}{2}$ inches in length; C is a cork inserted in the lower end of the tube, so formed that either end of it may enter the tube. To this cork are attached two silver wires, bearing at their extremities delicate cones of cork or pith. In *fig.* 70. the wires are seen deposited in the glass tube as in a case, the instrument not being in use. In *fig.* 71. the cork is reversed, and the wires

Fig. 70.

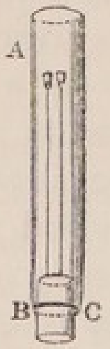


Fig. 71.

Fig. 72.

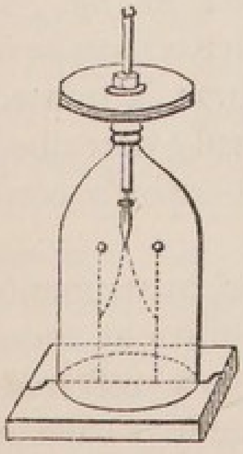
presented downwards, the cones being represented as when similarly electrified. The glass tube forms a handle for the instrument, and is varnished throughout

its lower half. A wooden case opening at one end by a screw is represented in *fig.* 72., in which the glass tube is inclosed when not in use. At one end, B, this case is covered with a piece of smooth amber, by the friction of which negative electricity is produced; and at the other end is an ivory knob, insulated by a rim of amber, for the production of vitreous electricity by rubbing the ivory with a woollen cloth.

Condensing Electroscopes.

(253.) The combination of the condenser with the electroscope has vastly augmented the power and extended the usefulness of that instrument. Among the phenomena which present themselves in electrical researches, it frequently happens that electricity is presented so extremely attenuated and feeble that even the electrometer of Coulomb in the highest state of its sensibility is incapable of affording any indication of it. In such cases, the electricity may be accumulated in a depth so highly augmented by means of the condenser that it will affect the leaves of the electroscope. For this purpose, electroscopes have a provision by which a condenser can be attached to them. An electroscope, with such an appendage, is represented in *fig.* 73. The condenser is screwed on the top of the instrument; the lower plate communicating with the leaves of the electroscope, while the upper plate rests upon it. It is usual to use the lower as the collecting plate, and therefore to put it in communication with the source of electricity which is to be examined, and consequently to put the upper or condensing plate in communication with the ground. When the lower plate has been charged, no influence will be produced on the electroscope while the upper plate is held in con-

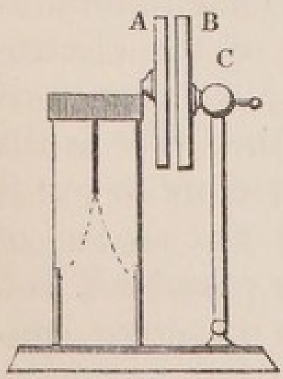
Fig. 73.



tact with it, since the electricity on the lower plate is dissimulated by the influence of the upper plate. But when the upper plate has been removed by raising it by its insulating handle (the communication of the lower plate with the source of electricity being previously broken to prevent the escape of the electricity drawn to the lower plate by the influence of the upper), the leaves of the instrument will diverge by the effect of the electricity thus collected and set free. If it be desired to determine the *kind* of electricity with which it is charged, this may be done by presenting to the cover of the electroscope, or to the lower plate of the condenser, a rod of glass charged with positive electricity. This, by its influence, would cause the leaves to diverge with positive electricity. If then its approach increases their divergence, their electricity must be positive; and if it have a contrary effect, it is negative.

It is sometimes more convenient to use the superior plate of the condenser as the collecting plate. In that case, the lower plate must be put in communication with the ground; and this communication must be broken before the removal of the superior plate. It is evident that the electricity with which the instrument will be charged under such circumstances will be of a different kind from that which is to be examined, and by which the upper plate is charged.

Fig. 74.

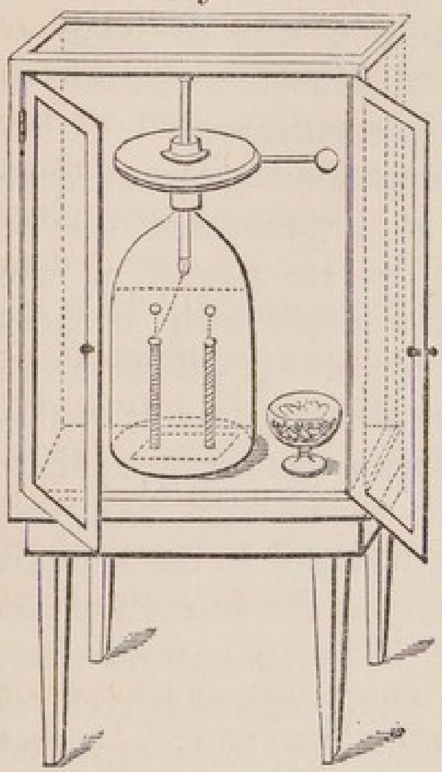


(254.) The usual form given to Bennett's condensing gold-leaf electroscope is represented in *fig.* 74. The plates of the condenser are here vertical; and one of them is jointed at the bottom, as already described in the case of Cuthbertson's condenser.

(255.) In the use of instruments of such extreme sensibility as those to which we have now referred, many precautions are necessary to guard against various causes which would disturb and interfere with their

indications, and expose the observer to error. The plates of the condenser in some experiments may be exposed to chemical action, which, as will be hereafter explained, is attended with a greater or less evolution of electricity. In such cases, discs of copper gilt are preferable to brass. Glass plates, coated with gold leaf, are also resorted to with advantage, when the chemical effect of liquids on the metal is to be guarded against. Sometimes it is desirable to inclose the instrument in a glass case, as represented in *fig.* 75. To preserve its glass cover from hygrometric effects, a cup of quick lime is placed in the case to absorb the humidity.

Fig. 75.



(256.) The plates of the condensers used for such purposes vary from four to ten inches in diameter. When to augment their power enlarged dimensions are given to them, it is difficult to make them with such precision as to insure the exact contact of their surfaces; and to prevent large plates from suffering change of figure it is necessary to give them considerable thickness, which renders them heavy and unmanageable. Becquérel states, that he used two plates of glass twenty inches in diameter, the faces of which were accurately ground together with emery, and coated with very thin tin foil. He found the manipulation of these so inconvenient that he suspended the superior plate by a pulley, and sustained it by a counterpoise. This apparatus had great sensibility; but as the metal with which it was coated was very oxidable, the results of his experiments were so compounded with the chemical effects that it was not always possible to render them useful.

A coating of platinum would have removed this inconvenience.

To the inferior plate of the condenser a rod of brass should be screwed, terminated in a ring or hook, to which metallic cups or other small objects necessary in experiments might be attached or suspended.

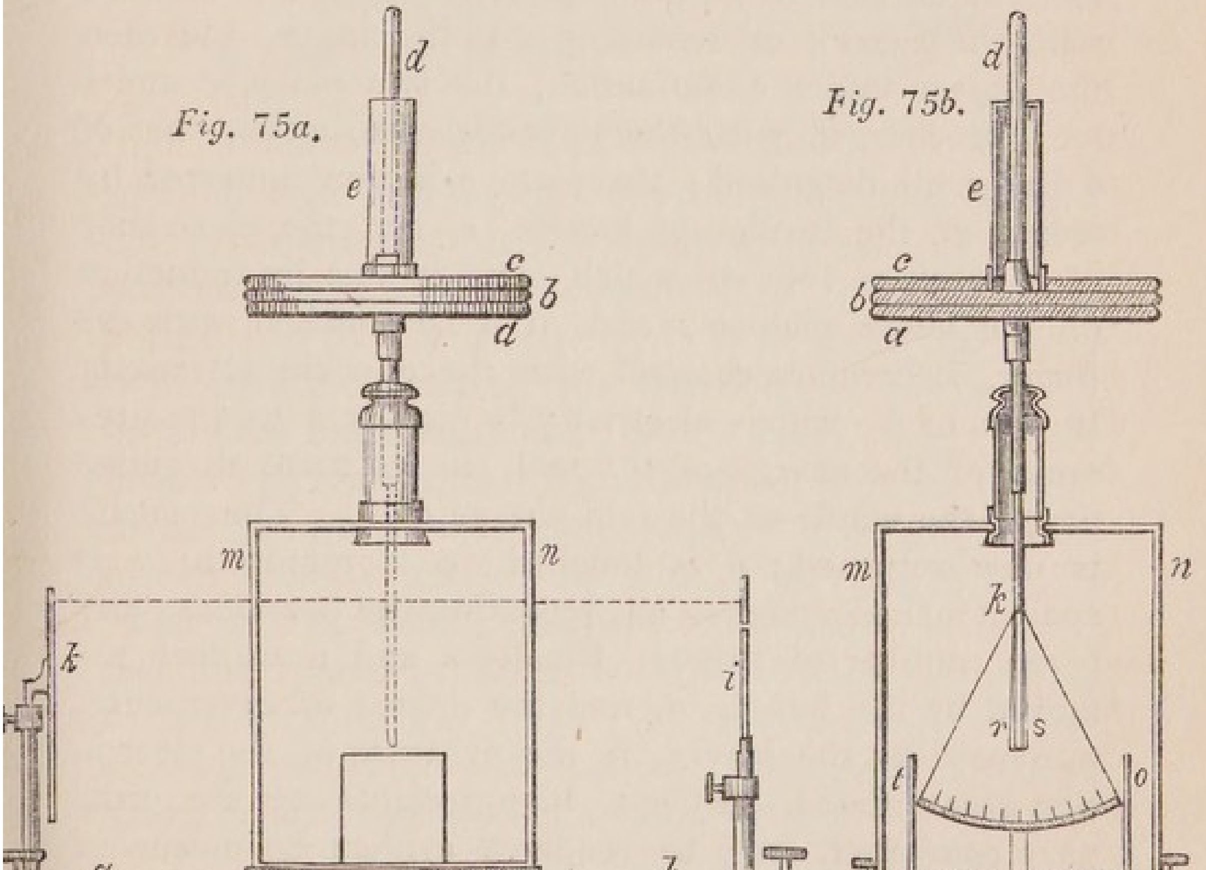
(257.) The sensibility of the condensing electroscope has been greatly augmented by an improvement due to M. Bohenberger.* Two dry piles are placed on the base of the instrument, so that a single strip of gold leaf may be suspended between them. It will be hereafter shown that these piles have the property of maintaining a permanent charge of feeble electricity at their summits; and in this case they are so arranged that positive electricity shall always be developed at the summit of the one, and negative electricity at the summit of the other. So long as the gold leaf is in its natural state, it is not affected by these; but the moment it receives from the condenser a feeble electricity, it is attracted by the pile which developes electricity of the opposite kind, and repelled by that which is charged with electricity of the same kind. This instrument has such sensibility that in dry weather, when the piles are in good action, a stick of gum lac rubbed with a cloth will produce a sensible effect on the gold leaf at a distance of eight or ten feet. This apparatus is represented in *fig.* 75.

It has been objected against this apparatus, that its indications are so irregular, by reason of its extreme sensibility, that it is rendered nearly useless. This may, in a great degree, be remedied by using for the condenser plates of copper gilt, since the chief source of irregularity arises from the chemical action of the metal on the moisture that adheres to the fingers. In all cases, the effects of the electricity of the hands or hair of the operator, acting by induction on the instrument, are to be guarded against.

* See Bibl. Univ., Nov. 1820; and Annales de Chimie et de Physique, tom. xvi.

In establishing a communication between the condensing plate of the condensing electroscope and the ground by touching it with the finger, the finger should be previously moistened; and if the hand of the operator be naturally dry, the entire hand should be previously bathed in distilled water, for these instruments in delicate cases often fail on account of the skin of the hand being so dry as to retain insufficient conducting power.

(257′.) [Peclet's Electrical Condenser* must not be excluded from this list. *Fig.* 75 *a* gives it in eleva-



tion; *fig.* 75 *b* gives it in section; *a* is a gilded plate of glass varnished on its *upper* surface, and metallically connected with the gold leaves, *r s*; *b* is a gilded glass plate, varnished on *both* sides, but not at the circumference, and furnished with an insulating handle, *d*; *c* is

* *Annales de Chim.*, Mai, 1840.

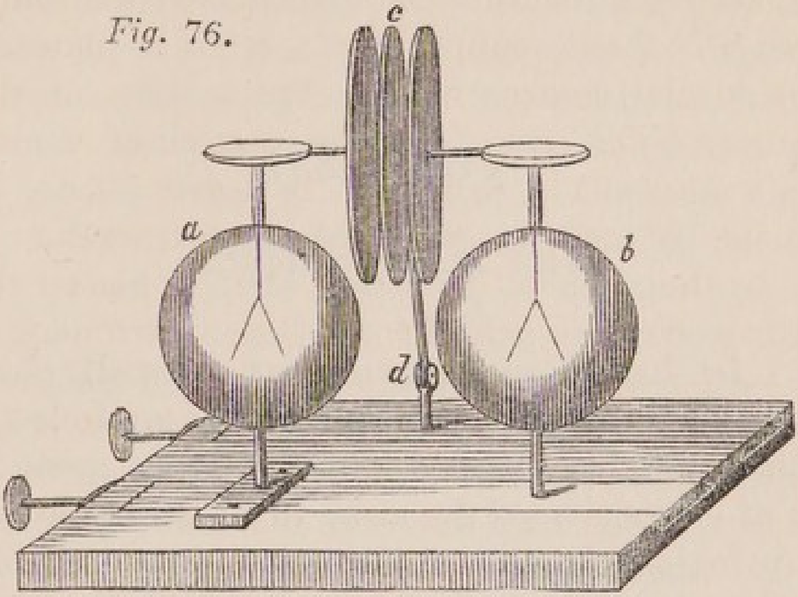
a similar gilded plate, varnished on its *lower* surface, and furnished with an insulating tube *e*, through which *d* can pass; *g h* is the stand, furnished with adjusting screws; *i* is a rod, supporting a circular plate, having a sight in the centre, which gives a view of the gold leaves *r s*, (*fig.* 75 *b*), and the section of a circle *k*; *m n* is a glass shade, covering the leaves, &c.; *o t* are two plates of copper, to assist the divergence of the leaves by their inductive action, but so placed that the leaves can never touch them. The instrument is thus used: — the upper plate *c* is touched with the object to be examined, while the edge of the plate *b* is touched with the finger; on removing first the finger, and then the object under examination, the two plates *c* and *b* are left charged with the opposite electricities, that of *b* being all disguised; the plate *c* is now removed by means of the insulating handle, *e*, and the electricity of *b* becomes free, in which state it acts by induction on the lower plate *a*; and, if *a* be touched with the finger, it becomes charged with the opposite electricity to that of *b*, which electricity is disguised by the presence of the charge of *b*; and, in its turn, disguises nearly the whole of the said charge of *b*. The plate *c* is now returned; *b* is touched; *c* is removed; *a* is again touched; and so on, repeating the operations any given number of times. Finally *c* and *b* are *both* removed by the handle *d*, and the degree of divergence, presented by the leaves, is the evidence of the electricity accumulated. Effects, inappreciable by the ordinary condenser, may be rendered evident by means of this apparatus.]

(257″.) [By means of Mr. Gassiot's Double Electroscope *, (*fig.* 76.) the phenomena described in Chap. X. may be beautifully illustrated. If, for instance, (the plate *c* being turned out of the way by the hinge *d*), the instrument *a* be charged with positive electricity, its leaves will diverge, and the leaves of *b* will also diverge with the same electricity; on touching *b* its electricity is

* Proceed. Elec. Soc., p. 445.

disguised, and the leaves collapse; if the instrument, *b*, be now gradually removed from *a*, its leaves gra-

Fig. 76.



dually diverge with *negative* electricity; if it be brought back to its original position, they again collapse; if it pass that point, and be brought close to *a*, the leaves diverge with *positive* electricity. If now the two plates are brought into contact, the electricity of the one will not *exactly* compensate that of the other, but a small portion will remain distributed between the two instruments, the leaves remaining slightly diverged. This portion bears a ratio to the value of *m* (239); and is greater as the distance between the plates is greater when the charge is first given. With this instrument, and an electrophorus (260), all the leading facts of inductive action may be studied. The plate *c* is used when only one instrument is employed.]

CHAP. XII.

THE ELECTROPHORUS.

(258.) It has been shown that a small charge of electricity may, by decomposing the natural electricities of conductors, produce a comparatively great charge either of electricity of the same or of an opposite kind. This principle in the condenser and its combination with the electroscope has been applied to detect the existence of electricities too feeble to be rendered sensible by the immediate application of ordinary tests. We shall now proceed to explain the application of the same principle to the production of free electricity of either kind in unlimited quantity by the agency of a small charge originally excited by friction or otherwise.

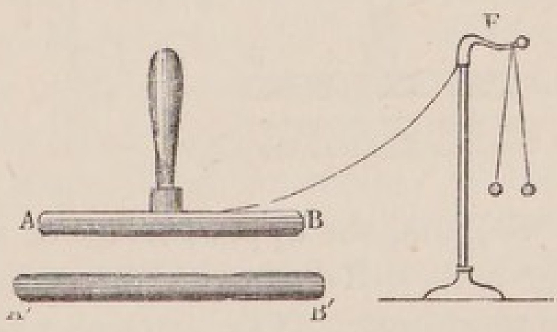
(259.) [It has been seen (257″.), that when *a* (*fig* 76.), is charged with positive electricity, the leaves of *b* diverge by induction; and that when *b*, under those circumstances, is *first* touched, and *then* removed, it exhibits a *negative* charge. If it is now discharged, and again returned to its old position, it again diverges by induction, and can be again charged with negative electricity, by being touched and removed as before. It is very evident, therefore, that one charge, given to *a*, is available in producing an apparently unlimited number of charges in *b*. Indeed, if it were not that the contact with the particles of dust and moisture contained in the air in time dissipates the charge of *a*, there would be *no* limit to the action. However, it will remain charged for a considerable time; and, during that time, *b* may be constantly charged and discharged; and, if the *discharge* is made to any piece of apparatus, in which

we desire to accumulate electricity, we can by this means add little by little till a large charge is gained. This, in fact, is the *modus operandi* of Peclet's Condenser, when the middle plate *b* (*fig.* 75 *a.*) is repeatedly discharged on the lower plate *a*, till a great accumulation has been made: the manipulation varies only in removing the charged plates from *b*, instead of *b* from the charged plates. I have not alluded to the amount of the divergence exhibited by the leaves of *a*, as seen *before* and *after* *b* has been touched; because the whole train of the preceding illustrations will have shown that it *decreases*, as soon as contact has liberated the positive charge from *b*; because the effect of this charge, as long as it is present, is to cause the leaves of *a* to diverge.]

[The power obtained on these principles of *carrying electricity*, as it were, drop by drop, gives the name *Electrophorus* to an instrument, by which this power is obtained under the most favourable form.]

(260.) The electrophorus, as it was first constructed by Volta, consists then of a thick cake of resin, A′ B′ (*fig.* 77.), on the upper surface of which negative

Fig. 77.

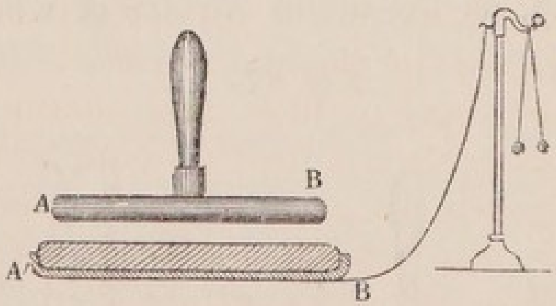


electricity is excited by rubbing or striking it with the fur of a cat. Let A B, a metallic disc with an insulating handle, be gradually brought near to the excited cake. As it approaches to it, the balls F will diverge, (as did the leaves of *b* of the double electroscope (*fig.* 76.), when under similar circumstances), by induction, and with electricity similar to that evolved on the cake of resin, viz. *negative*. The divergence is

the evidence of the condition of the *upper* surface of the plate, or rather of the part of the system *most distant* from the exciting cause; the *lower* surface being now *positive*. This will be remembered from what was said in the chapter on "*Induction*," (121, &c.), and the closer the discs are to each other, the greater is the divergence; being greatest when they are in actual contact. If the upper disc is then touched, the negative electricity escapes; and the positive, now disguised by proximity to the excited resin, may be rendered free by removing the disc; and thus a succession of charges may be conveyed to any conductor.]

(261.) [If the cake of resin were contained in a tin mould, as is actually the case in the ordinary structure of the instrument, the same phenomena would occur at the respective surfaces of the metal constituting the base, as occur at the disc A B; as, for instance, if such an electrophorus be insulated and connected with pith-

Fig. 78.



balls F′. (*fig*. 78.), and the upper surface be excited as before (260.), the balls will diverge with *negative* electricity as in the last experiment. The reaction of this negative charge of the base of the instrument on the charge contained by the surface of the resin, operates against the *increase*, and even against the *existence* of the charge on the resin; a way, therefore, of escape must be opened to it, by connecting the base with the earth during the process of exciting the instrument. If the instrument be insulated, after the escape has been allowed, and the plate A B be gradually brought near, its inductive action *exalts* the negative condition of the

resin, and so gives a further negative charge to the base; which reacts with a tendency to diminish the positive charge which might otherwise be given to the disc. The base, therefore, of the instrument, both during the charge and during the subsequent experiments, must be connected with the earth.]

(262.) [In all experiments with the electrophorus, the effect of the atmosphere in dissipating the electricity must be always included; otherwise many anomalies, apparently in contradiction to the laws now laid down, will present themselves. Bearing these hygrometric effects in mind, the anomalies present a fertile series of lessons on induction, and may be turned to good account by the persevering student.]

(263.) [The best mode of retaining the charge on the electrophorus, is to cover it with the disc A B, and touch the disc to complete the equilibrium. Under these circumstances the instrument has been found to retain a charge, without sensible diminution, for several months.]

(264.) [There is evidently a peculiar attraction, which retains the electricity on the resin, in preference to permitting its escape to the metalic disc. By favour of this, it is very easy to have two instruments charged with the opposite electricities; for nothing more is necessary than to excite one electrophorus, place the disc on it, touch the disc, and then take it with its positive charge and place it on the surface of the other electrophorus, when it will part with the greater portion of its charge, and leave it on the surface of the resin.]

(265.) By touching the surface of a cake of resin with an electrified metallic ball, the surface of the resin may be electrified at the points where it is thus touched with the electricity of the ball; and if balls oppositely electrified be provided, figures of any kind may be traced upon the resin in electrified outline, some with one, and some with the other kind of electricity. These figures may be made visible by blowing over the surface of the resin any coloured powder composed of a nonconducting substance, which will be attracted by the elec-

trified parts of the resin, as light bodies are attracted by excited surfaces. These are called the figures of Lichtenberg.

A powder produced by triturating in a mortar a mixture of sulphur and minium, or red lead, is sometimes used in such experiments. In the process of trituration, the particles of these substances are electrified, the sulphur positively, and the minium negatively. When this powder is blown upon the resin, the sulphur is attracted by and adheres to those parts of the resin which are negatively electrified, and the minium to those parts which are positively electrified. These substances having different colours, the sulphur being yellow and the minium red, the figures of each kind are immediately distinguishable.

When the attention of electricians was first called to these experiments, it was observed that the resinous powder spread on the cake was subject to slow and irregular motions, like the spontaneous motion of animals. Philosophers were not slow to raise up ingenious theories to account for such a phenomenon. It was soon found, however, that the effects were produced by a certain small insect called *Acarus*, found in the powder of the resin.

(266.) The best composition for the resinous plate of an electrophorus is a mixture of equal weights of shell-lac, resin, and Venice turpentine, melted together. These ingredients are to be poured while in a fluid state into a tin case prepared for their reception; or if no permanent case be required, a tin rim half an inch deep may be used as a mould for the cake. This rim may be placed on a marble slab on which the cake may be formed, and from which it is easily separated when cold.

(267.) Cavallo states that an electrophorus, which he made of sealing-wax spread upon a thick plate of glass six inches in diameter, when once excited, would charge a coated phial several times so strongly as to pierce a hole through a card with the discharge.

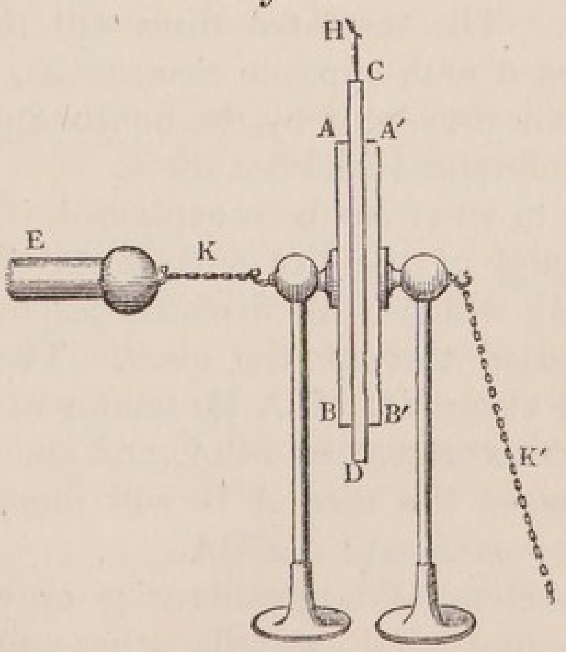
CHAP. XIII.

THE LEYDEN JAR.

(268.) The same effects produced by the electricities of bodies acting on each other at a distance, which have supplied the means in the condenser of increasing the power of the electroscope, and of perpetuating the fountains of free electricity in the electrophorus, are still more conspicuous in the agency which they place at the disposal of the electrician to accumulate and direct the course of charges of artificial electricity, by which the lightning of heaven is copied in some of its most conspicuous effects.

Let C D (*fig.* 79.) be a large disc of glass suspended

Fig. 79.



by a silken thread from H, and let A B and A′ B′ be two insulated metallic discs of less diameter than the glass placed in contact with opposite faces of the latter.

Let K be a metallic chain connecting the disc A B with an electrified conductor E, and K′ another connecting the disc A′ B′ with the ground. If the conductor E be strongly charged with electricity, the disc A B will be covered with the fluid in much greater depth, as has been shown in Chapter X., and the disc A′ B′ will be charged with dissimulated electricity of the contrary kind. If the electrical machine by which the conductor E is supplied be kept in action, the depth of fluid on A B will continue to increase, which, by increased action on the natural fluids of A′ B′, will produce on that disc a corresponding increase; and this accumulation of electricity will continue until the repulsion of that part of the electricity on A B which is not dissimulated exerted on the fluid diffused on the conductor E, and the repulsion of the latter upon the fluid evolved upon the cylinder, become so great as to stop the further propagation of electricity on the conductor E, or from the conductor to the disc A B.

When this has taken place, let us suppose the communication of the disc A B with the conductor E, and the communication of the disc A′ B′ with the ground, to be broken. The insulated discs will then be each strongly charged with opposite electricities, whose combination is only prevented by the nonconducting virtue of the glass interposed between them.

According to what has been explained, if A represent the whole charge of the disc A B, m A will be that of the disc A′ B′, which is all dissimulated by the attraction of A exerted through the glass. The charge mA acting on the electricity of A B, retains in equilibrium a portion of it expressed by m^2 A, and the free portion of the charge of the disc A B will therefore be expressed by $A-m^2A=(1-m^2)A$.

Now, if one end of a metallic wire or chain be attached to the disc A′ B′, and the other end be brought into contact with the disc A B, a part of the free electricity $(1-m^2)$A of the disc A B will, by the conducting power of the wire, be diffused on the disc

A′ B′, where it will combine with, neutralise, and reduce to its natural state an equal portion of the electricity m A with which the disc A′ B′ is charged. The remainder of the charge is no longer capable of retaining the quantity m^2 A dissimulated on the disc A B. A portion of this will, accordingly, be liberated, and a further quantity will pass by the chain or wire to A B, where an increased quantity of the original charge will be neutralised, and this will continue until the whole charge m A of the disc A′ B′ has been neutralised.

Of the entire quantity A of electricity with which the disc A B was originally charged, a portion, expressed by m A, therefore, will combine with and neutralise the electricity of A′ B′, and a quantity of uncombined electricity, expressed by $\mathrm{A}-\mathrm{A}m=(1-m)\mathrm{A}$, will remain. This being free will be diffused over the two discs; and if they be equal and symmetrical, and the surface of the chain or wire be inconsiderable compared with them, it will be equally shared between them, each being charged with the quantity $\frac{1}{2}(1-m)\mathrm{A}$.

If E be the charge of electricity which the disc A B would receive from the conductor in the absence of A′B′, we shall have

$$\mathrm{E}=(1-m^2)\,\mathrm{A}\,;\ \therefore\ \mathrm{A}=\frac{\mathrm{E}}{1-m^2}.$$

Hence the free electricity diffused on each of the discs, after a conducting communication has been opened between them, will be

$$\frac{(1-m)\mathrm{E}}{2(1-m^2)}=\frac{\mathrm{E}}{2(1+m)}.$$

But since the distance between the surfaces of the discs is very small, m is very nearly $=1$. Hence the free electricity diffused on each disc will be

$$\frac{\mathrm{E}}{4};$$

that is, one fourth of the charge which the disc A B would have received from the conductor in the absence of the disc A′ B′.

(269.) The total magnitude of the charge which under such circumstances the disc A B is capable of receiving, evidently depends conjointly on the magnitude of the discs and the thinness of the glass. To the latter there is a limit, since the glass must have sufficient strength to resist the tendency of the opposite electricities diffused on its faces to force their way through it by their mutual attraction, and to break it. With all the necessary thickness of the plate of glass, the number $(1 - m^2)$ which varies in some inverse proportion to that thickness is necessarily extremely small, and consequently the actual charge A of the disc A B bears a very high ratio to the charge E, which it would receive directly from the conductor.

Whatever this charge may be, it must transmit nearly its entire influence instantaneously through the chain, wire, or whatever other communication may be made between the two discs to discharge them; and in whatever way the conducting power may be viewed, a sudden and violent change in the electrical state of such conducting substance must ensue. If the intermediate conductor be merely a channel of communication through which the electric fluid of the one disc may pass to the other to neutralise it, so large and sudden an afflux of electricity may be expected to be attended with some violent effects. If, on the other hand, the opposite fluids are reduced to their natural state by decomposing the natural electricity of the intermediate conductor, and taking from the elements of the decomposed fluid the electricities necessary to satisfy their respective attractions, a still more powerful effect may be anticipated from so great and sudden a change.

It is accordingly found that such phenomena are attended with some of the most remarkable effects presented in the whole range of physical inquiry. If the

charge be sufficiently strong, and the intermediate conductor be metallic wire, it will be instantly rendered incandescent and will be fused. If the human body be made the conducting medium, however inconsiderable the charge may be, an effect is produced on the nerves, which is to most persons extremely disagreeable; and if the charge be considerable, it may even have the effect of destroying animal life.

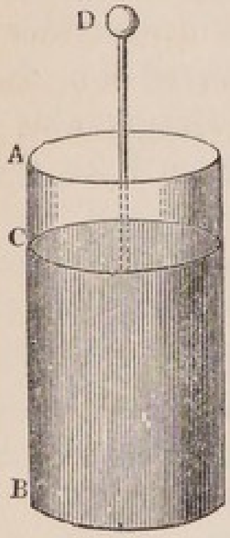
(270.) With a view to divest the means of producing these effects of circumstances merely adventitious, and to bring the great general principle on which they rest more clearly into light, we have here presented them in a form somewhat different from that in which they are commonly seen in electrical experiments.

The phenomenon which has just been explained, consisting merely in the accumulation of powerful charges of electricity of contrary kinds on the opposite faces of glass, by means of metal maintained in contact with the glass, it is evident that the form of the glass, and of the metal in contact with it, have no influence on the effects; neither has the thickness or volume of the metal any relation to the experimental result. Thus the glass, whose opposite faces are charged, might, without any change in the effects produced, have the form of a hollow cylinder or globe, or, it might be, a common flask or bottle. The metal in contact with the glass need not be massive or solid plates, but may consist merely of metallic foil, forming a coating on the glass. Indeed, metal is only used as being a convenient conductor. Any other conducting substance which could be applied to the glass would be attended with like effects.

(271.) In experimental researches in electricity, the form which is commonly given to the glass for this purpose is that of a cylindrical jar, A B (*fig.* 80.), having a wide mouth above, and a flat bottom. The shaded part terminating at C in the figure represents a coating of tin foil, attached by paste or gum-water to

the exterior surface of the bottom and sides of the jar, and a similar coating is attached to the corresponding parts of the interior surface. To improve the nonconducting power of the glass above the termination C of the foil, it is coated with a varnish of gum lac, which also renders it more proof against the deposition of moisture.

Fig. 80.



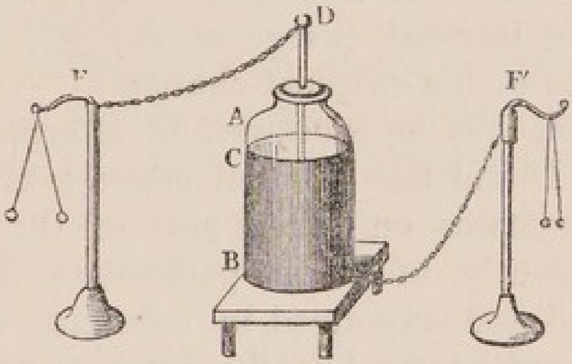
A metallic rod, terminated in a ball, D, descends into the jar, and is maintained in contact with the inner coating. Such is the apparatus commonly called the LEYDEN JAR, or the LEYDEN PHIAL.

(272.) To comprehend the application of the Leyden jar to the accumulation of electricity, it is only necessary to consider the inner coating and the metallic rod in contact with it as representing the disc A B (*fig.* 79.), and the outer coating the disc A′ B′, while the jar itself takes the place of the glass plate C D. If the ball D (*fig.* 80.) be placed in contact with the prime conductor of an electrical machine, and the outer coating be put in communication with the ground, all the effects will be produced which have been already so fully explained in reference to the glass plate, C D (*fig.* 79.), and the metallic discs in contact with it. The inner surface of the glass in contact with the tin foil will become strongly charged with the electricity of the conductor, and the exterior surface will be charged with the opposite fluid; and if a communication be made between these by any conducting body, the opposite fluids will combine, and neutralise each other.

(273.) If a practical illustration of the identity of the effects produced by the internal and external coating of the Leyden jar, and those produced by the two metallic discs represented in *fig.* 76., merely separated by a stratum of air (which, in principle, are the same with those

represented in *fig.* 79.), be desired, let the jar be charged with electricity as already described, by putting the ball D in contact with the conductor of an electrical machine, the external coating being, at the same time, in communication with the ground; and let it then be placed upon an insulating stool, as represented in *fig.* 81.

Fig. 81.



Let the external coating communicate by a chain with the insulated pith balls F′, and let the internal coating in like manner communicate by a chain with the pith balls F.

According to what has been formerly explained, if the total charge of the inner coating be represented by A, that of the external coating will be m A, and this latter will be dissimulated. The free part of the charge A will be $(1-m^2)$A, by which the balls F will diverge. We will suppose, in the present case, that the charge of the inside of the jar is positive. In that case the electricity of the balls F will be found to be positive by the usual tests. If the finger be now applied to the ball D, the free electricity will pass away to the ground, and the inner charge of the jar will be reduced to m^2A. This will set free a portion of the external charge mA, by which the divergence of the balls F′ will be immediately produced. Indeed, the moment the finger is applied to D the balls F will collapse, and the balls F′ will diverge. If the latter be examined by the usual means, they will be found to be negatively electrified, showing that the external charge of the jar is negative.

The quantity of dissimulated electricity on the exterior of the jar will now be m^3 A; and if the finger be applied to the external coating of the jar, the free electricity will pass to the ground, and the dissimulated alone will remain. The balls F′ will accordingly collapse the moment the finger touches the exterior coating, and a simultaneous divergence of the balls F will take place. This will arise from the liberation of a portion of the internal charge of the jar, by the diminished force of the external charge.

This process may be continued by alternately touching the knob D and the external coating, until no sensible charge remains on either side of the jar. The process is evidently, in all its particulars, the same as that described and explained in reference to the two discs represented in *fig.* 76., the internal and external coating taking the place of the discs, and the interposing nonconductor being a plate of glass instead of a plate of air.

(274.) It will be evident, from all that has been stated, that there is no real difference in relation to the phenomena produced between the functions of the external and internal coating of the jar. In the preceding observations, the internal charge has been supposed to be received from the conductor, and the external consequently to be produced by the decomposition of natural electricity effected by the influence of the internal charge. But the results would have been similar if the external coating were first charged by putting it in contact with the conductor of the machine, the internal coating, or, what is the same, the knob D being at the same time in communication with the ground. In that case, the external charge would be of the same kind with the electricity of the conductor, which, in the present case, is supposed to be positive; and the internal charge would be negative. In the first instance, also, the balls F′ would diverge with positive electricity, and after touching the external coating the balls F

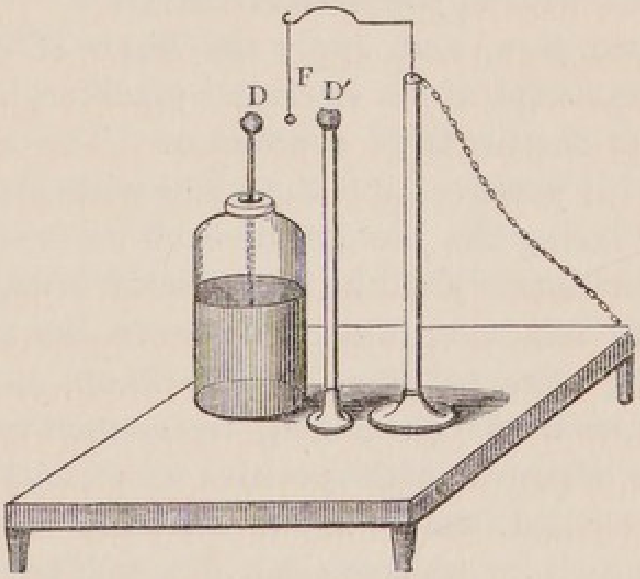
would diverge with negative electricity, and so on alternately as before.

If the jar be charged, either internally or externally, at the negative conductor of an electrical machine, such as Nairne's, the effects will be similar *mutatis mutandis*.

(275.) The gradual discharge of a jar, by alternately putting its internal and external coating in communication with the ground, may be elegantly exhibited in the following manner.

Let the charged jar be placed as before on an insulating stool, and let a metallic pillar, terminated in a ball D′ (*fig.* 82.), communicate by a chain with the ex-

Fig. 82.



ternal coating, the ball D′ being at the same level with the ball D, and within a distance of it great enough to prevent the spontaneous discharge of the jar taking place between the two balls. Let F be a small ball of metal or pith suspended by a wire or linen thread, and standing midway between D and D′, and communicating with the ground by a metallic chain. If the jar be charged on the inside, the ball will be attracted to D, and by the contact the free electricity of the inside of the jar will pass to the ground through the wire or linen thread. The ball F being thus immediately restored to its natural state, will be attracted to the ball D′ by the electricity now liberated on the

external surface of the jar, and after contact this electricity will, in like manner, pass off through the wire or linen thread to the ground. The ball F will then be again attracted by D, and so on alternately. The ball F will continue to vibrate between the two balls D and D′, touching them alternately, and at each contact discharging the free electricity of one or other side of the jar, until the charge is rendered so feeble that the balls D and D′ are unable to attract F. The discharge may be completed by bringing the balls D and D′ into metallic communication with each other.

(276.) The following experiment was one of those made by Dr. Franklin to illustrate the electrical state of jars charged with opposite electricities.

Take two jars, and apply the knob of one to the positive conductor of an electrical machine, and that of the other to the negative conductor. The one will be charged with positive, and the other with negative electricity. Placing the jars beside each other on a table, so that their knobs shall be at the same level, let an insulated pith ball hang midway between the knobs. The ball will be attracted first by one knob, suppose that which is positively electrified, by contact with which it will be charged with positive electricity. It will then be repelled, and will be attracted by the other knob, by which its positive electricity will be neutralised, and by which it will be charged with negative electricity. It will then be again repelled, and will be attracted by the other knob, by which the negative electricity will be neutralised, and it will be charged with positive electricity, and so on. The ball will thus continue to vibrate between the two knobs. At each contact a portion of the free electricity of each jar will be neutralised equal to the charge received by the ball from the other jar, and this will continue until all the free electricity of the internal charges of the jars has been neutralised.

A portion of the external charges of the jars being then set free, the ball, if placed between the external

coatings, will, in like manner, vibrate between them till they are discharged, and may afterwards be again applied between the knobs, and so on.

(277.) To charge a jar internally, hold it between the hands on that part of the external surface which is coated with foil, and apply the knob to the conductor of the machine. The body of the operator in this case forms a conducting communication with the ground, which enables the jar to take its external charge. To charge it externally, hold it by the neck in one hand, and, applying the other hand to the knob, bring the external coating in contact with the conductor of the machine. The body of the operator in this case supplied the necessary communication between the internal coating and the ground.

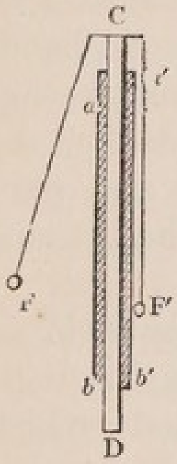
If the jar be too large to be conveniently held in the hand, it may be charged internally by laying it on a table and surrounding it by a metallic chain which communicates with the ground. By another metallic chain, a communication may be made between the knob of the jar and the conductor of the machine; or this may be done by touching the knob of the jar with one ball of a jointed discharger, and the conductor with the other knob. It may be charged externally by a like process connecting the external coating with the conductor by a chain, or the discharger and the knob of the jar with the ground by another chain; but in this case the external coating must be insulated by placing the jar on an insulating stool.

Instead of connecting the one or the other coating of the jar with the ground, it may be put into connection with the negative conductor or the rubber of the machine. Thus, if the jar be placed on an insulating stool, and a chain be carried from its external coating and suspended on the rubber, while another chain is carried from the knob to the prime conductor of the machine, the effect of the machine will be to decompose the natural electricities of both coatings, and to accu-

mulate the positive fluid on the one and the negative fluid on the other.

(278.) The following very beautiful experiment of Richmann affords a striking illustration of the reciprocal effects of the contrary fluids diffused on opposite surfaces of glass. Let C D (*fig.* 83.) represent a plate of glass suspended vertically; and *a b*, *a′ b′*, two coatings of tin foil attached to its opposite faces, leaving a portion of the glass round their edges uncovered. Let F and F′ be two pith balls suspended by silken threads so as to hang in contact with the coatings respectively. If the coating *a b* be put in contact with the conductor of an electrical machine, while the opposite coating *a′ b′* is in communication with the ground, *a b* will become charged with electricity, and the other coating *a′ b′* will become charged by induction with the opposite electricity. The ball F will be repelled by the free part of the charge of the face *a b*; but the ball F′ will not be affected, because the whole charge of the face *a′ b′* is dissimulated.

Fig. 83.



If the apparatus be allowed to remain in this state, the ball F will be observed to descend slowly and gradually towards the glass, and after the lapse of a certain time it will rest in contact with it; and if the state of the opposite surfaces be then examined, they will be found to be discharged. This may be easily ascertained by applying one ball of the discharger to one surface, and approaching the other ball to the other surface. It will be found that no spark will pass between them, and, consequently, no free electricity will be diffused on either surface.

If instead of leaving the face *a′ b′* in communication with the ground, that communication be broken after the face *a b* has been charged, the effects will be different. In that case the slow descent of the ball F towards the glass will be accompanied by a simultaneous repulsion of

the ball F′ from the opposite surface, and this contrary motion of the balls will cease when F has descended to about half its original distance from the glass, at which time F′ will have ascended to an equal distance from the other surfaces. Both balls will then for a moment seem stationary, diverging at equal angles from the opposite surfaces. If they be afterwards observed, it will be found that both will very slowly and gradually descend towards the glass at equal rates, and after the lapse of a certain time both will rest in contact with it.

These effects are easily explained by considering the agency of the atmosphere in dissipating the free part of the electric charges of the plate. In the first case, the surface *a′ b′*, being in communication with the ground, can never retain any free electricity upon it; therefore the ball F′ is never repelled. The free electricity of *a b* being slowly absorbed by the contact of the air, the total amount of the charge of *a b* is diminished, and a less amount of the other fluid can be dissimulated by its attraction on the opposite surface. A liberation of electricity, therefore, takes place on that surface, and the portion thus liberated instantly escapes to the ground. There is thus a continual dissipation of electricity on the surface *a b*, which produces a corresponding liberation and escape to the ground of the electricity on *a′ b′*. This again produces a corresponding liberation of dissimulated fluid on *a b*, and so on until the whole of the charge of the surface *a b* is absorbed by the air, and the whole charge of the surface *a′ b′* passes to the ground.

If the quantity of dissimulated fluid on *a b* liberated at each instant were equal to the quantity of free electricity absorbed by the air in the same instant, the quantity of free electricity on the face *a b* would continue the same, and the ball F would not commence to descend to the glass until all the dissimulated electricity were liberated. But that this is not the case can be easily shown. Let *e* be the quantity of electricity absorbed by the air on the face *a b* in any small given interval of time. The quantity of the opposite fluid

which it would retain on the face $a' b'$ would be $m e$. This quantity, therefore, will escape to the ground, and the quantity $m^2 e$, which this last would dissimulate on the face $a b$, will be set free. Hence, while the air absorbs the quantity expressed by e on the face $a b$, the quantity expressed by $m^2 e$ will be liberated on the same face. But since m is a quantity nearly equal to, but *less than* unity, the quantity $m^2 e$ will be less than e, therefore the quantity of free electricity lost by the surface in the given interval of time will be $(1-m^2)e$. The rate at which the ball F will approach the glass will therefore depend on the quantities m and e. The former is dependent on the thickness of the glass, and the latter on the hygrometric state of the air.

In the second case, both surfaces being insulated, no electricity can escape to the ground. In this case, when a small portion of the free electricity of $a b$ has been absorbed by the air, a corresponding portion of the dissimulated electricity of $a' b'$ is liberated; but since it cannot, as before, escape to the ground, it remains in a free state on $a' b'$ and repels the ball F′. It is also, like the free electricity of the other surface, liable to absorption by the air. This absorption being proportional to the quantity of free electricity on the surface, will in the beginning be less than the quantity liberated by the diminished quantity of electricity on $a b$, and there will be, on the whole, an increase of free electricity on $a' b'$, and an increased divergence of the ball F′ from the glass, and this will continue until the absorption of the electricity on $a' b'$ by the air becomes equal to the quantity of dissimulated electricity liberated in the same time. The quantity of free electricity on $a' b'$ will then be a maximum, and afterwards the quantity absorbed by the air will be more than the quantity of dissimulated electricity simultaneously liberated, and the free electricity will consequently be gradually diminished in quantity until the entire charge has been dissipated.

All the circumstances of these cases admit of being

reduced to strict mathematical analysis, by due consideration of the principles explained in the chapter on the dissipation of electricity by the contact of the air, combined with the formulæ by which the effects of induced electricity are expressed. (See Vol. I. p. 284.) As those who are familiar with the processes of analytical science will have no difficulty in the solution of this problem, we shall not here pursue the subject further.

(279.) The metallic coating of the inner and outer surfaces of the Leyden jar discharges no other function in the phenomena except to conduct the electricity to the surface of the glass, and, when there, to supply for it a free passage from point to point. Any other conductor would, abstractedly considered, answer the purpose equally well; and metallic foil is selected for the facility and convenience by which it may be adapted to the form of the glass and permanently attached to it. That like effects would attend the use of any other conductor may be easily shown.

Let a glass jar be partially filled with water, and hold it in the hand by its external surface; let a chain or rod connected with the conductor of an electrical machine be immersed in the water. After the machine has been worked for some time, let the jar be disconnected with it; and while it continues to be held by its external surface in one hand, let the other be put in contact with the water contained in it. A shock will immediately be suffered, proceeding from the discharge of the jar. In this case, the water being a conductor, performs the office of the inner coating of the jar; and the hand in which the jar is held being also a conductor, communicating by the body of the operator with the ground, performs the office of the external coating. The other hand, when immersed in the water, plays the part of the discharger.

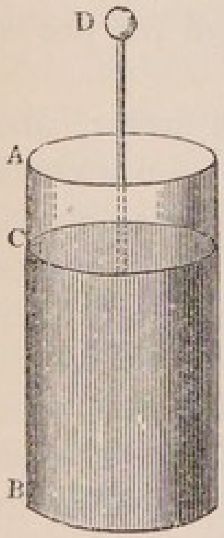
(280.) It is apparent that the electricity with which the jar is charged either resides on the glass, or on the conductor by which it passes to the glass; or, finally, it may be shared between these. To determine

this, it is only necessary to provide means of separating the jar from the conductor after it has been charged, and examining the electrical state of the one and the other.

(281.) This may be very easily done if water be used as in the last experiment. After the jar has been charged as above described, let the water be poured from it into another glass vessel previously ascertained to be free from electricity. If the water thus discharged be examined, it will be found in its natural state. If an equal quantity of other water be now poured into the jar, it will be found to be still charged as if the original water had not been removed from it.

(282.) A similar experiment may be made by providing movable coatings of tin foil to fit a jar (*fig.* 84.) internally and externally. Let two pairs of such coatings be made, so that the jar may be let into the case of external coating, its surface being in contact with it, and so that the internal coating may, by means of a metallic wire attached to its bottom, be let down into the jar. One pair of these being fitted to the jar, let it be charged in the usual manner. Let the internal coating be then lifted out of it, and let the jar itself be lifted out of the external coating. If these two coatings be now examined, they will be found in their natural state. Let the jar be next let down into the other external coating, and let the other internal coating be let into it. If it be examined, it will be found charged, as if no change had taken place in the coatings.

Fig. 84.



From these experiments it follows that the charges of electricity of the jar, both internal and external, reside on the glass, and not on the metallic coating; at least, if they lie between them, they remain by preference on the glass when they are separated. Sup-

posing the jar to be charged internally, it is easy to conceive that, on removing the external coating, the external charge m A will be retained on the glass by the attraction of the internal charge A. Again, on removing the internal coating, the external charge m A will retain a part of the internal charge expressed by m^2A on the inner surface of the glass. The only part of either charge, therefore, which would be at liberty to be carried away by the coating would be the free part $(1-m^2)$A of the internal charge ; and it appears from the preceding experiments that there exists on non-conducting surfaces, such as that of glass, some feeble attraction for the electric fluids, in virtue of which, whenever either fluid is in a free state, in contact at the same time with a conducting and a non-conducting surface, the fluid will remain upon the latter when they are separated.

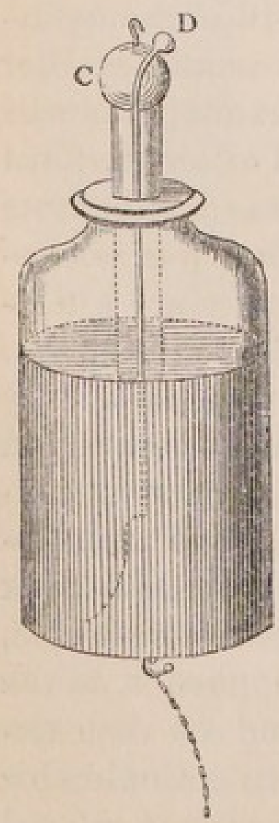
[(282′.) A most ingenious illustration of the arrangement of the electricity on a charged surface was introduced by Professor Faraday, in his recent lectures.* He placed before him a gauze cylinder, open at the top, within this he placed a disc of shell-lac ; and, within the cylinder, resting on the shell-lac, he placed a second smaller gauze cylinder. In fact, he built up an extemporaneous Leyden arrangement, in which an interval of air supplied the place of the glass, and the gauze was a substitute for the tin foil. The object he had in view was to contrive a system, which would permit him to place a testing instrument *between*, as well as *outside*, the coatings, in order to examine the condition of every part. By means of a brass ball, suspended with silk, he conveyed a spark from the prime conductor of the electrical machine to the inner cylinder of gauze, and thus communicated a very small charge to the system. He then took a *proof-plane* (246)., which is a small piece of leaf-gold, insulated on a handle of shell-lac, and applied it to the *inner* coating of the inner cylinder ; and on then examining the condition of the proof-plane by a Coulomb's electroscope (246.), it was found in its original normal

* May 20. 1843.

condition. It might have contained a small fraction of the free electricity (E 231.), existing on the inner coating, which would have been evident by a more delicate test; but it was inappreciable to the test applied. He then touched the *outer* coating of the inner cylinder, by passing down the *proof-plane* between the two; and, on applying the test, he found it charged with *positive* electricity. He touched the *inner* coating of the outer cylinder, and obtained *negative* electricity; he touched the *outer* coating of the outer cylinder, and obtained no charge. This instructive experiment can readily be repeated by means of either the condensing plates (222.), or the double electroscope (257.). It affords an actual demonstration of the place occupied by the electricity during the period of its *disguise;* and opens a new series of experiments on the abstraction of the electricity from that place.]

(283.) The Leyden jar, in its most improved form, is represented in *fig.* 85. Besides the provisions which have been already explained, there is attached to this jar a hollow brass cap, C, cemented into a glass tube. This tube passes through the wooden disc which forms the cover of the jar, and is fastened to it. It reaches to the bottom of the jar. The wooden disc which closes the mouth of the jar should be well dried by baking it, and should be varnished on both sides, and cemented into the mouth of the jar.

Fig. 85.



A communication is formed between the brass cap C and the internal coating of the jar by a small brass wire which terminates in a knob D. This wire passing loosely through a small hole in the cap, may be removed at pleasure for the purpose of cutting off all communication between the cap and the interior coating. This wire does not

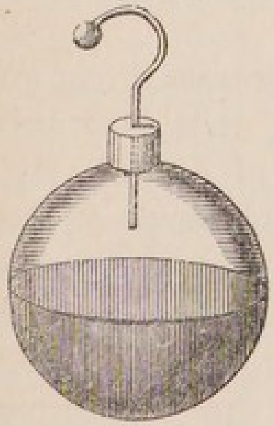
extend quite to the bottom of the jar; but the lower part of the tube is coated with foil, which is in contact with the wire, and extends to the inner coating of the jar.

At the bottom of the jar a hook is provided, by which a chain may be suspended to form a communication between the external coating of the jar and other bodies.

When a jar of this kind is once charged, the wire may be taken away, or allowed to fall out by inverting the jar, in which case the jar will remain charged, since no communication exists between its internal and external coating; and as the internal coating is protected from the contact of the external air, the absorption of electricity by that cause is prevented: an electric charge may thus be transferred from place to place, and preserved for any required time.

(284.) In the construction of cylindrical jars it is impossible to obtain glass of an uniform thickness. For this reason jars of the spherical form, represented in *fig.* 86., have sometimes been preferred.

Fig. 86.

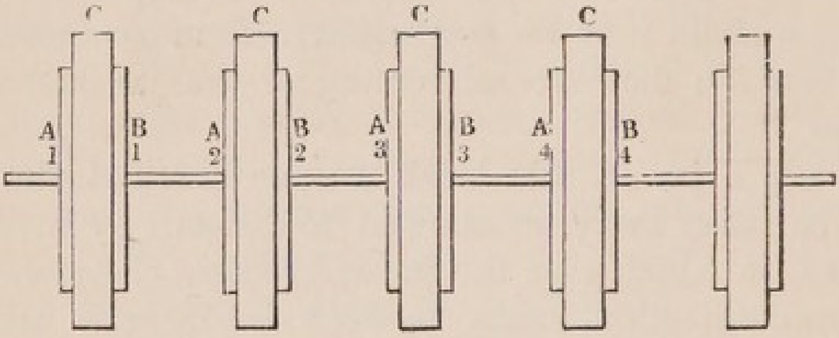


(285.) Jars have sometimes been constructed of metal, coated with wax. A long-necked phial, made of sheet tin, is coated on the outside with sealing-wax, to the depth of three tenths of an inch. Tin foil is then attached to the sealing-wax, covering every part of the vessel except the neck. In such a jar, the tin plate of which it is originally formed performs the office of the inner coating; the sealing-wax of the glass and the tin-foil attached to the outside represents the external coating.

(286.) By charging a single jar, an unlimited number of jars connected together may be charged with very nearly the same quantity of electricity. The general principle on which this process depends is only another of the many applications of the play of induction.

Let A_1, B_1, A_2, B_2, A_3, B_3, &c. (*fig.* 87.) represent a series of metallic discs, separated in pairs by plates of

Fig. 87.



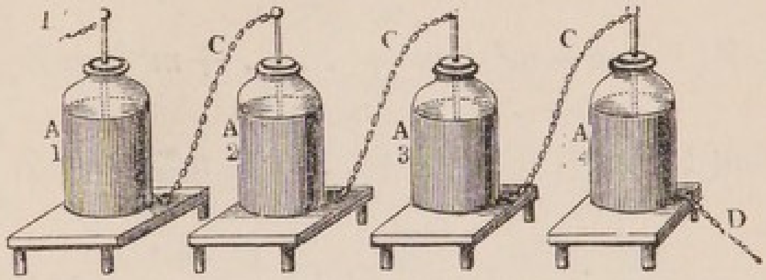
glass, C, C, C, &c., or other nonconducting matter. Let movable bars of metal be interposed between B_1 and A_2, B_2 and A_3, &c.; and let the last disc of the series be in communication with the ground. Let a charge of electricity, positive for example, be given to A_1 by putting it in communication with the conductor of an electrical machine, and let the charge thus imparted to it be expressed by Z.

(287.) [Now, if m, as before (231.), expresses the ratio, dependent on the thickness of the glass, it is very evident that the respective positive charges of A_1, A_2, A_3, &c. will be Z, mZ, m^2Z, &c., and that the charge of the nth plate, A_n, will be $m^{n-1}Z$; in like manner it appears that the negative charges of the series B_1, B_2, B_3, will be mZ, m^2Z, m^3Z, &c.; and the charge of B_n will be m^nZ. The charges, therefore, on the respective coatings of the last plate is in the ratio of $m^{n-1}Z : m Z = Z : mZ$. These conditions are of course true, only when all the glass plates are of equal thickness.]

(288.) To apply this method to the Leyden jars, let A_1, A_2, A_3, A^4 (*fig.* 88.), be a series of jars placed on insulating stools; and let C be metallic chains forming a communication between the external coating of each jar and the internal coating of the succeeding one. Let D be a chain forming a communication between the external coating of the last jar and the ground.

Let the chain D′ be carried to the conductor of an electrical machine, from which the first jar shall receive

Fig. 88.



its charge Z. [The whole series will then be charged in the same manner as were the plates (*fig.* 87.); and the more nearly m approaches to unity, the more nearly will the intensity of the charge of the last jar equal that of the first.

If, while the series is insulated, a discharge be made by connecting the outer coating of the last jar with the inner coating of the first, the compensating quantity of electricity required by the former will be $m^n Z$. The free electricity then remaining to be distributed between the coatings will be $Z - mZ = (1 - m^n)\, Z$; which exceeds the free electricity remaining after a proper discharge between the coatings of the same jar, (268.), in the proportion of $1 - m^n Z : 1 - mZ$. When such a neutralisation is effected between the extremes of the series, the intermediate plates neutralise each other, by allowing the return of the respective electricities.]

(289.) Instead of thus producing a system of simultaneous but separate discharges, an arrangement may be made by which all the separate discharges may be combined so as to produce one discharge, of which the force shall be equal to the sum of all the separate ones. For this purpose, after the series of jars has been charged, let the chains C connecting the external coating of each jar with the internal coating of the succeeding one be removed, and let them be carried from knob to knob, so as to connect all the internal coatings. Let another chain be carried from stool to stool, and put in contact with the jars so as to form an unbroken communication between the external coatings.

[By this means the sum S of all the positive charges is obtained, and the sum S′ of all the negative. The respective values of the sums are readily shewn to be

$$S = Z(1 + m + m^2 + m^3 + \ldots\ldots + m^{n-1}) = Z\frac{1-m^n}{1-m};$$

$$S' = Zm(1 + m + m^2 + m^3 + \ldots\ldots + m^{n-1}) = mZ\frac{1-m^n}{1-m}.$$

If m were unity, the multiple $\frac{1-m^n}{1-m}$ would be exactly equal to n, the *number* of jars, but as it is something less than unity, every turn of the series falls short of unity; and, therefore, the sum of the united charges is rather less than n times the charge of the first jar. The more extensive the series, the greater is this difference.

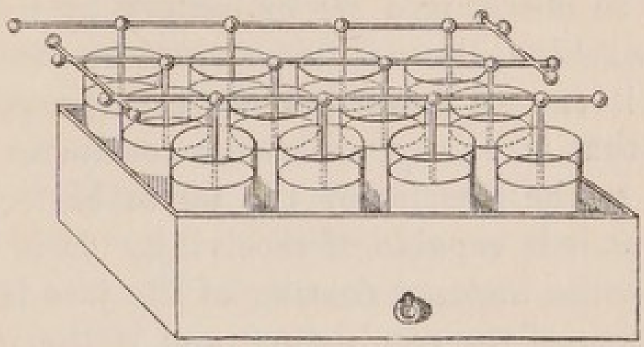
This consecutive charging of jars is very instructive, in that it presents evidence of the characteristics of charge: it shows many features of induction, and especially of that polarity of molecules of which further mention will be made when we come to describe Faraday's researches on static electricity, (Chap. 8.)

(290.) When several charged jars are thus combined for the purpose of obtaining a more energetic discharge than could be given by a single jar, the system is called an *electrical battery*. The method of charging the battery, which has been explained above, by giving a direct charge to the first jar only, and effecting the charge of the others by induction, is called charging *by cascade*.

It is not always convenient in practice to charge a battery by cascade. The jars composing the battery are usually placed in a box or case, as represented in *fig.* 89. This case or box is formed of wood, and is coated on the inside with tin foil, on which the jars rest, and which forms a communication between their external coatings. This metallic lining of the box communicates with a metallic ring seen in front of it, by which, in charging the battery, the external coatings of the jars are put in communication with the ground. The knobs of the jars are connected by rods which pass through

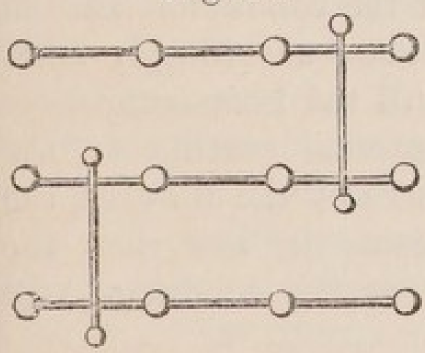
holes in them. These rods afford a metallic connection between the internal coatings of the jars. Each

Fig. 89.



row of jars is connected with the others by placing rods of metal transversely or at right angles with the former. It is convenient to lay these transverse rods loosely upon the others, so that they may be easily removed or replaced. By this means it is always easy to charge only a single row of jars, or two or more rows, to the exclusion of the others, according to the strength of the charge which is required. In the figure all the twelve jars are connected by two short transverse rods, one of which lies across the first and second rows, and the other across the second and third rows of jars, as represented in *fig.* 90.

Fig. 90.



(291.) An electrical battery is charged and discharged in the same manner as a single jar. To charge it, let a metallic communication be made between one of the knobs of the jars, or of the rods by which they are connected, and the conductor of the machine, and at the same time let a communication be made between the external coatings of the jars (by means of the ring before mentioned) and the ground. Let the machine be then worked until the necessary charge is given to the jars. Other things being the same, it may be

stated, generally, that the amount of the charge which a battery is capable of receiving, or the force of the battery, is in the direct ratio of the quantity of coated surface.

(292.) In charging a jar or battery by means of an electrical machine, there is no external or obvious means by which it can be known when the charge has been effected—that is to say, when the conductor has communicated to the interior of the jar or battery as much electricity as it is capable of receiving. It is to be considered that the internal coating of the jars is, in effect, a continuation of the conductor; and if the jars had no external coating, the communication of the internal coating with the conductor would be attended with no other effect than the distribution of the electricity over the conductor and the internal coating, according to the laws of electrical equilibrium. But the effect of the external coating is to dissimulate, or render latent, the electricity as it flows from the conductor; so that the repulsion of the portion of it which remains free is less than the expansive force of the electricity of the conductor, and an afflux of the fluid from the conductor accordingly takes place. This process goes on, until the increasing force of the *free* electricity on the internal coating of the jars becomes so great that the force of the fluid on the conductor can no longer overcome it, and then the flow of electricity to the jars from the conductor will cease.

It appears, therefore, that during the process of charging the jars, the depth or tension of electricity on the conductor is just so much greater than that of the *free* electricity in the jars as is sufficient to sustain the flow of electricity from the one to the other; and as this is necessarily so extremely minute an excess as to be insensible to any measure which could be applied to it, we may assume that the depth of electricity on the conductor is equal to that of the free electricity on the interior of the jars. If A, as before, express the actual depth of the electric fluid at any time on the interior

coating, $(1 - m^2)A$ will be the depth of free electricity; and since, throughout the process, m does not change its value, it follows that the actual depth of the electricity, and therefore the actual magnitude of the charge, is proportional to the depth of free electricity on the interior of the jar, which is sensibly the same as the depth of free electricity on the conductor. It follows, therefore, that the magnitude of the charge, whether of a single jar or several, will always be proportional to the depth of electricity on the conductor of the machine from which the charge is derived.

If, then, during the process of charging a jar or battery, an electrometer be attached to the conductor, this instrument, at first, will give indications of a very feeble electricity, the chief part of the fluid evolved by the machine being dissimulated on the inside of the jars. But as the charge increases, the indications of an increased depth of fluid on the conductor become apparent; and at length, when no more fluid can pass from the conductor to the jars, the electrometer becomes stationary, and the fluid evolved by the machine escapes at the points, or otherwise into the circumjacent air.

Henley's quadrant electrometer, described in (249.), is the instrument commonly used for this purpose. It is inserted in a hole on the conductor; and when the pith ball attains its maximum elevation, the charge of the jars may be considered to be completed.

(293.) The charge which a jar is capable of receiving, besides being limited by the strength of the glass to resist the mutual attraction of the opposite fluids, and by the imperfect nonconducting power of that part of the jar which is not coated, is also limited by the imperfect nonconducting power of the air itself. If other causes, therefore, permitted an unlimited accumulation of electricity in a Leyden jar, its discharge would at length be determined by the elasticity of the free electricity within it overcoming the opposing pressure of the air; and accordingly the fluid of the interior would

pass over the mouth of the jar, and unite with the opposite fluid of the exterior surface.

(294.) This may be illustrated by the following very beautiful experiment. Let a charged jar be suspended under the receiver of an air-pump in a dark room, and let the air within the receiver be slowly and gradually rarified by the action of the pump. When the internal fluid is sufficiently relieved from the restraining pressure of the air, it will be seen to overflow the mouth of the jar, and descend the sides in a cascade of light to meet and combine with the external fluid.

(295.) The electrometer attached to the conductor indicates the epoch at which the charge is completed, but it affords no direct or exact measure of the actual quantity of the charge. If the value of m corresponding to the glass of the jars were known, and the depth E of free electricity on the conductor were determined by the proof plane and the electrometer of Coulomb, then the depth of fluid on the interior of the jars would be expressed by

$$\frac{E}{1 - m},$$

in the same manner as in the case of the condenser; and this multiplied by the superficial magnitude of the coating would give the total amount of the charge.

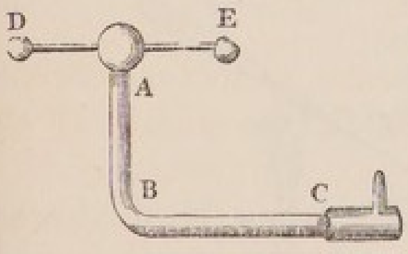
(296.) This method, however, has not been resorted to in practice, and the strength of the charge has been generally estimated, without much precision, by one or other of its effects. When a charge of electricity is passed through a metallic wire, an evolution of heat takes place in the wire, which increases with the thinness of the wire and the force of the charge. This heat may become so considerable as to fuse the wire. This test of the strength of the charge was proposed by Mr. Cuthbertson. Thus, the strength of the charge would be taken to be proportional to the length of wire of some given metal, of some given diameter, which it is capable of fusing. This method is, however, in-

capable of any tolerable degree even of approximation, much less of numerical estimation.

(297.) The extent of the charge which a jar is capable of receiving is found to be increased by moistening its coating. This circumstance was first observed by Brooke and Cuthbertson, who found that a jar which had been recently coated, and on which the solution of gum had not yet dried, received a greater charge than could be afterwards communicated to it. By breathing into a dry jar, it will acquire a power of receiving a greatly augmented charge. Mr. Cuthbertson, in March, 1796, on a dry day, found that by a battery of fifteen jars, containing seventeen square feet of coated surface, he could fuse eighteen inches of wire; but that by breathing into each jar through a glass tube, so as to leave a film of moisture deposited on the inner coating of each jar, the same battery received a charge which fused sixty inches of the same wire.

(298.) Lane's *discharging electrometer*, represented in *fig.* 91., is an instrument consisting of a bent glass-rod, A B C, at one end of which, C, is a brass socket, by which it may be attached to a charged jar or electrified conductor; and to the other end is attached a brass ball, A, perforated by a hole, through which a short brass rod, D E, terminated in balls, passes, and in which it freely moves.

Fig. 91.

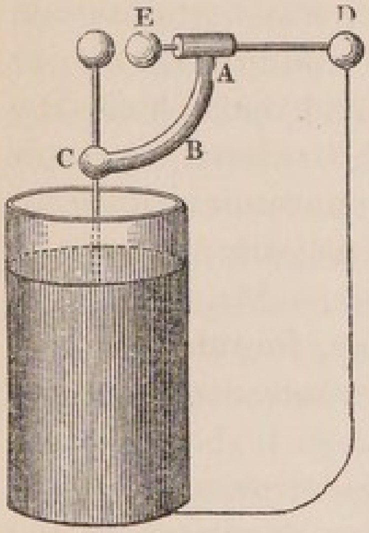


When the instrument is used, one of the balls, D for example, is put in communication with the ground, or with the external coating of the jar, and the rod D E is moved through the hole in A, until E is brought within such a distance of the electrified conductor or knob of the jar that a spark will pass from one to the other; and the force of the charge is estimated by the distance through which the spark is projected.

This instrument is shown attached to a jar in *fig.* 92., where the corresponding parts are marked by the same

letters. The ball D is connected by a chain with the external coating of the jar.

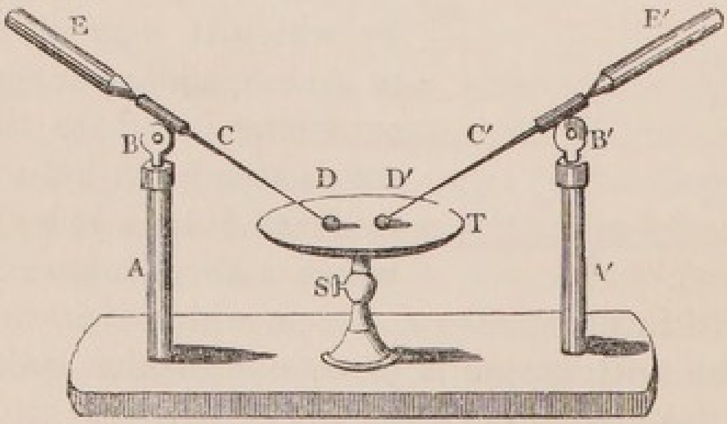
Fig. 92.



The indications of this instrument are modified by so many causes, that, as a measure of the electric force of the charge, it has but little value. The distance through which the spark will be projected will vary with the hygrometric state of the air, and probably with its temperature and other qualities. It will also vary with the magnitude and form of the part of the conductor or the knob of the jar to which it is presented.

(299.) Henley's *universal discharger*, an instrument of considerable convenience and utility in experimental researches in electricity, is represented in *fig.* 93. It consists of a wooden table, to which two

Fig. 93.

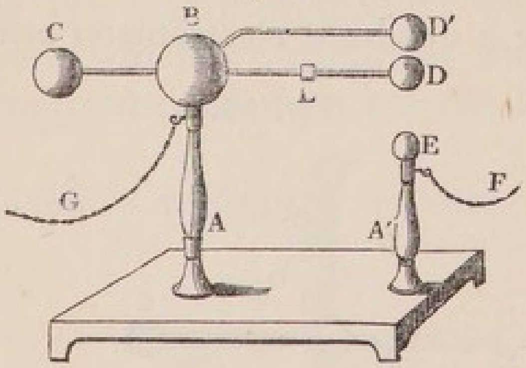


glass pillars, A A′, are attached. At the summits of these pillars are fixed two brass joints capable of revolving in a horizontal plane. To these joints are attached brass rods, C C′, terminated in balls, D D′, and having glass handles, E E′. These rods play on joints at B B′, by which they can move in vertical planes. The balls D D′ are applied to a small wooden table sustained on a pillar capable of having its height adjusted

by a screw, S. On the table is inlaid a long narrow strip of ivory, extending in the direction of the balls D D′. The balls D D′ can be unscrewed, and one or both may be replaced by forceps, by which may be held any substances through which it is required to transmit the electric charge. One of the brass rods, C, is connected by a chain or wire with the inner coating of the jar or battery from which the charge is to be transmitted, and the other, C′, is connected with the outer coating. The charge is transmitted by bringing the balls D D′, with the substance to be operated on between them, within such a distance of each other as will cause the charge to pass from one to the other through the intermediate substance.

(300.) Cuthbertson's *discharging electrometer*, represented in *fig.* 94., consists of two glass pillars supported

Fig. 94.

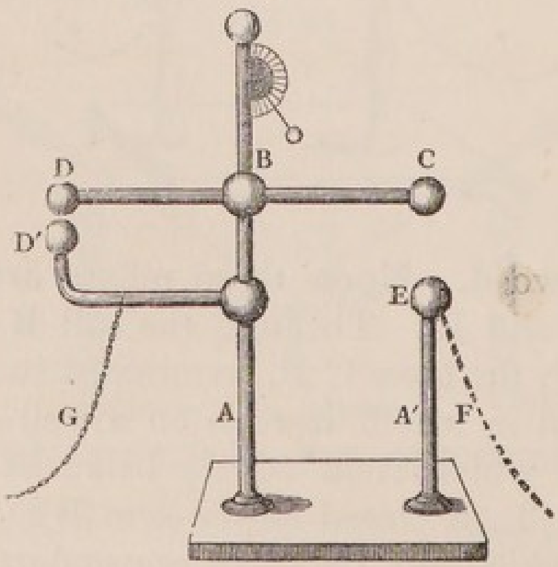


on a table of wood. Upon these pillars are fixed two brass balls, B and E. Through the ball B an opening is cut in which the lever C D, terminated in brass balls, is inserted, and in which it rests on a well-constructed knife-edge on which it is exactly balanced. A small sliding weight, L, is placed on the arm B D, by the adjustment of which any required preponderance can be given to the opposite arm, B C. The arm B D is graduated to indicate the number of grains weight at the centre of the ball D, which would be in exact equilibrium with the preponderance which C acquires from the position of the slider L. Another horizontal arm, B D′, is fixed to the ball B, terminated in a ball D′,

which is in contact with D when the lever C D is in the horizontal position. By the chain G the balls C D and D′, and the levers to which they are attached, are put in communication with the internal coating of the jar or battery, the free electricity of which will therefore charge the balls D and D′, and by the chain F the ball E is put in communication with the external coating, the electricity of which, being dissimulated, will not affect the ball E. The balls D and D′, being similarly electrified, will repel each other; and as soon as the charge of the jar is so great that the repulsive force given to the balls D and D′ by its free electricity is sufficient to overcome the preponderance given to the ball C by the position of the sliding weight, the ball D will be repelled by the fixed ball D′; and when the former comes into contact with E, the jar or battery will be discharged.

Another form of this instrument is represented in *fig.* 95., having a quadrant electrometer attached. The

Fig. 95.



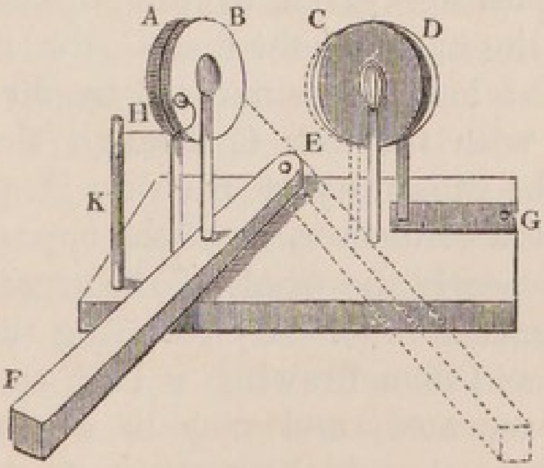
corresponding parts are marked by the same letters, so that its construction and operation will be easily understood. In this case D′ and D, receiving electricity from the inner coating, repel each other. The knife edge is within B, and the repulsion depresses C until it touches E, when the discharge is effected.

It is said that the accuracy of this instrument is confirmed by the results of experiments. Mr. Singer states, that two inches of steel wire employed for the hair springs of watches were fused by being placed in the circuit through which the discharge of the jar was passed when the beam C B was loaded with fifteen grains, and that the same jar was capable of fusing eight inches of the same wire with the charge which it acquired by loading the beam with thirty grains. If, instead of increasing the weight of the beam beyond fifteen grains, two such jars be employed, the eight inches of wire are equally fused. Hence it appears by experiment, as is evident by theory, that whether the intensity of the charge be doubled, or the extent of charged surface be doubled, the effect produced by the discharge is the same.

Before we dismiss the subject of the accumulation of electricity by the aid of induction, we shall describe two instruments which are applicable to cases in which neither the common condensers nor the Leyden jar can be applied.

(301.) Cavallo's *multiplier*, represented in *fig.* 96.,

Fig. 96.



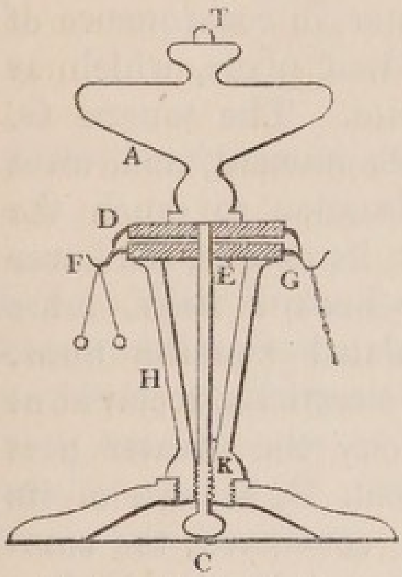
consists of four metallic plates, A, B, C, and D. The disc A is supported on a glass pillar, by which it is insulated; this glass pillar is fixed into a wooden table which supports the apparatus. The disc B is likewise

sustained by a glass pillar, which is fixed in a lever E F, moving on a pivot at E. The disc C is supported on a glass pillar fixed in the table ; and, finally, the disc D is supported on a metallic pillar attached to a slider G, by moving which backwards and forwards the distance between the faces of the disc C and D may be increased or diminished at pleasure. A small curved wire H is attached to the disc B; and when the discs A and B have their surfaces at the distance of about the twentieth of an inch, the wire H is in contact with a metallic pillar, K, which communicates with the ground.

Let us suppose the disc A to be put in communication with any feebly electrified conductor ; and suppose, for example, that the electricity with which it becomes charged is positive. The disc B being close to A, and through the wire H, and the pillar K in communication with the ground, this pair of discs is in the condition of the two coatings of a Leyden jar, or of the plates of a common condenser, and the disc B will be accordingly charged with negative electricity. Let the lever E H be now moved to the position represented by the dotted lines. The contact of the wire H with the pillar K being broken, the escape of the negative electricity from the disc B is prevented ; and the wire H, in the new position given to this disc, coming into contact with the back of the disc C, the negative electricity of B, no longer dissimulated by the proximity of A, is shared with the disc C through the conducting wire. But the proximity of the disc D, producing on C the effect of a condenser, or of the opposite coating of a Leyden jar, nearly the whole of the negative charge of B will be attracted to C. By restoring the lever to its first position and then drawing it back again, this process may be repeated, and may be continued until C becomes so charged with the negative electricity that it can receive no more of the fluid from B. The charge of C in this instrument is evidently limited by circumstances similar to those which limit the charge of the Leyden jar.

(302.) Nicholson's spinning condenser, represented in *fig.* 97., consists of a metallic vase, A, having a long steel axis, which passes through a hole in the stand H, and rests at its pointed end K in an adjustible socket at C. The use of the vase is to preserve by its weight for a considerable time a spinning motion given to it by the finger and thumb applied to the top of the instrument. The shaded parts, D and E, represent two circular plates of glass nearly an inch and half in diameter. The upper plate is fixed to the vase, and revolves with it, while the lower is fixed to the stand. In the lower plate are inserted two metallic hooks, F and G, diametrically opposite to each other; they are cemented into holes drilled into the edge of the glass: in the upper plate are inserted, in like manner, two small tongues of the fine flatted wire used in making silver lace; these tongues are bent downwards, so as to strike the hooks at each revolution, but in all other positions they move without touching any part of the apparatus. At C is a screw, which, by raising or lowering the vase, keeps the faces of the glass planes at any required distance from each other. The contiguous faces of the glass planes are coated with segments of tin-foil. Each of the tongues from the upper discs communicates with one segment of tin-foil from the same disc; the hook F also communicates with that coating of the lower plate which is nearest to it; but the hook G is entirely insulated from the whole apparatus, and is intended to communicate with the electrified body or an atmospheric conductor. The lower coating nearest to G is made to communicate permanently with the stand H, and consequently with the earth.

Fig. 97.



In this situation, suppose the motion of spinning to

be given to the apparatus. One of the tongues will strike the hook G, by which means the upper coating annexed to that tongue will assume the electric state of the body with which G communicates, and the electric charge thus received will be greater in consequence of the proximity of the lower insulated plane, which, at that instant, it is directly opposite. The tongue G, with its plate or coating, proceeds onward, and, after half a revolution, arrives at the situation to touch the hook F. The upper coating, with its tongue, the lower coating on the side of F, and the hook F itself, must then constitute one jointly insulated metallic mass, through which the charge of free electricity received at G is dispersed. Of this electricity the greater part will be determined towards the hook F, because of its pointed form. The motion being continued, the coating and its tongue instantly pass on, leaving F electrified, and proceed to bring another charge from G to be deposited at F, as before. The electroscopic balls at F will therefore be very speedily made to diverge.

CHAP. XIV.

EXPERIMENTS ILLUSTRATING ELECTRICAL ATTRACTION AND REPULSION.

(303.) Having in the preceding chapters explained the construction, form, and operation of the chief instruments of experimental research in electricity, we shall now conclude the present Book by a statement of a few of the more remarkable experiments made with them to illustrate the effects of electricity.

Experiment I.

(304.) Let the prime conductor of the electrical machine be removed; and when the cylinder or plate is being worked, let the back of the hand be brought near to the glass at the part where it passes from under the silk flap, and where, therefore, it is strongly charged with positive electricity. A peculiar sensation will be produced on the skin of the hand resembling what would be felt by touching a cobweb.

This may be accounted for by the natural electricity of the hand being decomposed, and the negative fluid being attracted to the surface of the skin near the glass. The small hairs on the skin are thus negatively electrified; and being attracted by the opposite electricity of the glass, they are drawn from their roots with a slight force.

Experiment II.

(305.) Let a small ball coated with gold-leaf, and supported by a silken thread, be hung between two con-

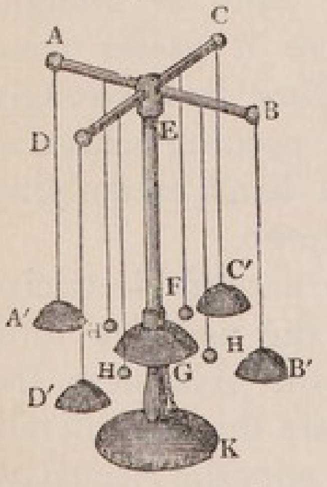
ductors, so as to be at a small distance from each. Let one of the conductors be insulated, and receive electricity from the machine, and let the other communicate with the ground. The ball will continually vibrate between the two conductors, alternately touching each.

This is easily explained. The insulated ball in its natural state is attracted by the electrified conductor, and when electrified by contact with it is repelled. It strikes the other conductor, to which it gives up its electricity, which passes to the ground. The ball being restored to its natural state is again attracted, and subsequently repelled by the electrified conductor, and again strikes the other conductor, and so on.

Experiment III.

(306.) On the same principle is constructed the well-known apparatus, called the electrical bells, represented in *fig.* 98.

Fig. 98.



A B and C D are two metal rods supported on a glass pillar, E F. From the ends of these rods four bells, A′, B′, C′, D′, are suspended by metallic chains. A central bell, G, is supported on the wooden stand which sustains the glass pillar E F; and this central bell communicates by a chain, G K, with the ground. From the transverse rods are also suspended by silken threads four small brass balls, H. The transverse rods, being put in communication with the conductor of an electrical machine, the four bells A′, B′, C′, D′, become charged with electricity. They attract and then repel the balls H, which, when repelled, strike the bell G, to which they give up the electricity they received by contact with the bells A′, B′, C′, D′, and this electricity passes to the ground by the chain G K.

The bells will thus continue to be tolled as long as any electricity is supplied by the conductor to the bells A′, B′, C′, D′.

Experiment IV.

(307.) Let a skein of linen thread be tied in a knot at each end, and let one end of it be attached to some part of the conductor of the machine. When the machine is worked the threads will become electrified, and will repel each other, so that the skein will swell out into a form resembling the meridians drawn upon a globe.

Experiment V.

(308.) Let a metallic point be inserted into one of the holes in the prime conductor, so that, in accordance with what has been explained, a jet of electricity may escape from it where the conductor is electrified. Let this jet, while the machine is worked, be received on the interior of a glass tumbler, by which the surface of the glass shall become charged with electricity.

If a number of pith balls be laid upon a metallic plate communicating with the ground, and the tumbler be placed with its mouth upon the plate, including the balls within it, the balls will immediately begin leaping violently from the metal and striking the glass; and this action will continue till all the electricity with which the glass was charged has been carried away.

This is explained on the same principle as the former experiments. The balls are attracted by the electricity of the glass, and when electrified by contact are repelled. They give up their electricity to the metallic plate, from which it passes to the ground; and this process continues until no electricity remains on the glass of sufficient strength to attract the balls.

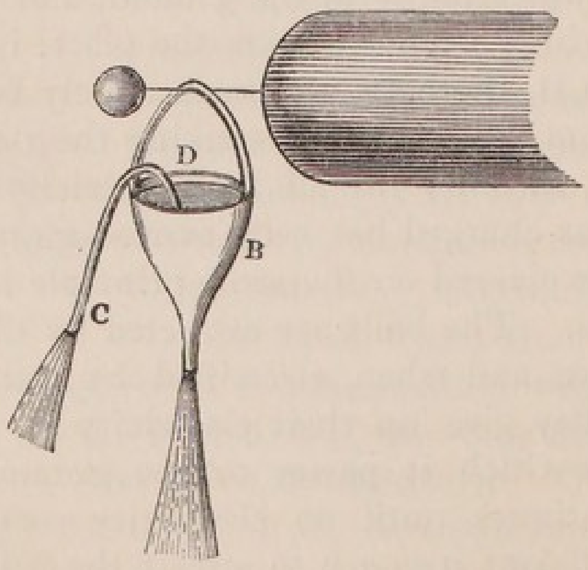
Experiment VI.

(309.) Let a disc of pasteboard or wood, coated with metallic foil, be suspended by wires or threads of linen from the prime conductor of an electrical machine; and let a similar disc be placed upon a stand, capable of being adjusted to any required height. Let this latter disc be placed immediately under the former, and let it have a metallic communication with the ground. Upon it place small coloured representations in paper of dancing figures, which are prepared for the purpose. When the machine is worked the electricity with which the upper disc will be charged will attract the light figures placed on the lower disc, which will leap upwards, and after touching the upper disc, and being electrified, will be repelled to the lower disc; and this jumping action of the figures will continue as long as the machine is worked. An electrical dance is thus exhibited for the amusement of young persons.

Experiment VII.

(310.) Let a small metallic bucket, B (*fig.* 99.),

Fig. 99.



be suspended from the prime conductor of a machine, and let it have a capillary tube, C D, of the siphon

form immersed in it; or let it have a capillary tube inserted in the bottom, the bore of the tube being so small that water cannot escape from it by its own pressure. When the machine is put in operation, the particles of water becoming electrified will repel each other, and immediately an abundant stream will issue from the tube; and as the particles of water, after leaving the tube, still exercise a reciprocal repulsion, the stream will diverge in the form of a brush.

Experiment VIII.

(311.) If a sponge, saturated with water, be suspended from the prime conductor of the machine, the water, when the machine is first worked, will drop slowly from it; but when the conductor becomes strongly electrified, it will descend abundantly, and in the dark will exhibit the appearance of a shower of luminous rain.

Experiment IX.

(312.) Let a piece of sealing-wax be attached to the pointed end of a metallic rod; set fire to the wax, and when it is in a state of fusion blow out the flame, and present the wax within a few inches of the prime conductor of the machine. Strongly electrified myriads of fine filaments will issue from the wax towards the conductor, to which they will adhere, forming a sort of net-work resembling wool. This effect is produced by the positive electricity of the conductor decomposing the natural electricity of the wax; and the latter being a conductor when in a state of fusion, the negative electricity is accumulated in the soft part of the wax near the conductor, while the positive electricity escapes along the metallic rod. The particles of wax thus negatively electrified, being attracted by the conductor, are drawn into the filaments before mentioned. *(Leithead on Electricity.)*

CHAP. XV.

ON THE ELECTRICITY EVOLVED BY THE FRICTION OF WATER AND STEAM AGAINST OTHER BODIES.

(313.) One day in the autumn of 1840, a workman at Sighill, near Newcastle, accidentally placed one of his hands in a jet of steam, which was issuing from a fissure in some cement of chalk and oil placed around the safety-valve of a steam-boiler, his other hand being at the time adjusting the weight on the lever; and he was greatly surprised at perceiving a spark, and receiving a smart electrical shock. Mr. Armstrong, of Newcastle, a gentleman attached to science, saw in a moment that this fact was the first fruits of a new line of research which was well worthy of pursuit, and he spared no pains in following it out. The results of his early enquiries appear in the November number of the *Philosophical Magazine.*

(314.) He found the boiler built in masonry: antecedently to his arrival, it had been cleaned from a deposit of calcareous matter, which had been followed by a great reduction of electric effects. About a week afterwards the incrustation had been regained, and the electric effects were increased. He attached a wire, having a metal plate at one end, and a brass ball at the other, to an insulating handle; and on placing the plate in a jet of steam, and the ball within a quarter of an inch of the boiler, he obtained sixty or seventy sparks per minute: he also readily charged a Leyden jar. The pressure of the steam at first was 35 lbs.; and, as it diminished, the electric action also diminished. He found the electricity of the *steam* to be *positive.* He could find no indications of electricity about the boiler, which was, indeed, in connection with the earth; and this, as we shall presently see (316.), was the reason

of its appearing neutral. He tried another boiler at Sighill, which, as well as the preceding, was supplied with *well water*, and succeeded in obtaining similar effects. On failing to obtain electricity from a third boiler, supplied with *pure water*, he inferred that the phenomena were partly due to the *nature of the water;* which, in the former case, contained sulphate of lime, oxide of iron, and insoluble argilaceous matter. Professor Faraday, in a note to the above, conceives that the phenomena might be due to an exaltation of the known effects of evaporation,—those of which mention is made hereafter. (*Atm. Elec.* § 6.)

(315.) Mr. Armstrong subsequently went through a regular series of experiments, in order to determine the situation at which the vapour first commenced being electrized; whether it is so *in the boiler*, or becomes so during its passage *through the orifice*, or only when it escapes *into the air*. Before commencing the experiments, he blew off some steam through a stop-cock *close* to the boiler, and obtained no electrical effects; which was proof sufficient that they are not due, as he at first thought, to the *character of the water* in the boiler; for, in this case, it was the same well water as that previously employed. His arrangement for determining the locality of electrization was this — he affixed to the above mentioned stop-cock a glass tube, having a stop-cock at the extremity, and another in the interval. On opening all three, the intermediate one gave no signs of electricity, whilst the upper one was highly *positive*. Whence it appeared to him probable that the electricity was not developed until the *escape of the vapour into the air*. But he felt it difficult to account for the absence of *negative* electricity, unless the extreme supposition were taken, that the condensation, which takes place in the jet, sets at liberty the electricity which the vapour had absorbed during its formation. He proved, however, that the vapour, when *in the boiler*, contained no free electricity, by introducing a metal point through the intermediate stop-cock, and then closing the latter to prevent the escape

of steam; for, under these circumstances, the metal gave no electrical indications.*

(316.) Mr. H. Pattinson describes † the results of some experiments he made with locomotive engines on the Newcastle and Carlisle Railway, to which he was led by Mr. Armstrong's discovery. In order to collect the electricity from the steam, he employed, first, a wire terminating in many points; and then a hollow truncated zinc cone, interlaced with copper wire, and furnished with a great number of points. The cone was three feet high, and its base three feet in diameter. He obtained sparks three or four inches long; and, by the latter of the two arrangements, he increased the *volume* of each spark, but not its length. He succeeded in *insulating* the locomotive on blocks of wood; and then was the first to find that, while the steam was charged with *positive*, the boiler was highly charged with *negative*, electricity. The inference he drew from his various experiments was the same as that suggested in Faraday's note, viz. that this liberation of electricity during vaporization is the same as that with which philosophers were already familiar, but on a much less extended scale. It appeared to him that the electricity was generated at the *moment of vaporization;* but he felt that this theory did not account for the variations of intensity, and the difference of intensity observed with boilers under the same pressure. He was induced to think it probable that a chemical action between the metal and the water exalts the electrical condition of the newly-formed vapour. In reference to this he notices that boilers, having copper tubes, give the greatest electrical effects. He concludes with remarking how curious a fact it is that locomotive machines are transformed into enormous electric machines, in which the *vapour* corresponds to the *glass plate* of a common machine, and the *boiler* to the *cushions;* and in this observation he unconsciously publishes the elements of *the true theory* which, as will

* Phil. Mag. Dec. 1840. † Phil. Mag. Nov. and Dec. 1840.

be seen in the sequel, was afterwards developed by Faraday (338.).

(317.) Mr. Armstrong, also, on continuing his experiments, insulated the boiler, and obtained no effects until the jet was opened, when the boiler was highly *negative;* and the *positive* state of the steam had certainly diminished in quantity. He found, also, that there was more electricity when the stop-cock was *partially closed* than when it was entirely open. He now was of opinion that, in proportion as the steam forms in the boiler, it *absorbs electricity* from neighbouring bodies, in order to obtain the neutral state; and that when, by condensation, this vapour returns to water, the electricity thus absorbed becomes free; and hence the positive electricity found in the jet; and that, if the boiler is insulated, it, as well as the uncondensed vapour contained in it, is negative, provided the vapour can escape, but not otherwise; for if the steam is retained in the boiler, the evaporation will not be attended with any *increase of volume,* and hence *absorption* of electricity cannot take place: whereas, when water is converted into vapour, its *capacity* is so altered, that it seemed to him rational to suppose that the quantity of electricity sufficient for rendering it neutral cannot be the same under both forms. He felt one serious objection to this theory, in the fact of its assuming that the boiler is *negative* independently of the *condensation* of the steam; and hence, if the exit of the steam be viewed exclusive of its condensation, there would be a development of *negative* electricity without an equivalent of *positive.**

(318.) M. Schafthœutl describes experiments † which he undertook (on finding scarcely any appreciable signs of electricity from a Perkins's boiler, under a pressure of 40 atmospheres) in order to determine whether this neutral effect were due to the absence of deposits in the boiler. He is the first to notice that the success of the experiments appears essentially to depend

* Phil. Mag. Jan. 1841. † Phil. Mag. Feb. and April, 1841.

on the quantity of *water, in very minute division,* which the steam carries out *with it,* which favourable circumstance is indicated by a peculiar noise; but he infers that the positive electricity is due to the condensation of the vapour, and the separation of the resulting water, and not to *friction.* He had suspected friction might occur in the *bell glass* wherein he condensed the steam; he therefore inverted the bell; and having placed some water in it, he allowed the steam to blow on the water, where condensation occurred, without friction, and electric effects were produced. He found, also, that distilled water, solution of common salt, or solution of sulphate of lime, under similar circumstances, produced the same amount of electricity.

(319.) Mr. J. Williams, in the *Phil. Mag.* for Feb. 1841, states that in 1838, on observing the repulsive character of the particles of steam, he thought them electrical; and that, on insulating the vessel in which the steam was formed, he found it decidedly negative when steam was blown off at a high pressure. He does not appear to have followed out this idea.

(320.) Pursuing his opinion of the development of electricity being due to change of capacity *, Mr. Armstrong examined the condition of jets of air, liberated under a high pressure, which he had condensed in a strong vessel to the amount of eight atmospheres. He found these jets, like those of steam, to be highly *positive,* while the vessel was generally *negative,* and sometimes furnished sparks a quarter of an inch long. The vessel was occasionally *positive;* this being the first indication of an anomalous effect often manifested in future experiments, and ultimately investigated by Faraday (332.). He succeeded better in *cold* and *moist* weather than *warm* and *dry;* and this tended to strengthen his opinion in favour of *condensation.*

(321.) M. Peltier gives the following observations † on the electricity of evaporation, as illustrating the

* Phil. Mag. Feb. 1841.

† Annales de Chim. et de Phys. Nov. 1840.

earlier experiments of Armstrong and of Pattinson.— 1. If a drop of pure water is placed in a red-hot platinum capsule, it undergoes certain tumultuous and giratory motions, during which the platinum remains dry: it then flattens out, wets the capsule, and is at once dissipated in vapour; but *no electrical* effects take place. 2. The same phenomena attend a weak solution of common salt, with the exception that it leaves behind it an incrustation of salt. 3. But when the incrustation is dissolved, by adding a second drop of the solution of salt, the water, thus more highly saturated, is gradually reduced in quantity; certain decrepitations succeed, attended by saline projections, and *simultaneously with them* negative electricity is developed. If the platinum is now cold enough to allow of being wetted, the liquid goes off *in vapour*, but with *no* electric effect. 4. The same occurs when salts themselves are used instead of solutions. The electricity, in these cases, is not produced when the superabundant water is being separated; but, at the moment when a *chemical decomposition* takes place, *i. e.* when the molecules of water of crystallization are released from combination. Whence he inferred that, to produce the effects observed by Mr. Armstrong, water, saturated to the point of *affording a deposit*, was necessary; also a high temperature; and that the electricity increases with the deposit, and varies with the temperature. He subsequently modified these views; and in a communication made to the Philomatic Society, Jan. 2. 1841, after alluding to the production of electricity from the vapour of *pure water* in a copper boiler, under high pressure, which with previous philosophers he found *positive*, while the boiler was *negative*, he says that the quality of the water, the pressure, *the form and material of the appendage forming the orifice*, vary the tension and the *nature* of the electricity.

(322.) M. de la Rive was of opinion* that thus far the various experiments had by no means established the cause whence so abundant a development of the

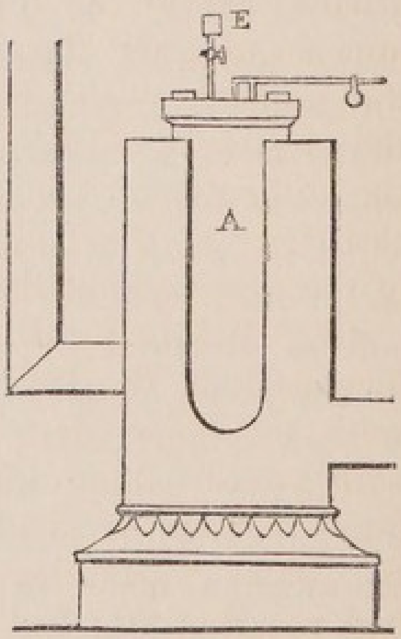
* Arch. de l'Elect. t. i. p. 174.

electricity of tension originated. Many of the experiments were in favour of vaporization, and in this respect the solution of the question had been approached, but not attained.

(323.) Mr. Armstrong pursued his inquiries, and besides confirming the facts relative to condensed air, he found that, when the air was *dried* by the presence of potash, almost the same effects occurred; it is fit to mention that the weather at the time was mild and *damp*. (336.) He found, on the other hand, that, if the vessel were made very dry by heat, no effects were produced. He noticed a peculiar noise attending some of the successful experiments, which appeared to correspond with that heard by Schafthœutl.

(324.) He had, by this time, at his command a boiler (*fig.* 99 *a.*), constructed for the special purpose of investigation. It was made of gun-metal, an alloy of copper and tin; was of cylindrical form, 30 in. by 4 in.; could be used with safety to 250 lbs. pressure per square inch, and was mounted on glass legs. A copper tube, E, proceeding from the top of the boiler, entered the furnace, and, after several coils, emerged laterally, when it was terminated by a stop-cock. This tube was for *drying* the steam. It could be removed at pleasure. In the course of experiments with this instrument, he discovered, with surprise, that the steam in some cases was *negatively* electrised, and the boiler *positively*. The only clue he could then obtain towards unravelling this mystery, which so overthrew his previous theories, was, that when the temperature of the upper part of the boiler was *very greatly elevated*, the change occurred; but he suspected there were other causes present. When he allowed the steam to escape *en masse* out of the safety-valve, *no* electrical

Fig. 99 *a.*



effects were obtained. On trying the comparative effects of steam at different pressures, with 3 lbs. he obtained 5 or 6 sparks per minute; he doubled this with 15 lbs.; tripled with 50 lbs.; quadrupled with 120 lbs., and not more than quintupled with 250 lbs. He does not appear to have been able to classify the various anomalies presented by the change of electric state; but he remarks that he has often obtained a *negative* jet from the tube, while a *positive* jet escaped from the safety-valve. By allowing the vapour to expand without condensing, by means of a *hot* metal cylinder affixed to the tube, he found that the steam, which passed on, was as much electrised as before; and hence he inferred *dilatation* was not the cause. Putting out of the question other causes, which were not influential, there appeared to him nothing left but to attribute it to the *precipitation of the vapour*, and he appears to trace the opposite condition of the boiler to the influence—the *inductive* influence apparently—of the electricity of the precipitated vapour; but he feels the difficulty of his position from the fact, that the electricity of the boiler appears altogether independent of the *proximity* of the jet.

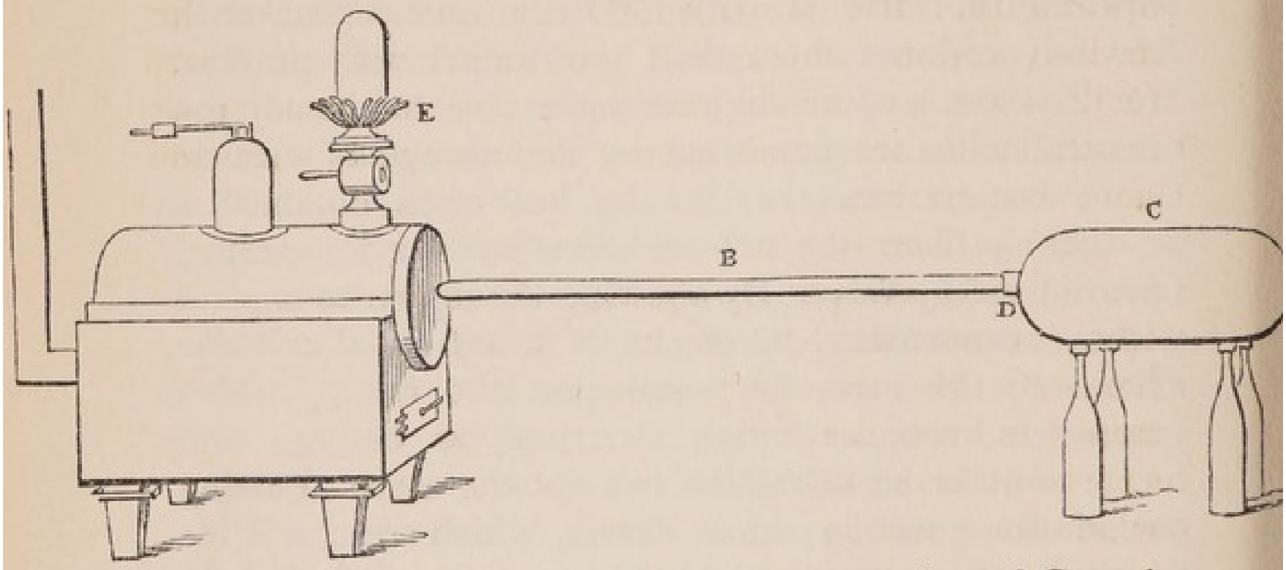
(325.) Finding that the *negative* tendency of the jet increased as the boiler was used, he was induced to wash the boiler first with water which did not, then with potash which did, restore it to its primitive condition. Soda acted like potash: a little nitric acid in the water made the vapours *negative;* hydrochloric had no effect, nor had sulphuric, even when iron filings were introduced; lime made the vapour *positive;* common salt, no effect; nitrate of copper, *negative.*

(326.) The idea now occurred to Mr. Armstrong of taking advantage of this new source of electricity in a practical point of view, for he conceived that a vaporo-electric apparatus might be constructed to supply the place of the common machine.* In pursuance of this idea he constructed† a boiler of forged iron (*fig.* 99 *b.*),

* Phil. Mag. May and July, 1841. † Phil. Mag. Jan. 1843.

three feet long and twelve feet diameter, with a series of steam jets at E. The rod B D and the conductor C

Fig. 99 *b.*



were subsequently added* at the suggestion of Captain Ibbetson. He had by this time discovered that the development of electricity takes place at the moment when the steam is subjected to *friction*, and that *hard wood* was the best material for it to rub against; and he also found it necessary that *water be mingled* with the steam in order to produce considerable effects; but he could not trace to *friction alone* the great developement of electricity which here took place, for the apparatus was *seven* times more powerful than a large electrical machine, so that it would appear he attributed the effects at that time to the *joint influence of friction and condensation.*

(327.) In the interval between the publication of the last letters of Mr. Armstrong, Professor Faraday was engaged in a series of researches, the results of which clear up many of the difficulties that had heretofore presented themselves.† His generating apparatus was an insulated boiler of the capacity of ten gallons, and he worked to two-fiths of our atmosphere.

(328.) At the outset, he satisfied himself that the electricity was neither due to *evaporation* nor *conden-*

* Proceed. Elec. Soc. p. 527.
† Phil. Trans. Part I. 1843, p. 17. Read Feb. 2.

sation; for if the valve were taken out, no electricity was manifested, though the evaporation was then very great: again, if the boiler were excited with resin, opening the valve produced no change. Moreover, he devised means which will be mentioned presently (332—334.), of making the boiler positive, negative, or neutral with the same steam, and therefore with the same evaporation.

(329.) Then he proved that *steam alone* is not sufficient. He attached to his boiler a horizontal tube, to which the "steam-globe" (*fig.* 99 *c.*) could be screwed: at the further side of the globe various forms of jet could be fixed, as (*fig.* 99 *d.*), which he terms the cone apparatus, and which is an admirable exciter. The following results are highly instructive:—

Fig. 99 *c.*

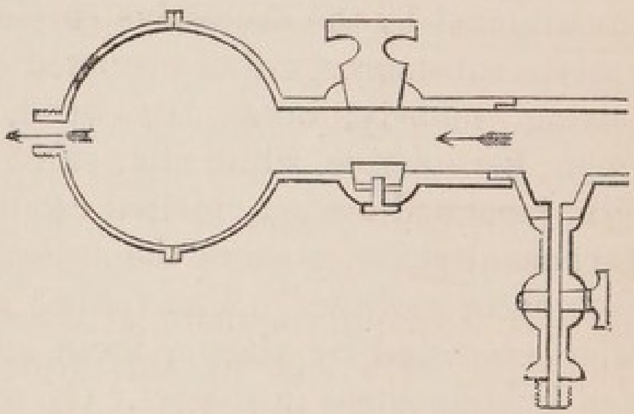
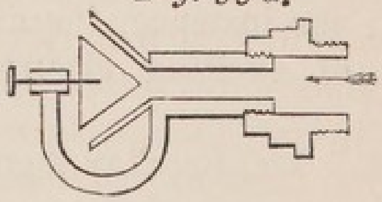


Fig. 99 *d.*



"If there be no water in the steam globe, upon opening the steam-cock, the *first effect* is very striking; a good excitement of electricity takes place, but it very soon ceases. This is due to water condensed in the cold passages, producing excitement by rubbing against them. Thus, if the passage be a stop-cock, whilst cold it excites electricity with what is supposed to be steam only; but, ás soon as it is hot, the electricity ceases to be evolved. If, then, whilst the steam is issuing, the cock be cooled by an insulated jet of water, it resumes its power. If, on the other hand, it be made hot by a spirit-lamp before the steam be let on, then there is *no* first effect. On this principle I have made an exciting passage by surrounding one part of an exit tube with a little cistern, and putting spirits of wine or water into it." (2089).

(330.) But the particles must be *pure water*. Distilled water in the globe produced the effect: the addition of common salt, sulphate of soda, nitre or sul-

phuric acid rendered the steam neutral; so did the common water of London. Potash, or any substances which gave conducting power to water, destroyed its exciting power as effectually as moisture destroys the exciting power of flannel. Ammonia, which adds but little to the conduction of water, did not destroy the power; but sulphate of ammonia, produced by the further addition of a little acid, did.

(331.) The influence of the *rubbed* substances he next investigated by the successive employment of "cones of various substances, either insulated or not; and the following, namely, brass, box-wood, beech-wood, ivory, linen, kerseymere, white silk, sulphur, caoutchouc, oiled silk, japanned leather, melted caoutchouc, and resin, all become negative, causing the stream of steam and water to become positive." The rubbed substances were likewise examined by placing them on insulating handles, and holding them in the jet. Of thirty substances thus tried, *all* were rendered negative though not in the same degree; for instance, "quill and ivory had very feeble powers of exciting electricity as compared to other bodies."

(332.) Mr. Faraday then alludes to the almost neutral effect of some bodies, especially ivory, already mentioned, and shows how it enabled him to test the series of substances by furnishing him with a neutral jet. He then adverts to effects produced by a positive jet, "which, if not understood, would lead to great confusion"—that a wire gauze, for instance, when in the jet *near the exit*, is rendered negative; because, as he explains, under such circumstances it is forcibly rubbed by the issuing stream; but if *further removed*, it is made positive, acting then only as a collector from the already excited stream; there is also a neutral point. These double effects do not occur with a neutral stream from an ivory jet.

(333.) He adds—

"With dilute sulphuric acid in the steam-globe, varying from extreme weakness to considerable sourness, I used tubes and cones of zinc, but

could obtain *no trace* of electricity. Chemical action, therefore, appears to have nothing to do with the excitement of electricity by a current of steam." (2106.)

The remarkable circumstance of water being *positive* to so many bodies, is then noticed; as also the probability that it may "find its place above all other substances, even cat's hair and oxalate of lime."

(334.) The effect of oil of turpentine in producing *negative* electricity in the steam, and *positive* in the boiler, is next described. "Hog's lard, bee's wax, castor-oil, resin applied dissolved in alcohol, these, with olive oil, oil of turpentine, and oil of laurel, all rendered the boiler positive, and the issuing steam negative." Some substances give variable results; but it is easy to comprehend that, according as a substance may adhere to the body rubbed, or be carried off by the passing stream, exchanging its mechanical action from rubbed to rubber, it would give rise to variable effects. These effects of oil involve the necessity of attention being paid to the condition of the screws connected with the various passages; for the unsuspected presence of a little oil may mar the effect of every arrangement; and perhaps some such influence may have been present to produce a few of the contradictory results we have noticed.

The author then goes on to explain how the introduction of oil virtually converts the watery globules, so far as their rubbing surface is concerned, into oil globules, by forming a film on their surface; and this, too, explains the "fact, that alkalined water, having no power of itself, should deeply injure the power of olive oil or resin, and hardly touch that of oil of turpentine; for the olive oil or resin would no longer form a film over it, but dissolve in it; on the contrary, the oil of turpentine would form its film."

(335.) Conceiving thus that steam, as such, was merely the mechanical agent to carry onward the rubbing particles, Mr. Faraday proceeded to experiment with compressed air, condensed into a strong copper box, which had been previously carefully cleaned from all

traces of oil by caustic potash: the average quantity of air which could be issued at each blast was 150 cubic inches. When common *undried* air was used, it rendered the cone negative, exactly as the steam and water had done.

"This," as the author expresses it, "I attribute to the particles of water suddenly condensed from the expanding and cooled air rubbing against the metal or wood: such particles were very visible in the mist that appeared, and also by their effect of moistening the surface of the wood and metal. The electricity, here excited, is quite consistent with that evolved by steam and water; but the idea of that being due to evaporation is in striking contrast with the actual condensation here." (2130.)

(336.) When the same experiments were repeated with *dry* air (dried by having placed potassa fusa in the box), it was found quite *incapable* of exciting electricity, precisely as had been proved to be the case with *dry steam*. The introduction of water, saline, or acid solutions, or the oils, in the course of the stream of common air, produced exactly the same effects "as if these substances had been carried forward in their course by steam."

(337.) A few experiments were tried, in conclusion, with the air current and dry powders. The results were somewhat irregular from the very nature of the rubbing materials, for in some cases they adhered to the cones and became the rubbed.

(338.) The memoir is terminated with the following deduction:—

"Finally, I may say that the cause of the evolution of electricity by the liberation of confined steam is not evaporation; and further, being, I believe, friction, it has no effect in producing, and is not connected with the general electricity of the atmosphere: also, that as far as I have been able to proceed, pure gases, *i. e.* gases not mingled with solid or liquid particles, do not excite electricity by friction against solid or liquid substances."

(339.) Several of the elements of this theory, as our readers have seen, had presented themselves to other philosophers; but until Mr. Faraday had investigated the subject, their connection had not been clearly developed, nor had those actions, which have no influence in the ultimate effect, been distinctly defined.

(340.) In the month of July, subsequent to the reading of this memoir, Mr. Addams illustrated the subject, before the members of the United Service Institution, by means of a boiler constructed for the lecture-room, which was heated by iron cylinders contained in tubes passing through the water. Without dwelling on the power of that instrument, we will conclude this chapter by a description of one on a gigantic scale constructed, by Watson and Lambert of Newcastle, for the directors of the Royal Polytechnic Institution, and just erected in the large lecture-theatre of their establishment; and to which Mr. Armstrong has given the name "Hydro-Electric Machine," in compliment to Professor Faraday, who has furnished so clear a demonstration of the influence of *watery particles* in producing the effect.*

ARMSTRONG'S HYDRO-ELECTRIC MACHINE.

(341.) *Fig.* 99 *e.* represents the machine. A is a cylindrical tubular boiler of rolled iron-plate; its extreme length is seven feet six inches, one foot of which is occupied by the smoke chamber, making the actual length of the boiler six and a half feet: its diameter is three and a half feet. The furnace B and the ash-hole C are contained within the boiler, and are furnished with a metal screen to be applied for the purpose of excluding the light during the progress of one class of experiments. D is the water guage. E the feed valve. F F two tubes leading from the valves I I to the two tubes G G. H H are forty-six bent iron tubes, terminating in jets; either half, or the whole, of which may be opened by means of the levers K K. L is a valve for liberating steam during the existence of the maximum pressure. M is the safety valve; N is a cap covering a jet, that is employed for illustrating a certain mechanical action of a jet of steam. O O, &c., are six stout pillars of green bottle glass, by means of which the boiler is insulated at three feet from the ground. P is the first portion of the

* Phil. Mag. Sept. 1843.

funnel, Q the second portion, which slides into itself by a telescope joint, so that the boiler may be insulated

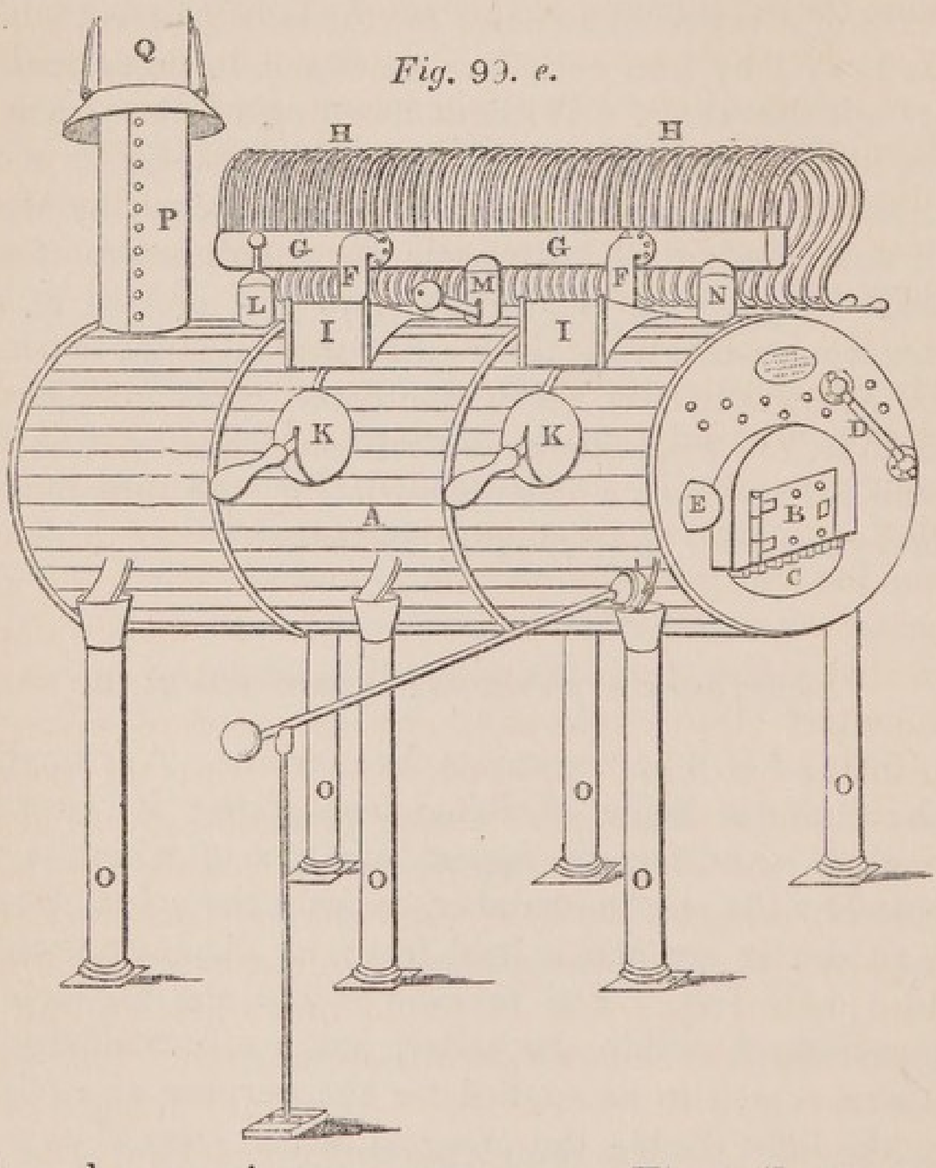


Fig. 99. e.

when the experiments commence. The boiler is cased in wood to reduce radiation of heat. *Fig.* 99 *f.* is a zinc

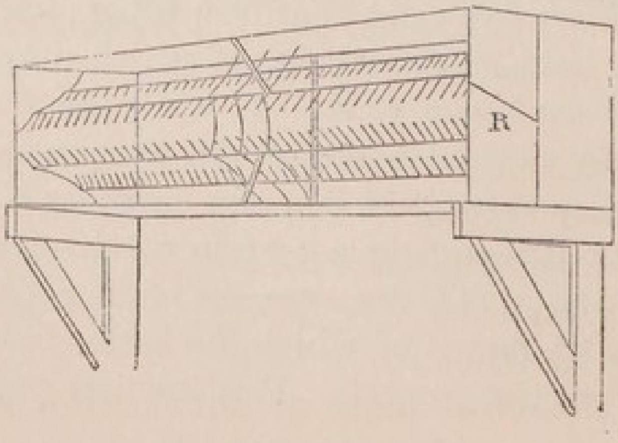


Fig. 99. *f.*

case, furnished with four rows of points, which is placed in front of the jets in order to collect the electricity from the ejected vapour, and thus prevent its returning to restore the equilibrium of the boiler. When a great quantity of electricity is required, the case is brought within a few inches of the jets; when long sparks are needed, it is moved to a distance of about two feet. The maximum pressure at the commencement of experiments is ninety pounds, which gradually gets reduced to forty or lower.]

[(342.) The portion of the apparatus, which is peculiarly connected with the generation of electricity, is the series of bent tubes with their attached jets. Mr. Armstrong very kindly superintended the structure of the boiler, and made repeated experiments in order to determine the most favourable conditions for obtaining the maximum effect. He had seen, with Professor Faraday, that moist steam is absolutely essential to the development of electricity; and, as high pressure steam is *dry* in the jet, which proceeds *directly* from the boiler, he has found a means of obtaining just sufficient condensation for the object in view, by interposing the bent tubes, H, between the boiler and the jets, where Faraday placed the "steam globe." For causes which are not at present apparent, he found that tubes of lead or tin were far less efficient than those of iron. The *form* and *material* of the jet exercise very great influence over the results. He has found partridge wood superior to any other material. The wood is formed into hollow cylinders, which are contained within an iron case, as in the annexed figure (*fig.* 100.). By this contrivance, Mr. Armstrong is of opinion, that a greater amount of friction against the inner sides of the cylinder is obtained. The particles of water may be thus regarded as the glass plate of an electric machine, to

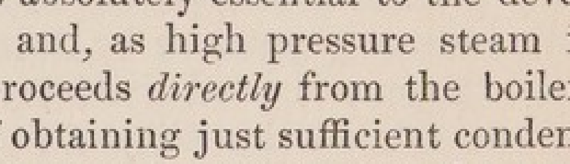


Fig. 100.

partridge wood as the rubber, and the steam as the rubbing-power.]

[(343.) The electricity produced by this engine is not so remarkable for its high intensity, as for its enormous quantity. The maximum spark obtained by Mr. Armstrong, in the open air, was twenty-two inches; the extreme length, under present circumstances, has been twelve or fourteen inches; but the large battery, exposing nearly eighty feet of coated glass, which, under favourable circumstances, was charged by the large plate machine seven feet in diameter, in about fifty seconds, is commonly charged by the hydro-electric machine in eight or ten seconds; and, on one occasion, was several times charged in three and a half seconds. The sparks which pass between the boiler and a conductor, are exceedingly dense in appearance. Their quick succession gives them more the character of the galvanic flame; indeed, they produce analogous effects; for instance, they not only inflame gunpowder by their direct action, but even ignite paper and wood-shavings, which never before occurred with the electricity of tension. Chemical decompositions also are much more readily effected by electricity of tension from this source than by that from any other. A series of electrolytic effects are given in the September number (1843.) of the *Philosophical Magazine*, to which we refer. The current, when passed through a galvanometer, caused the astatic needle to oscillate between twenty and thirty degrees; it also formed an electro-magnet, which deflected a needle.]

[(344.) The situation of this engine, in the same room with the colossal electrical machine (having a plate seven feet diameter, rotated by steam power), furnished a very favourable opportunity, not merely of contrasting the effects of the two, but of employing them simultaneously. On placing the large battery on an insulating stool, between the prime conductor and the boiler, and connecting the inner coating with the former and the outer with the latter, we several times failed in communicating a charge: on reversing connections, it was accom-

plished more readily, but in far longer time than would have been required by the boiler alone. Again, when the *aurora*, obtained by passing the electricity from the prime conductor through an exhausted tube four or five feet in length, was contrasted with that produced from the electricity of the boiler passing through the same tube, the latter was by many degrees more brilliant; but when the boiler was connected with one end of the tube, as it stood on an insulating stool, and the prime conductor with the other, the brilliancy greatly diminished. The first crude idea seemed to be that, if the earth in its *normal* condition could supply to the boiler electricity equivalent to the production of a certain effect in a certain time, the prime conductor in its *positively* charged state would produce a greater effect. But more mature reflection soon connected the fact of actual diminution of effect with the known laws; for, as the maximum supply of positive electricity which the conductor could furnish was at most not a *fourth* of that required by the negative boiler, and as the supply from the earth was *unlimited*, the whole equilibrium was restored in the one case, and only a portion of it in the other.*]

[(345.) Electrical developements, somewhat analogous to these, have lately been obtained by Dr. Elice, by firing a gun against the collecting plate of a condenser, or against discs of pewter, tin, glass, resin, wood, paper, &c.; in all cases, he found the body, against which he fired, positively electrized. He detected electricity in the gun itself, but not to any extent. He obtained similar effects from the discharge of an air-gun, the discs being, as before, positive. But no electricity was evolved from the mere burning of gunpowder on the plate of the electroscope. These effects are evident illustrations of the friction of watery particles against other bodies, and are strong confirmations of the accuracy of Mr. Faraday's views.]

* Abstract from Elect. Mag. No. 2. Oct. 1843.

BOOK THE SECOND.

ATMOSPHERIC ELECTRICITY.

CHAPTER I.

ON THE ELECTRICITY OF THE ATMOSPHERE IN CLEAR WEATHER.

(1.) Among the innumerable relations of the electric fluid with the phenomena of nature, there are none which present so many circumstances of general interest as its connection with the various states and appearances of the atmosphere. Indeed, it were difficult to name any atmospheric change which is not directly or indirectly connected with electric agency. It is true that these phenomena, fugitive and transitory as most of them are, have not been, in every case, traced to their causes; that the relation of many of them to the agency of electricity is rendered probable from general appearances, rather than distinctly and satisfactorily demonstrated; that some of them, which are evidently of electric origin, nevertheless have not been explained by or reduced to any of the known laws which govern that physical agent; — still, there is much that falls under the general principles of electrical science; and those phenomena which remain without any, or without satisfactory explanation, require to be stated, that those who pursue this part of physical science, with the view

to extend its limits, may be guided to the proper subjects of observation and investigation.

We shall first, then, state generally the apparatus used for observing the electric state of the air, and shall next proceed to explain the results at which those philosophers have arrived whose attention has been directed to atmospheric electricity.

I. *Apparatus for observing the Electricity of the Atmosphere.*

(2.) To construct a stationary apparatus for observing the electric state of the air, let a rod of iron, from twenty to twenty-five feet in length, be erected at the top of the building in which the observatory is placed, and let it be carefully insulated at the points where it meets the roof and other parts of the building. The lower parts of this rod should be in metallic communication with an electroscope placed in the observatory, by means of a chain or bar capable of being removed at pleasure. A moveable communication should also be provided between the pointed rod and a metallic bar continued to the ground, so that in cases of thunder storms, or at any other time when the electricity of the air is so strong as to be attended with danger, it may be allowed to escape to the earth by putting the pointed rod in communication with this conductor. If it be desired to observe the electric state of the air when it is strongly charged, the bar connecting the pointed rod with the conductor may be brought so near the latter as to allow the chief part of the electricity to pass through it to the ground; and, at the same time, the connection of the electroscope with the pointed rod being preserved, a sufficient quantity of electricity will affect it to indicate the species of electricity with which the air is charged.*

* For a detailed account of an apparatus of this kind, see Read, Phil. Trans. 1792.

(3.) For occasional observations a convenient and portable apparatus may be formed with a common fishing-rod, which is divided into several pieces capable of being united at pleasure, so as to form a single rod of considerable length. To the extreme piece of this let a rod of glass, terminated by a fine metallic point, be attached ; a metallic wire attached to this point is carried to the electroscope, which will thus receive the electricity collected by the the point of the rod. This rod may be elevated in any situation in which it is desired to examine the electric state of the air.

(4.) Various forms of electroscopes, some of which have been already described in Book I. Ch. XI., are used to observe atmospheric electricity. Saussure used two fine metallic wires, each having a small pith ball suspended at its lower extremity, and having its upper end attached to a rod of metal inserted in the top of a square tube of glass about two inches in the side. The two balls were suspended in contact in the interior of this tube, and the extent of their divergence was measured by a scale drawn on one of the sides of the tube. To the upper extremity of the rod supporting the wires was screwed a pointed conductor, composed of three parts fitting into each other, each measuring from three to four inches in length. This conductor, being elevated in the air, collected the electricity. To preserve the electroscope from the effect of the weather, a brass cap was provided, which was screwed upon the rod supporting the wires at the foot of the conductor.

This apparatus is usually affected sensibly by the electricity of the air, when raised in the atmosphere to the height of ten or twelve feet above the head of the observer. In order to compare numerically the intensity of the electricity which produces different degrees of divergence of the wires, Saussure adopted the following ingenious method. Having constructed two electroscopes as similar to each other in all respects as possible, and removed the conductors from them, he electrified one of them so as to produce a certain

divergence, six lines for example, of the balls. He then brought into contact the metal rods of the two instruments, so as to share equally between them the electricity with which the first was charged. The divergence was now reduced to four lines. Hence electric charges in the ratio of 1 to 2, corresponded to divergences of the balls in the ratio of 2 to 3. The second electrometer being discharged and again put in communication with the first, the remaining charge of the latter was again shared equally between them, so that the first remained charged with only a fourth of its original electricity. The separation of the balls was now found to be 2·8 lines. By continuing this process, a table was constructed by which the ratio of the intensities of the electricity could always be approximatively inferred from the extent to which the balls were separated. It is evident that such a table will not be the same for all electroscopes. Each observer must, therefore, construct, from immediate observation, a table suitable to the individual electroscope which he uses.

Volta used, for a like purpose, an apparatus similar to that of Saussure, but adopted the straw electroscope. He assumed that the angles of divergence of the blades of straw within the limits of 26° are sensibly proportional to the intensities of the electric charges, and that, provided the blades exceed an inch or two in length, the results are not affected by any small variation of length. It is safer, however, to construct a table according to the method explained above, whatever be the form of the electroscope.

To augment the sensibility of the instrument, Volta also fixed a lamp to the point of the conductor (Introd. 99.), and interposed a condenser between the conductor and the electroscope. Both of these expedients, however, render the indications of the instrument uncertain. In the process of combustion electricity will be liberated, the effects of which will combine with that of the atmosphere in affecting the electroscope; and unless the plates of the condenser be formed of gold or

platinum, or be coated with these metals, their oxidation by the deposition of moisture upon them would produce disturbing effects.

(5.) In some cases, the *multiplier* or *galvanometer* is advantageously applicable for meteorological purposes. Since, however, the electric current transmitted through it in such applications has greater intensity than that which is produced in voltaic arrangements, greater precautions must be taken to insulate the wire. For this purpose the wire, wrapped in the usual manner with silk, may be immersed in a concentrated solution of gum lac in alcohol. When well coated with this varnish, the electricity will not escape from one convolution to another. These instruments will be more fully explained hereafter.

In the application of the multiplier to detect the electricity of the air, one extremity of the wire is attached to the foot of a pointed insulated conductor elevated to the proper height in the atmosphere, and the other extremity communicates with the ground. The air and the earth being in opposite electrical states, a current will pass through the wire, the intensity of which will be indicated in the usual manner by the deviation of the magnetic needle.

II. *Of the ordinary State of the Atmosphere.*

(6.) One of the earliest results of the observation of the electrical state of the air was the discovery of the fact, that, in clear weather, when the natural state of the atmosphere is undisturbed by clouds, *it is always charged with positive electricity, and the surface of the earth is, on the contrary, charged with negative electricity.*

Volta explained this fact, by stating that in the evaporation of water the natural electricity of the liquid is decomposed, the positive fluid escaping with the vapour, and the negative fluid remaining on the vessel in which the liquid is evaporated; and, this process going on upon a large scale in the oceans, seas, and other large collections

[of water, might charge the atmosphere with free positive electricity. But we have seen from Peltier's experiment, that mere evaporation without *chemical* decomposition is not enough; we have seen, too, from Armstrong's and Faraday's experiments, that mere evaporation without *friction* is not enough; we are hence led to modify our views, and consider how far chemical effects and friction can be included as operating causes in the electrization of the atmosphere.]

[(7.) It is certain that such essential* chemical effects, as the liberation of particles of water of crystallisation from combination with salts, do not exist in the evaporations to which common consent has ascribed the electricity of the atmosphere, and philosophers have felt that the cause here assigned is inadequate to the effect. If they tacitly accept the theory, it is rather for want of a better, than from any feeling of conviction. They cannot imagine the connecting links between its assumed chemical origin and its ultimate conversion into the lightning-flash.]

[(8.) As the friction of watery particles is a discovery only just matured, the idea has not yet occurred of including it in the investigation of atmospheric electricity. Though the present state of our knowledge does not justify us to hazard an answer, yet we are called on to propose the question — Do the watery particles with which the atmosphere is charged acquire positive electricity as they are rubbed by the wind against the earth, and all it sustains, as hills, rocks, trees, &c., in the same manner as the stream of steam and water becomes positive by rubbing against the jet? If so, what connection may not be traced between the hurricane winds of the tropics and the prevailing lightning storms with which those regions abound? Does the friction together of two currents of air, charged to different degrees with moisture, develope the two electrical states?]

* Vide chap. xv. s. 321.

[Throwing out these hints, we come to consider the actual conditions presented by the atmosphere. The first fact which presents itself, is the extreme irregularity in the distribution of the electricity: and this would necessarily ensue from either theory; for local variation is an essential element in any view which we may be induced to adopt. Each theory includes evaporation, either as producing the electricity, or as providing the rubbing particles; so that, in the sequel, we may safely adopt the current language, without pledging ourselves against conviction to either theory, in the present undecided state of the question.]

(8.) If the evaporation or other processes by which positive electricity is supplied to the atmosphere were uniform over the surface of the globe, the spherical shell of air by which the globe is enclosed would be uniformly charged with positive electricity, and, being a non-conductor, it would be related to the crust of the globe on which it rests in the same manner as the cake of an electrophorus is related to the metallic disc in contact with it. The positive electricity of the atmosphere will then act by induction on the natural electricities of the superior parts of the earth; and, if we suppose them to possess conducting power in the same degree throughout the surface, the positive fluid resulting from the decomposition would be driven downwards, while the negative fluid would be drawn towards the surface, and would augment the intensity of the negative fluid already collected there from other causes.

Thus, the atmosphere over different parts of the surface of the earth will receive different quantities of electricity; and, since air is a non-conductor, the inequality of the electric state thus produced will continue, except so far as it may be modified by the effects of atmospheric currents.

III. *Diurnal Variation of the Electricity.*

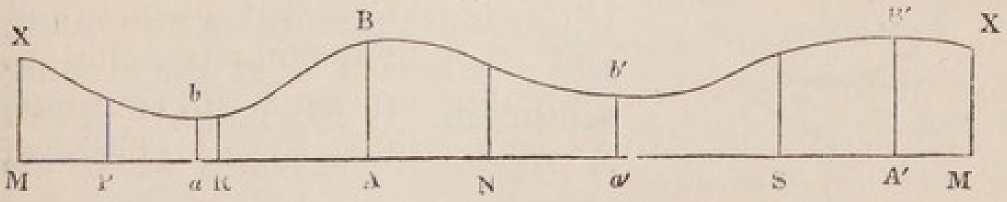
(9.) The electric state of the air depending then on the results of the evaporation of water on the

surface, that state may naturally be expected to be subject to periodical changes corresponding in some definite manner to the changes incidental to the process of general evaporation ; and, as these latter changes must be related to the influence of the sun on the atmosphere, a series of vicissitudes in the electricity of the air may be looked for, having some correspondence with the rising and setting of the sun and the epochs of noon and midnight. Observation accordingly sanctions this anticipation.

If the electricity of the air be examined by proper electroscopic instruments at and immediately after midnight, its intensity will be found to be gradually decreasing ; and this decrease will continue till a little before sunrise, when the intensity, becoming stationary for a short time, will afterwards begin to increase at a slow rate. This increase will continue, becoming more rapid for some hours after sunrise, when it will attain a maximum ; after which it will again decrease, at first slowly, and afterwards more rapidly. This gradual decrease will continue for some time after the sun passes the meridian, when it will cease, the electrical intensity again attaining a minimum. It will then begin to increase, at first slowly and afterwards more rapidly, until it attains another maximum some time after sunset. It will then begin to decrease, and continue to decrease until midnight.

(10.) If the line M N M (*fig.* 101.) be imagined

Fig. 101.



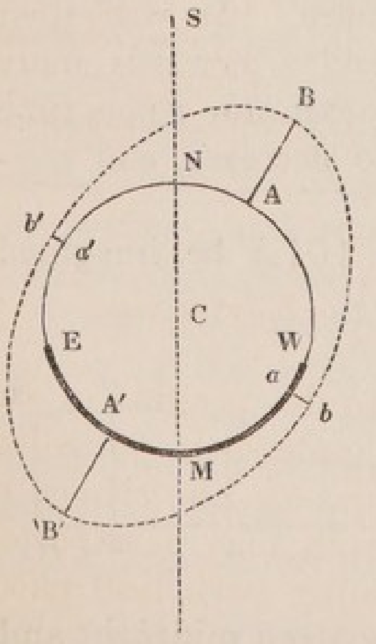
to represent the interval of time between midnight and midnight, its middle point, N, representing the intermediate noon, and the other points the various hours before and after noon ; and if from each point, such as

P, a perpendicular be drawn representing the intensity of the atmospheric electricity at the hour corresponding to P, a curve would be formed, the distances of which from the line M N M would represent the electric state of the atmosphere.

The undulating line X *b* B *b*′ B′ X then represents, in its general character, the diurnal variation of the electricity of the atmosphere when the weather is clear and no extraordinary disturbing influence intervenes to modify the common effects. The points *a* and *a*′ represent the times of the morning and evening minima, and the perpendiculars *a b* and *a*′ *b*′ the values of these minima; and the points A and A′ represent the morning and evening maxima, and the perpendiculars A B and A′ B′ the values of these maxima.

(11.) If, throughout the same parallel of latitude, no disturbing cause be supposed to be in operation, and the production of electricity in the same position of the sun be every where the same, the state of the electricity of the air around the parallel may be represented in a similar way. Let E N W M (*fig.* 102.) represent the parallel; E N W the enlightened, and E M W the dark part; C S the direction of the meridian passing through the sun.

Fig. 102.



At the point N the time will be noon, and at M it will be midnight; at E it will be sunset, and at W sunrise. The point *a* represents the place where the electricity is at the morning minimum, and *a*′ where it is at the evening minimum. In like manner, A and A′ represent the places where the electricity is at the morning and evening maximum. The curve of electric intensity has therefore the form of an oval; the longer axis, B B′, being inclined at a small angle to the direction of the sun; and the lesser axis, *a a*′, being at

right angles to it. As the position of the sun is gradually changed by its apparent motion from east to west, these axes of the oval follow it, always keeping the same relative position with respect to it in the absence of disturbing causes.

(12.) The first philosopher who presented a complete and connected series of observations on the electricity of the air was SCHUBLER; who observed at Stuttgard, and published his observations, taken at various hours, daily, from May 1811 to June 1812. As an example of the actual succession of changes exhibited in a single day, the following table of the observations taken on the 11th of May, 1811, will serve.

Hour.	Electrometer.	Hygrometer.	Thermometer.	Weather.
4 A. M. 5 6 7 8	+ 5 + 6½ + 8 + 11 + 12	88 88 87 86 84	+ 9·3 + 9·5 10·5 12·1 13·5	Perfectly clear. After a short time the heavens became vaporous, and dew began to fall.
9 10 12 2 P. M. 4 5	+ 10 + 8 + 7 + 6½ + 5½ + 5	76 70 63 61 60 62	15·5 17·0 20·1 21·6 21·3 20·9	The heavens clear to the horizon; the tint of the firmament a pure blue.
6 7½ 8½	+ 6 + 8 + 12	65 72 83	20·0 17·5 15·5	Vapours begin to be formed, and dew falls.
9½ 10½ 12	+ 8 + 7 + 6½	86 88 88	13·0 12·1 11·0	Heavens perfectly clear.

IV. *Annual Variation of the Electricity.*

(13.) As the diurnal change in the position of the sun, relatively to a given place, produces a periodical variation in the electric state of the air, the change of its declination, from month to month, may be expected to be followed by some corresponding periodical effect on the mean amount of the maxima and minima values of the electricity. On comparing the mean values from month to month, it is accordingly found that the values

of the two daily maxima and minima undergo a progressive decrease from January to July, and a progressive increase from July to January. It is found, also, that during the winter the electricity of the air increases as the thermometer falls.

On comparing the mean values of the maxima and minima throughout the year, it is found that the morning values of each are a little less than the evening values.

The hours at which the electricity attains its maxima and minima values are, likewise, subject to variation from month to month. The hour of the morning minimum and maximum continually advances towards noon from winter to summer, and undergoes the contrary change in the latter part of the year.

The observations of Schubler indicate that the hour of the evening minimum is invariable. From June 1811 to June 1812, it took place at Stuttgard always at 2 P. M. The hour of the second maximum also gradually approached nearer to noon from summer to winter, and receded from it again from winter to summer.

(14.) The series of observations on the diurnal changes of atmospheric electricity which Schubler made in 1811–12, were repeated by M. Arago at Paris in 1830, who obtained similar results. Thus, in the month of March 1811, Schubler found that the mean time of the morning maximum was 8 h. 30 m.; and M. Arago found the mean time for the same month, 8 h. 48 m.

V. *Local Variations of the Electricity.*

(15.) In all the preceding observations, the sources which supply positive electricity to the air are supposed to be uniformly distributed on the surface of the earth. A great variety of local causes, however, interrupt this uniformity. Saussure's observations show

that the positive electricity of the air has greatest intensity in the most elevated places, and in those which are best insulated. In the interior of buildings, under trees, in the streets, courts, and other enclosed and sheltered parts of towns, no free electricity is found in the air. In the midst of squares and other open spaces in cities, on the quays, but more especially on bridges, it is even more intense than in an open flat country. In particular localities, such as Geneva, where fogs prevail which lie low and are not converted into rain, the positive electricity of the air is most intense.

(16.) Although the general correspondence between the diurnal and annual variations of the normal electric state of the air indicates, unequivocally, its dependence on the variation of the sun's declination, and the diurnal motion of that body, and the local variations accord with the hypothesis that evaporation is the chief source of the electricity of the air, still no complete and satisfactory explanation has yet been proposed for the diurnal and annual electric periods.

(17.) Schubler observed that some correspondence may be perceived between the diurnal variation of the magnetic needle, and the diurnal variation of the electricity of the air; and that if such correspondence be admitted, it would follow that both these phenomena must be ascribed to the same cause. But this correspondence is far from being so exact as to justify even a probable conjecture as to their identity of cause. The maximum variation of the needle *east* takes place at half-past eight in the forenoon, from which time till a quarter past one in the afternoon it turns gradually round towards the west, attaining its maximum western variation at the latter hour. From that time till half-past eight the following morning, it returns gradually eastward. The times of greatest eastward and westward variation correspond nearly to the times of the morning maximum and evening minimum; but there are no effects exhibited by the needle corresponding to the other maximum and minimum.

(18.) Becquerel proposes the following explanation of the diurnal variation of the electricity of the air. Towards the morning the electricity ought to have a feeble intensity, because the humidity of the evening and night has restored to the earth a part of the electricity which had been accumulated in the air. When the sun at its rising begins to warm the earth, evaporation is promoted, and positive electricity supplied to the air. Hence, after sunrise, for some hours the intensity of the electricity of the air will be augmented. When the sun has attained a certain elevation, and the heat has increased, the air is dried, and transmits with less facility the electric fluid accumulated in the higher regions of the air; electrometric instruments, therefore, placed near the surface of the earth, will indicate a diminution of electricity, even though the electric fluid should continue to be augmented in the higher parts of the air. As sunset approaches the air is cooled, becomes humid, and begins to transmit the electric fluid, accumulated in the higher regions, more abundantly to the earth. The electric intensity would, therefore, increase with the humidity and the dew until two or three hours after sunset. Finally, when the air begins to be exhausted the electricity again diminishes, and continues to decrease till the next morning. According to the same principles, the annual variation of the electricity is explained. In clear weather the mean intensity of the electricity of the air will be much less in summer than in winter; for the air in summer, being warm and dry, resists more strongly the transmission of the electric fluid accumulated in the higher regions of the atmosphere, while in winter the air, being more humid, produces a contrary effect.

VI. *Distribution of Electricity of the Air.*

(19.) Although the negative electricity of the surface of the globe be a consequence of the ascertained

fact, that positive electricity is supplied by it to the air, it is necessary, nevertheless, that it be ascertained by immediate observation. This has accordingly been done by different observers, at different times and in different places. Among the more recent observations of this kind, are those of M. Peltier. To ascertain the electricity of the ground, this philosopher used a multiplier, placing one extremity of the platinum wire in a humid part of the soil, and attaching the other end to a pointed metallic conductor raised in the air. When the air was sufficiently humid to give it a conducting power, a current was established through the wire, by which the needle was sensibly affected; and the deflection of the needle proved that the negative current came from the ground, and the positive from the air.

(20.) The negative electricity of the ground, and the positive electricity of the stratum of air contiguous to it, have a continual tendency to recombine and neutralise each other. From this cause the lowest stratum of air in clear weather, apart from disturbing causes, is found to be in its natural state. This effect extends to the height of three or four feet from the ground, above which height the positive electricity begins to be perceivable, and increases in its intensity in ascending, according to some definite law, which observation has not yet disclosed.

(21.) To ascertain the increase of electricity in the ascending strata of air, Becquerel and Breschet made some experiments on the Great Saint Bernard, according to a method suggested by Saussure. These electricians, selecting a convenient platform of ground near the monastery, extended upon it a piece of gummed sarcenet, about ten feet long and seven feet wide, upon which they unrolled a silk cord interlaced with metallic wire, measuring about 250 feet in length. They attached one end of this cord to the hook or rod which communicated with the straws of an electrometer, by means of a loose knot, in such a manner that, when drawn upwards, it would be detached from the electrometer

without disturbing the instrument. The other extremity of the cord was tied to the tail of an iron arrow, which was projected upwards by means of a bow with such a force that, attaining a height of more than 250 feet, it detached the lower end of the cord from the electrometer. As the arrow ascended, the electrometer showed a gradually increasing divergence, which soon became so considerable that the straws struck the sides of the case enclosing them. When the cord was detached, the instrument retained the electricity it had received, which, on examination, proved to be positive.

Hence it appears that from three feet above the ground to the height of 250 feet, the air is charged with positive electricity, constantly increasing in intensity; at least in localities like that in which this experiment was made.

Lest it might be supposed that the electricity obtained was produced by the friction of the arrow against the air, the experiment was repeated, projecting the arrow horizontally at the height of three feet from the ground. In this case no effect was produced on the electrometer.

(22.) Becquerel made experiments with a like object in clear weather, on the summit of the rock called *Sanadoire*, near the *Mont-d'Or*. This summit, separated from the surrounding mountains, is terminated by a platform of the extent of several square yards at the height of about 4600 feet above the level of the sea. The electrometer of Saussure was surmounted by a pointed conductor about twenty inches long. A divergence of the straws, amounting to an eighth of an inch, was produced when the apparatus was raised about three feet above the head. The divergence was doubled when a wire attached to the electrometer was projected upwards by means of a stone to the height of about thirteen feet, and when projected to greater heights the divergence continued to augment.

When the apparatus, elevated to a certain height above the head, and showing a certain divergence, was

carried down the side of the hill, the divergence gradually diminished, and disappeared altogether before attaining the foot of the hill.

(23.) In the ascent made in a balloon by MM. Gay-Lussac and Biot, the increase of positive electricity in the ascending strata of air was also rendered manifest. These philosophers attached a metallic ball to a wire about 170 feet long, and suspended it from the car of the balloon, the upper end of the wire being attached to an electrometer. The weather being perfectly clear, the instrument diverged with negative electricity. This result, which was in apparent discordance with the results of observation in general, was, however, easily shown to be consistent with them. The wire in this case supplied a conducting communication between two strata of air, one 170 feet above the other. If they were equally charged with the same species of electricity, the electrometer would not have been affected; for the natural electricities of the wire being placed between two equal and contrary decomposing influences, no decomposition would take place, and the wire would remain in its natural state. If, however, the two strata at the ends of the wire were electrified positively *in different degrees*, a decomposition of the electricities of the wire would ensue, the positive fluid being repelled towards that stratum having the weaker positive charge, and the negative fluid being attracted towards that stratum having the stronger charge. Since, then, the electrometer at the upper extremity of the wire showed negative electricity, it follows that the higher stratum was more intensely positive than the lower.

In a similar experiment made by Saussure, the electrometer was placed at the lower end of the wire, and, in accordance with what has been just explained, the instrument diverged with positive electricity.

(24.) The method of explaining the apparently inconsistent results of the experiments of Biot and Saussure, proposed by the former, is imperfect, unless it be ad-

mitted that the two strata of air are both *electrified positively;* for if they were both *electrified negatively,* the *lower stratum having the stronger charge,* the same effects would ensue; or even if they were differently electrified, the upper stratum being positive and the lower negative, the effects would be the same.

Strictly speaking, therefore, the consequence which legitimately follows from all observations made on the electricity of the air at different heights, by means of a vertical conducting rod or wire extending from the electroscope to the stratum of which it is desired to ascertain the electric state, is, not that the electricity with which the instrument diverges is that of the air in which the remote extremity of the conductor is placed, but that if E' be the electricity of the stratum in which the electrometer is placed, and E that of the stratum in which the remote end of the conductor is placed, then, when the instrument diverges with positive electricity, $E - E'$ will be positive, and when it diverges with negative electricity, $E - E'$ will be negative. If the species of electricity of either stratum be otherwise known, such an observation will indicate the species of the other stratum; but if not, it will only give a differential result.

VII. *Electricity of the Air in clouded Weather.*

(25.) The electric state of the atmosphere in clear and unclouded weather only has been hitherto explained. We shall now proceed to state the observations which have been made when the heavens are more or less charged with clouds, whether attended or not with rain, snow, hail, or other phenomena of storms.

(26.) From the month of June, 1811, to May, 1812, both inclusive, M. SCHUBLER observed the electricity of the atmosphere in clouded weather, and in times of rain, hail, and snow. In the table in p. 106, 107. a synopsis is given of the results of his observations.

(27.) An examination of the results registered in this table will establish the following conclusions: —

1°. That in stormy weather, in rain, hail, or snow, the electricity of the air is much more intense than at other times.

2°. That in such weather the electricity is sometimes positive and sometimes negative, and nearly as often the one as the other.

3°. That in such weather the electricity often undergoes sudden changes from positive to negative, and *vice versâ*.

4°. That in clouded weather, unattended by storm, rain, hail, or snow, the free electricity of the air is positive.

5°. That the intensity of this electricity is greater in winter than in summer.

Month.	Electricity of the Air in Times of Rain and Snow.				Electricity in clouded Weather.		Mean Temp.	Rain. French Inches.
	Maximum Intensity of the Electricity.		Mean Intensity of the Electricity.		Greatest Intensity.	Mean Intensity.		
	Positive.	Negative.	Positive.	Negative.				
June	+ 400, on the 1st, in a storm of rain. Hail at 5 o'clock.	− 600, on the 30th, in a storm, attended by heavy rain. The electrometer oscillated to + 400.	+ 235, for nine days.	− 275, for nine days.	+ 16	+ 20, on the 23d, at 6 A.M.	60½°	5·71
July	+ 600, on 3d, at 6 P.M., in a violent storm.	− 500, on 16th, at 4 P.M., in a violent storm, attended with rain. At the commencement it was + 50.	+ 400, for five days.	− 280, for five days.			62°	1·05
August	+ 500, on 20th, at 7 A.M., in a storm, attended with rain.	− 140, on 28th, at 4 P.M., attended with rain.	+ 290, for seven days.	− 80, for seven days.	+ 25	+ 30, on 19th, at 7 A.M.	58°	1·66
Sept.	+ 30, on 27th, at 7 P.M., in a light rain.	− 10, on 25th, at 11 A.M., in a light rain.	+ 30, for one day.	− 10, for two days.	+ 20·5	+ 25, on 18th, A.M.	52°	0·70
October	+ 38, on 4th, at 7 P.M., in rain.	− 60, on 29th, at 2 P.M., in heavy rain.	+ 26, for five days.	− 31, for six days.	+ 18	+ 30, on 28th, at 7 P.M.	52°	1·89
Nov.	+ 55, on 11th, at 5 P.M., in heavy rain.	− 50, on 12th, at 2 P.M., in rain.	+ 24, twice in rain, and once in snow.	− 25, three times in rain.	+ 18·1	+ 28, on 10th, at 2 P.M.	41°	0·84

Dec.	+60, on 23d, at 6 P.M., in snow and wind.	—400, on 24th, at 2 P.M., in rain and wind.	+32, nine times in snow, and once in rain.	—157, three times in rain.	+32·7	+36	35°	1·42
January	+70, on, 13th, at 2 P.M., in heavy snow.	—20, on 21st, at 7 P.M., in snow. It oscillated to +20.	+40, seven times in snow.	—17·3, twice in snow, and once in rain.	+34·1	+44, on 30th, at 6 P.M.	27½°	1·06
Feb.	+90, on 16th, at 7 P.M., in snow and rain.	—150, on 16th, at 5 P.M., in rain. It occasionally became +.	+41, twice in rain, and once in snow.	—44, eight times in rain, and once in snow.	+33·2	+55, on 4th, at 7 P.M.	37½°	1·72
March	+200, on 5th, at 2 P.M., in snow and hail.	—340, on 22d, at 5 P.M., in heavy rain. It oscillated to +110.	+74, six times in rain, and twice in snow.	—65, eight times in rain, and three times in snow.	+21·0	+21, on 20th, at 9 A.M.	39°	1·61
April	+50, on 9th, at 2 P.M., in snow.	—80, on 22d, at 8 P.M., in rain.	+40, for four days in snow.	—58, for five days in rain.	+15·5	+17, on 7th, A.M.	40°	1·26
May	+600, on 16th, at 8 o'clock, in a storm, attended with rain.	—600, on 29th, at 8 P.M., in a violent storm, with rain.	+186, with rain for nine days.	—179, in rain for six days.	+14·0	+14, on 20th, A.M.	52°	2·14
Mean	+600 = the greatest mean.	—600. —245.	+117, for seventy-one days.	—101, for sixty-nine days.	+22·5	+55·0	46°	21·06

CHAP. II.

ANALYSIS OF STORMS.

(28.) Since the epoch of the memorable experiments of Franklin, meteorologists, in all parts of the world where physical science is cultivated, have observed with increased interest the phenomena of thunder-storms. Although a great body of facts have been, by such means, accumulated, the general conclusions deducible from them are few; nor are even these few invariably sustained by that consistency and harmony of effects which are necessary to command universal assent. Indeed, the facts themselves, on which alone any safe and certain generalisations could be based, were isolated and scattered through the memoirs of the various scientific bodies to which their observers had originally consigned them; and many of the most important and valuable observations remained in unpublished memoranda, or were incidentally mentioned in the narratives of voyagers and travellers, where they were little likely to attract the attention of those who alone are capable of estimating their value, until, by the indefatigable zeal of M. Arago, they were collected, arranged, and compared, and presented to the world invested with all those charms of style which render the productions of that philosopher so universally attractive.* It is natural that the impatient student should desire to be supplied with clear and comprehensive principles, and be relieved from the tedious details of particular observations and experiments; that

* See *Notice sur le Tonnerre dans l'Annuaire du Bureau des Longitudes pour l'An* 1838.

facts should be laid before him in extensive groups and classes, so as to suggest easy and obvious generalisations. It is equally natural that the authors of elementary and general treatises should desire in every case to present the scientific truths in concise and general propositions, connected together by distinct logical relations. The temptation to yield to this disposition, by presenting all physical problems as completely resolved, and all elementary questions as completely exhausted, of laying down sweeping and general principles on matters which in fact are surrounded with difficulty and doubt, is most hurtful to the progress of science, and a great impediment to the developement of truth. To no part of physical science do these observations apply with more force than to the subject of the present chapter. That the phenomena of thunder and lightning proceed from sudden and violent derangements of the electrical equilibrium of the atmosphere, or the clouds which float in it, may be regarded as certain; and that the laws which are observed to prevail among electrical phenomena offer various analogies which afford explanations more or less plausible and probable, for some of the facts observed in thunder-storms, may be admitted. But that any comprehensive and general principles have been established, from which the various atmospheric phenomena in which thunder and lightning are exhibited can be deduced in the same manner, and with the same clearness and certainty, as the effects of common electricity have been deduced from the theory of Dufaye, Symmer, and Poisson, cannot be maintained. Under such circumstances both author and reader must patiently submit to the investigation of facts, separated from theory or hypothesis; and when these facts have been clearly and fully stated, such general consequences as they justify may be easily deduced from them, and the apparent discordances, which by comparison may be apparent among them, will afford grounds for further observation and inquiry to those who devote their labour to such researches.

I. *Of common Thunder Clouds.*

(29.) It is generally agreed that the formation of clouds is due to the partial condensation, in the upper regions of the air, of the vapours which have exhaled from the surface of the earth. This condensation may be effected by any cause which produces a diminution of temperature, and is probably, in most cases, the consequence of the mixture of two currents of air charged with vapour, and having different temperatures. The positive electricity, which rises into the atmosphere with the vapour, and which augments in intensity as the height increases, to the greatest elevation to which observation is extended, is collected in the clouds thus formed; and when the globules or vesicles composing the cloud have collected together in sufficiently close proximity, the cloud takes the nature of one continued conductor, and the free electricity accumulates on its surface in the same manner as on the conductor of an electrical machine. The existence of positively electrified clouds is therefore easily conceived.

If the electroscopic observations which indicate negatively electrified clouds be rightly interpreted, and the existence of such clouds be admitted, several hypotheses have been proposed to explain them.

If a cloud in its natural state, or feebly charged with positive electricity, approach another cloud strongly charged with the same electricity, the latter will exercise upon it an inductive action by which its natural electricities will be decomposed, the positive electricity being repelled to the most remote part, and the negative fluid being accumulated at the nearest part. If, under these circumstances, the most remote part be in contact with the earth, as it might be with the summit of a mountain, for example, the positive electricity will escape to the earth, and the cloud will remain charged with negative electricity. If any cause disengage this

cloud from contact with the earth it will float in the atmosphere, and afford an example of a negatively electrified cloud.

(30.) If two clouds, one or both of which are charged with electricity, approach each other, the same phenomena must be evolved as when two conductors, one or both of which are similarly charged, come together. If it happen (a circumstance against which the chances are almost infinite) that the quantities of free electricity with which they are charged have the same relation as they would have when the clouds are in contact, then their approach and subsequent contact will cause no change in their electrical state, save what would be due to inductive action. Their charges after contact will be the same as before, no electricity passing from either to the other. But if their electrical charges have not this particular relation, then a new distribution of electricity will be the consequence of their mutual approach; that which has less positive electricity than the condition of contact requires will receive the deficiency from the other, and this change will be effected by an explosion before the actual contact of the clouds, in the same manner as the electrical equilibrium of two conductors is established by the transmission of the spark before contact. The distance at which the explosion will take place, and its force, will depend on many circumstances; such as the difference between the actual charges of the clouds and the charges due to contact, the form of the clouds, and the state of the intervening atmosphere.

(31.) It is evident, therefore, that an electrical explosion may take place between two clouds, whether they are both similarly electrified or oppositely electrified, or one be electrified and the other in its natural state.

(32.) As the ground is *in general* negatively and the clouds positively electrified, a discharge will take place between the clouds and the earth, when the former approach the earth within such a distance that the force

of the electricity shall overcome the resistance of the surrounding air.

Since free electricity accumulates in great intensity at prominences and points of a conducting body, the negative electricity of the earth may be expected to be most intense at mountain summits. Clouds being in general charged with positive electricity, an attraction will consequently be exerted upon them, which, conspiring with the attraction of gravitation, will draw them round such summits.

(33.) The mutual approach of two clouds oppositely electrified is promoted by the attraction due to their electricities; but when two clouds are similarly electrified, they will repel each other, and their approach must be due to contrary currents of air passing through strata of the atmosphere at different elevations, by which the clouds are brought one under the other.

(34.) Beccaria, who observed at Turin, in Piedmont, in a country eminently favourable for such observations, being almost surrounded by lofty ranges, has recorded, with great precision, the appearances of the clouds precursive of a storm.* The observations of this philosopher being limited to the lower surface of the clouds, M. Arago has obtained some accounts of the superior surface, from the military engineers employed in the great trigonometrical survey, and who, being placed at elevated stations on the Pyrenees, were enabled to observe the superior surface of strata of clouds situate below them. From the reports of these officers, and especially those of MM. Peytier and Hossard, it appears that there is no correspondence between the state of the lower and upper surface of a stratum of thunder clouds; that when the inferior surface is perfectly even and level, the superior surface will be broken into ridges and protuberances, rising upwards to great altitudes, like the surface of the earth in an alpine district. In times of great heat, such strata were ob-

* See Introduction, pp. 61—64.

served suddenly to send upwards lofty vertical cones, which, stretching into higher regions of the air, established, by their conducting power, an electrical communication between strata of the atmosphere at very different heights. This appearance was generally observed to precede a thunder storm.

(35.) Franklin, Saussure, and most other meteorologists, have agreed that thunder never proceeds from a solitary isolated cloud. Franklin states, that if a thunder cloud be at any considerable distance from the zenith of the observer, so as to be viewed obliquely, it will be apparent that there are in every such case a series of two or more clouds situate at different elevations one below the other; and that sometimes the lowest of the series is not far removed from the surface of the earth.

Saussure states that he never witnessed lightning to proceed from a solitary cloud. In observations on the *Col du Géant*, when a single cloud, however dark and dense it might be, was seen upon the summit, no thunder was ever heard to issue from it; but whenever two strata of such clouds were formed one below the other, or if clouds ascended from the plain and approached that collected round the summit, the encounter was attended by a storm of thunder, hail, and rain.

Such is the negative testimony of Franklin and Saussure against the fact of thunder proceeding from solitary clouds. Franklin is even more circumstantial than Saussure, and maintains that thunder never proceeds from any save a cloud of great magnitude, below which are placed a series of smaller clouds, identical, in fact, with the adscititious clouds of Beccaria.

(36.) Negative evidence is, however, not conclusive against a fact, unless the witness be actually present at the time and place of its alleged occurrence. Had the eminent philosophers above mentioned consulted the records of science, their persuasion of the

impossibility of thunder issuing from a single cloud would have been shaken. It is related in a memoir of the academician *Marcorelle*, of Toulouse, that on the 12th of September, 1747, the heavens being generally cloudless, a single small cloud was seen from which thunder rolled and lightning issued, by which a female, by name *Bordenave*, was killed.

In his meteorological observations made at Denainvilliers, Duhamel de Monceau relates, that on the 30th of July, 1764, at half-past five A. M., in bright sunshine and a clear sky, there appeared a small dark solitary cloud from which thunder and lightning proceeded, by which an elm tree, near the château, was stricken.

Similar observations of lightning having issued followed by thunder from solitary clouds have been recorded by Bergman and by Captain Hossard, already mentioned.

(37.) M. *Duperrey* who commanded the French corvette *Uranie*, relates, that, being in the strait of Ombay in November, 1818, he saw a small white cloud in a clear sky, from which lightning issued in all directions. It ascended slowly in the heavens in a direction opposed to the wind, and was at a great distance from all other clouds, which appeared to be fixed upon the horizon. This cloud was round in its form, and did not exceed the apparent magnitude of the sun. Zig-zag lightning issued from it followed by thunder, which resembled the irregular discharge of musketry from a battalion commanded to fire at pleasure. This phenomenon lasted for about thirty seconds, and the cloud completely disappeared with the last detonations.*

(38.) Such are the evidences on the question whether the presence and proximity of a plurality of clouds be essential to the developement of the pheno-

* See Letter of M. Duperrey to M. Arago, in Becquerel, tom. vi. p. 401.

mena of thunder and lightning. The analogies offered by common electricity favour the supposition that two or more clouds are essential; and for this very reason the greater should be the caution in receiving the testimony of observers. It is difficult for those whose minds are prepossessed by a theory, to observe and record facts and appearances as they are: there is a disposition, sometimes,—perhaps often,—to see them as it is supposed they *ought to be*, and consequently the testimony of the ignorant is frequently more deserving of attention than that of the better informed. Be this as it may, the subject is one well worthy of attention, and all persons who happen to be located in regions where these phenomena prevail will have it in their power to contribute to the real advancement of science by carefully and accurately noting down what passes above them, more effectually than those who, with greater pretensions, attempt to build up theories which, at best, can have no other object than as means of classifying facts and guiding observers to the fittest objects of examination.

II. *Of Volcanic Thunder Clouds.*

(39.) The clouds of ashes, smoke, and vapour which issue from volcanoes, exhibit the phenomena of thunder and lightning. All observers, ancient and modern, concur in their evidence on this question. *Pliny the younger*, in his celebrated letters to Tacitus, speaks of the lightning which issued from the clouds in the eruption of Vesuvius, in the year 79 of the Christian era, in which his uncle, *Pliny the naturalist*, lost his life. *Della Torre* gives the same evidence respecting the eruption of 1182, and *Bracini* states that the column of smoke which issued from the same volcano in the eruption of 1631, and which spread in the at-

mosphere to a distance of forty leagues, was attended by lightning, by which many persons and animals were killed. The lightning in all these accounts is described as being tortuous and serpentine. The same description is given by *Giovanni Valetta* of the appearance of the eruption of 1707.

The inhabitants of the foot of the mountain assured sir William Hamilton that, in the eruption of 1767, they were more terrified at the lightning which fell among them than at the burning lava and other fearful circumstances attending the eruption.

Sir William Hamilton states, that, in the eruption of 1779, there issued from the crater of Vesuvius, together with the red-hot fluid lava, constant puffs of black smoke intersected by serpentine lightning, which appeared at the moment it escaped from the crater.

In 1779, the lightning was not attended by any audible thunder. It was otherwise in the eruption of the 16th of June, 1794, of which an account has been supplied by the same observer. During the latter eruption, the loudest and most continued claps of thunder were heard. The lightning was in this case productive of the usual effects. Houses stricken by it were destroyed, and the cloud of ashes from which these lightnings issued, were carried by the wind as far as Tarentum, a distance of 100 leagues from Vesuvius, where the lightning struck a building and destroyed a part of it. The ashes of which this cloud was composed were as fine as common snuff.

According to Seneca *, a great eruption of Etna in his own time was accompanied by similar effects, and the same phenomena are recorded by the Abbé Francesco Ferrara of the eruption of 1755.

When the island called *Sabrina*, in the neighbourhood of the Azores (which has since disappeared), rose from the sea in 1811, columns of intensely black smoke,

* Natural Questions, lib. ii. sect. 30.

composed of dust and ashes, ascended from the bosom of the deep, and were intersected, in their darkest and most opaque parts, by vivid lightnings.

The same appearances were observed in the small volcano which, in July, 1831, appeared between Sicily and Pantellaria.

(40.) It would be natural to ascribe the electricity of volcanic clouds to the aqueous vapour which is ejected mixed with the dust, ashes, and lava in great quantities from the crater; but this supposition is not so free from difficulties as to be admitted without some hesitation. In the eruption of Vesuvius in 1794, it is hard to conceive that the vapour should be carried uncondensed from Vesuvius to Tarentum; nor was there any thing in the appearances on that occasion which indicated the presence of any other substance in the cloud, save a fine dust. Yet the lightning struck a building at that place. According to the narrative of M. Tillard, who witnessed the phenomenon, columns of black smoke rose from the ocean before the island of *Sabrina* was formed. In this case, any aqueous vapour which might have been ejected from the submarine crater must have been condensed before the column reached the surface of the sea, and the smoke which rose into the atmosphere must have therefore been free from vapour, yet this smoke or cloud of volcanic dust was intersected by lightning.

III. *Of the Height of stormy Clouds.*

(41.) The distance of the clouds from which lightning proceeds is estimated by observing the interval of time which elapses between the moment at which the flash is seen and that at which the thunder is heard. It has been demonstrated, by certain astronomical observations, that light is propagated through space at the rate of about 200,000 miles in a second of time. This space being greater, in a vast proportion, than the

greatest distance at which any thunder cloud can be placed from the observer, it may be assumed, that the moment at which the lightning is seen is practically coincident with the moment at which it emanates from the cloud. It has, however, been also proved, that sound is propagated through the air at the rate of about 1100 feet per second. This rate is subject to some small variation, depending on the temperature of the air, but for our present purpose it may be taken at its mean value. If, then, the number of seconds be observed which elapse between the moment a flash of lightning is seen, and the moment the thunder consequent upon it is heard, and 1100 feet be allowed for each second in that interval, the distance of the place whence the lightning issues from the observer will be determined. Thus, if five seconds elapse, the distance will be 5500 feet; for six seconds, it will be 6600 feet, and so on.

If the cloud be vertically over the observer, this distance will be equal to its actual height above the level of the observer. If it be not vertical, then its angular elevation must be observed, and the height above the level of the observer will be obtained by multiplying the computed distance by the trigonometrical *sine* of the angular elevation.

(42.) The height of thunder clouds is also attempted to be determined by observing the effects produced upon objects, in elevated situations, stricken by the lightning which issues from them. If it be admitted that lightning always *descends* from the clouds towards the earth, then it might be inferred that the place where such effects are manifested must be lower than the position of the cloud from which the lightning proceeds; but if it shall appear that lightnings sometimes dart *upwards*, nothing respecting the height of the cloud can be inferred from such effects. Among those effects which lightning produces when it strikes the earth is the superficial vitrification of rocks. Such effects have been

observed on the summits of some of the highest mountains in South America by HUMBOLDT, on the summit of Mont-Blanc by SAUSSURE, and on the Pyrenees by Ramond.

(43.) In cases where no means have been taken by those who witnessed thunder storms to determine the height of the clouds from which they proceeded, the situations of the observers themselves afford a minor limit of the value of that height. BOUGUER and LA CONDAMINE were assailed by a thunder storm on one of the summits of the *Cordilleras* in Peru; SAUSSURE and his son encountered violent storms on the *Col du Géant*, and on *Mont Blanc*. MM. Peytier and Hossard witnessed thunder storms on the *Pic de Troumouse*, the *Pic de Baletous*, and the *Tuc de Maupas* in the Pyrenees.

(44.) Such are the principal observations, collected by M. Arago, made in mountainous localities. The comparison of the results of these, with the heights of thunder clouds computed from observations made in flat countries and at sea, would supply means of determining whether the developement of storms is affected by the density of the air in which the clouds float, or by their proximity to the surface of the earth. Thus, if it should appear that in clouds at the same height above the level of the sea storms are developed more frequently when these clouds are in the neighbourhood of mountains, and therefore at a comparatively small distance from the surface of the earth, it will follow, with a probability proportionate to the number and character of the facts observed, that the earth exerts an influence on clouds charged with electricity, independently of the atmosphere in which these clouds float.

The heights of thunder clouds observed in a flat country, or at sea, are obtained by the method first mentioned, that is, by observing the interval between the flash and the thunder, and measuring, or estimating, the angular elevation of the cloud. Unfortunately, the latter element of the computation has been very frequently

neglected by observers, the sole object having been, apparently, to determine the *distance* of the cloud from their station, and not its vertical height. In some cases it appears incidentally, that the cloud from which lightning issued was in the neighbourhood of the zenith, and consequently the *distance* may be taken as equivalent to the height. In some few the angular elevation has been observed and recorded, and consequently the vertical height of the cloud may be computed.

(45.) The following results of the labours of various observers have been collected by M. Arago.

Place.	Observer.	Date.	Height of thunder-stricken Rock above the Level of the Sea.	Vertical Height of Thunder Cloud above the Level of the Sea.	Observations.
			Feet.	Feet.	
Toluca, in Mexico -	Humboldt		15,154		
Summit of Mont Blanc	Saussure		15,777		
Mont Perdu (Pyrenees)	Ramond		11,185		
Pic du Midi (Pyr.) -			9,627		
Pichincha (Cord.) -	Bouguer and La Condamine			15,967	Storm mentioned by Bouguer, in his work on the figure of the earth.
Col du Géant - -	Saussure	5 July, 1788		11,382	The thunder in this storm succeeded the lightning without any sensible interval.
Mont Blanc - -				14,760	
Pic de Troumouse (Pyr.) - - -	Peytier and Hossard	1826		9,840	
Pic de Baletous (Pyr.)				10,496	
Tuc de Maupas (Pyr.)		1827		10,824	
Paris - - - -	De l'Isle	6 June, 1712		26,500	
Tobolsk (Siberia) -	Chappe	2 July, 1761		10,955	
		13 July, 1761		11,382	
Berlin - - - -	Lambert	25 May, 1773		6,232	
		17 June, 1773		5,248	
Pondicherry - -	Legentil	28 Oct. 1769		10,824	
Tobolsk - - -	Chappe	1761		from 700 to 2,600	

(46.) The height of thunder clouds, determined by other data, being, in some cases, greater than the heights of rocks vitrified by lightning, there is nothing in the comparison of the results exhibited in the preceding table to justify the supposition that the vitrifications observed by Humboldt, Saussure, and Ramond, did not proceed from lightning which issued from clouds at a

greater elevation. But, on the other hand, facts are not wanting to show that this inference cannot be certainly made. There is a church in Styria, erected on the summit of a lofty peak, called *Mount Saint Ursula*. *Jean-Baptiste Werloschnigg*, a medical practitioner, who happened to visit this church on the 1st of May, 1700, observed a stratum of dense black clouds to be formed below him at about half the elevation of the place where he stood. These clouds soon became the seat of a violent thunder storm. Meanwhile the heavens remained perfectly clear, the sun shining with unusual splendour. No one thought for a moment of danger; nevertheless a flash of lightning, ascending from the cloud, struck the church, and killed seven persons who were in company with Werloschnigg.

It is therefore clearly established that lightning may issue upwards from thunder clouds.

IV. *Of Lightning.*

(47.) Lightnings are resolved by M. Arago into three classes: — *First*, the *zigzag*, which present the appearance of narrow well-defined threads, or lines of light, following a course which is clearly enough expressed by their name. In colour they vary, being often white, but sometimes purple, blue, or violet. *Second*, those lightnings which appear diffused over extensive surfaces, and which are commonly called *sheet-lightning*. In colour these also vary, being often an intense red, but occasionally white, blue, or violet. This lightning has the appearance of a momentary light seen through a plate of glass, rendered semitransparent by having its surface ground. *Third*, lightning which moves through the air at a comparatively slow rate, appearing like a luminous ball or sphere, or like a globe of fire. Let us call this *ball-lightning*.

(48.) The almost incredible velocity, as will hereafter appear, of lightning of the first class, would hardly

seem compatible with the sudden and extreme changes of direction to which its motion is subject. This frequent reversion of direction has been more especially observed in the lightning which traverses volcanic clouds. Minute and circumstantial accounts of such appearances have been supplied by Sir William Hamilton, and others who have observed the eruptions of Vesuvius. In the eruption of 1707, described by Sorrentino, the lightnings which issued from the crater traversed the cloud of ashes as far as the Cape Pausillippo, where the cloud terminated; after attaining that point the lightning retraced its course, and struck the summit of the volcano.

Sir William Hamilton states that, in the eruption of 1779, the lightning was generally confined in its play to the cloud of ashes which extended towards Naples; that in traversing that cloud from the crater to its limit it seemed to menace the city with destruction; but it, nevertheless, after reaching the limit of the cloud, returned towards the cratér, where it rejoined the ascending column from which it originally issued.

Zig-zag lightning seldom flashes between two clouds. It is generally manifested between a cloud and some terrestrial object.

(49.) It has been supposed, that the extremity of the lightning of the first class has a barbed form, like the point of an arrow. Of this there is no sufficient evidence. It is, however, sufficiently ascertained, that it is often attended by the effect which has given it the name of *forked lightning*. Thus, when a single luminous line issuing from a cloud has traversed a certain distance, it will sometimes divide itself into two lines, which diverging at an angle more or less considerable, will strike distant objects. In some cases it has been seen to separate into three perfectly distinct lines. The former may be called *bi-cuspidated*, and the latter *tri-cuspidated lightning*.

Well-ascertained examples of these phenomena are rare: their occasional occurrence is not, however, the

less certain. The ABBÉ RICHARD states that he witnessed a flash of lightning, which left the cloud in a single line of light, and at some distance from the earth, dividing into two, each part struck a separate object.*

NICHOLSON states that, in a storm which broke over the west end of London on the 19th of June, 1781, being at Battersea, he saw distinctly several flashes of bi-cuspidated lightning.

The ABBÉ FERRARA relates that, on the 18th of June, 1763, he witnessed tri-cuspidated lightning in the clouds, which issued from the southern side of Etna during an eruption.

The German meteorologist, KAMTZ, states that he witnessed, on one occasion, and one only, tri-cuspidated lightning.

If the simultaneous destruction of two or more objects, in the same locality, by lightning, could be taken as conclusive evidence of a corresponding subdivision of a single flash, numerous examples might be given of multi-cuspidated lightning. Such grounds, however, are too conjectural to be admitted as the basis of any safe conclusions.

It is a general opinion that cuspidated lightnings, or lightnings of the first class, are those only by which terrestrial objects are stricken.†

* "Histoire Naturelle de l'Air et des Météores."

† If the reader has attentively considered the preceding paragraphs, and what has been elsewhere written on this subject, he will be sensible of a deficiency in the vocabulary of the English language as regards the effects necessary to be expressed. There are three distinct terms in the French language, *Le Tonnerre*, *L'Eclair*, and *La Foudre*. The first expresses the sound proceeding from the clouds, which usually follows the flash of light, and is properly translated by *thunder*. The second expresses the *light* which precedes the thunder; and the third expresses the actual *matter*, the *physical substance*, whatever it may be, which strikes terrestrial objects, and produces those effects which are so well known. In English, there is, properly speaking, no term corresponding to *La Foudre*. The terms *thunder* and *lightning* are indifferently used to express the same effect, as when we say *thunderstruck*, and *struck with lightning*. In French there is also the useful and necessary verb *foudroyer*, of which there is no better English synonyme than *to strike with lightning*. The term *thunder-bolt* corresponds to *La Foudre;* but it is scarcely admissible into the nomen-

(50.) The lightnings of the second class, or *sheet lightnings*, are inferior in the intensity, and generally different in the colour of their light, from those of the first class. These distinctions are very apparent wherever the space over which sheet lightning is diffused is intersected by flashes of cuspidated lightning. Sheet lightning sometimes appears to illuminate the edges only of the clouds; occasionally, however, it seems to issue from the interior of their mass. The common expression that the clouds appear *to open*, is strongly indicative of its appearance.

Sheet lightning is that which is the most frequent; and every one is familiar with its appearance, many having never seen or never noticed any other. In common thunder storms, it appears in a thousand cases for one in which cuspidated or ball-lightning is exhibited.

The flashes of sheet lightning often appear in very rapid succession, and continue, with short interruptions, for many hours. In extreme heat, these flashes succeed each other as rapidly as the flapping of the wings of a small bird, and present a flickering appearance in the clouds which they illuminate. The thunder by which they are accompanied is generally low and distant.

(51.) Lightning of the third class, or ball-lightning, is still more rare in its appearance than the zigzag or cuspidated lightning. The following instances of this meteor have been collected by M. Arago: —

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clature of science. The *electric fluid*, which is sometimes used to avoid the term *thunder-bolt*, is faulty, inasmuch as an effect familiar to all mankind, in all ages, ought not to be expressed by a term having immediate reference to a modern physical theory.

Place.	Time.	Observer.	Appearance.	Effects.
Couesnon, near Brest - -	14, 15 Apr. 1718	M. Deslandes	Three globes of fire, 3½ feet diameter.	Destroyed a church.
Horn - -	March, 1720		A globe of fire struck the ground and rebounded.	After the rebound, struck the dome of a tower, and set fire to it.
Northamptonshire - -	3 July, 1725	Rev. Jos. Wasse	A globe of fire, the apparent size of the moon, accompanied by a hissing noise.	
Northamptonshire - -	3 July, 1725		A globe of fire, as large as the head of a man, which broke into four pieces near the church.	
Dorking, Surrey - -	16 July, 1750		Large balls of fire, which, breaking into a prodigious number of fragments, were dispersed in all directions.	A house near which they broke was struck by them.
Ludgvan, Cornwall -	Dec. 1752	Borlase	Several balls of fire projected from the clouds to the earth.	
Schemnitz, Hungary -	Jan. 1770		A globe of fire as large as a barrel (*tonneau*).	It struck the tower of the church.
Isle of France	1770	Legentil	Three globes of fire issued from low clouds suddenly, and as suddenly disappeared, without any explosion.	
Steeple Aston, Wiltshire -	1772		A globe of fire oscillated for a long time in the air over the village, on which it fell vertically.	It destroyed the houses on which it fell.
Wakefield -	1 March, 1774	Nicholson	Meteors, like falling stars, fell from the higher of two clouds to the lower.	
Eastbourne, Sussex -	Sept. 1780	James Adair	Several balls of fire fell from a large black cloud into the sea.	Two servants in the house of the observer were killed at the same moment.
Villers-la-Garenne - -	18 Aug. 1792	Haller	A globe of fire passed over the village.	It struck the house of Haller.
Portsmouth -	14 Feb. 1809		Three successive balls of fire fell from the clouds in a short interval of time.	They struck three times the ship Warren Hastings in the harbour, passing down the masts each time.
Cheltenham -	April, 1814	Howard	A globe of fire fell from the clouds.	It struck a mill, which it destroyed.
Vesuvius -	1779 and 1794	Sir W. Hamilton	Luminous globes appeared in the volcanic clouds, which burst like shells from a mortar, projecting on every side zigzag flashes.	
Chapel Royal, Madrid -			Two balls of fire bounded like elastic balls in the chapel, and burst in pieces.	The royal palace was struck with lightning.
Samford Courtney, Devonshire - -	7 Oct. 1711		A voluminous globe of fire fell among persons assembled under the porch of the church during a storm. At the same moment four smaller globes burst within the church, and filled it with a sulphureous smoke.	One of the towers of the church was destroyed by the lightning.

Place.	Time.	Observer.	Appearance.	Effects.
Steeple-Aston, Wiltshire -	1772	Rev. Messrs. Wainhouse & Pitcairne	In the same storm, the observers being in a room in the vestry, saw suddenly appear before them, at a foot distance, and about their own height, a ball of fire, about the size of a closed hand, surrounded by a black smoke. It burst with a noise like that of the simultaneous discharge of several pieces of ordnance. A sulphureous vapour was diffused through the house. Lights of various colours, and having various oscillatory motions, were seen to play through the room.	Pitcairne was dangerously wounded; his body, clothes, shoes, and watch showed the usual marks of being struck by lightning. He stated that he saw the globe of fire in the room for one or two seconds after he was sensible of having been struck.
Petersburgh -	1752	Sokoloff	On the occasion of the death of Richmann (Introd. p. 66.) a ball of fire passed from the conductor to his body.	Richmann was killed.
Newcastle-on-Tyne - -	1809	David Sutton	In a thunder storm, the lightning descended the chimney of the house of the observer, and, after an explosion, several persons assembled in a room saw at the door of the room a globe of fire, which, after remaining for some time immoveable, advanced to the middle of the room, where it burst into several fragments, with an explosion like that of a rocket.	
At sea, 35° 40′ lat. S., 52° lon. E. -	13 July, 1798		A globe of fire fell from the clouds upon the ship *Good Hope*, which burst with a violent explosion.	It killed one sailor, and severely wounded another.

Before the concurrent force of this evidence, all doubt as to the reality of ball-lightning must disappear.

[(52.) But while, on the one hand, we are compelled to admit that such phenomena do occur, and that they are true electrical effects, on the other hand, we are no less compelled to trace in them the characters of a different kind of electric discharge to the ordinary lightning flash. Professor Faraday * divides the forms of discharge into the spark, the brush, and the *glow*. The *glow* is most

* Experimental Researches. Twelve Series, § 1405.

readily obtained in the rarefied air of a *partially* exhausted receiver; and differs from the brush in being due to a constant renewal of discharge, instead of to an intermitting action. Now Mr. Snow Harris suggests, in his recent *Treatise on Thunder Storms*, p. 38., that the ball-discharge in question possesses many features of resemblance to the glow; and, in addition, it possesses *motion*. The latter fact is readily accounted for, inasmuch as the cloud, which causes the discharge, is always progressing. The transition from the *glow* to the spark or flash is easily explained; for when the cloud passes over any terrestrial object, by which the resistance to discharge is reduced within the striking distance, disruptive discharge must take place; the glow remaining only so long as the resistance opposed the actual flash. Such a ball-discharge is described as having approached the ship "Montague," and to have exploded on the top-mast; and this is just what Mr. Harris's theory would lead us to expect. And there is reason to believe that many of the cases before us are not to be classed among effects of lightning. We shall again advert to this (73.).]

V. *On the Speed of Lightning.*

(53.) The solution of this problem is due to professor Wheatstone, and like some other results of physical inquiry, such as the abstraction of lightning from the clouds, which was effected by a boy's kite, and the iridescent effects due to the varying magnitude of luminous undulations which were derived from observations on soap-bubbles blown from a tobacco-pipe, it is founded on the plaything of a child. Every one knows that if the end of a lighted stick be whirled rapidly round in a circle or other curve, it will present the appearance of a continued line of light, the lighted end, which occupies *in succession* every point of the curve, appearing to the eye to be *continually present* at all its points.

To develope the principle on which this fact rests, let

Fig. 103.

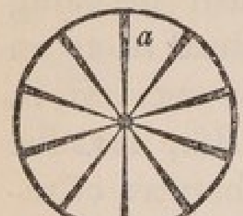
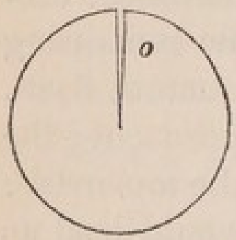


fig. 103. represent a wheel with ten thin spokes, or radii, dividing its circumference in ten equal parts, and of some strong bright colour, such as red. Let this wheel be put in communication with clock-work, so as to be made to revolve uniformly at any required rate. This wheel, having its face vertical, and turning on a horizontal axis, let a screen be placed before it so as to conceal it from view, and in this screen let an oblong opening be made corresponding in magnitude and position to that spoke of the wheel which is in the vertical position and presented from the centre upwards. Let the screen with such an aperture be represented in *fig.* 104., the wheel behind it and concealed by it being represented by dotted lines.

Fig. 104.



As the wheel revolves its spokes pass the opening *o* in succession, and if the motion of the wheel be not very rapid, a person placed before the screen will perceive the spokes appear and disappear in regular and uniform succession at the opening. If the velocity of the wheel be gradually increased, the succession of appearances and disappearances will be rendered by degrees indistinct, until at length a velocity will be attained which will cause a spoke to be continually seen at the opening *o*, in the same manner as if the wheel were at rest and the spoke *a* were placed behind the aperture. Now, since it is certain that in this case the presence of the spokes at the aperture is successive, and that the intervals which the spokes are absent bear to the intervals of their presence the proportion of the breadth of the spokes to the breadth of the spaces between them, it necessarily follows that the *eye perceives a spoke at the aperture during the intervals when no spoke is present there.*

This circumstance is accounted for by considering the manner in which vision is effected by means of the

mechanism of the eye. The light proceeding from a visible object entering the pupil strikes the retina, and produces in it a certain vibration, which vibration is the immediate cause of the perception of the object from which the light has been transmitted. After the object has ceased to transmit light to the eye, this vibration continues for a certain time, just as the vibration of a musical string continues for a certain interval after the bow which put it into vibration has been withdrawn; and as the vibration of the string which continues after the bow is withdrawn produces the perception of a proportionately prolonged sound, so the vibration of the retina after the visible object has been withdrawn produces a proportionately prolonged perception of its presence. In fact, there is no *damper* in the mechanism of the eye to stop the effect of the action of light at the instant that action ceases. It is, therefore, an interesting physiological problem to determine how long after that visible object is withdrawn, and the action of light ceases, the effect on the retina remains, and the object continues to be seen. This problem is beautifully solved by the apparatus above described. The velocity of the wheel being gradually augmented until the spoke appears to be continually present at the opening, it has been found that *this effect is produced when the wheel performs one complete revolution in a second of time.* Since the space round the centre of the wheel is equally divided by the ten spokes, it follows that in this case the interval between the arrival of two successive spokes at the opening is one tenth of a second, and this must, therefore, be the duration of the impression of an object on the retina, after it has been withdrawn. If the duration were *less* than this, the coloured spoke would not *appear* continually at the aperture *o* when the wheel revolves in one second, but would alternately appear and disappear. If it were *greater*, a less velocity than one revolution per second would be sufficient to cause its continuous appearance.

Since there is nothing in what has been stated to render it necessary that the aperture, through which the spokes are seen, should be in the vertical rather than any other position, it follows that, in whatever position round the centre that aperture be placed, a spoke will appear to be continually behind it so long as the wheel revolves at a rate of not less than one revolution per second.

If, therefore, there be two or more such apertures made in the screen, a spoke will appear constantly behind each of them. In fine, if there be an infinite number of such apertures round the centre, or, in other words, if the screen be altogether removed, spokes will be seen in every direction round the centre without any open spaces between them, or, what is the same, the wheel will appear as a circular disc of uniform red, no spokes being distinguishable.

We have here supposed that the wheel is continually illuminated. It is necessary now to inquire how long light must shine upon it, in order that, revolving once per second, it may appear as a plane disk without spaces between the spokes. If the light fall upon it only for an instant, that is, an infinitely short time, then the wheel will be distinctly seen for the tenth of a second in the position which it had when the light fell upon it. The spokes will be distinctly visible, as if the wheel were at rest. But if the light continue to fall upon the wheel during the tenth of a second, then each spoke will continue to be illuminated from the position it has at the moment the light first falls upon it until it arrives at the position which the preceding spoke had at that moment. Each spoke will therefore act upon the eye, while it passes through the space, between two successive spokes, and will therefore be seen at every point of that space; and as the perception it causes at any point will continue while the spoke passes through the whole of that space, it follows that the wheel will appear to the eye as a flat circular disc uniformly illuminated.

If, however, the light continue to fall on the wheel during an interval *less* than the tenth of a second, suppose, for example, the twentieth of a second, then each spoke will be illuminated while passing through half the interval between two successive spokes, and the wheel will present the appearance of a circle divided into ten equal sectors, half of each sector being visible, and half invisible. If the duration of the light be any other part of the tenth of a second, the wheel will, for the same reason, present the appearance of a circle divided into ten equal sectors, a portion of each sector being visible, bearing to the remaining portion invisible the same ratio as the duration of the light bears to the difference between that duration and the tenth of a second.

Such an instrument will therefore serve as the means of estimating the duration of any light which continues to illuminate the wheel for a period of time not exceeding the tenth of a second; and it is evident that, by varying the number of spokes and the velocity of the wheel, the duration of any light may be measured when its amount is greater or less than the tenth of a second.

(54.) Such is the instrument which has been applied by its inventor to measure the duration of a flash of lightning, and also of the electric spark. A wheel consisting of a hundred spokes, dividing the space round the centre into as many equal sectors, was exposed to the light of lightning during a thunder storm. By clock-work it was made to revolve ten times per second, making, therefore, one revolution in the tenth of a second, and moving through the interval between two spokes in the thousandth part of a second. If the duration of the light by which this wheel was illuminated amounted to the thousandth of a second, it would appear as a complete illuminated disc without spokes. If it amounted to half a thousandth of a second, it would appear as a circle divided into a hundred equal sectors, half of each sector being visible, and half in-

visible. If the duration of the light were instantaneous, it would appear as a wheel with a hundred spokes, stationary in the particular position it had at the moment the light fell upon it.

(55.) Now such a wheel being thus exposed to the flashes of lightning in a storm, it was found that when illuminated it always appeared stationary, though revolving ten times in a second. The spokes were seen distinctly with no more than their proper thickness. It therefore follows, that the duration of the light of the flashes did not amount to so great a fraction of the thousandth part of a second as was capable of being appreciated by estimating the apparent width of the spokes when seen by the light of the flashes. The duration of the flashes must then have been a very small fraction of the thousandth part of a second.

But the duration of a flash is the time which the lightning takes to move through that part of space which it traverses while it is visible. Hence it follows, that whatever be the extent of such a distance it is traversed in a very minute fraction of the thousandth of a second.

This method of observation has only been applied to lightning of the first and second kind, no opportunity having yet been found to apply it to ball-lightning.

VI. *Silent Lightning.*

(56.) When the heavens are perfectly serene in hot weather, lightnings are frequently observed to continue flashing in the atmosphere for many hours, unaccompanied by thunder. These have been called *Heat Lightning.* Such appearances are not confined, as has been supposed, to those parts of the atmosphere which are near the horizon; on the contrary, their light extends frequently over the whole visible firmament.

Lightning unaccompanied by thunder appears much more rarely when the heavens are clouded. Sufficient

evidence, however, of this phenomena in different parts of the globe has been collected by M. Arago.

Thibault de Chanvalon, in his Meteorological Observations, records its occurrence, on two days in July, 1751, at *Martinique*. Such lightning is very common at the *Antilles*. *Dorta* mentions the same phenomenon at *Rio Janeiro*, in a paper published in the memoirs of the Academy of Sciences of Lisbon in the years 1783, 1784, 1785, and 1787, during which time he witnessed 170 days on which lightnings were seen unaccompanied by thunder.

Lind witnessed at *Patna*, in India, lat. N. 25° 37′, in the year 1826, on seventy-three days, lightning without thunder; but neither *Lind* nor *Dorta* state whether the heavens were clear or clouded. The probability is that where the occurrence of the phenomenon was so frequent they were sometimes clouded.

De Luc the younger mentions a great storm which took place at Geneva on the 1st of August, 1791, during which very vivid lightnings were seen without any audible thunder. Some of the flashes on this occasion were so strong, that the loudest claps of thunder would have been expected to follow them. In the same storm, however, other flashes were accompanied by loud thunder.

Dalton states that, in *Kendal*, on the 15th of August, 1791, at nine o'clock in the evening, he witnessed in a storm vivid and continual flashes of lightning, but heard only *some* thunder, which was distant.

(57.) At Philadelphia, in the month of July of the present year (1841), and at New York in the next month, I witnessed frequent *thunder bursts* (as they are there called), in which, in a clouded sky, I saw a constant succession of flashes of lightning, which sometimes continued for several hours, accompanied by very short occasional showers of rain. On these occasions thunder was sometimes not heard at all, and sometimes it was only heard after long intervals of silence, and seemed, from its sound, to be distant. The

lightnings, nevertheless, were vivid, and illuminated the heavens to the zenith. They appeared generally like a light behind the clouds, the edges of which were strongly illuminated, the centres more faintly. These lightnings sometimes succeeded each other so rapidly, that they had a *fluttering* appearance, like the motion of the wings of a small bird; and this fluttering of light would be often continued for three or four seconds. These trembling lightnings would succeed each other at intervals of some minutes.

VII. *Of Luminous Clouds.*

(58.) In the darkest nights of winter, at the hour of midnight, when the influence of the solar light is altogether withdrawn from the atmosphere, and in the absence of moonlight, a sufficient quantity of light is always diffused to render objects around us faintly visible, and to enable us to walk, without hesitation, in any open country. If the firmament be serene and cloudless, this light is ascribed to the stars. But let the heavens be overcast; let the stars be hidden by an unbroken mass of the most dense clouds, and still a sufficiency of light will be diffused in the open country to prevent any of the difficulty and inconvenience which would attend any attempt to walk in a dark cave, or in an apartment with closed windows. It cannot, then, be doubted, that in the most clouded nights of deep winter light proceeding from some source is diffused through the air. If this light be supposed to be that of the stars penetrating the clouds, it is necessary to admit that the light of the stars in *a clear night* is greater in the same proportion as the splendour of the unclouded noonday sun exceeds the light when the firmament is covered with dense clouds. No one, having the least powers of observation, can admit such an assumption; and, if it be not admitted, there remains no other explanation of the nocturnal light of a clouded sky,

except in the admission that *the clouds themselves are faintly luminous.*

(59.) If the supposition of the self-luminous property of clouds be entertained, the probability that, under varied circumstances of form, density, mutual position, temperature, and many other conditions which will easily suggest themselves to every mind, clouds may be endowed with this quality in various degrees. The probability, therefore, of the hypothesis which we have just proposed to account for nocturnal light will be strengthened, if it can be shown that, on particular occasions, clouds have been observed unequivocally, and in much higher degrees, luminous.

(60.) In a memoir of Rozier, dated 15th of August. 1781, that philosopher states that, being at *Béziers* on that day in the evening, at a quarter before eight o'clock, the sun having gone down, and the firmament being overcast, thunder was heard. At five minutes past eight, it being then complete night, the storm having attained its height, Rozier observed a luminous point above the brow of a hill fronting his house, which gradually augmented in magnitude until it assumed the form and appearance of a phosphoric zone, subtending at his eye an angle of about sixty degrees, measured horizontally, and having the apparent height of a few feet. Above this luminous zone was a dark space, equal to its own breadth; and over that space appeared another horizontal zone of the same breadth, and about half the apparent length. The middle of each of these zones exhibited an uniform brightness, but the edges were irregular. Lightning issued three times from the edges of the inferior zone, but no thunder was audible. The duration of this extraordinary phenomenon was nearly a quarter of an hour.

(61.) Nicholson relates that, on the 30th of July, 1797, at about five o'clock in the morning, he observed the heavens covered with dense clouds, which moved rapidly to the W. S. W. Lightning played constantly at N. W. and S. W., which, after an interval of twelve

seconds, were succeeded by loud claps of thunder. The lower parts of the clouds, which were undulated and checkered, exhibited a red light, which was very vivid. At one moment, houses placed in front of that which he inhabited had the appearance which would have been produced by viewing them through a deep blue glass: at that time, on looking at the clouds, they appeared to emit a blue light.

Beccaria states, that the clouds over his observatory at Turin frequently diffused, in all directions, a strong reddish light, which was sometimes so intense as to enable him to read a page printed in ordinary type. This nocturnal light was especially observed in winter, between successive snow showers.*

The same self-luminous quality has been observed in fogs. The dry fog of 1783 was described by M. Verdeil, a physician of *Lausanne*, as having diffused, at night, a light sufficiently strong to render distant objects visible, and this light was equally spread in all directions. It resembled the light of the moon seen through clouds.

De Luc † states, that returning home to his lodgings in the neighbourhood of London on a winter night, when the atmosphere was clear and not cold, he saw a band of clouds intersecting the southern meridian, about thirty or forty degrees from the zenith, and extending, on either side, nearly to the eastern and western horizon. The brightness of this cloud resembled that of a thin cloud concealing the moon, and was sufficient to render the stars in its neighbourhood invisible.

(62.) Dr. Robinson, professor of astronomy at *Armagh*, states, in a letter to M. Arago, that during the voyage of Major Sabine in *Scotland*, undertaken to observe the lines of equal magnetic intensity, that officer being at anchor in *Lough Scavig*, in the *Isle of Sky*, observed a cloud which constantly enveloped the summit of one of the naked and lofty mountains which surround that island. This cloud, which resulted from the pre-

* Del Ellettricismo terrestre Atmosferico, p. 288.
† Idées sur la Météorologie.

cipitation of the vapour, brought by the constant west winds from the Atlantic, was self-luminous at night, not occasionally, but permanently. Major Sabine saw frequently issue from it jets of light resembling those of the aurora. He rejects, however, the supposition that these jets were produced by real auroras near the horizon, and which were concealed from direct observation by the mountain. He regarded all these phenomena of continued and intermitting light as originating in some physical property of the cloud itself.

VIII. *Of Thunder.*

(63.) Thunder, as every one knows, is a certain noise proceeding apparently from the clouds, which usually follows, after a greater or less interval, the appearance of a flash of lightning. Of all natural phenomena, those which occupy the meteorologist present the greatest difficulties when it is necessary to convey a precise notion of them to those who may not immediately have witnessed them. It is, doubtless, to this difficulty that we must ascribe the practice of meteorological writers of resorting to similes, and other like illustrations, in their descriptions.

Thunder is described by some as a sound resembling the acute noise produced when stiff paper is torn — or when a strong silk cloth is suddenly torn — or when a heavy waggon is rolled rapidly over a rough stony road. It is imitated with much effect in theatres by shaking a piece of sheet iron, about four feet long and two feet broad. This is held in the hand at one of its corners, and the varieties of thunder may be imitated by skilfully varying the movement of the hand.

Thunder sometimes is heard as a single, clear, and distinct sound, like the report of a gun unattended by any reverberation. More frequently the sound is deep, or, in a musical sense, *grave*, and consists, not of a single sound, but of that rapid succession of sounds, first in-

creasing and afterwards diminishing in intensity, which has been expressed by the term *rolling*.

The difficulty of expressing and recording in *words* the exact nature of such phenomena has limited to a small number the observations on which any safe reasoning can be based.

(64.) The duration of the rolling of thunder was observed and recorded by *De L'Isle*, in Paris, in the year 1712. On one occasion it was observed to endure for 45 seconds. On other occasions, during the same storm (17th of June), the roll continued from 34 to 41 seconds. On the 3d, 8th, and 28th of July, the roll continued, on different occasions, from 35 to 39 seconds.

De L'Isle also observed the varying intensity of the sound in each roll. In some cases the clap is loudest at the commencement, and afterwards declines gradually until it ceases to be heard. Sometimes it commences with a low and barely audible sound, which augments in force until it attains a maximum of loudness, after which it diminishes gradually in intensity until it becomes inaudible. These changes were carefully observed and recorded on several occasions by De L'Isle. The following examples will suffice to illustrate the phenomenon: —

1712.	Seconds.	
17th June	0	Lightning flashed.
	3	Thunder feebly audible.
	12	Thunder loudest.
	19	Thunder became gradually inaudible.
21st July	0	Lightning flashed.
	16	Thunder feebly heard.
	20	Thunder loudest.
	32	Thunder became gradually inaudible.
8th July	0	Lightning flashed.
	11	Thunder feebly heard.
	12	Thunder loudest.
	38	Loudest thunder began to decrease in force
	47	Thunder became gradually inaudible.
8th July	0	Lightning flashed.
	11	Thunder feebly heard.
	12	Thunder became loudest.
	38	Thunder began to decrease in loudness.
	47	Thunder became gradually inaudible.
8th July	0	Lightning flashed.
	10	Thunder feebly heard.
	13	Thunder became loud.
	20	Thunder broke with redoubled force.
	35	Thunder began to lose its force.
	39	Thunder became gradually inaudible.

It appears from these observations that the durations of the loudest part of each roll varied from twenty to thirty seconds.

The degree of loudness is also very various. On the 2d of March, 1769, the tower of the church at Buckland-Brewer was struck by lightning followed by a clap of thunder, described by an ear-witness as equal to the simultaneous report of 100 pieces of cannon.

(65.) The most violent thunder sometimes follows ball-lightning. When the ship *Montague* was struck on the 4th of November, 1749, the captain (Chalmers) declared that the sound produced by the explosion was equal to the simultaneous discharge of several hundred pieces of ordnance, but that it did not last above half a second.

(66.) The interval of time which elapses between the flash of lightning and the thunder which succeeds it is an important element in the theoretical investigation of the atmospheric conditions which produce these phenomena. It is especially useful to ascertain the major and minor limits of this interval. The observations of this kind collected by the research of M. Arago are arranged in the following table:—

Place.	Time.	Observer.	Intervals.
			Seconds.
Petersburgh - -	2 May, 1712 - -	De L' Isle - - -	42
			48
			48
	6 June, 1712 - -		47
			48
			48
			49
	30 April, 1712 - -		72
Tobolsk - - -	2 July, 1761 - -		42
			45
			47
	10 July, 1761 - -		46
			2
		De L' Isle - - -	3
			4
			5

M. Arago states as the general impression on his memory, that he has often observed the thunder follow the flash after an interval so brief as half a second.

(67.) In the early part of June last (1841), being

in the reading room of the *Athenæum* at Philadelphia, I witnessed a vivid flash of lightning, which was succeeded by the loudest clap of thunder I ever recollect to have heard. The interval was, by my estimation, a very small fraction of a second. An ordinary observer would have said that the flash and the sound were simultaneous.

(68.) The occurrence of thunder not preceded by lightning has not been proved by evidence as clear and satisfactory as that by which the existence of silent lightnings has been established. No example of it is found in any of the meteorological registers kept at observatories in Europe. *Thibault de Chanvalon*, already quoted, mentions, in the register of his observations made at *Martinique*, that in October, 1751, there were two days on which thunder was heard without the appearance of lightning, and that on one day in November there were three loud claps of thunder without lightning.

On the 19th of March the vessel in which *Bruce* the traveller had embarked on the Red Sea, near Cosseir, encountered a clap of thunder so violent as to strike the seamen with terror. There was no lightning.

The occurrence of thunder when the firmament is cloudless has been doubted. SENEBIER * speaks of thunder on clear days as a known fact, but does not state whether such was the result of his own observations. VOLNEY states that on the 13th of July, 1788, at six o'clock in the morning, the sky being unclouded, he heard at *Pont Chartrain*, a place four leagues from *Versailles*, four or five claps of thunder. At a quarter past seven, clouds began to rise in the south-west, and in some minutes the heavens were covered. Soon afterwards, hailstones fell as large as a man's fist.

(69.) The noise which often attends earthquakes is similar to thunder, and by an acoustic deception not yet clearly explained, it is heard as if it proceeded from the

* Journal de Physique, tom. xxx. p. 245.

upper regions of the air. Observations, therefore, of supposed thunder with a clear sky, in places subject to earthquakes, cannot safely be received as evidence of real thunder.

IX. *Of the Attempts to explain the Phenomena of Thunder and Lightning.*

(70.) Although the investigations of Franklin removed all doubt respecting the identity of lightning and artificial electricity, still, in the great variety of atmospheric phenomena, developed in the disturbances of electrical equilibrium, which are produced on so grand a scale in the vast regions of the air, much remained, and still remains, unexplained. Succeeding philosophers have accomplished little more than exhibiting, by direct experiments and by the comparison of numerous observations, analogies which throw more or less light on the relations between the appearances which are exhibited in the atmosphere, and those general laws which have been deduced from experiments made on artificial electricity.

The luminous appearances which attend the electrical discharges in the atmosphere, and which characterise the different kinds of lightning, must be regarded as explicable on the same principles as those of artificial electricity, and the various hypotheses and conjectures, more or less plausible, which have been proposed to account for the one must equally be brought to bear on the other.

(71.) To regard the principle which darts through space, with the enormous velocity which the observations of professor Wheatstone has shown lightning to be endowed with, as ponderable matter, is extremely difficult. If it be ponderable matter, it must follow the path of projectiles, and consequently its course must be curved with a concavity turned towards the earth, except when it follows the vertical direction. In the zig-zag path of

cuspidated lightning there is nothing analogous to this. On the other hand, such rapid and rectilinear motions are quite consonant with the supposition of a system of undulations propagated through a highly elastic medium, and are, in all respects, analogous to the actual phenomena of light. The bi-cuspidated lightning finds its obvious type in the double refraction of crystallised media, and the heterogeneous matter suspended in different strata of the air through which the lightning is transmitted completes the parallel.

(72.) The undulatory hypothesis is nevertheless beset with its own difficulties. How can the pulsations of an imponderable ether be reconciled with the mechanical effects of lightning? The analogy to the phenomena of light fails, when it is considered that, notwithstanding its velocity of 200,000 miles per second, light has never acquired in its motion, even when condensed by the largest burning reflector, sufficient momentum to affect, in any sensible degree, the lightest substance suspended in vacuo by a filament of spider's web, while, on the contrary, the electric fluid, issuing from the clouds, splits rocks, overturns the most massive structures, destroys gigantic trees, and projects to a distance enormous weights.

(73.) But of all the forms under which the results of electrical explosions in the air present themselves, the most inexplicable is that of *ball-lightning*. Observation seems to countenance the supposition, that these globes of fire are real agglomerations of ponderable matter formed in the regions of the air by some unexplained process. Where such formations are made; whence proceed their ponderable constituents; what is their nature; what sustains them in the air; and what causes finally precipitate them? are questions before which science is mute.

The constituents of the atmosphere are oxygen and azote, in the proportion of four parts by weight of the former to fourteen of the latter. If the electric spark be transmitted through a mixture of these two gases

confined in a glass tube, a portion of the oxygen will combine chemically with a portion of the azote, and nitric acid will be formed. What the electric spark does in such a mixture, the transmission of the electric fluid accomplishes in the atmosphere, and nitric acid is formed, distinct traces of which are discoverable in the rain which falls in thunder storms. If, then, this power of determining the chemical combination of these constituents of the air be undeniable in this case, we cannot reject the possibility of other combinations being effected by the same agency. Besides oxygen and azote, the proper constituents of pure atmospheric air, there are various foreign substances occasionally suspended in it, of which the chief, but not the only one, is the vapour of water. Carbonic acid exists in it in variable quantity, but is no where totally absent. SAUSSURE found it in air collected at the top of Mont Blanc. FUSINIERI states that he constantly found sulphur, iron, and its different oxydes, in fissures through which lightning has forced its way.

If such analogies be considered to have any weight, it is not impossible to imagine the constituents of solids to be suspended in the atmosphere in a vaporous or sublimated state, and to coalesce and enter into combination by the transmission through them of a strong discharge of electricity. But, as a matter of *fact,* is it *proved* that ponderable masses in a state of ignition have actually fallen from the clouds? The following evidence is produced by M. Arago on this question: —

(74). Boyle states, that in July, 1681, the British ship, Albemarle, was struck with lightning off Cape Cod. A mass of burning bituminous matter fell in the boat suspended at the stern of the vessel, which diffused an odour like that of gunpowder. It was consumed in the place where it fell, after ineffectual attempts to extinguish it by water, or to throw it out of the boat with rods of wood.

(75.) Silent lightnings, whether they appear in a clear or clouded sky, are usually explained by the supposition that they are the reflection of lightnings which

issue from clouds below the horizon, and so distant, that the thunder which accompanies them cannot be heard. It has been, on the other hand, objected, that the splendour of lightning is not sufficiently intense to cause a reflection so bright as the silent lightnings, and that a reflection, inferior in splendour to lightning itself, in the same proportion as twilight is to the brightness of the sun, would not be visible. To this objection, M. Arago replies by the following facts:—

CASSINI and LACAILLE, when engaged in making a series of experiments on the velocity of sound, in the year 1739, saw the light produced by the discharge of a piece of ordnance, placed at the base of the lighthouse of *Cette*, although at the station they occupied both the town and the lighthouse were concealed by intervening hills.

In 1803, M. ZACH gave signals on the *Brocken* (a mountain of the *Harz* range) by exploding six or seven ounces of gunpowder. The light produced by this was seen by observers stationed on Mount *Kenlenberg*, at the distance of nearly three degrees from the *Brocken*. Since a direct view would have been rendered impossible by the convexity of the earth, the light must have been seen by reflection.

The flashes of artillery discharged at the base of the *Hôtel des Invalides* at Paris are visible in the gardens of the *Luxembourg*, near the *Rue d'Enfer*, although the highest point of the dome of the hotel is invisible from that place.

(76.) If, then, the feeble effect produced by the explosion of a few ounces of gunpowder be sufficient to be so apparent by reflection, may it not be expected that the more resplendent illumination produced by lightning would be infinitely more vivid?

That this mode of explaining silent *lightning* may not take the character of mere conjecture, it will be necessary to show that distant lightnings are actually visible when the thunder which accompanies them is inaudible. Two unexceptionable observations are adduced for this purpose.

On the night between the 10th and 11th of July, 1783, the weather being calm, and the sky unclouded, Saussure, stationed at the *Hospice* of the *Grimsel*, looking in the direction of Geneva, saw on the horizon some streaks of clouds from which lightning issued, but no thunder was heard. It was afterwards ascertained, that, at the moment this occurred, a storm broke over Geneva, the most terrific that the people of that country ever witnessed.

On the 31st of July, 1813, Mr. LUKE HOWARD observed at *Tottenham*, near *London*, in a clear sky, lightning, such as is called heat-lightning, appear towards the south-east. It was afterwards ascertained that a violent storm at that moment raged in France, which extended from *Calais* to *Dunkirk*. This lightning, above fifty leagues' distant, was visible in the atmosphere of London.

(77.) It must then be admitted as proved that silent lightnings *may be*, and *sometimes are*, produced by the reflection in the atmosphere of lightning, of which the thunder is too distant to be heard. But it does not, therefore, follow that such appearances *must be*, and *always are*, produced by that cause. On the contrary, heat-lightnings frequently present appearances to explain which it would be almost impossible to admit the hypothesis of distant storms. Thus it frequently happens that when the whole visible firmament is unclouded, these lightnings will play for entire nights on every side of the horizon, and will extend even to the zenith. If distant storms were admitted to explain such phenomena, it would be necessary to suppose that portion of the atmosphere visible from a single place clear and serene, yet surrounded on every side by a ring of clouds, throughout which storms rage. The improbability of such an hypothesis is apparent.

(78.) M. Arago proposes for the decision of this question the same expedient which he suggested a few years ago, in his essay on comets, to determine whether their tails were self-luminous, or derived their light from the sun. There are certain crystals endowed with optical properties, in virtue of which objects viewed through them are seen under different appearances, according as those objects are self-luminous, or illuminated by light derived from other objects. He proposes that the silent lightnings shall be observed through such crystals, and the question whether they be actual lightnings unattended by thunder, or only reflections of distant lightnings, be thus decided.

(79.) Thunder unaccompanied by lightning is explained by M. Arago by supposing two strata of clouds at different heights, of which the superior stratum is

the seat of a thunder storm, and of which the inferior stratum is sufficiently dense to be impervious to the light which precedes the thunder. Nevertheless, the density of the inferior cloud will not at all impede the transmission of sound through it, and the thunder will, consequently, be heard while the lightning is invisible.

(80.) The method of computing the distance of stormy clouds, by observing the interval which elapses between the flash and the thunder, is based upon the assumption that the sound is produced *in the cloud*. It has been, however, maintained by some persons, that when the electric discharge takes place between a cloud and the earth, the lightning issues from the earth to the cloud. According to the hypothesis of a single electric fluid, this would always be the case when the cloud is negatively electrified. As a test of this, M. Arago proposes to observe the interval between the appearance of the lightning and the perception of the thunder under circumstances in which the distance of the cloud is known *by other means* within a given limit. If the distance obtained by computation from observing the interval between the light and the sound be manifestly less than the known minor limit of the distance of the cloud, it must then follow that the seat of the sound *is not the cloud*, but is some place in the atmosphere less distant, which would necessarily be the case if the lightning issued upwards from the earth. This method of observation might be practised in the neighbourhood of any lofty tower or steeple, or near a hill, or by means of a small balloon confined by a cord to a given height. If the cloud were observed to be considerably *above* any such objects, and yet the computed distance of the seat of the sound considerably *below* them, the conclusion just stated would be justified.

(81.) From the observations which have been recorded of the time between the flash and the thunder, it appears that although in one instance this interval amounted to seventy-two seconds, it usually does not exceed forty-eight seconds. It follows, then, that the greatest

distance from which the atmospheric explosions which produce thunder are heard is about *ten miles*. If the single recorded observation of an interval of seventy-two seconds can be relied on, it would follow that in that particular case thunder was heard at the distance of *fifteen miles*.

(82.) Evidence still more direct and convincing can be adduced that beyond the distance of eight or ten miles thunder is usually inaudible.

When the steeple of Lestwithiel, in Cornwall, was struck by lightning, on the 25th of January, 1757, and almost entirely destroyed, the thunder was terrific; yet Smeaton, the engineer, who was then within thirty miles of the place, heard no thunder. Muschenbroeck states, that thunder at the Hague is inaudible at Leyden and at Rotterdam, the distance of the former being ten, and of the latter twelve, miles. There are also examples of violent storms breaking over Amsterdam which were inaudible at Leyden, the distance being about twenty miles.

(83.) To deduce right conclusions from these facts, it will be necessary to consider the distances at which other sounds, generally much less intense than thunder, are heard. Cannon discharged at Florence are heard at Leghorn, a distance of fifty miles; at Leghorn, are heard at Porto Ferraio, the same distance. The cannonade at the siege of Genoa by the French was audible at Leghorn, a distance of ninety miles. It may be added that the great bell of St. Paul's cathedral in London is said to be audible at Windsor, a distance of about twenty-four miles.

(84.) The conditions of the atmosphere which affect the transmission of sound are imperfectly understood, and it is, therefore, the more necessary to accumulate well-ascertained facts, to form a sound basis for general reasoning. It is generally believed that sounds are heard more distinctly and at greater distances in winter, especially in frost, than in summer. This popular impression has been corroborated by the narratives of those who have made voyages to the polar regions. Parry states * that he frequently heard dis-

* First Voyage, p. 143.

tinctly, at the distance of a mile, men conversing in their ordinary tone of voice. On the 11th of February, 1820, he heard a man singing to himself (and therefore, probably, in rather a low tone,) at more than a mile distant.

Derham observes, that new-fallen snow impedes the transmission of sound, and that fogs also deaden its force. This latter effect, however, is not invariable. In a November fog, in 1812, Mr. Howard heard distinctly, at five miles from London, the noise of the carriages rolling over the streets.

Humboldt has proved that sounds are audible at greater distances by night than by day; and from the circumstances under which his observations were made, it would appear that the silence of night could not be assumed as an explanation of this.

It seems to be established that an adverse wind is an impediment to the transmission of sound; but, according to the observations of M. *F. Delaroche*, a favourable wind *does not assist it.*

(85.) VOLNEY, at *Pont Chartrain*, heard four or five claps of thunder. Looking carefully round him, he could see no cloud either in the heavens or near the earth. Now, since thunder has never been heard at a greater distance than fifteen miles, and since an object to be invisible at that distance, with a well defined horizon, must have an elevation less than about one hundred feet, it follows, either that the thunder heard by Volney on that occasion was produced in the clear atmosphere, or that it proceeded from a cloud not more than thirty-three yards from the ground, at a distance of about fifteen miles from the observer.

It has been elsewhere stated, that the explanation proposed and universally received, as accounting for the phenomena, is a sudden displacement of the air produced by the electrical discharges in which lightning is evolved. Since all sound must proceed from an agitation of the air, and since lightning and electricity are identified, this explanation consists of little more than a statement

of the facts. A more rigorous account, however, must be exacted from those who would propound an adequate theory of thunder.

(86.) Some have explained the origin of thunder, by supposing that the electric fluid, in passing with great velocity through the air, leaves behind it a vacuum; that the air, rushing suddenly into this vacuum, produces a detonation like that which takes place in the common experiment, in which a vacuum being produced under a bladder, extended tightly over the mouth of a receiver, the bladder is broken by the pressure of the external air. To make this explanation valid, it would be necessary to show *how* the vacuum is produced, or that it *is, in fact,* produced, otherwise the explanation is reduced to a mere conjecture.

(87.) It is also explained by supposing that the electric fluid, in passing through the air, compresses successively the air lying before it, from whence there results a displacement of those masses of air which are contiguous, and consequently a series of contractions and dilatations, which, extending to a distance, produce long-continued reverberations.*

(88.) M. Pouillet rejects these hypotheses as insufficient to explain the phenomenon. He considers that if such were the cause of thunder, the passage of a cannon ball through the air ought to produce a like effect. M. Pouillet maintains, that when an electric discharge takes place between two bodies charged with opposite electricities, the fluid does not actually pass from the one body to the other, but that the effect is produced by a series of decompositions and recompositions of the natural electricities of the molecules of the intervening medium, precisely similar to that which takes place in a liquid solution, in which the poles of a voltaic arrangement are immersed. He argues that there must thence result vibrations more or less violent in the pon-

* Becquerel, tom iv. p. 128.

derable matter of that medium, which would be sufficient to explain the sound.

(89.) The rolling of thunder has by some been ascribed to the effects of *echo*. That echo has, *in some cases*, a share in the production of the phenomena, cannot be doubted by any one who has ever witnessed an alpine storm. A multitude of causes affecting the loudness, the reverberation, and the continuity of the peals, are quite apparent. The question is, whether echo is the only cause of the *rolling of thunder*.

It has been shown that the duration of the thunder-roll amounts sometimes to forty-five seconds. Whether the echoes of any sound ever have such duration can only be determined by observation. The example of the often-reiterated echo at a certain island on the lake of Killarney is known to all travellers. Mr. Scoresby observed on a particular occasion its duration, and found it to be about thirty seconds. The original sound is usually produced by the discharge of a small piece of cannon.

It would seem that on the occasion of Mr. Scoresby's observation a pistol was used. It is argued by M. Arago, that if a cannon had been used, the duration would have been much greater, and probably equal to the continuance of the longest roll of thunder.

(90.) During the experiments made to determine the velocity of sound in June, 1822, MM. Humboldt, Bouvard, Gay-Lussac, and Emile de la Place, heard the echo of a cannon discharged near them during twenty-five seconds.

(91.) Mariners state that thunder heard at sea is marked by rolling as long continued as at land, although none of those causes which are generally supposed to produce echoes, such as walls, rocks, wood, hills, or mountains, are present. Unless the surface of the clouds reflect sound, no means of producing echo can exist under such circumstances. Although it might seem that the clouds would be as little capable of reflecting sound as the air itself, there appears to be some reason

to judge otherwise. Muschenbroeck states, as the result of his own observation, that a cannon which being discharged when the heavens are unclouded produced only a single report, had its sounds several times reverberated when discharged in the same place under a clouded sky. In the course of experiments made in 1822, to determine the velocity of sound already referred to, the same observation was made.

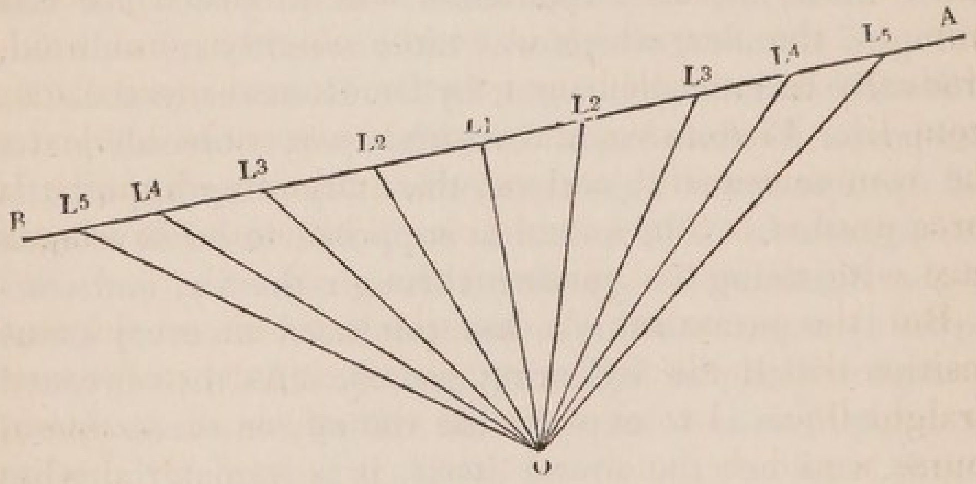
(92.) In the posthumous works of Hooke, published in 1706, an explanation was proposed for the rolling of thunder, which was more recently reproduced, with more full developement, by Dr. Robison, in the *Encyclopædia Britannica*, and which seems more adequate, and open to fewer objections, than any other hypothesis yet suggested. The sound is supposed to be developed by the lightning in passing through the air, and consequently separate sounds are produced at every point through which the lightning passes. As the object of the hypothesis is to explain the *rolling*, or *succession* of sounds, and not the sound itself, it is immaterial what the manner of producing the sound may be.

Let us first suppose that the lightning were to move in a circle, of which the observer is the centre. The velocity of the lightning is so extreme, that for the purposes of this explanation it may be assumed to be at the same moment in every part of the circle. Explosions will therefore be produced simultaneously at every point in the circumference of the circle, and, as all these sounds have the same distance to traverse in coming to the observer, they will arrive at his ear at the same instant; the effect would, therefore, be a single sound, having a force due to the combined effects of all the sounds produced in the circumference of the circle. To apply this reasoning to the actual case of thunder, let it be supposed that two small clouds, oppositely electrified, are situated near each other and at the same height in the zenith of the observer. The clouds may be considered as placed in the surface of a sphere, in the centre of which the observer stands. If the electric discharge

takes place between the clouds, the thunder would be heard by the observer as a single clap, without any roll or reverberation.

Let us next suppose the lightning to move in any line, which is not part of a circle or sphere, with the observer in the centre; let its course be a straight line; for example, such as A B (*fig.* 105.) the observer being

Fig. 105.



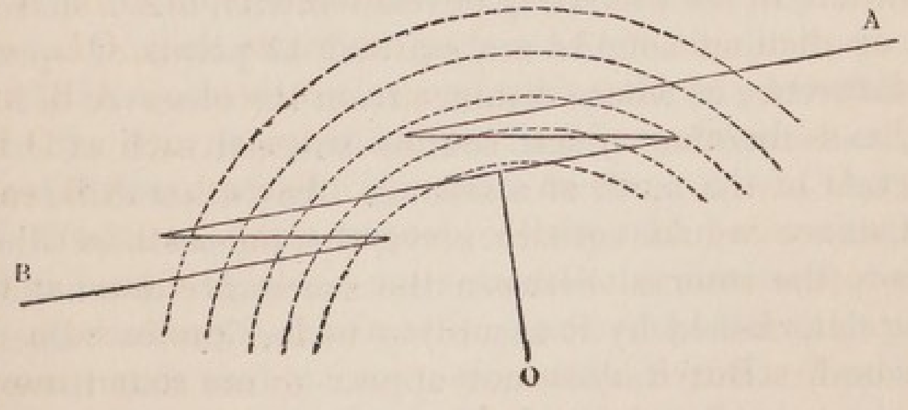
at O. From O suppose a perpendicular, O L_1, drawn to A B, and let two lines O L_2, the length of which shall exceed O L_1 by 110 feet, be inflected from O on A B, one on each side of O L_1. Let other two lines, OL_3, exceeding OL_2 by 110 feet, be also inflected on A B, and in the same manner let a series of lines, such as O L_2, O L_3, O L_4, ... be successively inflected on A B, each line exceeding that which precedes it by 110 feet. If we suppose sounds to be simultaneously produced at the points L_1, L_2, L_3, ..., that which is produced a L_1 will be first heard by the observer. Since sound moves at the rate of 1100 feet per second, it will take the tenth of a second to move through 110 feet; therefore the two sounds emitted at L_2 will arrive together at the ear of the observer a tenth of a second after the sound at L_1 has been heard. In the same manner, the two sounds emitted at L_3 will arrive after another tenth of a second, and so on. Thus every ten sounds of the series, though simul-

taneously produced, would take a second in being heard, and would be recognised by the ear as a distinct though rapid succession of ten sounds. If it be admitted, then, that the electric fluid, in passing through the air with the great velocity it is proved to have by the experiments of Professor Wheatstone, produces sonorous vibrations of this kind in the air, the rolling of thunder would be a necessary consequence.

(93.) According to this manner of viewing the phenomena the thunder would be loudest which proceeds from L_1, the nearest point to the observer, and would gradually be enfeebled for points more and more distant from L_1. Therefore the roll would always be loudest at the commencement, and would gradually diminish in force until it becomes inaudible. This is not in accordance with the actual phenomena.

But the preceding explanation proceeds on the supposition that the lightning moves continually in the same straight line. Let us see what the effects of a zig-zag course would be, such as that represented by the line A B, *fig.* 106. Taking the place of the observer, O, as a

Fig. 106.



common centre, let a series of circular arcs be drawn, with radii increasing in magnitude each successive distance, exceeding the last by 110 feet. These arcs will intersect the zig-zag course of the lightning in several points, more or less in number, according to the position of the directions of the lightning, and the magnitude of

the radius of the circle. The first sound which will reach the observer will be that produced at the points where the least of the circles meets the lightning, and the succeeding sounds will correspond to those emitted at the points of intersection of the succeeding circles with the course of the lightning. It is easy to conceive that the mutual position of the zig-zag lightning and the observer may be such, that the number of points of intersection of the circles with the lightning may alternately augment and diminish, in a manner corresponding to any supposable variations in the intensity of the rolling of the thunder.

It is evident that, independently of the infinite varieties of sound capable of being explained by this hypothesis applied to zig-zag lightnings, the changes are not less various for lightning which preserves a single course; the same flash, according to its direction with respect to the observer, being susceptible of an infinite variety of sonorous effects.

(94.) An objection to this fascinating hypothesis occurs to me, which appears to have escaped the attention of its advocates, and which, nevertheless, is entitled to consideration. I have supposed, for the sake of illustration, in the preceding developements, that a succession of distinct sounds are emitted at points of space, the difference of whose distance from the observer is 110 feet, and therefore these sounds succeed each other at intervals of the tenth of a second. Any other difference of distance would equally serve the purposes of illustration, the interval between the successive detonations being determined by it according to the known velocity of sound. But it does not appear to me that there is any thing in the physical effects to warrant the supposition of a series of separate sounds emitted at points of space more or less distant from each other. The electric fluid rushes through space, producing *the same effect at every point*. The analogy, on which Dr. Robison bases the explanation, to a file of soldiers placed at certain distances asunder, who discharge their muskets at the

same instant, but are nevertheless heard in succession, does not seem to be in accordance with the phenomena. The passage of the electric fluid through the air would be more aptly illustrated by a bow drawn over the string of a violin, or the current of air driven by the mouth through a wind instrument, or by the bellows through an organ pipe. There would, according to such analogy, be one sustained sound, instead of a succession, or series, of distinct sounds. It is true, that in the gravest notes on an organ, and even in those produced on certain wind instruments (the trombone for example), and on the strings of the double bass, the *vibrations* are distinguishable; but these vibrations do not seem to have any analogy to the series of sounds which form the rolling of thunder.

(95.) If this hypothesis, nevertheless, be admitted to explain the rolling of thunder, the *duration* of the rolling will become an important element in determining the minor limit of the space through which the lightning passes. Supposing that no line drawn from the observer to the course of the lightning is perpendicular to it, it will follow, that one extremity of the course is nearer than any other point of it to the observer, and the other extremity more remote. The difference between the distances of these extreme points would be the length of the flash, if its direction were immediately towards or from the observer; and if it have any other direction, this difference will be *less than* the length of the flash. The duration of the roll of the thunder being the time sound would take to move over the difference between the greatest and the least distance, this difference may be computed, and thence a minor limit of the length of the flash may be obtained.

From the observations of De L'Isle, it appears that the rolling of thunder observed by him in 1712 lasted, in some instances, forty-five seconds. Allowing 1100 feet for each second, this would amount to 49,500 feet, or very nearly *ten miles*. The length of the flash must therefore have *exceeded* this distance.

CHAP. III.

THE EFFECTS OF LIGHTNING.

(96.) The effects which have been observed to attend the transmission of lightning through bodies which it strikes are so various, and apparently unconnected, that any classification of them is extremely difficult. We shall here adopt that which M. Arago has given. The chief effects of lightning may then be enumerated as follows: —

I. The diffusion of smoke occasionally, and a sulphureous odour almost invariably.

II. The production of chemical changes in the atmosphere itself, and in substances suspended in it.

III. The fusion of metals, and sometimes the contraction of their dimensions without fusion.

IV. The vitrifications of earthy substances, and the formation of *fulgurites*, or thunder tubes.

V. Mechanical effects in piercing, splitting, and transporting from place to place the parts of bodies which it strikes.

VI. The production of magnetic effects.

VII. It passes along certain substances in preference to others; and, in general, its effects are dependent on the nature of the bodies it strikes.

VIII. The existence of a storm in the atmosphere is accompanied by a state of the surface of the earth beneath it, in which lightning issues upwards from it, and objects upon it are struck from below.

IX. Luminous rain.

X. Rain, snow, and hail, falling in a storm, sometimes emit light when the drops strike each other, or strike the earth.

We shall consider these classes of effects in succession.

I. *The sulphureous Odour developed by Lightning.*

(97.) The following instances have been collected by M. Arago: —

In a thunder-storm on the Isthmus of Darien, WAFER, a surgeon, observed that the air was infected with a sulphureous odour, so strong as to check respiration, especially in the woods.

On another occasion, the same observer, crossing a hill after sunset, was overtaken by rain so terrible that it seemed as though heaven and earth were coming together; there were loud claps of thunder, and the lightning was attended by an odour of sulphur so intense that the travellers were nearly suffocated by it.

BOYLE, in his memoirs for a general history of the air, relates that, in a thunder storm which he encountered on the borders of the Lake of Geneva, the air was impregnated with a sulphureous odour so strong, that a sentinel stationed near the Lake was nearly suffocated.

LEGENTIL witnessed a storm in the Isle of France, in February, 1771, in which a strong sulphureous odour was perceived.

On the 4th of November, 1749, in N. lat. 42° 48′, and W. lon. 3°, the ship *Montague* was struck by lightning: it seemed as if the vessel was filled with burning sulphur.

On the 19th of April, 1827, the packet ship *New York*, in N. lat. 38°, and W. lon. 53°, was twice struck by lightning, being nearly 500 miles from land. When first struck, the paratonnerre was not put up, yet the lightning, finding metallic bodies in its route, was conducted to the water, having done much injury to the vessel. The cabins were filled with a thick sulphureous smoke. When she was struck the second time, the paratonnerre was in its place, and no damage was done; nevertheless, various parts of the ship, and the ladies' cabin in particular, was filled with sulphureous vapour, so thick that objects could not be seen through it.

On the 31st of December, 1778, at 3 P.M., the India Company's ship *Atlas*, lying in the Thames, was struck by lightning, and a sailor was killed in the rigging. The ship, for a moment, seemed to be on fire, but, in fact, suffered no damage. A strong sulphureous odour was, however, diffused through it, which continued during the day and ensuing night.

On the 18th of July, 1767, lightning passed down the flues of six chimneys of a house in the *Rue Plumet*, in Paris. A suffocating odour was diffused through the house.

On the 18th of February, 1770, the church of St. Kevern, Cornwall, was struck with lightning during divine service, when the whole congregation were struck senseless. The church was filled with a suffocating sulphureous odour.

On the 11th of July, 1819, the church at *Châteauneuf-les-Moustiers* (Basses

Alpes), being struck by lightning, was filled with a dense black smoke which rendered it so dark that one could walk in it only by groping.

(98.) That the sulphureous odour developed by lightning arises from the actual presence of some vaporous matter seems to be demonstrated by those observations in which an opaque cloudy vapour filled the rooms. Whether this matter diffused through the air is transported from the higher regions of the atmosphere by the lightning, or is developed by the action of the lightning on the bodies which it strikes, is still undecided. The possibility of matter being brought by the lightning from the clouds is countenanced by the phenomena of ball-lightning, and by the results of the investigations of M. Fusinieri, already mentioned. Although the odour diffused by lightning has been generally compared to that produced by the combustion of sulphur, some observers have assimilated it to phosphorus, and others to *nitrous gas*. If the last were its true description, an easy explanation of it would be obtained by considering the effect of electricity on the constituents of the atmosphere.

II. *Chemical Changes operated by Lightning.*

(99.) The experiment formerly alluded to, in which, by transmitting the electric spark through atmospheric air confined in a glass tube, a combination took place between a portion of its constituents, and liquid nitric acid was formed, was due to the celebrated Cavendish. After the identity of lightning and electricity was established, no doubt was entertained that the same process took place in the atmosphere whenever lightning was transmitted through it. The direct demonstration of this important fact was made by professor Liebig in 1827.

That philosopher submitted seventy-seven samples of rain-water, collected on different occasions, to the process of slow distillation. Of these samples, seventeen were

collected during or immediately after thunder storms. In the residue, obtained from these seventeen, nitric acid was found in greater or less quantities, in combination with lime, or with ammonia. In fifty-eight of the other samples these substances were not found; and in the remaining two mere traces of nitric acid were just discoverable.

The formation of nitric acid in the atmosphere during thunder storms suggests to philosophical observers various important objects of attention and inquiry. Under what circumstances of season, locality, height, and temperature of the clouds does the quantity of nitric acid thus formed vary? In tropical regions, where thunder storms are phenomena of daily occurrence for entire months, is the quantity of nitric acid generated in the air sufficient to feed the natural veins of nitre found in certain localities where the absence of animal matter has rendered such formations a matter of great theoretical difficulty? The researches may also lead to the solution of the origin of the other substances, such as lime and ammonia, detected by Liebig in the pluvial waters falling from stormy clouds, and possibly for the sulphureous gas, of which the odour is so remarkable in places where lightning penetrates. It would be a curious and interesting result of scientific investigation to demonstrate that the thunder of heaven elaborates in the clouds the chief ingredient of the counterfeit thunder which man has invented for the destruction of his fellows.

III. *The Fusion and Contraction of Metals.*

(100.) The power of lightning to effect the fusion of metals was observed by the ancients. Aristotle, Lucretius, Seneca, and Pliny mention this property, but in a manner and attended by circumstances which, in the judgment of many, cast doubts on the truth of their statements. Aristotle mentions the copper on a

shield being fused by lightning, while the wood which it covered was uninjured. Seneca states that the coin contained in a purse was fused while the purse was unchanged; that a sword was liquefied while the scabbard in which it lay was untouched; and that the iron points of spears being melted, flowed along the wood to which they were attached without burning it. Pliny relates that coins of gold, silver, and copper sealed up in a bag were melted by lightning, the bag not being burned nor the wax which sealed it softened.

(101.) If the fusion or liquefaction here referred to were understood to mean the *complete* fusion of the various pieces of metal mentioned by these several writers, there would be undoubtedly great difficulty in reconciling their statements with the known properties of matter. But if, on the other hand, partial or superficial fusion be meant, the well ascertained results of modern observation corroborates this ancient evidence.

In 1781, M. D'Aussac and the horse on which he was mounted were killed by lightning in the neighbourhood of *Castres*. The blade of the sword which he wore was fused upon its surface at several places, while the scabbard containing it was not burned. This circumstance is not inconsistent with the known properties of bodies. The part of the blade not fused, being a good conductor of heat, abstracted the heat from the fused part before it had time to burn the scabbard.

The statements of the ancient writers above quoted being taken literally, led Franklin to adopt the hypothesis of *cold fusion*. To admit the possibility of a wooden scabbard containing the heavy mass of incandescent liquid metal which must have resulted from the fusion of a Roman sword without being burned was impossible. He therefore proposed to remove the difficulty by admitting that lightning possessed the property of melting metals *without heating them*. This affords one of the many instances of the errors which arise from framing hypotheses to explain phenomena,

the existence and nature of which are not accurately ascertained. The strict rules of philosophical reasoning required that Franklin should demonstrate as *a matter of fact* that the metal liquefied by lightning is actually cold while in the state of fusion.

(102.) That lightning fuses metals by raising their temperature to the point of fusion is proved by the fact that metal fused by lightning falling in liquid drops on a wooden floor, or on the deck of a vessel, has burned holes in the wood.

(103.) The fusion effected by lightning, is not confined to that of thin wire or to the slight superficial fusion above mentioned. Considerable masses of metal have been on various occasions melted. When the power has not sufficient energy to produce fusion, the iron is often rendered incandescent and soft, and reduced to the state necessary for welding it. With a still more feeble power it is only raised to a temperature more or less elevated. The following facts are collected by M. Arago in illustration of these principles: —

On the 20th of April, 1807, at *Great Mouton*, in Lancashire, a windmill was struck with lightning, which, having passed along a large iron chain, softened the links, so that by their own weight they were welded together and the chain was converted into a rod of iron.

In June, 1829, the same occurrence took place at a windmill at Toothill, in Essex.

On the 5th of April, 1807, at *Vezinet*, near *Paris*, lightning struck a key, and softened it so, that, by its weight, it was welded to its ring.

In March, 1772, lightning struck a bar of iron inserted at the most elevated part of the dome of *St. Paul's Cathedral*, which was intended by the architect to be in metallic connexion with the pipe by which the water is conducted from the roof to the ground. This connexion was accidentally interrupted at a certain point, and *there* it was found that the bar had been rendered *red hot*. This bar was four inches broad, and half an inch thick.

In August, 1777, the weathercock of a tower in *Cremona* was struck by lightning, and the marble stones of the tower broken and scattered. The thunder was the most violent heard in that place. The iron rod of the weathercock, which was half an inch in diameter, was broken, but showed no mark of fusion.

On the 12th of July, 1770, lightning struck the house of Mr. *J. Moulde*,

in *Philadelphia*, and fused a rod of copper six inches long, but of unascertained diameter.

In 1754, the steeple at *Newbury*, in the United States, was struck by lightning, after which it was examined by Franklin, who found that the lightning had passed along an iron wire twenty feet long, and about the thickness of a knitting-needle, which it reduced to smoke. The course of the wire along the walls and floors was marked by a black line, like that left by a train of gunpowder which has been fired. In this case the wire was probably burned. Another wire in the same tower, of the thickness of a goose-quill, transmitted the lightning without being fused.

When Captain Cook was anchored in the roadstead of *Batavia*, his ship was struck by lightning, which produced a shock like that of an earthquake. An iron wire, a quarter of an inch in diameter, extending from the mast top to the water, appeared for a moment to be on fire. No damage was sustained.

On the 18th of June, 1782, lightning struck the house of Mr. *Parker*, at Stoke Newington, near London; and having passed down one of the pipes provided to conduct the pluvial waters from the roof, from that it passed into a bed-chamber, where it followed the course of a wire which connected a cord at the bedside with a night-bolt at the door, by which a person could bolt or unbolt the door without leaving the bed. Such a bolt passes through two rings attached to the door frame, which, in this case, served as a gauge for the length of the connecting wire. After the lightning had passed along it, the wire was found so much *shortened* that the bolt could not be let fall.

Wire extended between two fixed points is often broken by lightning, which may be explained by the contraction just mentioned, and the fixed points not allowing the wire to yield.

IV. *Of Vitrifications and Fulgurites.*

(104.) As evidence of the heights at which the presence of lightning has been manifested, the vitrifications observed in certain places have been already mentioned. SAUSSURE, in 1787, observed these effects on the *Dôme de Gouté*, one of the summits of *Mont Blanc*. RAMOND observed them on several summits of the *Pyrenees*, especially the *Pic du Midi* and *Mont Perdu*, and on the rock *Sanadoire* in the *Puy-de-Dôme*. HUMBOLDT and BONPLAND found similar appearances on the rock *El Frayle*, at the top of *Teluca*, one of the *Cordilleras*, near the city of *Mexico*.

(105.) These several observers merely *saw* the vitrifications; they *inferred* their cause by the form of

reasoning called in logic a disjunctive syllogism, that is, by severally rejecting every other possible cause, they concluded that lightning must have been the true one. That a question so important may not rest solely on such negative proof, M. Arago has collected the following facts in support of it:—

On the 3d of July, 1725, at *Mixbury*, in *Northamptonshire*, lightning struck on an open field, and killed a shepherd and five sheep. Close to the body of the man were found two holes, five inches in diameter, and forty inches deep. Near the bottom of one of them was found a very hard stone, measuring ten inches long, six inches broad, and four inches thick, with its surface *vitrified*.

In the year 1750, lightning struck the tower of *Asinelli*, at *Bologna*, and did some injury to it. BECCARIA, who examined it, found the bricks, at the place where the lightning struck, *vitrified*.

On the 3d of September, 1789, lightning struck an oak in the park of Lord Aylesford, and killed a man who sought sheltér under it. This person carried a walking-stick, which apparently conducted the lightning to the ground, for at its point was found a hole five inches in depth, and two inches and a half in diameter; and below this, to a depth of twelve inches, were found marks of vitrification.

(106.) The fact last mentioned leads to the consideration of *fulminary tubes* or *fulgurites*, of which it may almost be regarded as an example.

These tubes were first discovered in 1711, by *Herman*, a shepherd at *Massel*, in *Silesia*. Specimens of them were sent to the mineralogical museum at *Dresden*, and are still preserved there. Nearly a century elapsed before they were seen again, when, in 1805, Dr. *Hentzen* found them in *Paderborn*, commonly called *La Senne*. This philosopher first assigned their origin. They have been since found in great numbers at *Pillau*, near *Konigsberg*; at *Nietleben*, near *Halle* upon *Saale*; at *Drigg*, in *Cumberland*; in the sandy country at the foot of *Regenstein*, near *Blankenburg*, and in the sands of *Bahia* in *Brazil*.

At *Drigg* the fulgurites are found in hillocks of movable sand, about forty feet high, close to the sea. At *La Senne*, they are usually discovered on the brow of hills of sand about the same height; sometimes also

in a cavity formed like a basin 100 feet in circumference, and fifteen feet deep.

(107.) Fulgurites are usually hollow tubes. At *Drigg* their diameter is generally $2\frac{1}{4}$ inches. Those at *La Senne* vary from $\frac{1}{50}$th of an inch to half an inch in diameter, and contract as they descend, terminating frequently in a point. The thickness of their sides varies from the fiftieth of an inch to an inch. These tubes usually descend in the vertical direction, being occasionally, however, inclined at an angle of 40° to the horizon. Their total length sometimes amounts to above thirty feet. Numerous transversal fissures divide them into fragments, the lengths of which vary from half an inch to six inches. The sand by which they are surrounded dries and falls off after a lapse of time, and these fragments are then seen on the surface of the ground, the sport of the wind.

Most commonly, in clearing away the surrounding sand, the fulgurite is found to consist of a single tube. On following it to a certain depth, this is divided into two or three branches, each of which again divides into small lateral ramifications, varying from one inch to twelve inches in length. These final ramifications are conical, and terminate in points which are gradually inclined downwards.

The interior surface of the tubes is coated with a perfect and very brilliant glass, resembling vitreous opale or *hyalite*. It cuts glass and strikes fire with steel. Whatever be the form of these tubes, they are always surrounded by a crust composed of grains of *quartz* agglutinated together. This crust is sometimes round; it is oftenest like the bark of a stump of an old birch tree. The interior and exterior surfaces correspond in form as if the tube were soft and flexible, and acquired hardness after being bent.

(108.) When examined with a microscope, the exterior crust presents marks of fusion. At a certain distance from the centre of the tube, the grains or

globules acquire a reddish tint. The colour of the material of the tube, and especially of the exterior parts, depends on the nature of the sandy soil in which it has been formed. In the superior strata, which consist of common soil, the exterior of the tube is usually black ; deeper, it is a yellowish grey, and deeper still, a greyish white. Finally, where the sand is pure and white, the tube exhibits nearly perfect whiteness.

(109.) Such being the appearances presented by *fulgurites*, the question is presented, whence do they originate, and by what natural process have they been formed? Four hypotheses were proposed to explain them:—1. They might have been incrustations formed round roots, which disappeared after the operation. 2. They might be stalactites or other mineral formations. 3. They might be cells belonging to ancient marine animals of the worm species. 4. They might be produced by lightning penetrating the ground.

(110.) The first three of these hypotheses include as a necessary condition the formation of the fulgurites at an epoch more or less remote from the present time. If it can be shown, then, that whatever be their origin, it must in some cases at least be recent, these hypotheses must be severally rejected. The phenomena at *Drigg* are conclusive as to the recency of the formation of the fulgurites, and are therefore fatal to these hypotheses.

The hillocks of sand in which the fulgurites at *Drigg* are formed are *shifting*, being subject to constant change by the wind. The tubes in them must, therefore, be of recent formation.

(111.) But it is necessary to show that the state in which the sand is found in the internal and external coating of the tube, as well as in every part of its thickness, *can be* produced by intense heat. This has accordingly been done. The sand in which the tubes have been formed has been exposed to the action of various degrees of heat by means of the blowpipe, and

effects have been produced which correspond with the state of the tubes, and prove that intense heat *can* produce the observed effects.

(112.) Since we have, in the electricity of the machines, another lightning infinitely less in its degree, but still the same in *kind*, a further corroboration of this hypothesis would be obtained, if, by means of this artificial lightning, artificial fulgurites could be formed. MM. Savart, Hachette, and Beudant, transmitted the charge of a powerful electrical battery through a mass of glass reduced to powder, and obtained fulgurites an inch in length, and having an external diameter, varying from an eighth to a tenth of an inch, with an internal diameter of about the twenty-fifth of an inch.

(113.) One step more is necessary to establish the origin of fulgurites. This step would consist in producing an example of the lightning being actually seen to strike the ground where a fulgurite was afterwards found, none having been there before. This step is not wanting.

(114.) Dr. Fiedler, who has published a work in German on fulgurites, supplies the following facts: —

An apothecary of *Frederichdorf* was brought to two men who had been struck with lightning. He found in the ground where they lay two fulgurites like those of *La Senne*.

On the confines of Holland, in a sandy country, a shepherd, after having seen the lightning strike a hillock of sand, found in the very point where it struck a fulgurite.

On the 13th of July, 1823, lightning struck a birch tree near the village of *Rauschen*, in the province of Samlande, on the shores of the Baltic, and at the same time set fire to a juniper bush. The inhabitants ran to the spot, and found near the tree two narrow and deep holes. One of them, notwithstanding the cooling effect of the rain which was falling, was hot to the touch. Professor Hagen of Konigsberg examined these holes, and found them, after excavation, to have all the usual characters of fulgurites.

The origin of fulgurites may then be considered as demonstrated.

V. *Mechanical Effects.*

(115.) The mechanical effects of lightning seen in piercing solid bodies with holes, in splitting them in pieces, and in projecting their fragments, sometimes of enormous weight, to great distances, are so well known and so generally admitted, that it will be needless to multiply instances in proof of it; but a circumstantial statement of some remarkable cases of this kind may throw light upon the manner in which the electric fluid acts.

In the autumn of 1778 lightning struck the house of CASELLI, an engineer at *Alexandria*. It did no damage, but pierced the panes of glass in the windows with several small holes, about the sixth of an inch in diameter. Small cracks in the glass diverged from these holes as centres.

In August, 1777, lightning struck the steeple of the parish church of St. Sepulchre, at *Cremona*, broke the iron cross which surmounted the tower, and projected to a distance the weather-cock, which revolved under the cross, and which was made of copper, tinned, and coated with oil paint. This weather-cock was found to have been pierced with *eighteen holes*, nine of which were very prominent on one side, and the other nine on the other. As there was no appearance of more than one stroke of lightning, all these holes must be supposed to have been pierced at once. The position of the holes was such as would have been produced by blows imparted simultaneously in opposite directions on parts of the metal nearly contiguous, and the inclination of the beards or projecting edges of the holes on one side corresponded exactly with those on the other, the directions of all the eighteen beards being parallel.

On the 3d of July, 1821, lightning struck a house at Geneva, and pierced the tin which covered a part of the roof with several holes, leaving evident marks of fusion. One piece of tin, in particular, which covered the angle made by a chimney with the surface of the roof near it, was pierced with three nearly circular holes about an inch and three quarters in diameter, and about five inches apart measured from centre to centre. The metal at the edges of these holes was bent, as it would have been by a force bursting through it in one direction or the other. The edges of the two holes were bent on contrary sides.

On the night between the 14th and 15th of April, 1718, the church of *Gouesnon*, near Brest, was struck by lightning with such force that it shook as if by an earthquake. The stones of the walls were projected in all directions to a distance of from 50 to 60 yards.

The lightning which formerly struck the *château* of *Clermont*, in *Beauvoisis*, made a hole twenty-six inches wide and the same depth in the wall,

the date of the building of which was so far back as the time of Cæsar, and which was so hard that a pickaxe could with difficulty make any impression upon it.

On the night between the 21st and 22d of June, 1723, lightning struck a tree in the forest of *Nemours*. The trunk was split into two fragments, one seventeen and the other twenty-two feet long. These fragments, so heavy, that one of them would require the combined strength of four men, and the other that of eight men to lift it, were nevertheless projected by the lightning to the distance of about 17 yards.

In January, 1762, lightning struck the church of *Breag*, in *Cornwall*, the south-west pinnacle of the tower of which it destroyed. A stone, weighing 170 lbs., was projected from the roof of the church to a distance of 60 yards in the direction of the south. Another fragment of stone was projected to the north to a distance of 400 yards. A third was projected to the south-west.

About the middle of the last century, a rock of micaceous schist, measuring 105 feet long, 10 feet wide, and about 4 feet thick, was struck by lightning at *Funzie* in *Fetlar*, in *Scotland*, and was broken into three principal fragments, not counting smaller pieces. One of these fragments, twenty-six feet long, ten feet wide, and four feet thick, had been merely inverted in its position; another twenty-eight feet long, seven feet wide, and five feet thick, was projected over the hill to a distance of 50 yards. The remaining piece, 40 feet long, was projected in the same direction, with still greater force, and fell in the sea.*

On the 6th of August, 1809, at *Swinton*, about five miles from *Manchester*, lightning struck the house of Mr. Chadwick at 2 P. M. A sulphureous vapour immediately filled the house. The external wall of a building erected against the house as a coal-shed was torn from its foundations and raised in a mass. It was transported, maintaining its vertical position to some distance from its original place; one of its ends was transported nine and the other four feet. This wall, thus raised and transported, was composed of 7000 bricks, which, independent of the mortar by which they were cemented together, would have weighed about 26 tons. This wall was eleven feet high and three feet thick, and its foundation was about a foot below the level of the ground. Above this coal-shed was a cistern, which, at the time of the phenomenon, contained a quantity of water, and the shed contained about a ton of coals.

(116.) If these mechanical effects could be explained by supposing them to be produced by the moving force of the electric fluid itself impinging on the bodies which are struck, no difficulty would arise from the extreme lightness and tenuity of the electric fluid, for the momentum of a body depends as much on its velocity as on its weight; and however subtle the electric fluid may

* See Lyell's Principles of Geology, vol. i.

be, it is possible to imagine a velocity by which it may acquire any proposed moving force. There are, however, circumstances among the observed effects which cannot be explained by the mere impact of any fluid upon the bodies struck. One of those is, that the fragments of bodies struck by lightning are usually dispersed *in all directions*, and this is the case even when the fragments are large and heavy masses. If the pinnacle of the church at *Breag* had been struck by the mechanical force of a body moving in a determinate direction, it could not have happened that two large and heavy masses of stone would be driven, one to a distance of sixty yards south, and the other four hundred yards north. If the circumstances attending bodies struck by lightning be attentively considered, it will be apparent that they are such as would be produced by a force suddenly called into action, and directed outwards from the internal dimensions of the body, so as to *burst it in pieces*. If the approach of lightning could be shown to be capable of producing, instantaneously, within a body, a highly elastic fluid, such a fluid, in exerting an outward pressure, would burst the body exactly as the explosion of gunpowder forces out the ball, or failing to do so, bursts the gun.

(117.) From what has been established respecting the action of free electricity, it is evident that lightning will decompose the natural electricities of any bodies which it approaches, drawing towards itself the fluid of its own name, and repelling, to the more remote parts, the contrary fluid. If the body be a conductor, this decomposition will take place, and the free electricities of opposite names will be accumulated on opposite sides of it, and when their tensions exceed that of the atmosphere they will escape. If it be not a conductor, then the natural electricities, being forced asunder by the inductive action of the lightning, may produce the effect of a confined elastic fluid, and a separation of the parts of the body will be the consequence.

(118.) The hypothesis proposed by M. Arago to explain the mechanical effects of lightning refers their origin to the water, or other fluids contained in the pores of the body on which the lightning acts. Lightning is proved by observation to evolve heat sufficiently intense to reduce metallic wires suddenly to a state of incandescence. M. Arago argues, that it may therefore be reasonably inferred that it may also produce a like effect on the minute threads of water which pervade the interstices of certain bodies. By the experiments of MM. Dulong and Arago, the elasticity of steam at the temperature of 500° degrees Fahr. amounts to 45 atmospheres. But this temperature is much less than that of red-hot iron. It may therefore be inferred that any small portions of water contained in the pores of bodies, which suddenly acquire as much heat as would render iron red-hot, must acquire an elastic force so enormous as to be capable of producing any of the mechanical effects which have ensued from lightning. In founderies, where a small quantity of water has accidentally been deposited in the mould in which the liquid metal is poured, the most terrible explosions have taken place at the moment the metal comes in contact with the water. Admit that humidity is found in the fissures and cells of the blocks of stone which form a building, and if the thunder strikes this stone, the sudden production of vapour within it will break it, and its fragments will be projected in all directions. In like manner, the sudden formation of vapour in the ground beneath the foundations of the walls of a house would be sufficient to raise the walls in a mass and transport them to a distance. The circumstances attending the action of lightning on trees are still more easily explicable by M. Arago's hypothesis, since the sap and vegetable juices, being placed in lines parallel to the direction of the fibres, the vapour which would be formed would split them in pieces exactly in the manner in which trees are observed to be split by lightning.

(119.) This explanation, ingenious as it is, is not free from objection. That water may be suddenly and strongly heated by lightning when the body which contains it is a conductor of heat may be admitted. But when lightning strikes a large block of stone, the heat must penetrate its dimensions before it can reach the water which may be contained within them; but stone being almost a non-conductor of heat, its surface might be fused, while its internal dimensions would not suffer a sensible elevation of temperature; especially when the stone is exposed to the source of heat only for an instant. Wood is also a bad conductor of heat, yet M. Arago's hypothesis seems to require the admission, that a tree struck by lightning is heated sufficiently to produce aqueous vapour of enormous elasticity without producing the combustion, or even the carbonisation of the wood itself. The soil, or earthy matter, at the surface of the ground is also almost a non-conductor of heat, yet M. Arago requires the admission, that the lightning acting on it produces a vapour from water below it of sufficient pressure to lift the wall of a house and project it to a distance.

(120.) None of these difficulties appear to attend the supposition that the natural electricities of non-conducting bodies, being forcibly decomposed by the proximity of the electric fluid which forms the lightning, and which may be conceived to have an almost infinite intensity, their violent separation resisted, as it would be, by the non-conducting quality of the bodies themselves, would be attended with all the effects which M. Arago ascribes to the sudden formation of vapour, without any of the difficulties or objects which are involved in that supposition.

(121.) If the electricity projected from the thundercloud be supposed to be positive, that of the ground which it approaches will necessarily be negative, and more intensely negative the more intensely positive is the electricity coming from the cloud, and the more nearly it approaches the ground.

(122.) Whatever hypothesis may be adopted to explain the facts, the terms *ascending* and *descending* lightning may be allowed, if they be understood to refer to the direction in which the electricity is propagated, as manifested by its effects. Facts are not wanting to indicate the progress of the electric influence *upwards*.

On the 24th of February, 1774, lightning struck the steeple of the village of *Rouvroi* to the north-west of *Arras*. A pavement composed of large blue stones, which was laid under the steeple, was violently *raised upwards*.

In the summer of 1787, lightning struck two persons who took refuge under a tree near the village of *Tacon* in *Beaujolois*. Their hair was *driven upwards and found upon the top of the tree*. A ring of iron which was upon the shoe of one of these persons was found afterwards *suspended on one of the upper branches*.

On the 29th of August, 1808, lightning struck a small building near the hospital of *Salpêtrière*, in Paris. A labourer who was in it was killed, and, after the event, the pieces of his hat were found incrusted on the ceiling of the room.

When trees have been barked by lightning, it frequently happens that the bark is stripped from the base of the trunk *upwards* to a certain height, and the upper part of the tree is untouched. This occurred with several trees in the *Champs Elysées* at Paris, in a storm which took place in June 1778.

The leaves of trees which have been struck by lightning often exhibit the effects of heat on their lower surfaces, but not at all on the superior surfaces.

(123.) All these effects M. Arago thinks are capable of being explained by the vapour of water issuing upwards after being evolved by the lightning acting on water contained in the ground.

They are also capable of explanation by the escape of negative electricity from the ground upwards.

VI. *Magnetic Effects.*

(124.) This class of effects is so well known, and so perfectly explained by the principles established in Electro-magnetism, that it will not be necessary to devote any space here to the enumeration of instances of them.

VII. *Effects of Conducting Bodies on Lightning.*

(125.) Although the properties of metallic substances, and other conductors, in reference to lightning, are capable of being inferred by analogy from the principles of common electricity yet the difference of the intensity of the atmospheric electricity in storms, and the artificial electricity of the machines, is so enormous, that it cannot be without great utility to record the circumstantial statements of those effects of lightning which illustrate the influence of conductors, when affected by electricity of a tension so much greater than any which can be obtained in ordinary experiments.

(126.) The unvarying preference which electricity gives to conductors over nonconductors in the selection of its route is strikingly illustrated in the following narrative, addressed to the Abbé Nollet soon after the discovery of the virtue of conductors by the Count *Latour-Landry*.

On the 29th of June, 1763, in a violent thunder-storm, lightning struck the steeple of the church of *Antrasme*, near *Laval*. It entered the church, and fused or blackened the gilding of the frames and borders of particular niches. It blackened and scorched (*demi-grillée*) the cruets (*burettes*) which lay in a small cupboard, and finally it pierced two deep regular holes like those of an auger in a marble closet where the church-plate was kept, and which was placed in a niche formed in a wall of sandstone.

These damages were repaired, the gilding was restored, the holes stopped, the painting renewed. On the 20th of June, 1764, lightning again struck the steeple. It entered the church at the same place; blackened the gilding which it had blackened before; fused that which it fused before; extended its damage to precisely the same limits, without exceeding them; blackened and scorched (*grillée*), the cruets; and finally re-opened the two holes in the marble closet.

(127.) The protection afforded by conductors to surrounding nonconductors, and the damage done by lightning in forcing its way to the former and escaping from them through the latter, is proved by the following instances:—

When lightning struck the tower of *Newbury* in 1754, on the occasion formerly mentioned, it first destroyed the superior part, which consisted of a pyramid of carpentry about seventy feet high. Having scattered this mass of wood-work, it encountered a metallic wire which descended through the tower to a point about twenty feet lower. It fused this wire in several places, but the carpentry surrounding it suffered no damage, although the flash had by no means expended its force, as was proved by its effects in descending lower. Arriving at the lower extremity of this wire, the lightning again passed through the carpentry, which it damaged considerably, and such was its intensity, that when it reached the ground it tore up several of the foundation stones of the building, and projected them to a considerable distance.

(128.) The power of metals and similar conductors to give a free passage to the electric fluid is not the only quality from which they derive importance in reference to atmospheric electricity. When lightning comes into the neighbourhood of masses of metal, whether they be exposed or covered by nonconductors, the lightning will force its way to them, bursting through any intervening nonconducting bodies, and fracturing or otherwise damaging them. This may be easily explained by the known effects of induction. The inductive action of the lightning decomposing the natural electricities of the metal attracts the fluid of the same name to the end nearest to it, and is reciprocally attracted by it. The energy of this attraction may be sufficient to produce the effects which are observed. Lightning will also desert a smaller metallic conductor, and rush to a larger one, breaking its way through intervening nonconductors. The principle of induction is equally applicable to the explication of this effect.

Lightning having struck a large rod of iron placed on the roof of the house of Mr. Raven, in Carolina, U. S., passed along a brass wire which was carried down the external surface of the wall and connected with a bar of metal which was sunk in the ground. In its descent, the lightning fused all that part of the wire extending from the roof to the first floor above the level of the ground without damaging the wall against which the wire was attached. At the height of the first floor it took another course, deserting the wire, bursting through the wall, in which it made a large aperture, and entering the kitchen. The cause of this singular deviation at right angles to its former course became manifest, when it was found that a gun standing on its stock rested with its barrel against the

kitchen wall exactly at the place where the lightning forced its way through it. The lightning passed along the barrel of the gun without injuring it, breaking, however, the stock, and damaging the hearth-stone near it.

In the night between the 17th and 18th of July, 1767, lightning struck a house in the *Rue Plumet*, in *Paris*. Several frames were suspended in one of the rooms, one of which only was gilt. This one it attacked, neglecting all the others. A tin lantern and two thin glass bottles lay upon the table. It demolished the lantern, but spared the bottles. In another room was placed an iron stove. This was destroyed, while every thing else in the room was uninjured. In another room was a wooden chest containing several articles made of iron. The chest was broken, the iron articles presented evident marks of fusion, yet half a pound of gunpowder, which was contained in an open powder-horn which lay among these articles, was not fired.

On the 15th of March, 1773, lightning struck the house of lord *Tilney* at *Naples*. A large assembly, consisting of not less than 500 persons, happened to be in the house at the time, among whom were SAUSSURE and sir WILLIAM HAMILTON. Almost all the gildings of the rooms, the cornices of the ceilings, the rods supporting the drapery of the furniture, the gilding of chairs and sofas, the gilded frames of the doors, and the bell cords, were fused, blackened, or scaled off. As usual, the greatest effects were produced wherever the continuity of the conducting matter was interrupted. It is certain that lightning sufficiently powerful to fuse wire would kill a man. In this case, therefore, lightning sufficiently intense to produce death traversed nine rooms, containing 500 persons, without injuring any one, its course being confined to a series of accidental conductors supplied by the walls and furniture.

In 1759, the detachment of French soldiers which conducted captain Dibden, a prisoner of war at *Martinique*, took shelter from rain under the wall of a small church which had neither tower nor steeple. Lightning struck the building, killed two of the soldiers leaning against the wall, and made a breach in the wall immediately behind them, four feet high and three feet wide. On examining the place, it was found that within the chapel, at the place of the breach, a collection of massive bars of iron were placed, intended to support a monument. Those soldiers who were not placed opposite to the iron were uninjured.

On the 10th of June, 1764, lightning struck the steeple of *St. Bride*'s church in *Fleet Street*, *London*, and did great damage. The weathercock was first struck; from that the lightning descended along a bar of iron buried among the massive stones of which the steeple is built. This bar was two inches in diameter and twenty feet long, and its lower end was let into a cavity five inches deep in a stone, and secured there by lead. The gilding on the cross and weathercock was partly destroyed, and all that remained was blackened. The soldering in several places was fused. Along the descending bar no trace of the fluid was discoverable; but at its lower extremity, where the continuity of the metal was broken, were marks of violent effects. The stone in which the end of the bar was inserted was broken in pieces; a large breach was made at the same place in the side of the steeple. The lightning from thence seemed to have descended by leaps from one iron cramp to another immediately below it. It did not,

however, confine its path merely to the descending direction ; wherever iron cramps were inserted within the masonry, to bind the blocks of stone together, the fulminating fluid penetrated and left its marks. In fine, the stones were split, broken, pulverised, displaced, and launched to a distance like projectiles, in the neighbourhood of the extremities of all the bars of iron used in the construction of the building.

In the case of the house struck in 1767, in the *Rue Plumet*, in *Paris*, already mentioned, a remarkable example of the influence of a hidden mass of iron was offered. The only injury done to the exterior of the building was the entire demolition of the entablature, behind which was disclosed a number of large pieces of iron used in its construction.

(129.) It is evident, from these instances, that so long as a continuity of metal is afforded, no damage is done by lightning. But a continuity of any *conducting* matter ought to produce the same effect. If the metal be continued to the ground, and the ground be sufficiently humid to afford a free passage to the electricity, no injurious effects ensue, and the lightning passes quietly into the crust of the globe. But if the ground be dry, it becomes a non-conductor, and the electricity escapes with an explosion.

On the 28th of August, 1760, lightning struck a bar of iron erected on the roof of the house of Mr. Maine, in the United States, and partially fused it. This bar descended to the ground, which it penetrated to some depth, but the soil not being sufficiently humid, the lightning produced an explosion, broke up the ground, and damaged the foundations of the house.

On the 5th of September, 1779, at *Manheim*, on the *Rhine*, lightning struck an iron bar raised on the roof of the hotel of the ambassador of Saxony, by which it was conducted along the roof and walls of the building to the ground. The ground being dry, it quitted the bar with an explosion which produced a vortex of sand, which was witnessed by several persons, and of which evident traces remained.

(130.) When the continuity of the conductor is broken, and the lightning escapes by an explosion, the whole conductor is rendered luminous, which never happens when the conductor is uninterrupted.

Lightning struck the conductor on the house of Mr. *West*, in *Philadelphia*, and the place where its lower extremity met the ground at about five feet below the surface being dry, the lightning escaped by explosion. A heavy shower fell at the moment, which having moistened the pavement, the whole surface of the ground for several yards round the conductor seemed to be on fire.

VIII. *Effects proceeding from the Surface of the Earth.*

(131.) The class of appearances now to be noticed require the more detailed and especial description, in as much as they are more rarely subjects of observation, and many of them are difficult to be connected with the known principles of electricity.

When storms are breaking in the heavens, and sometimes long before their commencement, and when their approach has not yet been manifested by any appearances in the firmament, phenomena are observed, apparently sympathetic, proceeding from the deep recesses of the earth, and exhibited under very various forms at its surface. Instead of recounting these extraordinary class of physical facts in general terms, which, from their nature, must want that precision so desirable in such descriptions, and which are always liable to inaccuracy when a legitimate theory of the phenomena is wanting, we shall here state the particular facts collected by the active zeal of M. Arago on this interesting subject.

Davini wrote to Vallisneri that he had observed, near *Modena*, a fountain whose waters were clear or turbid according as the sky was clear or clouded. Vallisneri himself states that he observed that the salt marshes of *Zibia*, *Quevcola*, *Cassola*, and also in the duchy of *Modena*, and the sulphur springs, announce an approaching storm before there is any appearance of it in the heavens, by a sort of ebullition, and by subterranean noises like that of thunder, and sometimes even by actual thunder.

Toaldo relates that in the hills of *Vicentino*, at a little distance from the parish church of *Molvena*, there is a fountain called by the people of the place *Bifoccio*, because it has two sources. When a storm is approaching, this fountain, even after a long drought and at times when it is completely dry, gushes out suddenly, and fills a large canal with turbid water, which spreads over the adjacent valleys.

At two miles from the sources of this fountain, near the parish church of *Villa-raspa*, in the court-yard of M. *Joseph Pigati* of *Vicenza*, is a deep well which, on the approach of a storm, boils with such violence as to terrify the inhabitants of the place.

It is stated in the Journal of Brugnatelli that, on the 19th of July, 1824,

immediately after a storm, the waters of the lake *Massaciuccoli*, in the duchy of *Lucca*, became as white as if a quantity of soap had been dissolved in them. This appearance continued during the following day, and on the next day multitudes of fish of every size were found dead upon its banks.

(132.) No one who has witnessed the local floods which take place in storms of thunder and rain can fail to be struck with the inadequacy of the quantity of rain, however highly estimated, which can fall within given limits, to account for the enormous quantity of water discharged over plains and through valleys from the higher regions. Direct evidence is not, however, wanting to prove, that in such cases the internal waters of the earth are often discharged through temporary fissures, which break open in the sides of hills and other places. An occurrence of this kind took place in Yorkshire, in the month of June, 1686, when two villages were entirely destroyed by the flood. During a storm an immense chasm was opened in the side of a hill, and a mass of water issuing from it contributed much more than the rain to the flood which ensued.

In October, 1755, a sudden inundation produced immense ravages in Piedmont: the Po overflowed its banks. This disaster was preceded by horrible thunder; and the unanimous opinion of all who witnessed the occurrence, including the celebrated Beccaria, who left the record of it, was, that its chief cause was an immense volume of subterraneous water, which, during the storm, suddenly issued from openings which it made for itself in the bosom of the hills.

(133.) It is impossible to contemplate these phenomena without calling to mind the Mosaic record of the flood: in that record, the source of the waters by which the earth was submerged is stated not to arise solely from the rain which fell from the clouds: —

" In the six hundredth year of Noah's life, in the second month, the seventeenth day of the month, the same day were all the fountains of the great deep

broken up, and the windows of heaven were opened." (*Gen.* vii. 11.)

The breaking up of the fountains of the great deep, as distinguished from the opening of the windows of heaven, either has no meaning, or must be taken to express the breaking out of the subterraneous waters by clefts and fissures in the crust of the earth. That the expressions are not accidental tautology or pleonasm is proved by their repetition in the next chapter, where the termination of the flood is described: —

"And God remembered Noah, and every living thing, and all the cattle that was with him in the ark; and God made a wind to pass over the earth, and the waters assuaged. The fountains also of the deep, and the windows of heaven, were stopped, and the rain from heaven was restrained." (*Gen.* viii. 1, 2.)

The rupture of the crust of the globe by the influence of the electricity of the atmosphere exerted upon large masses of subterraneous water would not be inexplicable if it could be shown as a matter of fact that the same influence is capable of producing a swelling and heaving upwards of the unconfined waters of the ocean. Incontestable and recent evidence of this fact is not wanting.

In April, 1827, the packet ship New York, between that port and Liverpool, was assailed by a violent storm, in which the sea appeared to boil as if a thousand submarine volcanoes were in a state of eruption at its bottom. Three columns of water were seen, which rose towards the clouds, falling back in foam, then rising anew to fall back again.

On the Mont d'Or, in Auvergne, is an ancient building, in the middle of which is a cistern hewn out of a single block of stone, called Cæsar's cistern. In the bottom of this are two holes communicating with a spring, through which water rises with a motion and noise like that of ebullition. Frequent observations have been made on this spring by Dr. Bertrand, who states that it increases considerably when the weather is stormy. The increase of noise which attends it is known among the inhabitants of the valley as a presage of coming storms; it is a sign which they say never deceives them.

The celebrated Duhamel du Monceau states that silent lightnings, unaccompanied by wind or rain, called heat lightnings, have the property of breaking the ears of corn. Farmers are well acquainted with this fact.

On the 3d of September, 1771, Duhamel himself witnessed this fact: on the morning of that day there was much lightning, and he afterwards found that all the ears of corn which were ripe were broken off at the nearest knot: the only ears which remained standing were the green ones.

(134.) These and similar effects indicate an influence emanating from the ground. Such effects are not confined to corn, but probably extend to all vegetable substances. The following fact, as stated in the *Bibliothèque Britannique* of Geneva for the year 1796, supplies an example of this: —

A wood of oak situated on an eminence two leagues from Geneva was barked in May, 1795. This operation can only be effected in the season of the year when the sap, moving between the wood and the bark, diminishes sufficiently the adherence of the latter to be enabled to be separated with facility from the tree. The workmen remark also, that the state of the atmosphere produces an evident influence on the process

One day the wind was blowing from the north and the sky unclouded, the bark was removed with more than usual difficulty. In the afternoon, clouds rose in the west, thunder rolled, and at the same instant the bark, to the great astonishment of the workmen, fell spontaneously from the trees. They soon had reason to ascribe this to the state of the atmosphere, since the effects ceased when the storm passed away.

(135.) There are a multitude of popular impressions respecting the effects of thunder, which have been generally regarded as destitute of foundation, and not even worthy of serious attention: such are the received opinions that thunder curdles milk, renders wine, beer, and other fermented liquors sour, taints fresh meat. After the facts, however, which have been stated above, it would be rash to pronounce assertions so unanimous of cooks, brewers, wine-makers, butchers, &c. to be false. Instead of being regarded as subjects of ridicule and contempt, such questions should be submitted to serious experimental inquiry.

(136.) Among the numerous manifestations of the discharge of electric matter from the surface of the earth produced by the influence of the electricity of the air, one of the most circumstantial and authentic is due to *Brydone*, who, being on the spot where the occurrences took place, was in part witness to them,

and collected the particulars from other eye-witnesses with scrupulous care.

On the 10th of July, 1785, a storm broke out between noon and one o'clock in the neighbourhood of *Coldstream*. During its continuance, there occurred in the surrounding country several remarkable accidents.

A woman who was cutting grass on the banks of the *Tweed* was suddenly thrown down without any apparent cause. She called her companions immediately to her aid, and told them that she received a sudden and violent blow on the soles of her feet, but whence it proceeded she could not tell. At the moment this happened there was neither thunder nor lightning.

A shepherd attached to a farm called *Lennel Hill* saw a sheep suddenly fall which, the moment before, appeared in perfect health. He ran to raise it from the ground, and found it stiff dead. The storm was then approaching, but distant.

Two coal waggons driven by two boys seated on the benches in front of them had just crossed the *Tweed*, and were in the act of ascending a hill on the banks of the river, when a loud explosion was heard like the report of several guns fired nearly together, and unattended by any rolling or continued sound like that which usually accompanies thunder. At the moment of this explosion, the boy who drove the second waggon saw the foremost waggon with the two horses and driver suddenly fall to the ground, the coal being scattered about in all directions. On examination, the driver and horses were found to be stiff dead. The coal which was dispersed had the appearance of having been for some time in the fire. At the points where the tires of the wheels rested at the time of the explosion the ground was found to be pierced by two circular holes, which, being examined by *Brydone* half an hour after the occurrence, emitted a strong odour resembling that of ether. The tires of the wheels showed evident marks of fusion at the points which were in contact with the road at the moment of the explosion, and at no other part. The hair was singed on the legs and under the bellies of the horses; and by a careful examination of the marks left in the dust of the road where they fell, it was apparent that they must have been struck suddenly stone dead, so that no life remained when they touched the ground. Had there been any convulsive struggle, the marks would have been visible. The body of the driver was scorched in different places, and his dress, shirt, and particularly his hat, were reduced to rags. A strong odour proceeded from them.

All the witnesses of this occurrence agreed that no luminous appearance whatever attended it. The driver of the second waggon was conversing with his comrade, and was looking towards him at the moment he was struck down, being at about twenty yards behind him, but saw no light. A shepherd, standing in an adjacent field, told Mr. Brydone that he had his eye on the waggon at the very instant of the explosion, but he saw no light. He saw a vortex of dust arise at the place of the explosion, but unaccompanied by any luminous appearance. Finally, Mr. Brydone himself, at the moment of the event, was standing at an open window, with a watch in his hand, explaining to the persons around him the method of calculat-

ing the distance of the lightning, by observing the interval between the flash and the thunder, and he heard the explosion, but perceived no light.

(137.) The explanation of these effects, which naturally presents itself to a mind conversant with the laws established by experiment on artificial electricity is, that the natural electricities of some subterraneous conductors are decomposed by the inductive action of the atmosphere or by other causes, and that the fluid thus liberated and accumulated immediately under the non-conducting crust which forms the surface breaks through that crust, and passes to the nearest external conductor. Hence the fusion of the tires of the wheels by electricity issuing from holes immediately under them.

(138.) The absence of light in the electric emanations which proceed from the ground is not general. The following statements, coming from an authority not to be questioned, will illustrate this: —

On the 10th of September, 1713, MAFFEI relates, that having been delayed for some time near the *château* of *Fosdinovo*, in the territory of Massa-Canara, he took shelter from a storm in the château, where, with the *Marquis de Malaspina*, he was received by the mistress of the house, in a room situate on the ground-floor. There they saw suddenly appear on the surface of the ground a vivid flame, having a light partly white and partly azure. This flame was much agitated, but had no progressive motion. After gradually acquiring a considerable volume, it suddenly disappeared. At the instant of its disappearance, Maffei felt in his shoulder, proceeding from his back upwards, a peculiar tickling sensation (*un chatouillement particulier*); plaster detached from the ceiling of the room fell upon his head, and, in fine, he heard an explosion, different, however, from the sound of thunder.

In a letter addressed to APOSTOLO ZENO, MAFFEI states, that on the 26th of July, 1731, lightning struck at *Casalaone*, accompanied by thunder as loud as a cannonade, the principal tower, tore away the escutcheon bearing the arms of the town, destroyed the stone mouldings, and did other damage. This occurrence was preceded by the appearance of a great flame at a little distance from the ground.

The following statement is on the authority of the Abbé Richaud* : —

* "Histoire Naturelle de l'Air et des Météores," tom. viii. p. 291.

"On the 2d of July, 1750, at three o'clock in the afternoon, being in the church of *St. Michel*, at *Dijon*, during a storm, I saw appear suddenly, between the first two pillars of the principal nave, a red flame, which was suspended in the air at the height of three feet from the floor. This flame then gradually augmented its volume until it attained the height of from twelve to fifteen feet. After having risen through several fathoms in a diagonal direction, nearly to the height of the organ gallery, it disappeared with an explosion like the report of a cannon discharged in the church."

(139.) The fire evolved from the earth by the influence of atmospheric causes is not extinguished by passing through water.

On the night between the 4th and 5th of September, 1767, during a violent storm, the keeper of a fish-pond near *Parthenai*, in *Poitou*, saw the entire pond covered with a flame, so dense as to prevent him from seeing the surface of the water. The next day dead fish floated on the pond.

(140.) The existence of a storm in the air is not a necessary condition in the causes which govern the evolution of these terrestrial fires.

On the 4th of November, 1749, in lat. N. 42° 48′, long. W. 2°, a few minutes before noon, the sky being unclouded, a globe of bluish fire, having the appearance of a millstone, rolled rapidly along the surface of the sea, towards the British ship *Montague*, already referred to (p. 139.). At a little distance from the vessel it rose vertically from the water, and struck the masts with an explosion like that of several hundred pieces of artillery, committing much damage to the masts and rigging. Five sailors were laid senseless on the deck, one of whom was severely burned. The usual effects of lightning were observed. A sulphureous odour was diffused through the ship, and large iron nails, torn from various parts of the vessel, were projected on the deck with such force that strong pincers were necessary to draw them out.

(141.) Sometimes luminous emanations assume the appearance of a cloud of light maintaining a stationary position.

Major Sabine and captain James Ross, in their first northern expedition, being in the Greenland seas during one of the dark nights of these regions, were called up by the officer of the deck to observe an extraordinary appearance. Ahead of the vessel, and lying precisely in her course, appeared a stationary light resting on the water and rising to a considerable elevation, every other part of the heavens, and the horizon all around the ship, being as black as pitch. As there was no known danger in this phenomenon, the course of the vessel was not changed. When the ship entered the region of this light, the officers and crew looking on with the liveliest interest, the whole vessel was illuminated; the most elevated

parts of the masts and sails, and the minutest parts of the rigging, became visible. The extent of this luminous atmosphere might have been about 450 yards. When the bow of the ship emerged from it, it seemed as if the vessel were suddenly plunged in darkness. There was no gradual decrease of illumination. The ship was already at a considerable distance from the luminous region, when it was again visible as a stationary light astern.

This narrative was addressed to M. Arago in a letter from Dr. Robinson of *Armagh*, who received it from MM. Sabine and Ross. "The cause of these phenomena," says M. Arago, "to use the beautiful expression of Pliny, is still hidden in the majesty of nature."

(142.) Besides these unusual luminous phenomena, many philosophers, among whom are Maffei and Chappe, have maintained that storms are almost always attended by common lightning, which issues from the earth and strikes the clouds. Nor are such statements made in a general and vague form; but the partisans of this doctrine declare that they have themselves *distinctly seen* such lightning rise like a rocket. If such statements be correct, it must be assumed that the speed of this ascending lightning is infinitely less than that of the cuspidated lightning, since the progressive motion of the latter cannot be observed. The ascending lightning, if the accounts of it be correct, must be analogous in its motion to ball-lightning.

(143.) Of the flames which issue from the earth and form objects upon it, the most common and most frequently observed are those which have appeared on the points of spears, and more frequently still on the extremities of the masts and yards of ships. These were observed by and known to the ancients long before electricity assumed its place among the sciences.* When they appear in two flames on the masts and rigging of vessels seamen call them *Castor* and *Pollux*; when as a single flame, *Helen*. The latter is regarded as an evil omen; the former a presage of a favourable voyage.

* See Introduction, p. 4.

Passing over many examples of these phenomena of remote date, and which might be considered of doubtful accuracy, we shall here state a few of the more recent instances of them.

On the 25th of January, 1822, during a heavy shower of snow, M. DE THIELAW, on his route to *Freyburg*, observed the branches of the trees, in a heavy shower of snow, to emit a bluish light.

On the 14th of January, 1824, immediately after a storm, a large black cloud overspreading the sky, M. MAXADORF saw a waggon on which a load of straw was transported into the middle of a field near *Cathen*, and observed that the blades of straw stood on end, and seemed to be on fire. A vivid flame also issued from the whip of the driver. This appearance lasted about ten minutes, and ceased when the wind had dispersed the cloud.

On the 8th of May, 1831, some officers of the French engineers and artillery were walking after sunset, with their heads uncovered, on the terrace of *Bab-Azoun*, at *Algiers*. Each looking at the other's observed, with unqualified astonishment, that the hairs of his companion's stood on end, and little jets of flame issued from them. When the officers raised their hands similar jets issued from their fingers.

Similar phenomena are seen to issue from the pointed extremities of steeples and other elevated structures.

IX. *Luminous Rain.*

(144.) The following are the proofs and examples of the occurrence of this class of phenomena collected by M. ARAGO: —

On the 3d of June, 1731, HALLAI, prior of the Benedictines of *Lessay*, near *Constance*, states, that he saw in the evening, during a thunder-storm, rain fall like drops of red-hot liquid metal.

In 1761, BERGMAN wrote to the Royal Society of London that he observed on two occasions towards evening, and when no thunder was heard, rain which sparkled as it struck the ground, which seemed to be covered with waves of fire.

On the morning of the 22d of September, 1773, in the district of *Skara*, in *East Gothia*, in *Sweden*, a thunder-storm broke, attended by very violent rain. The rain commenced at six o'clock in the evening. All the accounts agree in stating that the drops struck fire, and scintillated on touching the ground.

On the 3d of May, 1768, near *La Canche*, about two leagues from *Arnay-le-Duc*, M. *Pasumot* was caught on an open plain by a violent storm. The rain-water collected abundantly on the leaf of his hat, and when he stooped his head to let it flow off, he observed that in its fall, encountering that

which fell from the clouds at about twenty inches from the ground, sparks were emitted between the two portions of liquid.

On the 28th of October, 1772, on his way from *Brignai* to *Lyons*, the Abbé Bertholon was caught in a storm at five o'clock in the morning. Rain and hail fell heavily. The drops of rain and the hail-stones which struck the metallic parts of the mounting of his horse's trappings emitted jets of light.

A friend of Howard the meteorologist, on his way from *London* to *Bow*, on the 19th of May, 1809, during a violent storm, saw distinctly the drops of rain emit light when they struck the ground.

On the 25th of January, 1822, the miners of *Freyberg* informed Lampadius, that the sleet which fell during a storm emitted light when it struck the ground.

(145.) This emission of light is not peculiar to water whether in the liquid or frozen state.

During the eruption of *Vesuvius* which took place in 1794, a shower of dust, as fine as snuff, fell in *Naples* and its environs. This dust emitted light which, though pale, was distinctly visible at night. Mr. James, an English gentleman, who happened at the time to be in a boat near *Torre del Greco*, observed that his hat and those of the boatmen and the parts of the sails where the dust lodged shed around a sensible light.

These several phenomena seem capable of easy explanation, by admitting the rain, hail, or snow coming from the clouds and the surface of the earth and objects upon it to be in opposite electrical states.

CHAP. IV.

OF THE GEOGRAPHY AND CHRONOLOGY OF THUNDER STORMS.

(146.) THE paucity of meteorological observatories and observers even in Europe where physical science is most cultivated, and where even the smallest and least important discoveries affecting its progress are sure sources of honour and distinction, and their total absence from almost every other part of the globe, are causes which leave but few facts for the historian of thunder to collect and arrange under the heads which appear in the title of this chapter. Whether the mean prevalence of storms on the globe or on any specified parts of it have undergone any variations as age has rolled after age within the limits of human records, and if they have, what is the law which governs that variation, and what will be their future mutations? How the prevalence of storms in different parts of the globe is affected by the vicissitudes of seasons? How it is affected by the position of places with reference to the equator and the poles? How it is affected by the distribution of land and water on the surface of the earth? How it is affected by the geological character of country or by the physical conformation of the surface? These, and many other questions of a like nature, must continue without clear or satisfactory solutions until the number, zeal, and efficiency of meteorological observers bear some comparison to that which has brought other branches of physics to so high a degree of perfection.

Nevertheless, something has been accomplished by individual exertion and zeal, — nothing systematic, nothing directed with a view to the developement of any great general principles, it is true, — but still facts and

observations which, being brought together from an infinite variety of scattered sources, often from quarters where the record of scientific facts would be least expected, may be usefully arranged so as to illustrate the geography and chronology of thunder storms, and to form at least a nucleus round which the results of future investigation may be collected. This useful service has been performed by the zeal of M. Arago.

(147.) Ancient writers, historians, and poets, mention incidentally effects of lightning which afford some countenance to a conjecture,—a *mere conjecture*,—that formerly thunder storms prevailed more than at the present day. Herodotus states that the army of Xerxes, when near *Troy*, was struck by lightning, and a number of men killed. Pausanias records a like occurrence to a Lacedæmonian army near *Argos*. Pliny, the naturalist, mentions that the towers erected, during the war between *Terracina* and the temple of *Feronia*, were so often destroyed by lightning that their construction was discontinued. In Virgil, Ovid, and Propertius, are recorded the death by lightning of a greater number of *remarkable* persons than all human record could supply for the last 2000 years. As examples may be cited, the names of *Salmoneus*, *Capaneus*, *Semele*, *Remulus*, *Enceladus*, *Typhon*, *Ajax* the son of *Oileus*, *Esculapius*, *Adimanthus*, *Lycaon*. To these may be added *Tullus Hostilius*, and the emperors *Carus* and *Anastasius* I. If so many notable persons were so destroyed in an age and country when newspapers and reporters were unknown, and when mail-coaches, railways, and steam-ships had no existence, it may be reasonably inferred that the same visitation must have reached an infinitely greater number of the obscure who have no historian to record and no poet to sing their fate.

It is certain that neither in the same localities, nor in other parts of Europe or Asia, does lightning strike and destroy now so frequently as to account for such effects. If the ancient historians and poets are to be credited, thunder storms must be less frequent now than formerly.

(148.) If the positive testimony of ancient writers be regarded with limited confidence, their negative evidence must be received with great distrust. Pliny states that it never thunders in Egypt, and Plutarch that Ethiopia is free from that meteor. It is now known that thunder is not unfrequent at Cairo and more usual at Alexandria; and as there is abundant evidence of thunder in countries adjacent to Ethiopia, there is little doubt that the atmosphere at that part of Africa is not exempt from such phenomena.

(149.) In the warmer climates, there is one place and one only where it is known that thunder is never heard. The inhabitant of *Lima* who has never travelled knows thunder and lightning only by description. In the atmosphere of that country, clouds, properly so called, never appear.

(150.) From the testimony of Phipps, Scoresby, Parry, Ross, and all others who have navigated the polar seas, it has been ascertained that the frequency of thunder diminishes in approaching the pole. It appears to be certain that it never thunders in north latitudes above the 75th parallel. Between 70° and 75° thunder is sometimes, but rarely, heard. Below 65° storms become more common, and their frequency increases as the latitude diminishes, the intertropical regions being those which, in general, present the most violent and frequent manifestations of this meteor.

(151.) By comparing the recorded cases of thunder storms at land and at sea, it appears to be established, on grounds at least of strong probability, that storms are more frequent on land than at sea; that at sea the frequency of storms diminishes as the distance from land increases, and analogy leads to the probable conjecture that there is a certain distance from land at which it never thunders.

(152.) The principal data from which the geographical distribution of storms and their prevalence at different seasons of the year can be conjectured are collected and arranged in the following table:—

Place.	Lat.	Lon.	Period of the Observations	Days of Thunder in each Month.												Total Days of Thunder per Annum.	Greatest Number in one Year.	Least Number in one Year	
				Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.				
Calcutta - - -	22½° N.	96° E.	Yrs. 1	0	4	6	5	7	8	6	10	9	5	0	0	60	-	-	Year 1785.
Patna - - -	25° 37′ N.	-	1	-	-	-	-	-	-	-	-	-	-	-	-	53	-	-	These days were included between May and Dec., observed by Mr. Lind.
Rio Janeiro - -	23° S.	35½° W.	6	10·2	9·7	4·3	1·7	0·8	0·7	1·3	1·1	2·8	3·7	6·0	9·0	50·7	77 in 1782	38 in 1786	These are the mean results. The observations were from 1782 to 1787 inclusive.
Maryland, U.S. -	39° N.	69° W.	1	0	0	5	1	10	8	11	5	0	1	0	0	41			
Martinique - -	14½° N.	53° W.	-	-	-	-	-	-	-	-	-	-	-	-	-	39	-	-	No thunder from Jan. to Dec. inclusive; most frequent in Sept.
Abyssinia - -	13° N.	45° E.	1	0	0	4	4	6	7	3	6	4	4	0	0	38	-	-	Observed by Bruce the traveller, 1770.
Guadaloupe - -	16¼° N.	54° W.	-	-	-	-	-	-	-	-	-	-	-	-	-	37	-	-	No thunder from Jan. to Dec. inclusive; most frequent in Sept.
Viviers — France -	47½° N.	12¼° W.	10	0·0	0·1	0·6	2·2	4·0	3·4	5·1	3·4	3·1	2·2	0·6	0·0	24·7	35 in 1811	14 in 1814	Observations from 1807 to 1816 inclusive.
Quebec - - -	46¾° N.	63½° W.	-	0·0	0·0	0·0	0·6	2·5	5·5	8·0	5·0	1·0	0·5	0·1	0·1	23·3	-	-	Period not stated.
Buenos Ayres -	34½° N.	50¾° W.	7	1·9	2·6	2·1	1·8	1·7	1·1	1·3	1·0	2·9	2·3	1·8	2·0	22·6			
Denainvilliers -	48° N.	10° E.	24	0·1	0·1	0·5	1·6	3·6	4·5	4·4	3·5	1·5	0·5	0·3	0·0	2·06	32 in 1769	15 in 1765	Observed by Duhamel. Period from 1755 to 1780.
Smyrna - - -	38½° N.	34¾° E.	1	2	4	4	1	1	0	0	0	3	0	1	3	19	-	-	Observed by M. de Nerciat.
Berlin - - -	52½° N.	21° E.	15	0·0	0·0	0·1	0·6	2·6	3·9	4·2	5·3	1·3	0·1	0·1	0·1	18·4	30 in 1783	11 in 1780	Observed by M. Béquelin. Period from 1770 to 1785.

Padua - - -	45½° N.	19½° E.	4	0·0	0·0	1·2	2·2	1·2	3·5	3·5	2·5	0·7	1·0	0·5	0·0	17·5			
Strasburg - -	48⅗° N.	15½° E.	20	-	-	-	-	-	-	-	-	-	-	-	-	17	21 in 1831	6 in 1818	Observed by M. Herrenschneider.
Maestrecht - -	51° N.	13½° E.	11	0·0	0·1	0·4	1·5	2·5	2·9	3·7	3·3	1·4	0·5	0·1	0·1	16·2	27 in 1826	8 in 1823	Observed by M. Crahay.
Lachappelle - -	50° N.	11½° E.	18	0·2	0·2	0·5	1·1	2·6	3·2	2·3	1·8	1·3	0·7	0·8	1·0	15·7	23 in1828	6 in 1820	Observed by MM. Nell de Bréauté and Racine.
Toulouse - -	43½° N.	11° W.	7	-	-	-	-	-	-	-	-	-	-	-	-	15·4	24 in 1788	4 in 1784	Period from 1784 to 1790.
Utrecht - -	52° N.	12¾° W.	-	-	-	-	-	-	-	-	-	-	-	-	-	15	23 in 1737	5 in 1740	Observed by Mushenbroek for a long period.
Tubingue - -	48½° N.	16¾° E.	9	-	-	-	-	-	-	-	-	-	-	-	-	14·6	-	-	Observed by Kraaft.
Paris - - -	48½° N.	10° E.	19	0·1	0·1	0·2	0·8	1·8	3·0	2·5	2·2	0·7	0·6	0·1	0·1	12·2	22 in 1794	7 in 1796	Period from 1785 to 1803.
Paris - - -	48½° N.	10° E.	10	0·0	0·3	0·1	0·5	3·2	3·1	2·7	2·4	1·5	0·7	0·1	0·3	14·9	25 in 1811	8 in 1815	Period from 1806 to 1815.
Paris - - -	48½° N.	10° E.	10	0·1	0·0	0·5	1·0	3·0	2·8	2·1	1·5	1·6	0·3	0·2	0·1	13·2	22 in 1822	6 in 1823	Period from 1816 to 1825.
Paris - - -	48½° N.	10° E.	12	0·0	0·1	0·3	0·9	3·1	2·9	3·2	2·2	1·2	0·6	0·0	0·1	14·7	20 in 1827	8 in 1831	Period from 1826 to 1837.
Paris - - -	48½° N.	10° E.	51	0·1	0·1	0·3	0·8	2·7	2·9	2·6	2·1	1·3	0·5	0·1	0·1	13·8	-	-	Mean of the preceding periods.
Leyden - - -	52° N.	12° E.	29	0·1	0·4	0·2	0·3	2·1	2·7	2·9	2·9	1·0	0·3	0·3	0·2	13·5	17 in 1748	5 in 1835	Observed by Muschenbroeck.
Athens - - -	38° N.	31¼° E.	3	-	-	-	-	-	-	-	-	-	-	-	-	11	18 in 1834	7 in 1—	Period from 1833 to 1835.
Polpero (Cornwall) -	50½° N.	-	13	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-	Observed by Mr. Jonathan Crouch.
Petersburg - -	60° N.	38° E.	11	0·0	0·0	0·0	0·7	2·7	2·1	2·5	0·9	0·1	0·0	0·1	0·0	9·2	-	-	Observed by Kraaft, 1726 to 1736.
London (near) -	51½° N.	12½° W.	26	0·0	0·2	0·4	0·4	1·8	1·4	2·0	1·3	0·4	0·4	0·2	0·1	8·5	13 in 1809	5 in 1819	Observed by Howard at different places near London, 1807 to 1822.
Pekin - - -	40° N.	124° E.	6	0·0	0·0	0·0	0·2	0·5	2.0	1·7	1·0	0·3	0·1	0·0	0·0	5·8	14 in 1762	3 in 1757	Observed by the missionaries, 1757 to 1762.
Cairo - - -	30° N.	39° E.	2	1·0	0·0	0·5	1·0	0·0	0·0	0·0	0·0	0·0	0·0	0·5	0·5	3·5	4 in 1835	3 in 1836	Observed by Dr. Destouches 1835 to 1836.

*** The fractional numbers in the above table may appear to some persons to require explanation. They are to be understood thus:— the decimal 0·9, under the month of March, means, that in ten years it thunders on nine days in that month. The number 2·9, under June, means, that in ten years it thunders on twenty-nine days in the month of June, and so on.

(153.) On inspection it will be evident from this table, that thunder-storms occur more frequently in the summer months than at any other seasons.

(154.) With the view of comparing the damage sustained from lightning at different seasons, M. Arago has collected an account of ships struck by lightning between the latitudes of the Mediterranean and the coasts of England. This enumeration is necessarily imperfect, being collected from the information gleaned from the memoirs of Mr. Harris and other sources, without the aid of any regular or certain reports. The dates of the accidents extend from 1681 to 1832.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Number of Ships struck - -	8	6	1	8	0	0	3	1	6	2	4	4	43

Of *forty-three* recorded cases, *twenty-three* occurred in the first four months of the year, and *sixteen* in the last four.

If storms, therefore, be more prevalent in the summer, it would seem that they are attended with more dangerous effects in the winter. The data are, however, too scanty to afford safe ground for any general inference.

[(155.) But we have hopes of gaining much information on these matters from a series of papers, which Mr. Harris is now (1843) publishing in the *Nautical Magazine*. He is giving an alphabetical list of the ships of her majesty's navy, which have suffered from lightning, including authentic notices of the attendant phenomena; and, at the end of the series, he purposes entering upon a critical examination of the whole, with a view of drawing such practical deductions as the list may present.]

CHAP. V.

OF DANGER FROM LIGHTNING, AND THE MEANS OF PROTECTION.

(156.) The apprehension of danger from lightning, and the solicitude to discover and adopt means of security against it, are proportionate to the magnitude of the evils it produces, rather than the frequency of their occurrence. The chances which any individual of the population of a large city incurs of being struck with lightning during a storm are infinitely less than those which he encounters in his daily walks of being destroyed by the casual fall of the buildings near which he passes, or by the encounter of carriages crossing his path, or from the burning of the house in which he lodges, or from a thousand other causes of danger to which he exposes himself without apprehension. Still, even those who possess the greatest animal courage are struck with awe, and affected more or less by fear, when exposed to the war of the elements in a violent storm; and there are none who, in such cases, will not willingly avail themselves of any means of protection which they believe to be availing. Augustus entertained such a dread of lightning, that in storms he took refuge in caves, thinking that lightning never penetrates to any considerable depth in the ground.

(157.) Strong fear, operating on ignorance, has prompted, in times past and present, a multitude of absurd and unavailing expedients, among which, nevertheless, chance seems to have flung some in which analogies to the results of modern science are apparent. When a cloud menaced thunder, *the Thracians shot their arrows at it.** The arrows being metal were con-

* Herod. lib. iv. ch. 94

ductors, and being pointed had the virtue of attracting lightning. Pliny states, that the *Etruscans* had a secret method *by which they could draw lightning from the clouds, and guide it at their pleasure.* Numa possessed the method; and Tullus Hostilius, committing some oversight in the performance of the ceremony, was himself struck. For Numa substitute Franklin, and for Tullus, Richmann, and the Roman legend is converted into a true historical record of the last century.

(158.) It was formerly believed, that persons in bed were never stricken by lightning; and a modern meteorologist, Mr. Howard, apparently favours such an idea, by relating two cases in 1828, in which beds were completely destroyed by lightning, while the persons who lay in them were uninjured. Against this, however, many contrary instances may be cited. On the 29th of September, 1779, Mr. *Hearthley* was killed in his bed by lightning, at *Harrowgate*, while his wife, who lay beside him, escaped. On the 27th of September, 1819, a servant was killed in her bed at *Confolens*, in France. In 1837 a house was struck with lightning at *Kensington*, near *London*, where a man and his wife were killed in their bed.

(159.) The Romans believed that *seal's skin* was a preservative against lightning; and tents were made of this material for timid persons to shelter under in storms. Augustus was always provided with a seal's skin cloak. However ineffectual may be such an expedient, experience abundantly proves that the material of the dress is not without considerable influence on the course which lightning follows, and may therefore augment or diminish the peril of the wearers. When lightning struck the church at *Château-neuf-les-Moutiers*, during the celebration of mass, of the three priests who officiated at the altar two were struck dead, the third was uninjured. The vestments of the last were *of silk*.

(160.) There are some well-attested facts which indicate a relation between *colour* and the movements of

the electric fluid. Three cases are cited in which horses and oxen, having white spots, were struck by lightning, and had all the white hair burned off, while the remainder of the hide remained unaltered.

(161.) It has been supposed that certain species of trees are proof against lightning and never struck by it. TIBERIUS was accustomed to wear a crown of laurel from the idea that lightning never struck it. Observations made in districts where extensive forests present all varieties of trees to the chances of the storm afford no grounds for any certain conclusions on this subject.

(162.) When assailed by a storm in an open plain, the danger is greatly augmented by seeking the shelter of a tree. Experience and theory combine to prove this. The position of greatest safety is such a distance from a tree that it shall act as a conductor, diverting the lightning from the place assumed for safety. A distance of half a dozen yards may serve for this purpose.

(163.) Glass being a non-conductor of electricity is generally supposed to have a protective virtue. Thus it has been presumed that a person enclosed in a cage of glass exposed to a thunder-storm would be in absolute safety. This is proved to be a fallacy by many examples of lightning striking and penetrating the panes of windows and the frames of conservatories.

(164.) Nothing is more clearly established than that pieces of metal of any kind carried about the person augment the danger of being struck by lightning; and this increase of peril is greater in proportion to the magnitude of the metallic appendages. That this material principle, illustrating, as it does, one of the elementary laws of electricity, may be appreciated as fully as it ought to be, we shall here cite some of the numerous recorded examples of it.

On the 21st of July, 1819, lightning struck the prison of *Biberac* in *Swabia*, and, passing into the grand hall, struck an individual prisoner who was one in a group of twenty; the nineteen others were untouched. This

individual was a brigand chief, who, being under sentence, was *chained round the waist*.

When Saussure and his party were at *Breven* in 1767, the metal band and gold button on the hat of M. Jallabat *emitted sparks*.

Constantini relates that, in 1749, a lady wearing on her arm a gold bracelet raised her hand to shut the window during a thunder-storm: the bracelet suddenly disappeared; not the slightest trace of it remained. The lady was slightly wounded.

Brydone relates that a lady of his acquaintance, Mrs. Douglas, sitting at an open window during a storm, had her bonnet completely destroyed, but suffered no injury in her person. He accounts for this by the wire of the form of the bonnet attracting the lightning.

(165.) These, and many other instances which might be mentioned, sufficiently prove that safety is best consulted in time of storm by laying aside all metallic appendages of the person, such as chains, watch, ear-rings, hair ornaments, &c. The source of the greatest danger is in the bars or plates of steel which are used in the corsets of females, and which ought to be abandoned by all ladies who do not desire to invite the approach of lightning.

(166.) It has been already shown that when lightning passes along a line of conducting matter, the only points where explosion takes place and damage ensues is at the parts where the lightning enters and leaves the conductor; and as a necessary consequence of this, all interruption of continuity in any part of a conductor or series of conductors is attended with explosion and corresponding damage. Since, then, the bodies of men and animals afford a free passage to the electric fluid, it may be expected by analogy that when lightning is transmitted through a chain of animals, either in mutual contact or connected by conductors, the chief, if not the only injury would be sustained by the first and last individuals of the series. This principle is accordingly supported by the results of experience. The following instances will illustrate it: —

On the 2d of August, 1785, a stable at *Rambouillet* was struck by lightning. A file of thirty-two horses received the fluid; of these the *first* was laid stiff dead, and the *last* was severely wounded. The intermediate thirty were only thrown down.

On the 22d of August, 1808, lightning struck a school-room in *Knonau*, in

Switzerland. Five children read together on the same bench. The *first* and *last* were struck dead; the other three only sustained a shock.

At *Flavigny* (*Côte-d'Or*) lightning struck a chain of five horses, killing the first two and the last two, the middle horse suffering nothing.

At a village in *Franche-Comté* lightning struck a chain of five horses, killing the first and last only.

At *Praville*, near *Chartres*, a miller walked between a horse and a mule loaded with grain. Lightning struck them, killing the horse and mule. The man was unhurt, except that his hat was burnt and his hair singed.

(167.) The danger from lightning during storms may be lessened by observing some precautions suggested by the known properties of the electric fluids. Chimneys often afford an entrance to lightning, the soot which lines them being a conductor. Keep, therefore, at a distance from them. Avoid the neighbourhood of all pieces of metal, gilt objects, such as the frames of glasses, pictures, and chandeliers. Mirrors, being silvered on the back, augment the danger. Avoid the proximity of bell-wires. The middle of a large room, in which no chandelier is suspended, is the safest position, and is rendered still more so by standing on a plate of glass, or a cake of resin or pitch, or sitting on a chair suspended by silken cords.

(168.) The danger of being struck with lightning is augmented by being placed in a crowd of persons. The living body being a conductor of electricity, a connected mass of such bodies is more likely to be stricken, for the same reason that a large mass of metal is more liable than a small one.

(169.) Besides this, the vapour which arises from the transpiration of a crowd of persons rising through the air plays the part of a conductor, and attracts the lightning in the same manner as a metallic rod, though in a less degree. For these reasons, those who are very solicitous for their personal security should not remain in churches, theatres, or other places of public assembly during a storm. The same causes expose flocks of sheep and herds of cattle, or horses collected together in the same stable, to increased danger. Barns and granaries are liable to exhale vapour in such quatities as

to produce a column of conducting matter above them, and are, for this reason, often struck by lightning, when not provided with the means of protection afforded by PARATONNERRES.

(170.) It sometimes happens that lightning falling among a crowd selects an individual through whose body it passes to the ground, neglecting the rest, and this without any discoverable cause. A case has been already mentioned in which this occurred from the influence of a mass of metal concealed behind the wall, against which the person who suffered stood. But cases are not wanting in which we are compelled to admit that different individuals are endowed with the conducting power in different degrees, and, therefore, that the lightning strikes by preference the best conductor. The results of experiments with artificial electricity corroborate this; for in transmitting the electric discharge through a chain of persons, it has sometimes happened that one individual in the chain stops the fluid. From some unknown peculiarity of his organisation his body is a non-conductor. If, then, it be ascertained that in some, though very rare instances, individuals are found who are *non-conductors*, analogy leads to the inference that different individuals have the conducting quality in different degrees.

(171.) The fear engendered by the proximity of the cloud in which lightning is elaborated is founded not on any distinct and explicable principles, but on a vague impression that the chances of damage are augmented as we approach the cause of danger, whatever that cause may be. If, then, the risk of injury be admitted to increase as the distance from the thunder cloud is diminished, it would follow, by necessary inference, that destruction would be inevitable to those whose temerity or misfortune might place them actually within the dimensions of the cloud. Experience, however, does not justify this. On the contrary, thunder clouds have been repeatedly traversed with impunity. In August, 1770, the Abbé Richard passed through a thunder cloud on

the small mountain called *Boyer*, beween *Chalons* and *Tournus*. Before he entered the cloud the thunder rolled as it is wont to do. When he was enveloped in it, he heard only single claps with intervals of silence, without roll or reverberation. After he passed above the cloud the thunder rolled *below him* as before, and the lightning flashed.

(172.) The sister of M. Arago witnessed similar phenomena between the village of *Estagel* and *Limoux;* and the officers of engineers engaged in the trigonometrical survey repeatedly experienced the same occurrences on the *Pyrenees*.

(173.) The history of the invention of modern *paratonnerres*, and the electrical laws on which their efficacy depends, have been fully stated in previous parts of this work. These appendages to buildings and ships consist of a pointed metallic rod attached to and projecting upwards from the highest point of the structure placed under their protection. The lower end of this rod is connected with a series of other metallic rods, or with a metallic chain, which is continued to the ground. If the paratonnerre be applied to a building, this series of rods being attached to the walls and carried to the ground, must be continued to such a depth, and brought to such a position, that its inferior extremity shall either be immersed in water or in soil which is in a permanent state of moisture. The water, or moist soil, possessing the conducting power, receives the electricity from the extremity of the rod without explosion; but if the rod terminated in dry earth the fluid would escape from the extremity, or, worse still, from some other part of the series of rods with an explosion, and would damage whatever bodies might be adjacent to it. If it be applied to a ship, the pointed rod is attached to the point of the maintopmast, and the lower end of the rod is connected with a chain which is carried down the mast and rigging over the side of the vessel, and finally plunged in the sea. The highest point of the rod being liable to

be heated by lightning, and to be oxydated, is formed of platinum, or gilt, so as to resist oxydation.

(174.) That paratonnerres exert their protective power only when lightning strikes the structure over which they preside, is an error easily corrected by immediate experiment, independently of the refutation it might receive on theoretical grounds. Let the continuity of one of these apparatus be broken, by separating any two bars of the series, so that their ends, instead of being in immediate contact, shall be distant by the eighth or tenth of an inch from each other. When stormy clouds pass over the apparatus, a continual stream of electrical light will be visible in the interval between the separated points of the bars. If their distance be increased to an inch, sparks will be observed to pass between them in rapid and continual succession, accompanied by detonations as loud as the report of a pistol.

(175.) Captain Wynne, who commanded a British frigate, lately observed, during a storm, at a point where, by accident, an interruption of the metallic continuity of his paratonnerre occurred, an almost uninterrupted succession of sparks, which continued for two hours and a half, the whole interval during which the thunder clouds were over the vessel.

(176.) It is apparent, then, that paratonnerres are not merely instrumental in saving a structure when lightning actually falls upon it, but they also possess a preventive power, and gradually and silently disarm the clouds *by draining* the electric fluid from them ; and this process commences the moment the clouds approach a position vertically over the paratonnerre.

(177.) The explanation of these phenomena is easy, when the principles which govern the movements of the electric fluids are understood. From the moment that a stormy cloud passes over a paratonnerre, and comes within the range of its influence, the electricity of the cloud decomposes the natural electricities of the rod, attracting that of the contrary name, which is accordingly accumulated at the point, and repelling that of the same

name which is driven into the crust of the earth, or into the water with which the lower extremity of the paratonnerre is in communication. The electricity of the contrary name, collected at the point, soon acquires so great a tension, that it overcomes the restraining pressure of the air, and escapes in a jet, which may often be seen in the dark, in the form of a luminous *aigrette,* issuing from the metallic point. The fluid which thus escapes enters into combination with the fluid of a contrary name, with which the cloud is charged, and neutralises it.

(178.) On land, and especially in cities, numerous objects are presented to the electricity of the air which have this tendency to neutralise it, and marked effects, such as that now referred to, are of more rare occurrence; but at sea such appearances are common, as is proved by the familiarity of all seamen with the fire of St. *Elmo, Castor* and *Pollux,* and *Helen,* already mentioned.

(179.) Experience proves that, *ceteris paribus,* the more elevated a paratonnerre is, the more efficacious it will be.

(180.) This is easily verified by immediate experiment. The influence of a paratonnerre, or, what is the same, the rate at which it neutralises the electricity of the air, is estimated by the number of sparks which pass in a given time through a space of a given length; suppose, for example, an inch, by which its metallic continuity is broken. It is found, that according as the elevation of the point of the rod is increased the number of sparks transmitted undergoes a corresponding increase. The height of the point being preserved, the number of sparks transmitted in a given time is diminished by bringing other pointed conductors near it, and still more so if these conductors are more elevated.

(181.) The increased efficacy obtained by augmenting the elevation of the metallic point of a paratonnerre is strikingly illustrated by the experiments which the contemporaries and successors of FRANKLIN made with

kites. Romas, having elevated kites by means of cord lapped with metallic wire, like the bass strings of a harp or violin, drew from the lower extremity of the cord flashes of lightning from three to four yards long, and an inch in thickness, accompanied by a report as loud as that of a gun. It was remarked, on several occasions, that thunder and lightning ceased when the fire was thus drawn from the cord. By the same expedient thunder clouds were drained of their fire, and converted into common clouds, by Dr. Lining of Charleston and M. Charles.

(182.) M. Arago proposes this expedient for averting the calamitous effects of hailstones, which are so great a scourge to the agriculturist in several parts of France. As the formation of hail is undoubtedly an effect of the sudden disturbance of the electric equilibrium of the clouds, if the electric fluid could be quietly and gradually drawn away, hail would be altogether prevented. Captive balloons might be substituted with advantage for kites, since they could be elevated in a calm, and maintained at any required height. By such means a multitude of experimental researches in electro-meteorology could be prosecuted. The atmosphere could be *sounded*, and the clouds themselves *searched*, and their electrical contents submitted to careful and deliberate examination.

(183.) The contest respecting pointed and blunt conductors, which was maintained about the middle of the last century, has been already noticed.* Although the electrical laws which have since then been so fully and clearly established can leave no doubt as to that question, an experiment decisive of it made by Beccaria may be mentioned here. This philosopher placed on the roof of *San-Giovanni-di-Dio* at *Turin* a bar of iron, at the lower part of which was such an interruption of continuity as to produce sparks when electricity passed along it. The metallic point at the top was

* See Introduction, p. 57.

movable on a joint, and connected with a silken cord, by drawing which the observer could at pleasure convert it into a *blunt* conductor, or restore to it the pointed form. In a storm, so long as the point was presented upwards, a stream of sparks was seen at the place where the breach of continuity was provided; but the moment it was converted into a blunt conductor, the sparks either disappeared altogether (which generally happened), or passed in much less rapid succession.

(184.) An ingenious calculation of the *quantity* of lightning drawn from the clouds *, by paratonnerres, has been made by M. Arago. He states that in an ordinary storm, a hundred sparks would be transmitted through a small breach of continuity in the conductor, of which the combined effect would be sufficient to kill a man, and these would pass in ten seconds. As much lightning would therefore pass per minute as would destroy six men, and as much per hour as would kill 360 men. He calculates, in this way, that the paratonnerres erected by Beccaria on the palace of Valentino, combined with the effect of the pointed parts of the roof, must take as much lightning per hour from the clouds as would be sufficient to destroy 3000 men.

(185.) The quantity of electricity which pointed conductors neutralise may be imagined from the following circumstance. The British frigate Dryad, provided with a paratonnerre, (constructed according to the method proposed by Mr. Snow Harris, by fixing to the mast itself narrow plates of thin copper,) was several times exposed to violent tornadoes off the coast of Africa. The electric fluid was seen on every part of these copper plates, in such quantity as to produce

* I use the expression *drawn from the clouds*, as the most convenient to express the effect of paratonnerres. According to the theory of two fluids, the actual process is the transmission from the paratonnerre to the atmosphere of a stream of electricity contrary to that with which the cloud is charged. According to the theory of a single fluid, the paratonnerre *receives* the electricity from the cloud when the latter is positive, and *gives* it when negative.

around them a sort of luminous atmosphere, accompanied by a noise like that of water boiling violently.

(186.) In the practical adaptation of paratonnerres, the determination of the range of their protective influence is a problem of great importance. The physical section of the Academy of Sciences at Paris, being consulted by the ministry of war on this point in 1823, adopted the estimate of M. Charles, and assumed that a circle of double the height of the rod would be protected.

If this estimate be interpreted with geometrical rigour it would appear, that the space over which a pointed metallic rod extends its protection is a CONE, *of which the vertex is the point of the rod, of which the rod is the axis, and of which the section made by any horizontal plane is a circle, whose diameter is four times the distance of such plane from the point of the rod.*

(187.) This estimate, which is evidently empirical, and of which the experimental grounds are not stated, requires much elucidation before it can receive unqualified assent. Does the conductor extend no protection to any surrounding points, at the level of its own points? To what depth below the point does the surface of the cone, bounding the protected space, extend? or what is the position of the base, which limits the protected space taken in the vertical direction downwards? Does the same form of cone limit the protected space for all kinds of structures? Is the angle of the cone affected by the presence of large masses of metal, such as the guns in a battery, or the machinery used in certain large factories, or the armament of a ship of war, or the engines of a large steam-ship?

[(188.) Theory affords no grounds for the law laid down by M. Charles, and observation is not wanting to shew its fallacy: —

The foremast of the ship Endymion was struck by lightning at Calcutta, in March 1842. The mainmast, not 50 feet distant, had a chain conductor, which, according to the above law, would protect a circle of 150 feet diameter.]

The bow of the ship Etna was struck at Corfu, Jan. 1830, although the mainmast had a chain conductor.

Other cases of similar character have occurred to buildings on shore, one of which has very recently been communicated to the French Academy. M. Arago, and many with him, were unwilling to admit so vague a law, and experience confirms their decision. To protect an extensive building several paratonnerres would be necessary, and the less the height of each the greater should be their number, which, as well as their position, must be determined by the condition that no part must be more distant from the foot of the rod than twice its height.

(189.) Although lightning falls *generally* by preference on the highest points of buildings it does not *always* do so. Many cases are recorded, in which, without damaging the summit, it has struck at the middle of the height. In some cases it has been *seen* distinctly to move in the horizontal direction, and strike the side of a steeple. Cases are also cited in which it has entered by the ground-floor, where it has struck persons and caused their deaths, doing slight damage to the first floor, and none to the higher parts of the house. Such facts suggest the utility of paratonnerres with points presented laterally and obliquely.

(190.) In some countries the superior extremities of paratonnerres are formed into a group of points, radiating in various directions, like a star. This method has been suggested by the supposed advantages of horizontal and oblique points. Experience has not yet supplied data on which any certain judgment can be formed as to the efficacy of this expedient.

(191.) The rod of a paratonnerre, by which it is intended to conduct the electric influence to or from the earth, should be of such thickness that it may not be fused by the most powerful current of electricity which is likely to pass through it. Experience indicates that this purpose will be sufficiently attained if it be a square of three quarters of an inch in the side, or a circle of the same diameter. Towards the base, an increased

thickness is sometimes given to it with a view to its stability. Paratonnerres are sometimes painted, to protect them from rust, and lampblack is selected as the material of the paint, in consequence of its conducting power.

(192.) It has been already stated, that the inferior extremity of the paratonnerres ought to be immersed in water or in wet soil. It is necessary to add, that if it be in water, an artificial cistern will not serve the purpose, as it is in general stanch, and enclosed on every side by non-conductors of electricity. Examples of the inefficiency of such a termination to the conductor are not wanting. The cathedral of *Milan* was struck by lightning on the 9th June, 1819, and the lighthouse at GENOA, on the 4th January, 1827; and in both cases damage was sustained, notwithstanding the paratonnerres. On examination, it proved that the inferior extremities of these apparatus were immersed in artificial cisterns.

(193.) To increase the surface of contact of the conductor with the ground it has been proposed to make it diverge into several points at its lower end, or to flatten it into a thin broad plate. It has also been proposed to immerse it in a bed of charcoal, previously raised to a red heat, this being a good conductor of electricity.

(194.) When several paratonnerres are erected on the same building, each should communicate with the ground by the nearest and most direct route, the fluid by such means passing more freely through them. Their efficiency will be still more augmented if they communicate with each other, and with all the metallic parts of the roof.

(195.) Flexible metallic wires, combined together so as to form a metallic rope, such as are sometimes used for suspension bridges, have been proposed as substitutes for rigid bars in paratonnerres, as being more capable of adapting themselves to the inequalities of buildings, and less liable to lose their metallic continuity, by the effects of rust.

When iron beams or cramps are used in the construction of a building, they are sometimes carefully separated from the paratonnerres by non-conductors, such as resin or pitch. If the paratonnerres be properly constructed, this precaution is unnecessary. The lightning will go to the earth in preference to any lesser mass of conducting matter.

(196.) In the adaptation of paratonnerres to powder magazines, danger is supposed to arise from the electric sparks which issue at parts of the conductor where minute and imperceptible breaches of continuity may take place. The sparks catching the powder which may be accidentally scattered on the projecting parts of the building, or lodged in crevices by the wind, may produce fatal effects. For this reason, it has been proposed that the paratonnerres for such structures should not be erected *on* the building, but that they should be planted in the ground *near it*. In that case, the practical principle already explained, by which the range of the protective influence of the conductor is limited, must be attended to, and a sufficient number of paratonnerres be placed round the building, to defend every part of it.

(197.) With the view to prove the efficacy of paratonnerres independently of all reasoning based on theory, M. Arago has collected a number of facts, which are too interesting, and have too strong a bearing on the subject of this chapter, to be passed without some notice here. We shall therefore briefly state the most important of them.

The Temple at Jerusalem stood from the time of Solomon till the year 70 of the Christian era, a period of above 1000 years. It was completely exposed to the violent storms incidental to *Palestine*. *It was never struck by lightning.* Neither the *Bible* nor *Josephus* mention any such fact, which, if it had occurred, must have strongly excited attention, and certainly been recorded. Besides, it was *covered with wood* both within and without, and must have been set fire to if it had been struck. Michaelis rightly infers that in the course of ten centuries, in the midst of continual thunder-storms, and ages before the invention of paratonnerres, this building *was never struck by lightning*. The cause is easily explained. By a circumstance apparently fortuitous, the Temple was provided with

paratonnerres similar in principle to those of Franklin! The roof of the building was formed of cedar covered with thick gilding, and from end to end was adorned by a row of long lances of iron or steel pointed and gilt. According to Josephus, the architect intended these numerous points to prevent birds from defiling the roof. The several fronts of the building were constructed, throughout their whole extent, of wood thickly gilt. Finally, under the porch were cisterns into which the waters of the roof were discharged through metallic pipes provided for that purpose. It appears, therefore, that the roof was protected by a vast number of pointed metallic rods communicating with a superabundance of metallic conductors which were continued to cisterns of water below, so that the most carefully constructed paratonnerres of the present day could not confer greater security.

The church of the château of Count Orsini in *Carinthia*, standing on an eminence, was so often struck by lightning, and so many fatalities occurred in consequence, that at length the celebration of divine service was discontinued there in summer. In the course of the year 1730, the steeple was entirely destroyed by lightning. After it was reconstructed, it continued to be struck four or five times a year. In 1778, it was entirely demolished, and being immediately rebuilt, it was now supplied with a paratonnerre. From that time, the building was free from damage by lightning. In five years it was struck but once, and then the fluid was conducted to the earth by the paratonnerre without injury to the church.

In 1750 and 1763, the Dutch church at *New York* was struck by lightning and sustained great injury. It was after that provided with a paratonnerre, and being again struck in 1765, sustained no damage.

The church of St. *Michael* at *Charleston* used to be struck and damaged once at least in two or three years. It was provided with a paratonnerre, after which it sustained no damage.

Before the time of Beccaria, the palace of *Valentino* at *Turin* was constantly struck by lightning and damaged. Beccaria erected paratonnerres upon it, and the damage ceased.

The tower of St. *Mark* at *Venice* was, until the year 1776, constantly struck by lightning, and sustained occasionally great damage. In that year a paratonnerre was placed upon it, and no damage occurred since.

Mr. Snow Harris states, that of six steeples in Devonshire all have been within a short period struck by lightning. One only sustained no damage, and that one alone was provided with a paratonnerre.

(a.) [The present chapter would be incomplete, were we to close it without adverting to the phenomena termed "the lateral discharge:" it bears intimately on the practical part of the subject, and will enable us, at the same time, to present certain illustrations of the action of electricity, which have not been included elsewhere. When a portion of the discharge from a prime conductor, for instance, or a Leyden jar, leaves the course marked out for it to pursue a side path, the spark,

consequent on such deviation, is termed the lateral spark: it is, in fact, a spark produced by the division of the discharge. It may be shown in the following manner: — Let a powerful electrical machine be in action, and sparks be thrown on a wire held by an insulated rod, but having its extremity connected with the earth; on applying the knuckle or a brass ball to any part of this wire, sparks may be obtained — not that the wire is incapable of carrying away the whole charge safely, but because of the repulsive action of the electricity, by which it has a tendency to spread over the surface of conductors, and take the widest path it can. The tendency is even developed when the side path only lasts for a part of the course to the earth, and the electricity has to return again to its original wire; for if the insulated discharging-rod (*fig.* 55.) have the ball B placed very close to one part of the wire, and the ball C very close to another part, a spark will appear at each ball. In this case, it is evident that the metal of the discharging-rod was of no ultimate service in furnishing a side path as a thoroughfare to the charge, but merely relieved the portion of the wire intervening between the balls. The same effects occur during the discharge of a Leyden battery, especially when it is insulated. But not only is it possible to obtain a spark from the wire itself; but even from any metallic system with which the wire is connected. We have ourselves obtained it from gas *burners* in *all* parts of a very large building, when the wire was connected with the gas *pipes* in *one* part.]

[(b.) This spark is much more readily obtained from the prime conductor than from the Leyden discharges, obviously on account of the low intensity of the latter; for it is an effect of intensity alone which enables electricity to pass at all through the air. Voltaic electricity, of which we shall hereafter speak, is abundant in quantity, but of such low tension as not to pass at all *before contact*, unless from a very extensive series of the pile.]

[(c.) Now, the law which regulates all discharges is, that they pursue the *line* or *lines of least resistance:* when, therefore, the sum of two paths, including the interval or intervals of air, involves *less* resistance than does the one original path, the division occurs; when it involves *greater* resistance, it does not occur: and this readily explains the greater facility for lateral discharge displayed by the electricity from the conductor, as contrasted with the Leyden flash. At the very outset, the former will overcome the resistance of many inches of air, while the latter is insulated by less than one inch; and hence the former has, throughout its brief existence, a power greatly exalted over that of the other. And this path or paths is not a mere matter of choice, determined on by the charge in its progress onwards; it is a course entirely marked out by the action of induction, antecedent to the original discharge. Indeed, it is the mere fact of the inductive action being able to find a path offering a resistance, which the charge can overcome, that first causes the discharge to take place. There are other instructive facts connected with the lateral discharge, for which we have not space here, and to which the reader must refer.*]

[(d.) The bearing of the observations just made upon the practical efficiency of lightning rods is very obvious. If there are near the rod any masses of metal, under the condition of forming with the rod itself a path or paths to the earth, involving less resistance than the rod alone, a division will occur. And it does not appear essential to the production of this effect, that the vicinal metals should be in metallic connection with the earth; for we have seen the sparks leave a wire only to return to it. Now the possibility of this deviation depends generally on three conditions — it is *directly* in some ratio to the original length of the flash of lightning; and this, we know, is subject to great variation, being measured by the distance between the object struck

* *Vide* Naut. Mag. Jan. 1840; Report of Committee of House of Commons on Lightning; Ann. Elect. 1840; Proceed. Elect. Soc. 1842; Harris, On Thunder Storms, 1843.

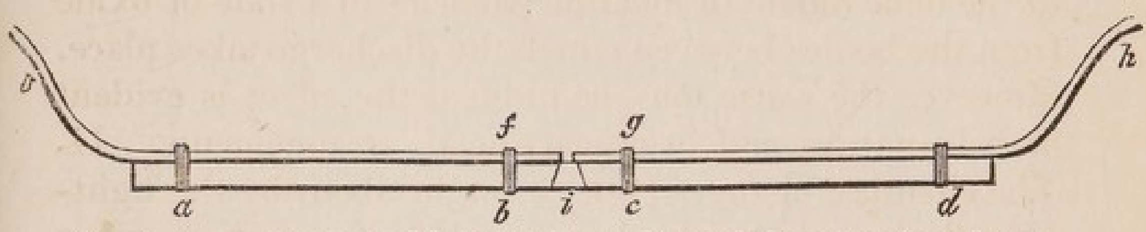
and the lowest part of the cloud. It is *inversely* in some ratio to the capacity of the rod, and also to the interval of air to be traversed. We have already (194.) directed the metallic vicinal bodies to be connected into one system with the rod: an additional reason for this will now be manifest. And cases have occurred of damage ensuing in obedience to the laws just laid down. To complete, then, the conditions for perfect security, we have to urge the necessity of avoiding the vicinity of large masses of metal in erecting paratonnerres; but when this caution cannot be admitted, of connecting such masses, as well as all vicinal metal gutters or roofs, into one system with the conductor, by means of metal bands. For, with such precautions, the charge will be led quietly to the suspected body, without passing in a flash through the air. We have carried out this principle to the fullest extent in protecting the new Royal Exchange. Different views have been maintained, and much argument has been advanced in reference to this point of philosophy; but the enquiries of all parties seem to terminate in the same practical inference of the necessity of these connections. We must add to this, that Mr. Snow Harris, in his late work, has advised that, as the resistance of metals increases with their length, the capacity of very long conductors should be increased.]

[(e.) Thus far have we investigated the various phenomena presented by atmospheric electricity; it remains only to point out some few experiments, by which they are artificially illustrated: — I. (97.) The *sulphurous* odour developed by lightning, described by some as *phosphoric*, and by others as similar to that of *nitrous gas*, has its type in the peculiar odour which is observed during the action of electrical machines. This odour has lately engaged the attention of Professor Schœnbein; and he has been induced to assign it to a peculiar body, which he has called *ozone*. He thinks that ozone exists in nature combined with hydrogen, and is liberated by the chemical action of electricity. Few philosophers have been willing to receive this

theory; indeed the Professor himself confesses that, so long as he fails in obtaining the said ozone in an isolated state, its existence must be deemed problematical. M. de la Rive is of opinion, that the odour is due to the detachment of metallic particles in a state of oxide from the bodies between which the discharge takes place. However the cause may be hidden, the effect is evident both in nature and in our artificial arrangements. II. The chemical changes (99.) brought about by the lightning-flash, meet with their parallel if we discharge a succession of sparks through moist atmospheric air contained in a closed tube; for, in both cases, the production of nitric acid and ammonia is evident. III. The fusion of metals (100.) is shown by spreading very fine wire on paper, and interposing it in the course of the discharge of a powerful Leyden battery. The metal is forcibly destroyed, and is impressed in the form of oxide, spread in beautiful shades on the paper. A splendid illustration of this was mentioned by Professor Faraday during a recent course of lectures (1843), as having been examined by himself at a house in Westminster, which had been struck by lightning. The electric fluid passed down the bell-wires, and entirely deflagrated them, impressing the oxides on a most magnificent scale, of eight or nine feet in width, upon the walls of the rooms. IV. The artificial production of Fulgurites has been already described (112.). V. There are many modes of showing the mechanical effects of electricity (115.). Slips of gold leaf pressed between two plates of glass are included in the circuit of a powerful Leyden discharge. When the discharge takes place, the glass is shattered to pieces, and the gold is quite driven into it. Two pointed wires, proceeding from either end of a Leyden battery, are thrust into a mass of soft clay, and placed nearly in contact. On making the discharge, the clay is burst asunder. The same takes place if wood is used instead of clay. So also if the discharge is passed through a small glass tube containing water, the tube will be destroyed. This

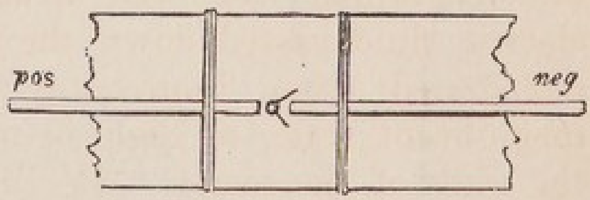
effect illustrates the disruption of trees. Mr. Crosse has given an interesting case of the mechanical action of electricity. In (*fig.* 106′.) *a b c d* represents a slip

Fig. 106′.



of window glass, half an inch wide and four inches long, with two platinum wires, *e f g h*, one thirtieth of an inch in diameter, secured to the glass by waxed silk *a b c d*; the interval *f g* is one twentieth of an inch. The wires *e h*, are to be connected—one with the negative conductor of a powerful machine, the other with a ball to receive sparks from the prime conductor. On placing the glass in a flat dish filled with water, and turning the machine, the glass between the points soon became fractured; and, after 100 revolutions, the fracture enlarged, and two small cracks appeared as in (*fig.* 106.″). After 200 revolutions an excavation was formed, but on the side *opposite* to that on which the wires were tied; after 250 revolutions,

Fig. 106.″



the glass was completely perforated. Many variations of this experiment were made, in all of which the same kind of mechanical effect is obtained.* Even quartz was excavated. Mr. Armstrong has repeated this experiment by means of the large hydro-electric machine, and has succeeded most readily. Nor should we exclude from these illustrations the repeated fracture of Leyden jars. *Fig.* 106‴. and 106⁗. are drawings from an actual fracture, as it appeared before and after the tinfoil was removed; the white surface at *a* and *b* is paper. VII. The effects of lightning conductors are generally shown by an arrangement, which

* Vide Proced. Elect. Soc. p. 57.

in one case represents the gable of a house, with a continuous wire down it; and in the other, with a break

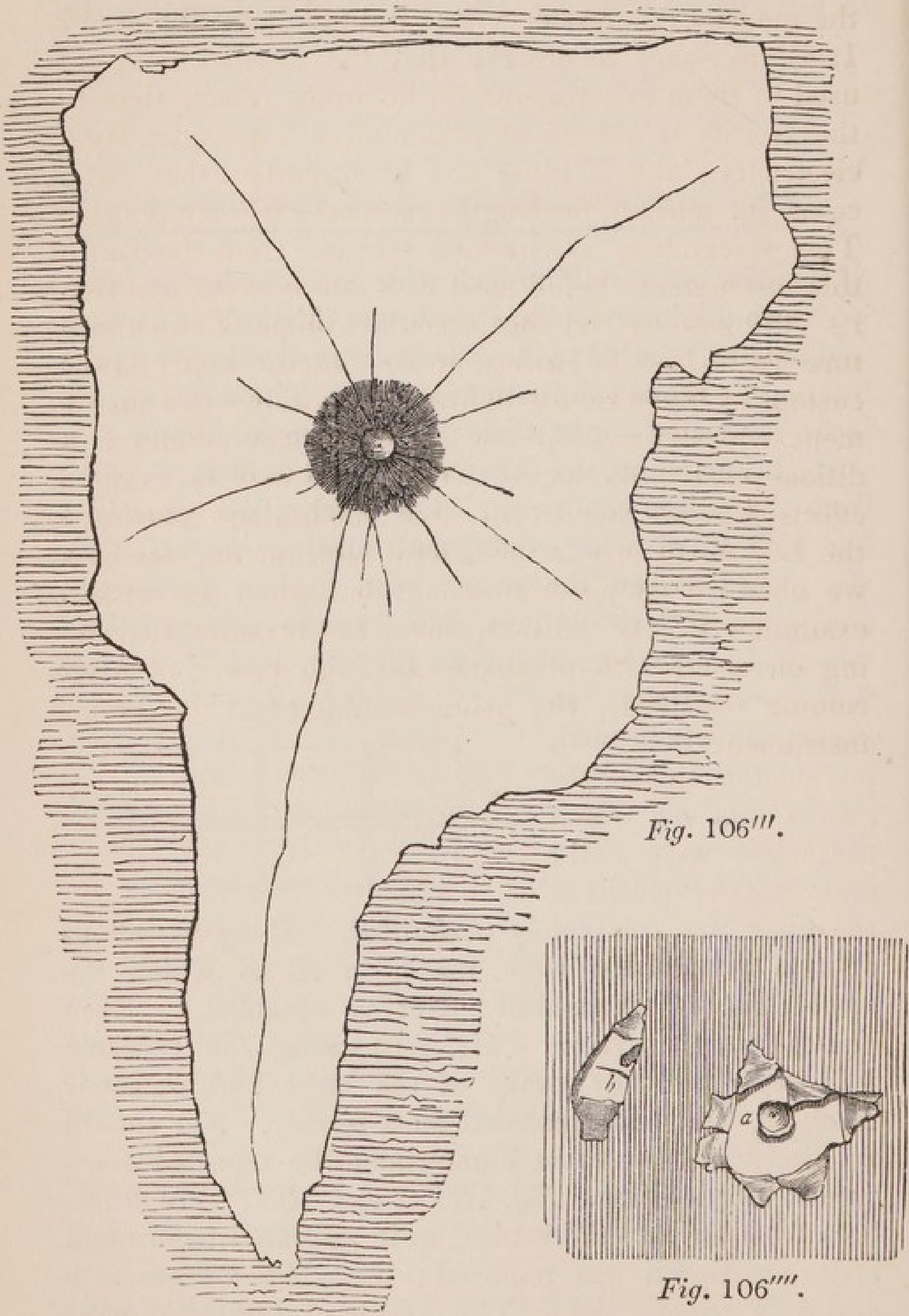


Fig. 106'''.

Fig. 106''''.

of continuity in the wire by the reversal of a small block of wood. A discharge passes tranquilly in the one case, but drives out the wood with an explosion,

in the other. Again, a break of continuity is allowed to occur among some naphtha or resin, placed within the model of a house, when ignition instantly occurs. It is necessary to observe that the Leyden battery is used in these experiments for no other reason than for the facility it affords of obtaining a large quantity of electricity; and it must not be forgotten, that, in all cases, its tension, or length of spark, is very reduced. This observation is requisite, because, from the fact of this instrument's being used in all these cases, and from its effects being, on this account, compared to miniature flashes of lightning, it has almost fallen into a custom to illustrate *all* lightning effects by this instrument without making due allowance for certain conditions of the discharge. When we wish to examine effects, wherein quantity of electricity is alone concerned, the Leyden battery is the lawful instrument; for by it we obtain great accumulations: but when we wish to examine effects of tension, those, for instance, depending on the length of spark, *i. e.* the power of overcoming resistance, the prime conductor is the proper instrument.]

CHAP. VI.

THE AURORA BOREALIS.

(198.) THE AURORA BOREALIS is a luminous phenomenon, which appears in the heavens, and is seen in high latitudes in both hemispheres. The term AURORA BOREALIS, or NORTHERN LIGHTS, has been applied to it because the opportunities of witnessing it are, from the geographical character of the globe, much more frequent in the northern than the southern hemisphere. The term AURORA POLARIS would be a more proper designation.

This phenomenon consists of luminous rays of various colours, issuing from every direction, but converging to the same point, which appear after sunset generally towards the north, occasionally towards the west, and sometimes, but rarely, towards the south. It frequently appears near the horizon, as a vague and diffuse light, something like the faint streaks which harbinger the rising sun and form the dawn. Hence the phenomenon has derived its name, the NORTHERN MORNING. Sometimes, however, it is presented under the form of a sombre cloud, from which luminous jets issue, which are often variously coloured, and illuminate the entire atmosphere.

(199.) A meteor so striking as the AURORA could not fail at an early period to attract the attention of scientific inquirers, and to give rise to various theories. Some supposed it to be the refraction of the solar rays; others ascribed it to the effects of the magnetic fluid. EULER identified it with the tails of comets. MAIRAN supposed it to proceed from the intermixture of the far-extending atmosphere of the sun with that of the earth.

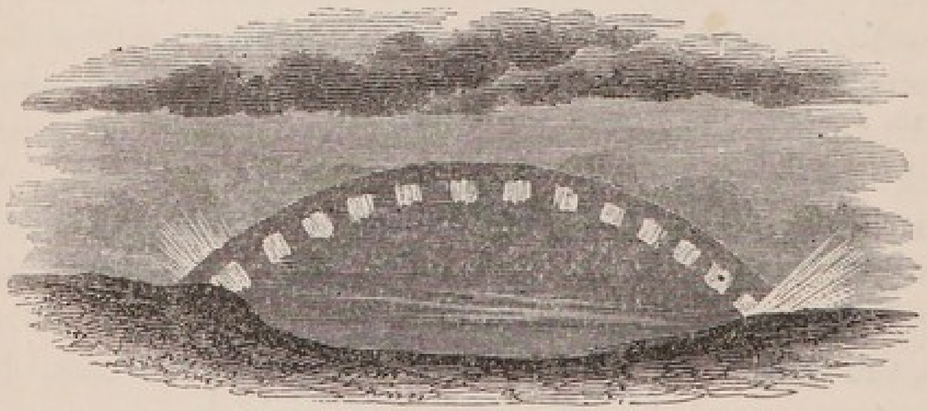
When, however, the luminous effects of artificial electricity were shown, when the electric light transmitted through rarefied air was exhibited, and when the identity of lightning with electricity was established, these various hypotheses were by common consent abandoned ; and the explanation proposed by EBERHART of *Halle*, and PAUL FRISI of *Pisa*, which ascribed the phenomenon to electricity transmitted through regions in which the atmosphere is in a highly rarefied state, was adopted. Any doubt which might have hung round this explanation was dispelled, when the relations between magnetism and electricity were demonstrated ; and although the complete explanation of the details of the aurora has not been accomplished, the electricity and magnetism of the earth and its atmosphere must now be regarded as its source.

(200.) In his treatise on these meteors, MAIRAN describes their appearance and the succession of changes to which they are subject with great minuteness and precision. The more conspicuous auroras commence to be formed soon after the close of twilight. At first a dark mist or foggy cloud is perceived in the north, and a little more brightness towards the west than in the other parts of the heavens. The mist gradually takes the form of a circular segment, resting at each corner on the horizon. The visible part of the arc soon becomes surrounded with a pale light, which is followed by the formation of one or several luminous arcs. Then come jets and rays of light variously coloured, which issue from the dark part of the segment, the continuity of which is broken by bright emanations, which indicate a movement of the mass, which seems agitated by internal shocks, during the formation of these luminous radiations, which issue from it as flames do from a conflagration. When this species of fire has ceased, and the aurora has become extended, a crown is formed at the zenith, to which these rays converge. From this time the phenomenon diminishes in its intensity, exhibiting, nevertheless, from time to time, sometimes on

one side of the heavens and sometimes on another, jets of light, a crown and colours more or less vivid. Finally the motion ceases, the light approaches gradually to the horizon; the cloud quitting the other parts of the firmament settles in the north. The dark part of the segment becomes luminous, its brightness being greatest near the horizon, and becoming more feeble as the altitude augments until it loses its light altogether.

(201.) The aurora is sometimes composed of two luminous segments, which are concentric, and separated from each other by one dark space, and from the earth by another. Sometimes, though rarely, there is only one dark segment, which is symmetrically pierced round its border by openings, through which light or fire is seen, as represented in *fig.* 107. A meteor of this

Fig. 107.



kind was observed by Mairan himself at *Breuille-Pont*, on the 19th October, 1726. This meteor was seen at the same time in distant parts of Europe, such as *Warsaw*, *Moscow*, *St. Petersburg*, *Rome*, *Naples*, *Lisbon*, and *Cadiz*. The least height which is compatible with its observed position in these places would be about fifty leagues above the surface of the earth.

(202.) In the year 1817, M. Biot made a voyage to the *Shetland Isles*, where he had frequent and favourable opportunities of observing these phenomena; and the known habits of accuracy and skill in experimental investigation of that philosopher must confer great value

on the results of his observations. A remarkable aurora was seen by him on the 27th August, 1817.

Several thin jets of light were first seen to rise at the north-east to a small height. Having played for some time, they were extinguished; but, after an hour and a half, they re-appeared, with increased extent and brilliancy, in the same part of the sky. They soon began to form above the horizon a regular arc, like a rainbow, which was not complete at first, but by degrees increased its amplitude, and, after some moments, was completed, by the sudden formation of the remainder, which rose in a moment, accompanied by a multitude of jets of light, which issued from all points of the northern horizon. The vertex of the bow then reached very nearly to the zenith. This bow was at first fleeting and undecided in its character, as if the matter of which it was composed had not yet taken a stable arrangement; but all this agitation quickly subsided, and then it remained hanging in the heavens in all its beauty for more than an hour, having a progressive motion barely sensible towards the south-east, where it seemed to be carried by a light wind which was then felt from the north-east. M. Biot had thus full time to contemplate it; and he observed its position with the instruments he had provided for astronomical purposes. He found that it embraced an extent upon the horizon of 128° 42′, and that its centre was placed precisely in the direction of the magnetic meridian. The whole extent of the firmament traversed by this grand arc, on the north-western side, was continually intersected, in every direction, by jets of light, the forms, motions, colours, and continuance of which strongly attracted his attention. Each of these jets, when it first appeared, was a simple line of whitish light: its magnitude and splendour were augmented rapidly, presenting sometimes singular variations of direction and curvature. When it attained its entire developement, it was contracted to a thin straight thread, the light of which was extremely vivid and brilliant, and of a decided red tint. After this it grew gradually fainter, and became extinct frequently at the same place precisely where it commenced its appearance. This permanence of a great number of jets, each in the same apparent place, while their brightness exhibited an infinite variety of degrees, renders it probable, in the opinion of Biot, that their light is not reflected, but direct, and that it is developed in the place where it is seen. This inference is farther confirmed by the circumstance that no trace of polarisation could be discovered in it. All these meteors, and the bow within which their play was confined, must have occupied a region above the clouds, since the latter occasionally intercepted their light.

(203.) One of the most recent and detailed descriptions of the aurora borealis is due to M. Lottin, an officer of the French navy, and a member of the scientific commission sent some years ago to the North Seas.

During the winter of 1838–9, M. Lottin observed the auroras at Bossekop, in the bay of Alten, on the coast of West Finmark, in the latitude of 70° N. Between September, 1838, and April, 1839, being an interval of 206 days, he

observed 143 auroras: they were most frequent during the period which the sun remained below the horizon, that is, from the 17th of November to the 25th of January. During this night of 70 times 24 hours, there were 64 auroras visible, without counting those which were rendered invisible by a clouded sky, but the presence of which was indicated by the disturbance they produced on the magnetic needle.

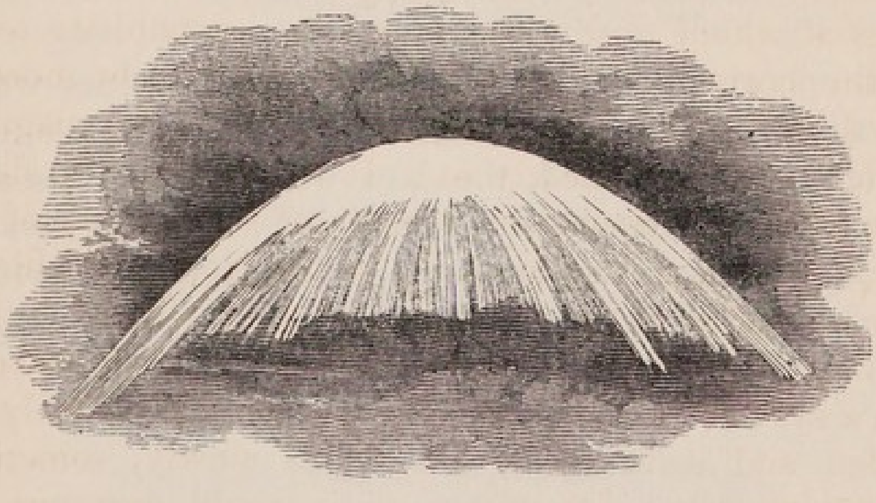
(204.) Without entering into the details of the individual appearances of these meteors, we shall here briefly describe the appearances and the succession of changes which they usually presented.

(205.) Between the hours of four and eight o'clock in the afternoon, a light sea-fog, which almost constantly prevailed, extending to the altitude of from 4° to 6°, became coloured on its upper border, or, rather, was fringed with the light of the aurora, which was then behind it; this border became gradually more regular, and took the form of an arc of a pale yellow colour, the edges of which were diffuse, and the extremities rested on the horizon. This bow swelled upwards more or less slowly, its vertex being constantly on the magnetic meridian, or very nearly so. It was not easy to determine this with precision, because of the motion of the bow, and the great magnitude of the circle, of which it formed but a small segment: blackish streaks divided regularly the luminous matter of the arc, and resolved it into a system of rays; these rays were alternately extended and contracted; sometimes slowly, sometimes instantaneously; sometimes they would dart out, increasing and diminishing suddenly, in splendour. The inferior parts, or the feet of the rays, presented always the most vivid light, and formed an arc more or less regular. The length of these rays was very various, but they all converged to that point of the heavens indicated by the direction of the southern pole of the dipping needle, as indicated in *fig.* 108. Sometimes they were prolonged to the point where their directions intersected, and formed the summit of an enormous dome of light, as represented in *fig.* 109.

The bow then would continue to ascend towards the zenith: it would suffer an undulatory motion in its

Fig. 108.

Fig. 109.

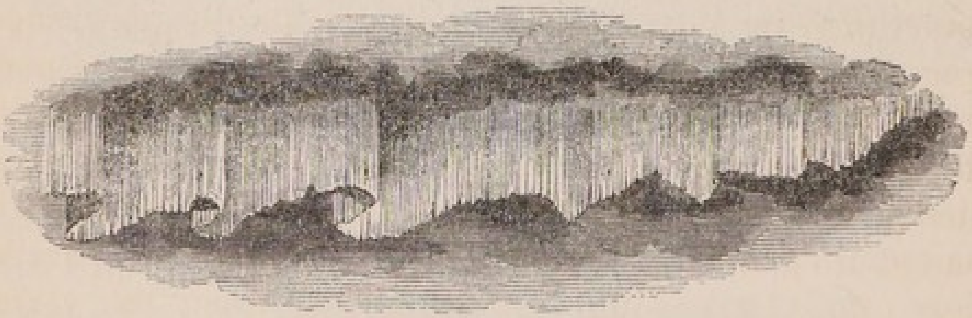


light; that is to say, that from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from west to east than in the opposite direction. Sometimes, but rarely, a retrograde motion would take place immediately afterwards; and as soon as this wave of light would run successively over all the rays of the aurora from west to east, it would return, in the contrary direction, to the point of its departure, producing such an effect that it was impossible to say whether the rays themselves were actually affected by a motion of

translation in a direction nearly horizontal, or if this more vivid light was transferred from ray to ray, the system of rays themselves suffering no change of position.

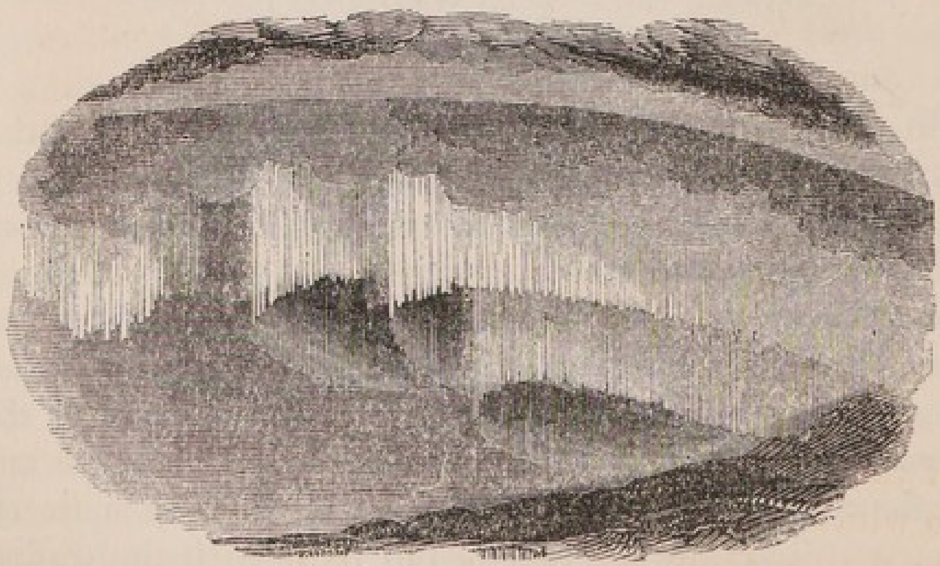
The bow, thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a riband, or flag agitated by the wind, as represented in *fig.* 110. Some-

Fig. 110.



times one and sometimes both of its extremities would desert the horizon, and then its folds would become more numerous and marked, the bow would change its character, and assume the form of a long sheet of rays returning into itself, and consisting of several parts forming graceful curves, as represented in *fig.* 111. The bright-

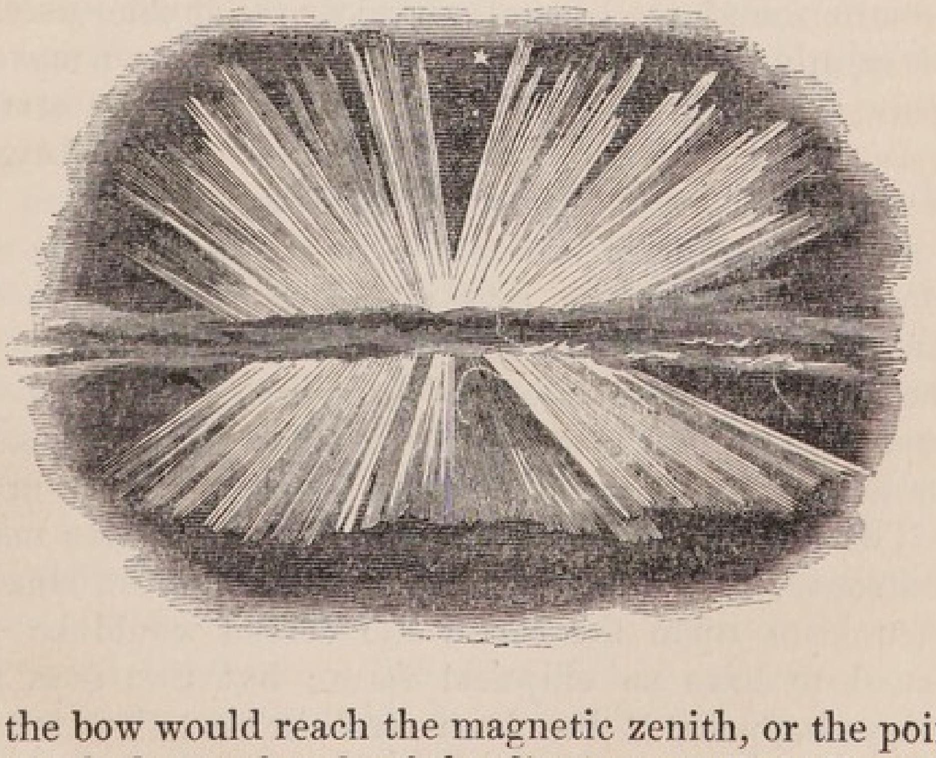
Fig. 111.



ness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude; these

rays would rapidly dart out, and curves would be formed and developed like the folds of a serpent; then the rays would effect various colours, the base would be red, the middle green, and the remainder would preserve its clear yellow hue. Such was the arrangement which the colours always preserved; they were of admirable transparency, the base exhibiting blood-red, and the green of the middle being that of the pale emerald; the brightness would diminish, the colours disappear, and all be extinguished, sometimes suddenly, and sometimes by slow degrees. After this disappearance, fragments of the bow would be reproduced, would continue their upward movement, and approach the zenith; the rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented then the appearance of a large zone of parallel rays (*fig.* 112.) would be estimated; then the vertex

Fig. 112.



of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed. At that moment the rays would be seen in the direction of their feet. If they were coloured, they would appear as a large red band, through which the green tints of

their superior parts could be distinguished; and if the wave of light above mentioned passed along them, their feet would form a long sinuous undulating zone, while, throughout all these changes, the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms.

While these appearances are manifested, new bows are formed, either commencing in the same diffuse manner, or with vivid and ready-formed rays: they succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, forming as many bows, having their ends supported on the earth, and, in their arrangement, resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone, traversing the heavens, and disappearing towards the south, becoming rapidly feeble after passing the zenith. But sometimes, also, when this zone extends over the summit of the firmament from east to west, the mass of rays which have already passed beyond the magnetic zenith appear suddenly to come from the south, and to form with those from the north the real boreal corona, all the rays of which converge to the zenith. This appearance of a crown, therefore, is doubtless the mere effect of perspective; and an observer, placed at the same instant at a certain distance to the north or to the south, would perceive only an arc.

The total zone, measuring less in the direction north and south, than in the direction east and west, since it often leans upon the earth, the corona would be expected to have an elliptical form; but that does not always happen: it has been seen circular, the unequal rays not extending to a greater distance than from 8° to 12° from the zenith, while at other times they reach the horizon.

Let it, then, be imagined, that all these vivid rays of

light issue forth with splendour, subject to continual and sudden variations in their length and brightness; that these beautiful red and green tints colour them at intervals; that waves of light undulate over them; that currents of light succeed each other; and, in fine, that the vast firmament presents one immense and magnificent dome of light, reposing on the snow-covered base supplied by the ground, which itself serves as a dazzling frame for a sea, calm and black as a pitchy lake; and some idea, though an imperfect one, may be obtained of the splendid spectacle which presents itself to him who witnesses the aurora from the Bay of Alten.

The corona, when it is formed, only lasts for some minutes: it sometimes forms suddenly, without any previous bow. There are rarely more than two on the same night; and many of the auroras are attended with no crown at all.

The corona becomes gradually faint, the whole phenomenon being to the south of the zenith, forming bows gradually paler, and generally disappearing before they reach the southern horizon. All this most commonly takes place in the first half of the night, after which the aurora appears to have lost its intensity: the pencils of rays, the bands and the fragments of bows, appear and disappear at intervals; then the rays become more and more diffused, and ultimately merge into the vague and feeble light which is spread over the heavens grouped like little clouds, and designated by the name of *auroral plates* (*plaques aurorales*). Their milky light frequently undergoes striking changes in its brightness, like motions of dilatation and contraction, which are propagated reciprocally between the centre and the circumference, like those which are observed in marine animals called Medusæ. The phenomena become gradually more faint, and generally disappear altogether on the appearance of twilight. Sometimes, however, the aurora continues after the commencement of daybreak, when the light is so strong that a printed

book may be read. It then disappears, sometimes suddenly; but it often happens that, as the daylight augments, the aurora becomes gradually vague and undefined, takes a whitish colour, and is ultimately so mingled with the cirrho-stratus clouds that it is impossible to distinguish it from them.

(206.) Among the various theories and hypotheses which have been proposed to explain auroras, that which appears most entitled to attention has been suggested by M. Biot.

The first question which naturally urges itself upon the consideration of the scientific inquirer is, whether the phenomenon is to be regarded as meteorological or astronomical; in other words, whether it takes place within the limits of our atmosphere, and partakes in common with that fluid in the diurnal motion of the earth, or is situate in a region beyond the limits of the atmosphere, being seen through it, like the stars, planets, comets, and other celestial objects. The relation which the form of auroras invariably bears to the direction of the magnetic meridian raises a *primâ facie* presumption in favour of the phenomenon being atmospheric; but all doubt on this question has been removed by the observations of M. Biot, from which it appears that the apparent place of the aurora in relation to celestial objects is not fixed; that its altitude and azimuth do not undergo those hourly changes to which celestial objects are subject; and that they undergo no motion, in reference to the zenith or horizon, such as would be produced by the diurnal rotation of the earth. It must then be taken as demonstrated, that the aurora borealis is a phenomenon placed within the limits of our atmosphere, and that it is connected with the atmosphere or with some matter suspended in it, partaking of the diurnal motion common to the atmosphere and the globe.

(207.) The fact that the rays or columns of light are always parallel to the dipping needle, and that the bows, coronæ, and other visible forms which the phenomena

affect, are always symmetrically placed with respect to the magnetic meridian. demonstrate that the cause of the phenomena, whatever it may be, has an intimate relation with that of terrestrial magnetism.

(208.) M. Biot conceives that the luminous columns composing the aurora have not in reality the position or form which they appear to the eye to have ; but that their apparent form is merely the result of perspective. He considers that the phenomenon is produced by an infinite number of luminous columns, parallel to the dipping needle and to each other, arranged side by side at nearly the same height from the surface of the earth ; these systems of columns being placed at unequal distances from the eye, and seen under different angles of obliquity, are projected into various figures, which are subject to variation arising from the varying splendour of their component rays.

(209.) It has been attempted on various occasions to determine the height of auroras by the same method which has been applied with such accurate results to the determination of the distances of the sun, moon, and other celestial objects. This method consists in the comparison of two observations of the exact apparent place in the heavens observed at the same moment in distant parts of the earth. Many causes, however, conspire to render this method inapplicable to auroras ; among which may be mentioned the difficulty of making the two observations at the same instant of time, and the total impossibility of the two observers being certain of directing their observations to precisely the same point of the aurora. To such causes must be ascribed the widely-varying estimates of the height of auroras ; obtained in this manner—estimates which vary from 50 to 300 miles from the surface of the earth. Meanwhile, whatever be their height, it is evidently subject to continual variation, even in the same aurora, as is rendered apparent by the sudden changes which the phenomenon undergoes, and by the progressive motion of its arcs.

(210.) Great differences have existed among meteorologists respecting the sounds which are said to proceed from auroras. The inhabitants of the northern regions, where these appearances most prevail, are unanimous in declaring that they are frequently accompanied by hissing and cracking noises in the air, like those produced by artificial fireworks. Persons engaged in the whale fisheries make the same statements. M. Biot found the inhabitants of the Shetland Islands unanimous on the question; and M. Lottin found the same impression among the far distant inhabitants of Siberia. On the other hand, during the sojourn of M. Biot in the Shetland Isles, he witnessed several great auroras, but heard no sound. During M. Lottin's expedition, he witnessed 143 auroras, in not one of which was he sensible of any sound. The only strictly scientific observer who appears to have personally experienced such sounds is Cavallo, who states that he has distinctly heard them on several occasions, but limits his testimony to this general form, assigning neither time nor place. Such discordancy of evidence can only be reconciled by the supposition that such sounds are audible on rare occasions, when the region in which the aurora is developed is within a very limited distance of the observer; and if the existence of such sounds be thus admitted, it must be also admitted that the height of the aurora is, at least in such cases, infinitely less than is commonly estimated; and if, in particular cases, its height be so small, it is probably in all others proportionally under the highest estimates which have been made of it.

(211.) From a comparison of all the observed effects, it may then be assumed as nearly, if not conclusively, proved, that the aurora borealis is composed of real clouds, proceeding generally from the north, and formed of extremely attenuated and luminous matter floating in the atmosphere, which frequently arrange themselves in series of lines or columns parallel to the dipping-needle. What the nature of the matter

is composing such clouds must, in the present state of science, rest upon mere conjecture. The following is the substance of the theory of M. Biot on this subject, already referred to: —

(212.) Among material substances, certain metals alone are susceptible of magnetism. Since, then, the luminous matter composing the aurora obeys the magnetic influence of the earth, it is very probable that the luminous clouds of which it consists are composed of metallic particles reduced to an extremely minute and subtile form. This being admitted, another consequence will immediately ensue. Such metallic clouds, if the expression be allowed, will be conductors of electricity, more or less perfect, according to the degree of proximity of their constituent particles. When such clouds arrange themselves in columnar forms, and connect strata of the atmosphere at different elevations, if such strata be unequally charged with electricity, the electrical equilibrium will be re-established through the intervention of the metallic columns, and light and sound will be evolved in proportion to the imperfect conductability of the metallic clouds arising from the extremely rarefied state of the metallic vapour, or fine dust, of which they are constituted. All the results of electrical experiments countenance these suppositions, when the phenomena are produced in the more elevated regions, where the air is highly rarefied, little resistance being opposed to the motion of the electric fluid: light alone is evolved without sensible sound, as is observed when electricity is transmitted through exhausted tubes; but when the aurora is developed in the lower strata of the atmosphere, it would produce the hissing and cracking noise which appears to be heard on some occasions. If the metallic cloud possess the conducting power in a high degree, the electric current may pass through it without the evolution of either light or sound; and thus the magnetic needle may be affected as it would be by an aurora at a time when no aurora is visible. If any cause alters the conductability

of those columnar clouds suddenly or gradually, a sudden or gradual change in the splendour of the aurora would ensue.

According as those clouds advance over more southern countries, the direction of their columns being constantly parallel to the dipping needle, they take gradually a more horizontal position, and consequently the strata of atmosphere at their extremities become gradually less distant, and consequently more nearly in a state of electrical equilibrium; hence it follows, that as the latitude diminishes, the appearance of aurora becomes more and more rare, until, in the lower latitudes, where the columns are nearly parallel to the horizon, such phenomena are never observed.

(213.) This ingenious and beautiful theory still, however, requires, before its validity can be admitted by the rigid canons of modern physics, that the main fact on which it rests should be proved: it is necessary that it should be shown that such metallic clouds as are here supposed, and on the agency of which the whole theory is based, should be accounted for. This demand is accordingly answered by M. Biot.

(214.) The magnetic pole, or its vicinity, is evidently the point from which these columnar masses of meteoric light proceed. Therefore, the extremely minute rays composing these columns must issue from the earth in that region. Now it is well known that that part of the globe is, and always has been, characterised by the prevalence of frequent and violent volcanic eruptions, and several volcanoes have been, and still are, in activity round the place where the magnetic pole is situate. These eruptions are always accompanied by electric phenomena. Thunder issues from the volcanic clouds ejected by the craters; and these clouds of volcanic dust, thus charged with electricity, are projected to great heights, and carried to considerable distances through the air, carrying with them all the electricity taken from the crater.

These vast eruptions, issuing from depths so un-

fathomable that they seem almost to penetrate the globe, and issuing with such violence from the gulfs by which they are projected into the atmosphere, must necessarily produce strong vertical currents of air, by which the volcanic dust will be carried to an elevation exceeding that of common clouds. Travellers who have visited Iceland have often seen suspended over it, during eruptions, a species of volcanic fog. Such clouds are known to be of a sulphureous and metallic nature, painfully irritating the eyes, mouth, and nostrils. Moreover, the existence of dry fogs, diffusing a fetid and sulphureous odour, was ascertained in 1783, when all Europe was enveloped in a fog of that description.

To this it may be added, that more recent observations have rendered it highly probable, if not certain, that metallic matter, and more particularly iron in a pure and uncombined state, is frequently precipitated from the clouds in thunder storms.

(215.) To the theory of M. Biot it is objected, by M. Becquerel, that the existence of metal in that uncombined form, in which alone it has the conducting power, in volcanic eruptions, has not been proved; that the matter ejected from volcanoes consists of vitrified substances, silicates, aluminates, and other substances, which are non-conductors, but that pure metal is never found.

(216). At the time when M. Biot promulgated his theory, it was necessary for him to assign an adequate source from whence the electricity was derived, to which he ascribed the aurora; and he accordingly supposed it to proceed from the polar volcanoes. In the progress of electrical discovery, so many new sources of electricity have however been since disclosed, that this part of his hypothesis has become needless.

[(217.) We are ourselves more inclined to look favourably on the idea suggested by Professor Faraday. (*Exp. Research* 192.):—

“ I hardly dare venture, even in the most hypothetical form, to ask whether the Aurora Borealis and

Australis may not be the discharge of electricity, thus urged towards the poles of the earth, from whence it is endeavouring to return by natural and appointed means above the earth to the equatorial regions. The non-occurrence of it in very high latitudes is not at all against the supposition; and it is remarkable that Mr. Fox, who observed the deflections of the magnetic needle at Falmouth, by the Aurora Borealis, gave that direction of it which perfectly agrees with the present view." The manner in which the electricity above alluded to is urged towards the poles, belongs to another division of our subject, "Magneto Electricity." If the above view is correct, may it not help us in the difficult question of atmospheric electricity?]

[(218.) The mode adopted to illustrate the electrical nature of the Aurora, is to exhaust a tall glass tube by means of the air-pump, and then to pass a succession of electric sparks down the interior of the tube, from the prime conductor of the machine. The effects produced by a powerful machine are most brilliant; a close inspection shews that the whole tube is at times filled with a mass of miniature flashes of lightning: the colour varies from the usual bright electrical light to a vivid violet. The most exalted effects have been produced by means of the hydro-electric machine. The tension of this machine is equal to a spark of twelve or fourteen inches in the atmosphere, and therefore of power to pass readily through four or five feet of partial vaccum, and its quantity is equivalent to a charge of eighty feet of coated surface in ten seconds. A peculiar effect attending this powerful discharge is, that sometimes the aurora appears with a bright line of light proceeding from each end of the tube, and a revolving spiral embracing the lower part.]

[(219.) The falling star is an experiment of the auroral character often introduced in books on electricity. Cavallo says (vol. ii. p. 101.), "When the receiver is not exhausted, the discharge of a jar through

some part of it will appear like a *small globule* exceedingly bright." Whence we often hear it said, that the discharge of a battery will produce a ball of light passing from one end to the other of the exhausted receiver. If this really were the case, it would be a most important experiment; for if the ball were *seen to pass* from one end to the other, it would follow that its *direction* had been actually seen; and, if so, the one fluid theory would have been *demonstrated*. But very little reflection will suffice to shew the impossibility of such an appearance; for, admitting the actual existence of a ball, though we are more inclined to suppose that any such thing would be like an oblong spheroid, the extreme velocity of electricity would take it to the end of its course before the impression of its first appearance on the retina had subsided; just, indeed, as the rotating wheel, elsewhere described. (53.), having red radii, appears entirely red during the period of rapid rotation; and so, instead of seeing a ball, if such really were there, the eye would recognise a continuous line of light. And this is actually the case. We have ourselves repeated the experiment under very favourable circumstances, and in the presence of very competent witnesses, and one and all agreed in perceiving in every case a distinct continuous line of light, but no appearance of a ball or falling star.]

(220.) An extraordinary experiment, illustrative of a theory of the aurora similar to that suggested by Faraday, with the addition "that electricity is radiated in a peculiar manner from magnetized bodies," was introduced by Mr. Nott at the meeting of the British Association at Cork (1843). He rotated a steel globe, and passed magnets from the equator to the poles, till the globe was perfectly magnetized. He then insulated the globe, and placed an insulated ring around its equatorial regions. He connected the ring with the prime conductor of the resinous plate of his "rheo-electric machine," and one pole of the globe with the conductor of the vitreous plate. It is necessary to men-

tion, that the machine alluded to consists of two parallel plates, one glass the other resin, rotating on the same axis, and provided with separate rubbers. The circuit, including the rubbers and conductors, is completed in various ways: the machine is described as producing a current of electricity of tension, analogous to that of the pile. In the present experiment, when the machine is rotated, a truly beautiful and luminous discharge takes place between the unconnected pole of the globe and the ring. A dense atmosphere is more favourable to the success of the experiment than a dry one. It had then the appearance of a ring of light, the upper part of which was brilliant, and the under dark: above the ring, all around the axis were foliated diverging flames, one behind the other.]

CHAP. VII.

WATER-SPOUTS AND WHIRLWINDS.

(221.) WATER-SPOUTS apparently consist of dense masses of aqueous vapour, presenting often a gyratory and progressive motion, and resembling in form a conical cloud, the base of which is presented upwards, and the vertex of which generally rests upon the ground, but sometimes assumes the contrary position. This phenomenon is attended with a sound like that of a waggon rolling upon a rough pavement.

Violent mechanical effects sometimes attend these meteors. Large trees torn up by the roots, stripped of their leaves, and exhibiting all the appearances of having been struck by lightning, are projected to great distances. Houses are often thrown down, unroofed, and otherwise injured or destroyed, when they lie in the course of a water-spout. Rain, hail, and frequently globes of fire, like the ball-lightning, already mentioned, accompany these meteors, which are manifested equally at sea and on land.

(222.) Although the electrical effects which attend this meteor prove that it is closely connected with atmospheric electricity, yet, as no theory has hitherto been proposed which affords a satisfactory and adequate explanation of the phenomena, it is the more necessary to state, with as much clearness and precision as possible, independently of all hypotheses, the exact circumstances which have been observed to attend them in the various parts of the globe where they have been observed. They are called water-spouts or land-spouts,

according as they take place over the surface of the water or the land.

(223.) In the History of the Academy of Sciences is the following narrative: —

On the 2d of November, 1729, about eight o'clock in the morning, at Montpellier, a small and very obscure cloud was seen, in a very elevated position, in the direction of the south-east, from whence the wind then blew. It advanced towards the town with a noise at first low, but which augmented as it approached: it gradually descended towards the ground, and a light was perceived to issue from it, like that which accompanies the smoke of a great fire. After the passage of this cloud, a strong odour of sulphur was perceived, like that which is diffused in places that have been struck by lightning. This cloud had a very rapid motion, and formed round it a whirlwind, which extended to a distance of above a hundred yards round, the force of which was so prodigious that it tore up trees by the roots, carried away the roofs of houses, overturned buildings, and scattered their ruins to a distance of nearly 500 yards. After having moved along half a league, with a width of above 200 yards, it was dissipated, followed by heavy rain, but not accompanied by thunder or lightning.

(224.) In the *Journal de Physique* for November, 1780, is the following description of one of these meteors, which took place at five o'clock in the evening, near Carcassonne: —

This meteor originated upon the borders of the Aude. It commenced by pouring down a great quantity of water; it then projected upwards, to a great height, quantities of sand. It unroofed eighty houses, and scattered over the country the sheaves of corn which it carried away. It tore up by the roots large oaks, and transported to a distance of fifty yards their branches, projecting them in a direction contrary to that of its own motion. It broke the doors, windows, and furniture of a château; it destroyed the pavement in the middle of a room, without deranging china cups which were placed there; it broke the frame of a looking-glass which was placed upon a chimney-piece, and scattered the fragments upon the chairs of the room, leaving the glass, however, in its place uninjured.

(225.) In the *Memoirs of the Academy of Toulouse*, vol. v., is the following description of a land-spout which, on the 15th of June, 1785, devastated the neighbourhood of Esclades, about four leagues from Narbonne: —

The night before this terrible visitation was very fine, the sun rose

unobscured by a single cloud, and the morning air was calm and pure. At half-past six o'clock the heat became very great, and continued to increase till seven o'clock, when it was excessive. At that time there appeared in the west a small cloud, which, gradually augmenting, extended in an hour over the whole horizon. The thermometer of Réaumur stood at 29° *, and the barometer at 28 inches. There was a light wind from the west. Such being the state of the atmosphere at two o'clock in the afternoon, a kind of smoky and blustering (*bruyante*) column was formed in the west, which passed between Esclades and Mont Brun. In its course it swept away earth and sand, tore up trees, and ravaged every thing which came before it. This lasted for about five minutes. At about five miles from Esclades it became stationary for about five minutes, after which it returned upon its steps: the noise which it made resembled the continual roaring of thunder. It burst upon Esclades in a terrific shower of hail. This hail was succeeded by a rain so abundant that the country was inundated. During this shower, which lasted three quarters of an hour, lightning fell in several places. The thermometer rose to 32°.†

The barometer rose a quarter of an inch, and the wind was very violent. After the meteor disappeared the weather became cool, and the barometer fell an inch and a quarter.

(226.) Humboldt states that, in the Steppes of South America, the plain or table land presents an extraordinary spectacle, which he describes as follows ‡: —

The sand rises in the middle of a rarefied whirlwind, probably charged with electricity, like a vapour, or a cloud in the form of a funnel, the point of which slides upon the ground, and resembling the blustering water-spout, so much feared by the experienced navigator. On the roads in Europe, we see something which approaches the singular appearance of these whirlwinds of sand; but they are especially observed in the sandy deserts situate in Peru, between Coquimbo and Amotape. It is worthy of remark, that these partial currents of air which encounter each other are only perceived when the atmosphere is entirely calm — the ocean of air, therefore, like the ocean of water, encountering each other only in a dead calm.

(227.) The *Courier* of the 19th of September, 1826, published the following narrative of a meteor which ravaged the arrondissement of Carcassonne on the 26th of August preceding: —

The wind was from the south, and the heat of the morning was suffocat-

* Equal to 100° Fahr.

† Equal to 104° Fahr.

‡ Tableau de la Nature, tom. i. p. 43. and p. 177.

ing. About noon, the clouds accumulated in the west, and a violent wind arose. A thick black cloud appeared, suspended over a piece of land near the château of La Counette. In the direction of Fombraise, the clouds were seen to encounter each other, and, after the collision, to descend very low, as if they were attracted by the earth. The thunder grumbled on every side with a dull rolling noise; domestic animals fled to their sheds. Suddenly a frightful explosion (*craquement*) was heard in the west; the air, violently agitated, was drawn with extreme velocity towards the black cloud above mentioned: the moment they encountered was signalised by a loud detonation, and the appearance of an enormous column of fire, which, sweeping over the field, tore up every thing in its way. A young man of 17 was carried away by this whirlwind, raised in the air, and dashed against a rock, by which his head was split; 14 sheep were carried away, and fell senseless.

This column of air and fire overturned walls, displaced enormous rocks, tore up by the roots the largest trees, broke into the château by two openings, tore up and overturned the stones of the *porte cochère*, broke the gate, twisted all the iron work, broke through a window, entered the saloon on the first floor, broke through its ceiling, entered the second floor, passed to the roof, and, in fine, reduced to ruin these three stories. The ladies, who were in the saloon on the first floor, saw a globe of fire enter it, and owed their safety only to an enormous beam which formed an arch to support the wood-work. A vortex of air, entering by the window above the kitchen, broke through a partition, raised the floor, broke the furniture, overturned the beds, opened the closets without disturbing their contents, penetrated a thick wall, and projected its ruins to a great distance, broke the timber-work of the château, tore up by the roots an enormous oak five feet in circumference, crushed two small houses, carried away waggons, which it precipitated into a ravine, uprooted several enormous walnut-trees, ravaged the vines, leaving in the earth deep trenches, and impregnating the air with a strong odour of sulphur. This meteor disappeared in the direction of Forcenas, and was succeeded by very heavy rain. The heavens then became serene, and a wind arose from the east.

(228.) In 1823, this meteor made great ravages in the neighbourhood of Dreux and Mantes in France.

In the village of *Marchefroid*, fifty-three houses were destroyed in the space of one minute, yet the storm was scarcely heard, and the appearance of the water-spout was only preceded by a little hail. A child three years old, who stood beside its mother in a court-yard, was killed upon the spot. On examining its body, no wounds were found upon it except a hole of a certain depth in the neck. Entire roofs were carried away either in the direction in which the meteor moved, or in the contrary direction. The four walls of a garden were thrown down in a regular manner, all falling on the outside of the garden: their fall was marked by great regularity. After the meteor passed away, the temperature did not seem changed, and the sun immediately re-appeared.

(229.) On the 6th of July, 1822, a land-spout was formed in the plain of Ossonval, near the village of that name, in the department of the Pas de Calais.

Clouds coming from different directions and collecting over the plain, ultimately formed a single cloud which covered the heavens: immediately afterwards a cone descended from this cloud, presenting its vertex downwards, and having its base in the cloud. This meteor, driven by the wind, beat down a barn, tore and carried away the tops of the largest trees, overturned twenty-five to thirty of them, and strewed them in different directions, proving that the meteor had a revolving motion. It carried away and crushed other trees from sixty to seventy feet high. Globes of fire and sulphureous vapour were seen from time to time to issue from its centre. This meteor, in its rapid course, was attended with a sound like that of a heavy carriage rolling on a paved road.

It then penetrated into the valley of *Wetternester* and *Lambre:* in the former of these villages, only eight habitations of forty were uninjured: the meteor left every where traces of its passage.

(230.) On the 18th of June, 1839, the neighbourhood of Chatenay, in the department of Seine et Oise, was visited by a meteor, which happened to be witnessed by MM. Peltier, Bouchard, and Becquerel. The following narrative of it is abridged from the account given of it by M. Peltier:—

In the morning, a storm was formed to the south of *Chatenay*, and about ten o'clock it took the direction of the valley between the hills of *Ecouen* and *Chatenay*. The clouds, which were high, after extending above the extremity of the village, came to a stand, the thunder muttered, and the first cloud followed the ordinary route, when, towards noon, a second storm coming also from the south, advanced towards the same plain and the same hills. Arriving near the extremity of the plain over *Fontenay*, in presence of the first storm which, by its elevation, it overtopped, a pause took place, doubtless while the two storms were presenting themselves to each other by means of their clouds charged with the same electricity, and repelling each other.

To this time, thunder which was heard proceeded from the second cloud, when suddenly one of the inferior clouds descending, fell into communication with the earth, and the thunder seemed to cease. A prodigious attraction was manifested; all light bodies and all the dust which covered the surface of the ground, was raised towards the point of the cloud: a continual rolling noise succeeded; little clouds were fluttering and whirling round the inverted cone, and rising and falling rapidly. Trees, placed to the south-east of the meteor, were struck on their north-west side which faced it, the other side remaining in its usual state. The sides which were struck exhibited strong marks of the meteor, while the other parts pre-

served their sap and their vegetable life. The meteor descended the valley to the extremity of *Fontenay*, towards a row of trees planted along the bed of a stream which was then without water, though still humid. After having broken and uprooted these, it traversed the valley, and advanced towards other plantations which it also destroyed. There, having arrived at the point vertically under the limits of the first cloud, it paused, and the latter, which was hitherto stationary, began to be agitated and to retreat towards the valley west of *Chatenay*, and, overthrowing all that it encountered in its way, it passed to the park of the château of *Chatenay*, which it completely desolated. The walls were overturned, and the roofs and chimneys of the buildings carried away. Trees were transported several hundred yards; windows, rafters, tiles were thrown to a distance of upwards of 500 yards.

The meteor, having ravaged that place, descended a mountain towards the north, and paused over a fish-pond, where it overthrew and parched the trees, killed all the fish, and proceeded slowly along an alley of willows. Here it lost a great portion of its extent and violence. It then proceeded still more slowly over a neighbouring plain, and after advancing three quarters of a mile, it divided itself into two portions near a clump of trees, one part rising into the clouds, while the other part sunk into the ground and disappeared.

All the trees struck by this meteor had their sap completely evaporated, the ligneous part being as much dried as if it had been exposed in a stove at the temperature of 300°. The immense quantity of vapour suddenly formed by the sap, having no means of escape from the interstices of the wood, split the tree in the longitudinal direction. All the trees presented marks of this effect.

(231.) By observing the progress of this phenomenon, the transformation of a common storm into a land-spout will be apparent. Two stormy clouds moved towards the same vertical line in which they settled at different altitudes. Being charged with the same electricity, the lower cloud descends towards the ground, and is put in electrical communication with the ground by whirlwinds of dust and by trees. This communication once established, the noise of the thunder immediately ceases, the discharge taking place by the continuous conductor formed by the clouds which have descended and the trees upon the plain. These last, traversed by the electricity, have their sap dried up and their trunks split; finally, flashes of light, balls of fire, and sparks appear, and a sulphureous odour remains in the houses for several days, the curtains of which are every where scorched.

(232.) M. Peltier, who has lately analysed with great care the circumstances attending these meteors, with a view to their explication, has collected, from various scientific memoirs and from the narratives of travellers, 116 cases in which they were observed and recorded with more or less accuracy. These he has arranged in two tables, the one containing fifty-six cases where the phenomenon occurred at sea or upon water, and the other containing sixty cases where it occurred upon land. He has collected also the opinions of thirty observers as to the cause of the meteor, and arranged them in a tabular form.

The following are these three tables:—

TABLE I.—WATER-SPOUTS.

	Place.	Time.	Authorities.	Observations.
1.	Off the island Quesomo	1664.	Thevenot, Voy. Lev. ii. 359.	Serpentine — two mutually intersecting.
2.	Off the island of Celebes	20th Nov. 1687.	Dampier, Voy. round the World, Ch. 16.	Surrounding calm — violent wind within a circumscribed space — cloud at first motionless — then moving progressively.
3.	Off the island of Kosiway	28th Dec. 1699.	Ib., Voy. to New Holland, Ch. 3.	Thunder and lightning.
4.	Off the coast of N. Guinea	12th April, 1700.	Ib. ib. Ch. 4.	Not proceeding from a cloud — rotation.
5.	In the Downs - -	24th March, 1701.	P. Gordon, Phil. Trans. xxii. 805.	Wind regular — sea agitated under the meteor — water projected.
6.	In the Mediterranean -	27th Aug. 1701.	A. Stuart, ib. xxiii. 1077.	No gyration — noise ends when the communication between the cloud and the sea is established.
7.	At sea - - - - -	29th April, 1716.	Le Gentil de la Barbinais, Voy. autour du Monde, 1733.	Six water-spouts simultaneous — low hissing noise — light uniform wind.
8.	At sea - - - - -	21st May, 1732.	J. Harris, Phil. Trans., 1734, xxviii. 77.	Surrounding calm — water springs up under the cone.
9.	In the Mediterranean	1736.	Shaw, Voyage to Barbary, ii. 55.	Water seemed to fall from the clouds.
10.	On the lake of Geneva	October, 1741.	Jallabert, Mém. Acad. de Paris, 1741, 20.	Surrounding calm.
11.	Ib. - - - - - -	9th July, 1742.	Ib. ib. 1767, 412.	Water springs upward at intervals (par élancements) — gyration.
12.	Deeping Feen - -	5th May, 1752.	B. Ray, Phil. Trans. xlvii. 479.	Flash of fire at the moment of the spout breaking; seen by several persons.
13.	At sea - - - - -	1749 to 1753.	Adanson, Voyage to Senegal, 123.	Nitrous odour — vapours proceed from the clothes — gyration.
14.	Antigua - - - - -	- - -	Dr. M. R. Lett, Frank., p. 241, Ed. 1774.	Luminous water — a small house carried away by the wind.
15.	At sea - - - - -	- - -	Franklin's Letters (20th letter), p. 227.	Surrounding calm — then current towards the meteor.

16.	Haarlem - - -	14th June, 1754.	Sigaud de la Fond, Dict. Phys.	Water thrown up sixty feet.
17.	West Indies - - -	Aug. (before 1756.)	Melling, Trans. Amer. Phil. Soc., 1786, ii. 335.	Fresh water falls from the meteor.
18.	Straits of Gibraltar -	ib. ib.	J. Wakefield, ib. ib. ib.	Water falls from the meteor — a slight wind under it.
19.	At sea - - - - -	ib. ib.	J. Howland, ib. ib. ib.	Ib.
20.	Strait of Malacca - -	ib. ib.	S. Spring, ib. ib. ib.	Ib.
21.	West Indies - - -	- - -	Franklin's Letters, 263.	No rotatory motion; sea concave under it — profound calm around — space between the apex and the sea — sudden gusts.
22.	Sea of Java - - -	About 1760.	Legentil (the Astronomer), Voy. Mers des Indes, ii. 14.	Double spout — the first between two clouds — second, between the first and the sea.
23.	Off the coast of Malabar	- - -	Ib. ib. ib. 15.	Very serpentine — no gyration.
24.	Off Penzance - - -	28th July, 1761.	Borlaze, Phil. Trans., 1762, lii. 507.	Sea rose towards cloud — thunder.
25.	Limay - - - -	23d June, 1764.	Du Bourdieu, Mém. Acad. Par., 1764, 32.	Preceded by thunder — followed by hail.
26.	Queen Charlotte's Straits	17th May, 1773.	Cook and Forster — Forster's Obs. p. 109.	Gyration — lightning appeared at the moment of the rupture of the spout, succeeded by hail.
27.	Ibid. - - - - -	29th Oct. 1773.	ib. ib.	No particulars.
28.	Off Nice - - -	12th April, 1780.	Michaud, Journ. Phil. Roz. xxx. p. 284.	No gyration — water projected up at intervals — the spout leaned towards the north, although its motion was towards the west — snow followed.
29.	Off Cuba - - -	12th April, 1782.	Baussard, Ph. Ann., 1798, xlvi. 348.	At first cloudless — clouds afterwards formed — gyration — thunder.
30.	Cape de Verd - -	7th Sept. 1783.	Isert, Voyage en Guirée, p. 9.	Gyration.
31.	In the Adriatic - -	23d Aug. 1785.	Spallanzani, Mem. della Soc. Ital. iv. 473.	Vortigenous cloud — lightning — thunder — several spouts — sea concave under the cone — profound calm.
32.	At sea - - - - -	24th May, 1788.	Buchanan, Edin. Phil. Journ, v. 275.	Gyration — ascending vapour.
33.	Off Nice - - - -	6th Jan. 1789.	Michaud, Mem. Acad. Turin, 1788–9, ix. 3.	Water and vapour projected — no gyration — hail and frozen snow.

	Place.	Time.	Authorities.	Observations.
34.	Off Nice - - - -	6th Jan. 1789.	Michaud, Mem. Ac. Turin, 1788-9, ix. 3.	Snow scarcely frozen.
35.	Ibid. - - - -	19th March, 1789.	ib. ib.	Thunder — snow.
36.	At sea - - - -	8th Jan. 1789.	Buchanan, Edin. Phil. Journ. v. 275.	Two clouds superposed—spout with triple origin.
37.	Ibid. - - - -	12th April, 1789.	ib. ib.	Sea agitated under the cone — very feeble wind.
38.	Lake of Geneva - -	1st Nov. 1793.	Wild, Phil. Journ., 1794, v. 39. 44.	Snow on each side of the spout — the water concave under it.
39.	Off Teneriffe - - -	22d Nov. 1796.	Baussard, Jour. Phil., 1798, v. 46. 348.	No gyration — water raised regularly.
40.	On the Mississippi -	1800.	Dunbar, Bibl. Britt. p. 38. 101.	No whirlwind.
41.	At sea - - - -	6th Sept. 1814.	Napier, Edin. Phil. Jour. vi. 95.	Gyration — meteor moved contrary to the wind — was divided by a cannon-ball — the ends afterwards were re-united — fresh water fell from it.
42.	On the Atlantic - -	May, 1820.	Ogden, Amer. Jour. of Science, Jan. 1836.	Seven spouts simultaneous — gyration — fire — thunder — fresh water falls from it.
43.	At sea - - - -	- - -	Maxwell, Edin. Phil. Jour., v. 39.	Vapour rising within it.
44.	Off Cape Blanc-Nez -	1st Sept. 1822.	Annales de Chim. et Phys., 1822, xxi. 409.	Clouds superposed — the meteor does not touch the water — no gyration — fine sand.
45.	Roseneath - - -	18th Sept. 1822.	ib. ib. xxi. 400.	Surrounding calm — gyration.
46.	At sea - - - -	19th March, 1823.	ib. ib.	Profound calm.
47.	Coast of Florida - -	5th April, 1825.	Lincoln, Amer. Jour., Ap. 1828.	Convex towards the wind — apex does not reach the water — motion of undulation — followed by a clap of thunder.
48.	Off Clermont-Tonnerre	Jan. 1826.	Beechey, Voyage to Behring's Straits, i. 148.	Gyration — three spouts from the same cloud — one re-united, and afterwards separated — lightning — thunder — fire-ball.

49.	Off Sicily - - -	27th June, 1827.	Mazzara, Lithagraphie d'Ingelmann.	Seven spouts simultaneous, the fourth having a spiral form.
50.	Lake of Geneva - -	11th Aug. 1827.	Ann. de Chim. et Phys. xxxvi. 415.	No gyration — undulation.
51.	Lake of Neufchâtel -	9th June, 1830.	Bibl. Univ. 1830, June.	No gyration.
52.	Mediterranean - -	10th June, 1830.	Elem. Geog., Lecoq. 468.	Numerous electrical discharges.
53.	Canal of Bahama - -	30th July, 1832.	Page, Echo du Monde Savant, i. No. 176.	Feeble wind — descending spout — no visible gyration — a second spout succeeded — with thunder and lightning.
54.	Lake of Geneva - -	3d Dec. 1832.	Mayor, Bibl. Univ., 1832, ii. 321.	Gyration — no clouds.
55.	Coast of Spain - -	- - - -	Page, Echo du Monde Savant, i. No. 176.	Seven spouts — no clouds.
56	Off Dover - - -	23d Oct. 1836.	Page, Echo du Monde Savant, 1836, Nos. 45. & 181.	Oscillation — lightning.

TABLE II. — LANDSPOUTS.

	Place.	Time.	Authorities.	Observations.
1.	Italy - - - - -	22d or 24th Aug. 1456.	Machiavelli, Hist. Fior. liv. vi.—Ammirati, Hist. Fior. liv. xxiii.	At night—parasite clouds rising and falling vertically, and occasionally turning with a gyratory motion—electrical discharges between them—objects raised up and transported to a distance without being overturned—evident effects of electricity.
2.	France - - - - -	Sept. 1669.	Du Hamel, Phil. Vet. Nov. 5. Météor. 7., Par. 1700.	At night.
3.	Hatfield (England) -	15th Aug. 1687.	De la Pryme, Phil. Tran., 1702, p. 1248.	Gyration—ascent of water.
4.	Topsham - - -	7th Aug. 1694.	Mayne, ib. ib. vol. xix. p. 28.	Gyration—an apple tree transported contrary to the wind.
5.	Hatfield - - - -	21st June, 1702.	De la Pryme, ib. 1702, p. 1248.	Gyration—no wind.
6.	Leyden - - - -	1715.	Muschenbroeck, Cowrs Ph. chap. 42. § 2383.	Whirlwind.
7.	Bocanbray - - -	30th March, 1725.	De Jussieu, Mém. Acad. Par., 1725, 5.	Fire—thunder—feeble wind—undulation—vapour with vortical motion.
8.	Moklinta - - -	27th Sept. 1725.	Kalsenus, Acad. Litt. Suec., Ann. 1725, ii. 106.	Revolving globes—roof carried against the wind—water of a lake raised like a wall—disagreeable odour.
9.	Capestan - - -	21st Aug. 1727.	Mém. Acad. Par., Ann. 1727, 4.	Surrounding calm—thunder—hail.
10.	Montpellier - - -	2d Nov. 1729.	Serres et Guettard, Mém. Sc. R. Montp. 2—24.	Brilliant light—sulphurous odour—whirlwind.
11.	Corne-Abbas - - -	30th Oct. 1731.	Derby, Phil. Tran. 41. 229.	Surrounding calm.
12.	Holkam - - - -	Aug. 1741.	Lovell, ib. 42. 183.	ib. ib. clear sky—fire—flame.
13.	Huntingdonshire - -	8th Sept. 1741.	Fuller, ib. 41. 851.	ib. ib. gyration.

14.	Rome - - - - -	11th to 12th June, 1749.	Boscovich. Dissert., Rome, 1749.	Lightning — thunder — flame — flooring raised up — walls pierced — thrown down against the wind — sulphurous odour — leaves reddened — lamp moved without being extinguished, &c.
15.	Venice - - - - -	- - -	ib. ib.	Five men carried off a vessel.
16.	Cuba - - - - -	- - -	ib. ib.	Two men carried off a vessel.
17.	Mirabeaux - - -	- - -	ib. ib.	Two large holes in the floor of an attic — a small one in the hearth.
18.	Verona - - - - -	28th July, 1686.	ib. ib.	Loaded boat overturned.
19.	Arezzo - - - - -	- - -	ib. ib.	Trenches formed on the ground—two men carried up, and let down unhurt.
20.	Rutland - - - -	15th Sept. 1749.	Barker, Phil. Trans. xlvi. 248.	Fire — lightning — surrounding calm — water of a river drawn up — gyration.
21.	Berkoude - - - -	24th June, 1750.	Muschenbroeck, Cowrs. Phil. chap. 42.	Formed in a storm.
22.	Malta - - - - -	29th Oct. 1757.	Chabert, Mém. Acad. Par., 1758, 19.—Brydone, Arch. Ile de France, No. 11.	Boards of a platform raised—cannons overturned — flame—seen at night.
23.	New England - -	10th May, 1760.	Winthrop, Phil. Trans., 1761, lii. 6.	Igneous meteor like a land-spout.
24.	Leicester - - -	10th July, 1760.	ib. ib.	A storm transformed into a land-spout — a tree carried against the wind — its force increased by a marsh at the bottom of a ravine.
25.	Oxford - - - - -	21st Sept. 1760.	Swinton, Phil. Trans. 1761, lii. 99.	Semicircular spout.
26.	Salisbury - - -	14th Aug. 1773.	S. Williams, Amer. Phil. Soc. ii. 436.	Boiling up of the river — another storm on same river at ten miles distance.
27.	Arcachon - - -	14th March, 1774.	Butet, I. Ph. Roz. vii. 334.	Fire — lightning — sulphurous odour — hail — grass reddened — parasite clouds ascending —no external gyration— internal gyration occasional.
28.	Orbassan - - -	19th April, 1775.	Mém. Acad. Toul. ii. 24.	No particulars.
29.	En - - - - - -	16th July, 1775.	Rozier, Jour. Phil. vii. 70.	This meteor presented all the signs of electricity, statical and dynamical — whirlwinds — trenches formed on the ground.
30.	Mont d'Alaric - -	6th Aug. 1776.	Mearcorelle, Mém. Acad. Toul. iii.	

	Place.	Time.	Authorities.	Observations.
31.	Dijon - - - -	20th July, 1779.	Maret, Mém. Acad. Dij., 1783, 152.	Thunder at the moment of the formation of the meteor — no gyration at first — rotation impressed by a shock — motion contrary to the wind.
32.	Carcassonne - - -	3d Nov. 1780.	Lespinasse, Jour. Phil. Rez. xvi. 355.	A very curious meteor — jets of sand — pavement raised — room unfloored in the centre without deranging the surrounding articles — no gyration.
33.	Escale - - -	15th June, 1785.	Mém. Acad. Toul. iii. 115.	Calm at commencement — lightning — thunder — hail — all the effects of statical electricity.
34.	Marliac - - - -	13th June, 1787.	D'Arbas, ib. iv. 77.	Calm — sparks — inflamed disc — thunder — leaves parched and burned.
35.	Peru - - - -	1802.	Humboldt, Tab. Nat. i. 43. 177.	Sand spout.
36.	Paris - - - -	16th May, 1806.	Lamarck, Ann. Météor., 1807.	Storm — thunder — followed by spout — slight gyration.
36.	Paris - - - -	16th May, 1806.	Debrun, Mém. sur les Trombes.	Two spouts — first a thunder-storm — then first spout — a transparent tube — slight gyration — then second spout — no gyration — ascending motion — neighbouring storm moving in contrary direction — surrounding calm.
37.	Illinois - - - -	4th June, 1814.	Griswold, Annuaire, 1838, 435.	Lightning along the spout.
38.	Flacq, Mauritius - -	5th Feb. 1815.	Mallac, Arch. Ile de France, No. xi.	Rotation — absorbs water — varies in diameter according to the conducting power of the ground.
39.	St. Angelo - - -	14th Aug. 1817.	Jour. Com. 18 Sept. 1817.	Water absorbed — holes formed in linen — linen scorched.
40.	Foix - - -	9th May, 1822.	Annales Chim. et Phys., 1822, 407.	Hail.

41	Régneville - - -	16th June, 1822.	ib. ib.	Sound diminished in passing over water.
42.	Assonval	6th June, 1822.	ib. ib. xxiv. 433.	Globes of fire — explosion — thunder — slow gyration — walls of a building thrown outwards.
43.	Rouvier - - - -	26th Aug. 1823.	Defrance, Bul. Ferus., 1823, iv.	Thunder — hail — leaves parched — bodies carried against the wind — walls of a garden thrown outwards.
44.	Valeggia - - -	16th Sept. 1823.	Pagliaris, Ann. Ch. et Phys. xxiv. 439.	Fire — smoke — water absorbed and raised to a great height.
45.	Messeling - - -	1824.	Kastner, ib. ib.	Hail.
46.	Several places - -	1824.	ib. ib. ib.	Lightning — globes of fire — sulphurous odour.
47.	Carcassonne - - -	26th Aug. 1826.	Cours Fran., 19th Sept. 1826.	Fire — thunder — conflicting clouds — cloud attracted by the ground — igneous explosion at the moment of the connection with the ground — floors and walls pierced — trenches formed — sulphurous odour.
48.	Ruwer - - - -	25th June, 1829.	Grossman, Ann.Ch. et Phys. xlii. 420.	Luminous mass proceeding contrary to the motion of the cloud — flames issuing from the cone—water projected in a column — progress slow — a man carried away by the spout, transported at one time forwards, at another upwards—two contrary currents—sulphurous odour — storm after the meteor — hail — profound calm.
49.	Gorschoff - - -	15th Aug. 1829.	Ann. Ch. et Ph. xlii. 419.	Calm — hail.
50.	Banks of the Ganges -	1831—1834.	Stephenson, Bibl. Univ., 1836, vi. 155.	Sand spouts — gyration — clear and pure atmosphere.
51.	Near Bronte - - -	1st Oct. 1834.	Elie de Beaumont.	Rotation — two cones united at the summit.
52.	La Française - - -	27th July, 1835.	Echo du Monde Sav., 1835, No. 73.	A storm — after spending its force, ended with a column of fire.
53.	Mornay - - - -	Sept. 1835.	Manduit ib. No. 83.	Water of a river raised in a column.

	Place.	Time.	Authorities.	Observations.
54.	Caux - - - - -	13th Sept. 1855.	Manduit, Echo du Monde Sav., No. 80—83.	All the water of a pond, with the fish contained in it, carried up.
55	Trebeurden - - -	29-30th Jan. 1836.	ib. ib. 1836, No. 7.	
56.	New Brunswick - -	June, 1836.	Hare, Silliman's Journal, April, 1837.	Trees lying in the midst of its course overturned—those on the sides thrown towards the middle of its course — walls thrown outwards — sand thrown up — thunder — leaves destroyed.
57.	Baltimore - - -	14th June, 1837.	Echo du Monde Sav., 1837, No. 99.	Thunder — calm.
58.	Chatenay - - -	18th June, 1839.	Peltier.	Preceded by thunder, which ceased when the spout was formed—fire at the inferior extremity — no gyration at first — parasite clouds moving in different directions along the meteor — trees thrown down in the direction of its course — those within the meteor thrown in all directions — those outside it leaning towards it — leaves reddened — trees split — fish killed, &c
59.	Petit Mont-rouge - -	1st Sept. 1839.	Peltier.	At night — storm — wall forty metres long overturned without being broken — foundations torn up.
60.	Between two clouds -	18th July, 1808.	Lamarck, Ann. Met., 1809.	Spout between two strata of clouds.

TABLE III.

Authors who have proposed Theories to explain the Phenomena.

Authors who ascribe the meteor to whirlwinds, but who differ in their explanation of the cause of the wind, its progress, and its influence on the clouds. Those who ascribe the whirlwind to contrary winds meeting suppose, what is an impossibility, that the tangental force of the whirlwind will produce a dilatation of the air in its centre greater than the compression from without which produces it.	Stuart	Phil. Tran. xxiii. 1077.
	Andoque	Mém Acad. Par., 1727, 50.
	Guettard	Mém. Soc. Roy. Montp., ii. 24.
	Shaw	Voyage to Barbary, ii. 55.
	Boscovich	Sopra il Turbine, &c., Rome, 1749.
	Franklin	Letters, &c., 20th Book.
	Muschenbroeck	Cours de Phys., chap. 42. §§ 2381—2385.
	Forster	Observations, &c., 109.
	Rozier	Jour. Phys. vii. 70.
	Perkins	Trans. Am. Phil. Soc., 1786., ii. 335.
	Spallanzani	Mem. della Soc. Ital. iv. 473.
	Oliver	Trans. Am. Phil. Soc., 1786., ii. 101.
	Lamarck	Ann. Met., 1807.
	Monge	Ann. Chim. v.
	Napier	Edin. Phil. Jour. vi. 95.
	Defrance	Dict. Sc. Nat., *art.* Trombes.
	De Maistre	Bibl. Univ., 1832., li. (3.) 226.
	Page	Echo du Monde Savant, i. 176.
	Ogden	Silliman's Journal, 1836.
Authors who ascribe the effects to electricity, without particularising the effects which proceed from that agency.	Brisson	Mém. Acad. Par., 1767. p. 11.
	Lacépède	Essai sur l'Electricité, ii. 332.
	Michaud	Jour. Ph. Roz. xxx. 284. ; Mém. Acad. Tur. ix. 3.
	Young	Leçons de Phys. i. 716.
	Humboldt	Tabl. de Nat. i. 43—177.
	Beechey	Voyage to Behring's Straits, i. 148.
	Horner	Gilbart, lxxiii. 95.
	Hare	Silliman's Journal, April, 1837.
Authors who ascribe the meteor to subterraneous eructations.	Lemery	Cours de Chimie.
	Buffon	Hist. Nat., 1re Partie.
An author who considers the meteor as merely a violent storm.	Eeles	Phil. Trans., 1755., xlix. 147.

(233.) Of these 116 cases, there are twenty-nine in which a gyratory or vortical motion was observed. Of these, eleven were at sea, and eighteen at land. There were twenty-two cases in which no internal motion was observed—nine at sea, and thirteen on land: forty-one were attended by thunder, lightning, or other luminous emanations—sixteen at sea, and twenty-five on land: ten transported objects against the wind; sixteen produced hail—seven at sea, and nine at land. In six cases, the meteor vanished in a cloudless atmosphere without producing any damage. In three cases at sea, vessels which fell in their way were inundated with fresh water, although the meteor was observed to rise from the deep. In three cases at sea, the surface of the water became concave under the meteor: in two cases, the meteor proceeded from two groups of clouds. In fifteen cases, the water was seen to ascend, and in eight to descend. In eight cases, a sulphureous odour was perceived. In six cases, several water-spouts were produced at the same instant.

The meteors at sea were attended by an agitation of the water and by numerous vapours which rose from it. Those on land were attended by the carrying upwards of light bodies. The sound was very various, but generally louder on land than at sea.

Of the thirty observers whose opinions have been collected, ten ascribed the phenomenon to currents of air, eight to electricity, and two to submarine eruptions.

(234.) In his voyage to the Pacific Captain Beechey witnessed water-spouts off Clermont Tonnerre, lat. 19° S. long. 137° west, of which he has given the drawings, from which *fig.* 113. and *fig.* 114. have been taken.

Colonel Reid in his work on storms has given the following extract from a letter addressed to him by Captain Beechey, containing a circumstantial account of water-spouts, witnessed by him in the same voyage: "The day had been very sultry, and in the afternoon a long arch of heavy cumuli and nimbi rose slowly above the southern horizon; while watching its movements a

Fig. 113.

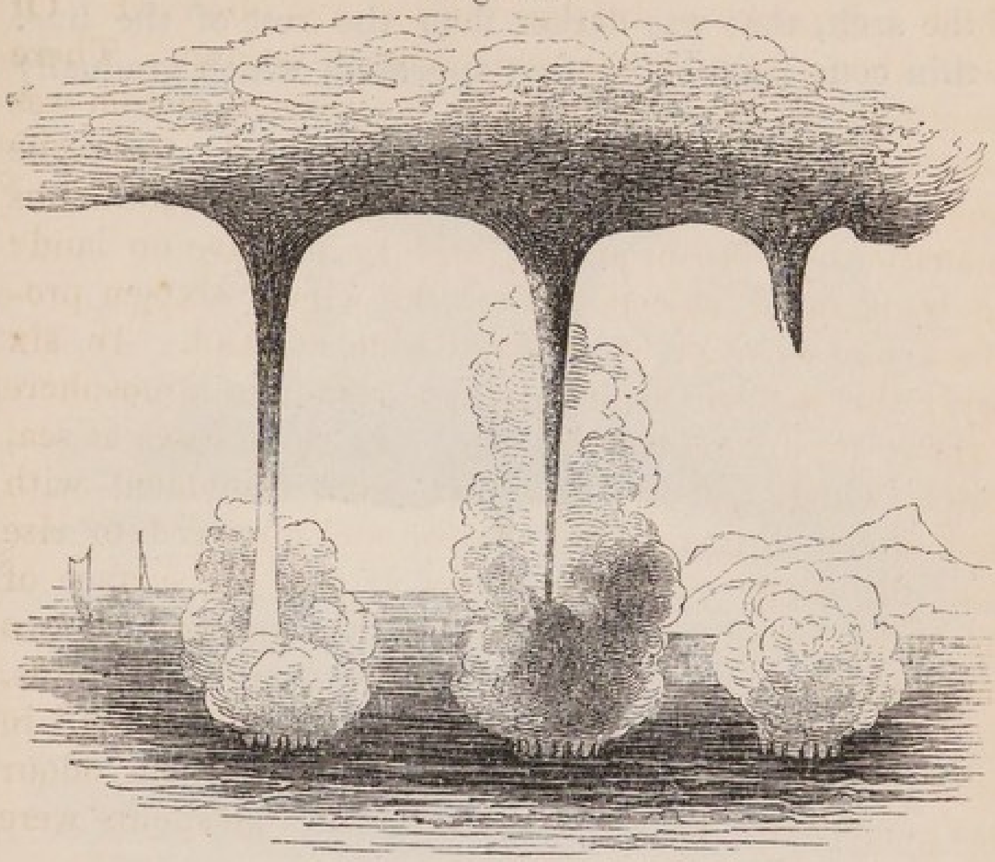
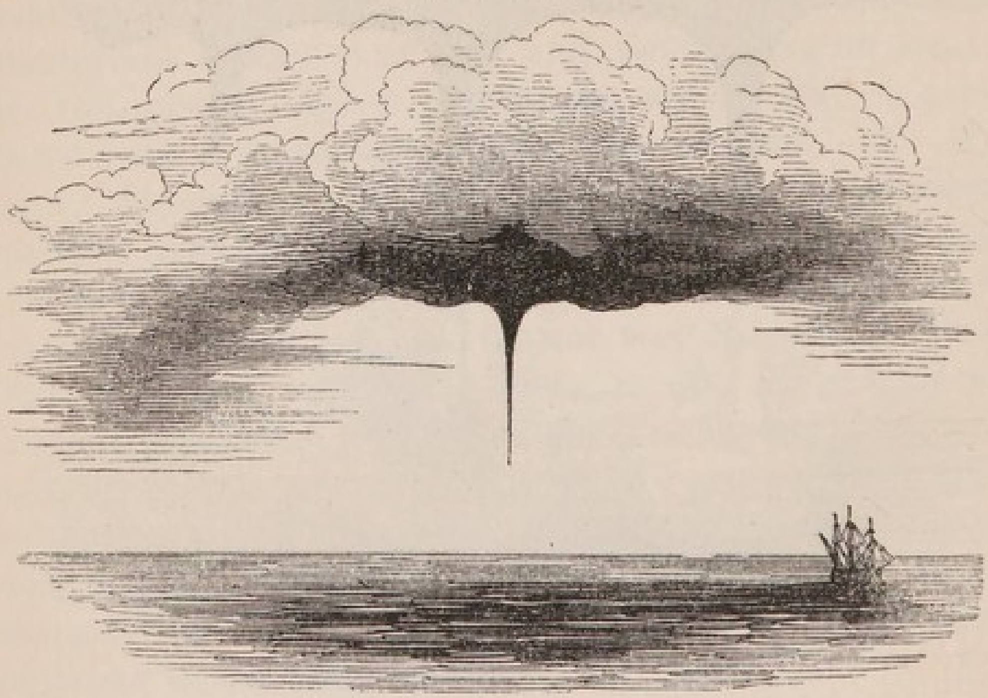


Fig. 114.

water-spout began to form, at a spot on the under side of the arch, that was darker than the rest of the line. A thin cone (*fig.* 115.) first appeared, which gradually

Fig. 115.

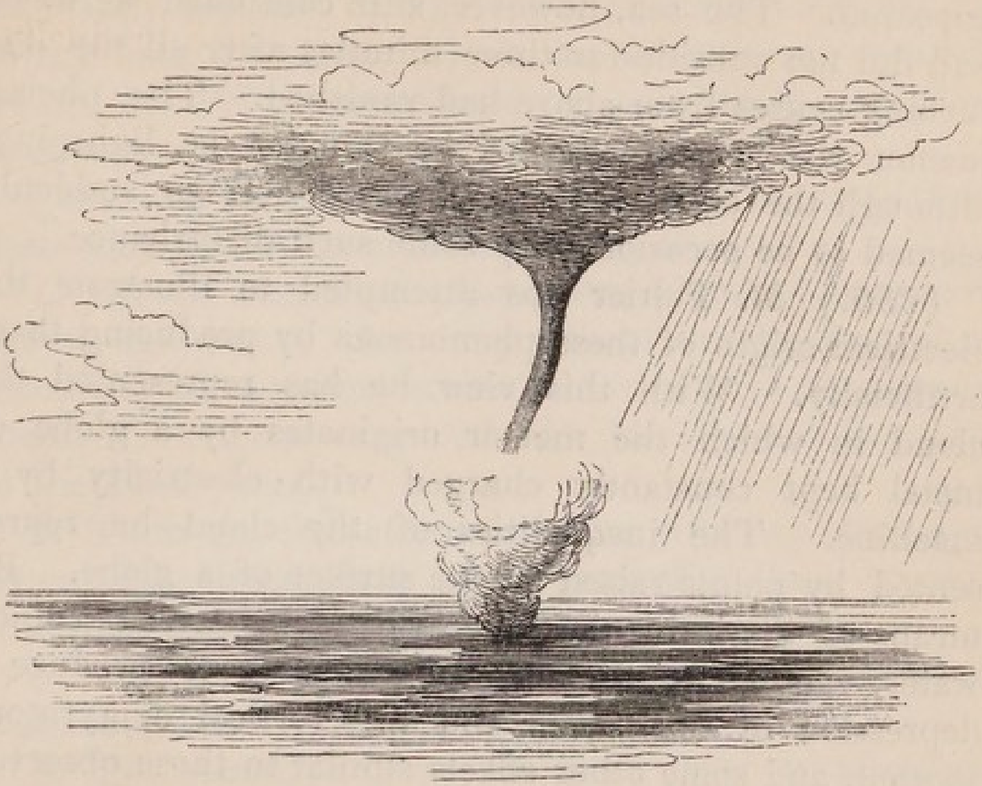


became elongated, and was shortly joined by several others which went on increasing in length and bulk until the columns had reached about halfway down to the horizon. The sea beneath had hitherto been undisturbed; but when the columns united it became perceptibly agitated, and almost immediately became whirled in the air with a rapid gyration and formed a vast basin, from the centre of which the gradually lengthening column appeared to drink fresh supplies of water (*fig.* 116.).

"The column had extended to about two-thirds of the way towards the sea, and nearly connected itself with the basin, when a heavy shower of rain fell from the right of the arch, and shortly after another fell from the opposite side. This discharge appeared to have an effect on the water-spout, which now began to retire.

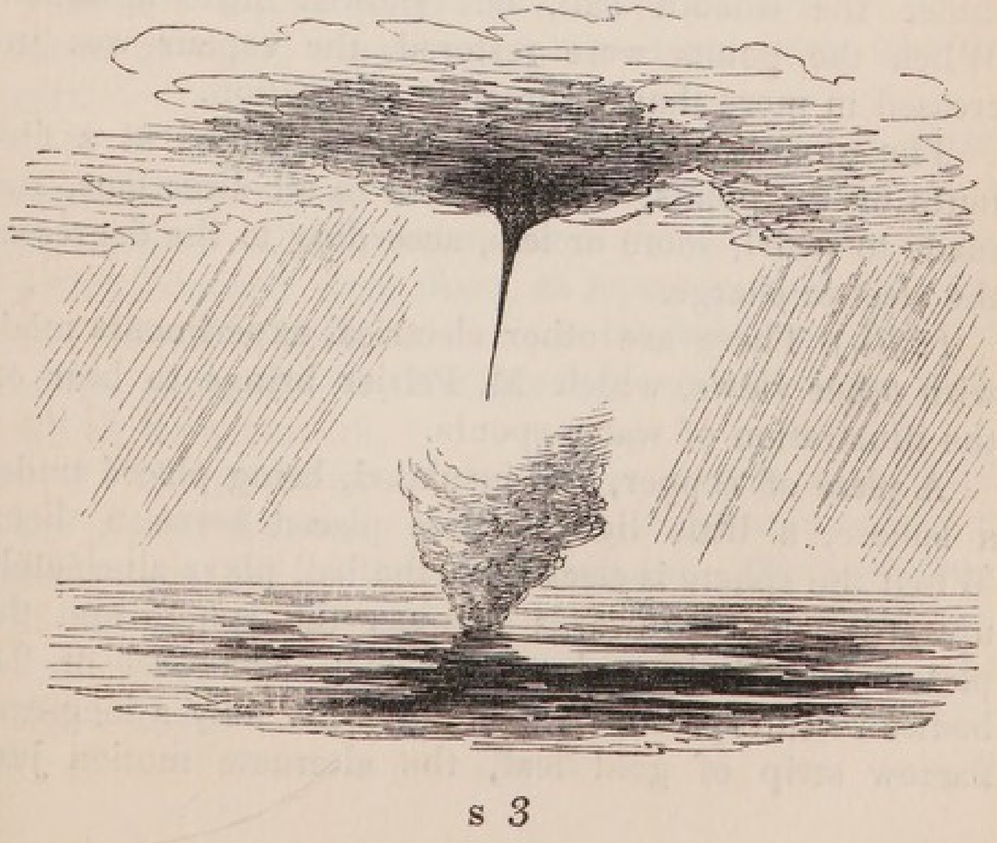
"The sea on the contrary was perceptibly more agitated, and for several minutes the basin continued to

Fig. 116.



increase in size, although the column was considerably diminished (*fig.* 117).

Fig. 117.



"In a few minutes more the column had entirely disappeared. The sea, however, still continued agitated, and did not subside for three minutes after all the disturbing causes from above had vanished. The phenomenon was unaccompanied by thunder or lightning, although the showers of rain which fell so suddenly seemed to be occasioned by some such disturbance."

(235.) M. Peltier has attempted to illustrate the electrical origin of these phenomena by producing them artificially. With this view he has represented the cloud in which the meteor originates by a globe of metal kept constantly charged with electricity by a machine. The inequalities of the cloud he represented by points raised on the surface of a globe. By means of the influence which this globe exercised upon water, vapours, and dust, he was able to produce a depression of the liquid and the vortical or gyratory motion, and some other effects similar to those observed in the meteor.

All these effects disappeared when the globe was divested of points. In this case, instead of a depression, an elevation was produced: the vapours rose under the smooth ball, but showed little agitation. When the points were restored, the vapour was increased in more than a threefold proportion.

The globules of vapour, being electrified at a distance by the points, were repelled in all directions, and made to whirl, more or less, according to the degree of the electric charge.

(236.) There are other electrical experiments made with other views, which M. Peltier brings to bear on the illustration of water-spouts.

A plate of copper, not insulated, being placed under a sphere, a little light ball is placed between them. When the sphere is electrified, the ball plays alternately upwards and downwards between the sphere and the plate; but if, instead of the ball, elongated or flat bodies be interposed, so as to present only a long and narrow strip of gold leaf, the alternate motion just

described is transformed into a vortical motion, which ultimately becomes one of rapid rotation between the sphere and the plate. Such are the gyratory motions which M. Peltier conceives to arise from electrical radiation.

(237.) The consequences which he deduces from these and similar facts are as follows: —

1. All the immediate phenomena observed in water-spouts are due to electricity: they are the results of secondary phenomena, which almost always accompany them. The latter vary with the locality and the state of the atmosphere.

2. Their general effects are due either to statical or dynamical electricity: most generally they proceed from both.

3. The statical effects are phenomena of attraction and repulsion.

4. The attraction of an electrical cloud is accompanied by a rush of the air towards this cloud, from whence result currents directed from the exterior to the interior, and proceeding from all surrounding points. It is manifested also by the projection of the vapour of water, of liquid water itself, and of bodies that it raises or tears, according to the force with which it acts.

5. The progress of its attractive power is plainly marked both on sea and land. On sea, it appears by the boiling of the waters, and the smoky appearance which is raised from them, as represented in *figs.* 113. and 114. On land its course is rendered manifest by its effects upon the air, the ground, and all loose bodies which it encounters.

6. The attraction of the clouds is also manifest by the greatly increased evaporation of the waters, and the consequent fall of their temperature. The repulsion is manifested by currents of air which issue from the electric cloud, and only exist in its neighbourhood. At a little distance from it a dead calm prevails. These

double currents undergo various modifications, produced by the localities and various qualities of the ground.

7. The repulsion is also manifested by the cone which is formed in the sea, in the very centre of the smoky vapours, an effect which can be easily reproduced experimentally.

8. If an inductive action take place between two clouds charged with opposite electricities, placed at a certain distance asunder, a portion of their vapour will resume the state of common vapour : this will lower the temperature of the neighbouring parts, which may descend even below the freezing point; then the vapour of water crystallises in snowy flakes, which act immediately after their formation, like other light bodies. The portion thus transformed into snow, and which is charged with the electricity of the inferior cloud, is attracted by the superior cloud, then there is a neutralisation of electricity, a fall of temperature, and so on.

9. Finally, the electrical tension of the superior cloud facilitates the evaporation of the liquid which moistens the snowy globule, or which already covers the ice.

The electrified clouds, acting by induction upon the ground, are attracted to it. The clouds thus approach the earth in a greater or less quantity, depending on the energy of the attraction, and their specific gravity.

(238.) When the tension of the clouds and their density differ little from those of the inferior strata of air, or when superior clouds, having the same electricity, act upon the inferior by repulsion, the latter may approach the earth sufficiently to be discharged without explosion by the intervention of other clouds which touch it.

It happens, often, that all the bodies placed upon the surface of the earth under these clouds, which have the form of an inverted cone, serve as conductors in various degrees, according to their constituent matter, their form, their extent, and the magnitude of their contact with the ground. Light and small bodies, oppositely electrified,

are attracted and raised towards the cloud; when their electricity is neutralised they fall again upon the earth, where, being once more charged with electricity, they re-ascend, and so on. It is thus that an immense cloud of dust is formed under the cone. If the bodies are attached to the earth, like trees or buildings, they are instantaneously charged with an immense quantity of electricity. The earth, which is contiguous to them, partakes of this electricity, yields to the attraction of the cloud, and the trees, buildings, or other objects upon it, are torn up and transported afar. It is in this manner that bodies, which are strongly attached to the earth, are torn from it, while others in their immediate neighhood are undisturbed. All these effects are subject to infinite variation, according to the conducting powers of the bodies, and of the parts of the earth to which they are attached.

If the great lightness of the clouds prevents them from falling sufficiently low to be in electrical communication with the ground, then the electricity will be discharged at a distance, attended by the flash of lightning and the roll of thunder. The electric tension will gradually diminish, rain will ensue, and the cloud will rise.

(239.) The sound which sometimes accompanies this phenomenon is attributed, by M. Peltier, to a number of small partial explosions, which take place between the cloud and the ground. They are louder in the case of water-spouts which traverse the land, because of the imperfectness of the conductors presented to them; they lose their intensity over the sea because water is a better conductor.

(240.) Considering the progress of the air under the different attractions and repulsions to which it is submitted, and the contrary and unequal currents encountering different obstacles, M. Peltier endeavours to explain how the direct motion impressed on the air is changed into a gyratory motion more or less decided. It results

from this, that the same meteor may present at different moments an example of direct and gyratory motion.

(241.) When the meteor is presented over water, its inductive action gives the water near the surface an opposite electricity, and a consequent attraction ensues. If the contrary fluids do not unite by explosion, the surface of the water will swell upwards at the several points of attraction, and the moment a discharge takes place, and the contrary fluids unite by explosion, this elevation subsides.

If, however, the electrified cloud is formed with points or prominences, which favour the escape of the electric fluid, the water becomes charged with the fluid descending from the cloud, and being similarly electrified is repelled by the cloud, and therefore depressed. Currents result from this in the water, which soon acquire a vortical motion.

(242.) On similar principles, M. Peltier explains the rapid disappearance of pools or small collections of water, the entire mass being electrified by induction, and raised like trees and other objects.

The discharge of electricity through water may kill the fish contained in it; but the mere transmission of an electric current through the liquid without explosion will not have this effect, unless a considerable elevation of temperature takes place. An electric discharge passing near water, but not through it, may kill animals in it, by the effect of the lateral shock. By these principles, many of the observed effects of water-spouts are explained.

When by induction the electrical tension of the ground and objects upon it is elevated, the fluid with which it becomes charged will have a tendency to escape by all pointed conductors, and to issue upwards towards the cloud. If the conductor be imperfect, an elevation of temperature will attend these upward currents, the effects of which will be apparent in the conductors by which they escape. Trees, plants, and

vegetables, conducting the electric fluid imperfectly by means of their sap, are dried up by this temperature; and when the elevation takes place suddenly, the vapour into which the sap is converted splits the wood.

Such is a general outline of the theory of M. Peltier, by which the phenomena attending water-spouts and whirlwinds are explained.

CHAP. VIII.

FARADAY'S THEORY OF INDUCTION BY CONTIGUOUS PARTICLES.

(243.) Thus far have we been occupied in describing the character and varied developments of electricity of high tension; and, though we are compelled to investigate it as if it were altogether another electricity than that obtained by chemical action, yet we shall soon perceive that these two, and indeed all the forms under which it is manifested, are only varied developments of one and the self-same power. The peculiar features of the form, which we discover by the friction of glass and other bodies, including the stream of steam and water, and the discharge of a thunder-cloud, are its comparatively *small quantity*, and its *great intensity*, or power of overcoming resistance. As an illustration of the former feature, we have the conclusive experiments of Faraday, who was indeed the first to demonstrate the oneness of these apparently distinct developments. The results of his experiments are thus expressed: —

"Hence, as an approximation, and judging from *magnetic force* only at present, it would appear that two wires, one of platina and one of zinc, each one-eighteenth of an inch in diameter, placed five-sixteenths of an inch apart, and immersed to the depth of five-eighths of an inch in acid, consisting of one drop of oil of vitriol and four ounces distilled water, at a temperature about 60°, and connected at the other extremities by a copper wire eighteen feet long and one-eighteenth of an inch thick (being the wire of the galvanometer coils), yield as much electricity in eight beats of my watch, or in 8-150ths of a minute, as the electrical battery charged by thirty turns of the large machine in excellent order. Notwithstanding this apparently enormous disproportion, the results are perfectly in harmony with those effects which are known to be produced by variations in the intensity and quantity of the electric fluid." — § 371.

(244.) He was enabled to institute the above comparison by passing the current from these two minute wires, and that from the charged Leyden battery,

respectively, through a coil of wire surrounding a magnetic needle; that is, through the instrument termed a *galvanometer*, a description of which belongs to another division of our subject. He also compared other effects of the same two quantities of electricity, and obtained a similar result. In fact, startling as it may seem, it is beyond contradiction certain, that the largest charge of the largest Leyden battery does not equal in quantity the electricity which passes between the tongue and a silver spoon, during the simple act of eating an egg. Indeed, if the quantity developed in the latter case were free to assume the form of the electricity obtained from friction, the result would be a lightning-flash of no small power. Indeed, when we find that the mutual action of the zinc and water is on so very minute a scale that no appreciable loss was sustained by either, and that no trace could be detected of the evolution of hydrogen, we are quite prepared to admit the following astounding inference:—

"What an enormous quantity of electricity, therefore, is required for the decomposition of a single grain of water! We have already seen that it must be in quantity sufficient to sustain a platina wire the 104th of an inch in thickness red hot, for three minutes and three quarters; a quantity which is almost infinitely greater than that which could be evolved by the little standard voltaic arrangement to which I have just referred. I have endeavoured to make a comparison by the loss of weight of such a wire in a given time in such an acid, according to a principle and experiment to be immediately described; but the proportion is so high that I am almost afraid to mention it. It would appear that 800,000 such charges of the Leyden battery as I have referred to above, would be necessary to supply electricity sufficient to decompose a single grain of water; or, if I am right, to equal the quantity of electricity which is naturally associated with the elements of that grain of water, endowing them with their mutual chemical affinity."—§ 861.

(245.) It may not seem easy at first to connect these apparently remote effects; for the mind is apt to inquire *how* a quantity of electricity capable, if *free*, of producing effects so exalted, can be packed, as it were, in so small a compass. If philosophy does not go so far as to unfold this, it at least gives us a kind of connecting link: and this link is to be found in the very charge of the battery itself; for the Leyden battery is

an instrument by means of which the repeated charges of the prime conductor, each having power to give a *long spark, i. e.,* to overcome considerable resistance, are accumulated to a great amount—are, in a great measure, converted into—what has been termed *disguised* electricity (230.); and their tension, or *striking distance,* is very considerably reduced. In fact, a succession of *small* quantities of *high* intensity, is converted into a *large* quantity of *low* intensity. Admitting this, we are only called on to go a step further, and consider the elementary parts of matter as, in some sort, each a minute charged system; and we are less astonished at finding that "the chemical action of a grain of water upon four grains of zinc, can evolve electricity equal in quantity to that of a powerful thunder-storm."—FARADAY, § 873.

(246.) But, before we enter into the investigation of the phenomena of voltaic electricity, and trace the various means by which quantities of such comparative magnitude may be obtained, we must give a hasty sketch of the chief results which have presented themselves to Professor Faraday during his recent researches on the electricity of tension.

In the eleventh series of his Researches, read before the Royal Society, Nov. 1837, he enters into the investigation of the phenomena of induction, to which we devoted a chapter in our first volume; and he follows up the subject in the 12th, 13th, and 14th Series, read respectively, Feb. 8th, March 15th, and June 21st, 1838. His first proposition is that induction is not an action from a distance, as assumed by Poisson, Cavendish, and others; but is *an action of contiguous particles: i. e.,* that the effect produced by the charged coating of a jar on the uncharged coating, is brought about by a peculiar molecular arrangement of the particles of glass which intervene; that they are thrown into a species of polarization, having the opposite electricities arranged on their respective sides. This led him to inquire whether matter could be charged with one electric force independently of the other; for, ac-

cording to the theory of molecular polarization, it would appear impossible. That conductors could not thus be *bodily charged* was evident from the whole history of electricity, which reveals the universal arrangement of surcharges on the *surface* of conductors. He proved that the same law holds good with non-conductors, by various experiments, among which was the following: —

"I had a chamber built, being a cube of twelve feet. A slight cubical wooden frame was constructed, and copper wire passed along and across it in various directions, so as to make the sides a large network, and then all was covered in with paper, placed in close connection with the wires, and supplied in every direction with bands of tin-foil, that the whole might be brought into good metallic communication, and rendered a free conductor in every part. This chamber was insulated in the lecture-room of the Royal Institution; a glass tube, about six feet in length, was passed through its side, leaving about four feet within, and two feet on the outside; and through this a wire passed from the large electrical machine to the air within. By working the machine, the air in this chamber could be brought into what is considered a highly electrified state (being, in fact, the same state as that of the air of a room in which a powerful machine is in operation); and, at the same time, the outside of the insulated cube was every where strongly charged. But, putting the chamber in communication with the perfect discharging train* described in a former series, and working the machine so as to bring the air within to its utmost degree of charge, if I quickly cut off the connection with the machine, and, at the same moment, or instantly after, insulated the cube, the air within had not the least power to communicate a further charge to it. If any portion of the air was electrified, as glass or other insulators may be charged, it was accompanied by a corresponding opposite action *within* the cube, the whole effect being merely a case of induction. Every attempt to charge air, bodily and independently, with the least portion of electricity, failed." — § 1173.

"I put a delicate gold-leaf electrometer within the cube, and then charged the whole by an *outside* communication, very strongly, for some time together; but neither during the charge, nor after the discharge, did the electrometer or air within show the least signs of electricity." — § 1174.

(247.) This, and the whole category of electric effects, led him to the following conclusions: —

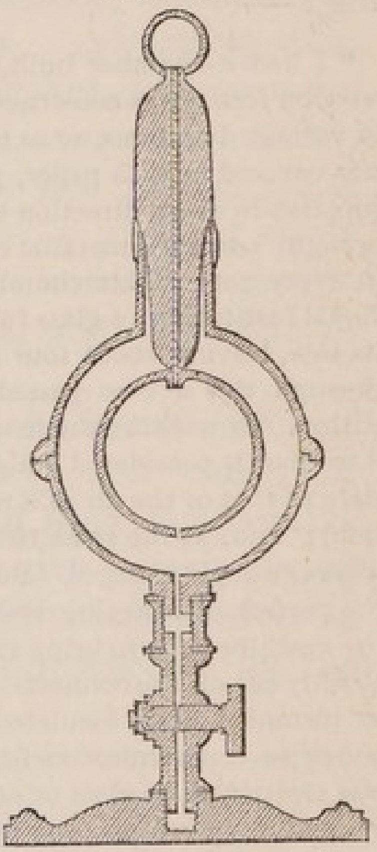
"Bodies cannot be charged absolutely, but only relatively, and by a principle which is the same with that of *induction*. All *charge* is sustained by induction. All phenomena of *intensity* include the principle of induction. All *excitation* is dependent on, or directly related to, induction. All *cur-*

* The gas and water pipes of London.

rents involve previous intensity, and, therefore, previous induction. INDUCTION appears to be the essential function both in the first development and the consequent phenomena of electricity." § 1178.

(248.) Consequent on the fact that induction was the action of *contiguous* particles, was the inquiry whether there was not a difference in the specific inductive capacity of the different insulating media. The instrument employed in this investigation is given, *fig.* 118. It consists of two metallic spheres of unequal diameter, the smaller within the larger, and concentric with it; the interval between the two being the space through which the induction was to occur. The spheres are properly insulated from each other by shell-lac; and the outer one consists of two halves closely fitted, like the Magdeburg hemispheres. The stop-cock and other arrangements are for inserting gases into the interval, as the insulating media. Two instruments were made in order to avoid errors. When solid media were introduced, they were cut into the requisite form. On instituting a series of comparative experiments, and expressing the inductive capacity of air by 1, other specific inductive capacities were found to be —

Fig. 118.



Shell-lac - - - -	1·5
Sulphur - - - -	2·24
Spermaceti - - -	1·3 to 1·6
Oil of turpentine - - -	1
Air (dense, rare, damp, or dry)	1
All gases - - - -	1

(249.) Subsequent experiments* by Mr. Snow Harris

* Phil. Trans., 1842. Part II.

on specific induction, are quite in confirmation of these results; and are the more valuable as they were obtained by means of quite a different mode of investigation. He gives:

Resin - - - - -	1·77
Pitch - - - - -	1·8
Bees' wax - - - -	1·86
Glass - - - - -	1·9
Lac - - - - -	1·95

(250.) From these experiments it is manifest that, though air and the gases are alike in their character, yet between them and solid bodies there are differences which prove, that some media are better than others for exalting the forced state or induction. An evident consequence of these views of induction is, that the thinner the intervening medium, *i. e.* the fewer the particles, which require being thrown into this forced state, the greater the charge or ultimate result. Theoretically, there is no limit of distance to the action. Professor Faraday says:

"I have traced it experimentally from a ball placed in the middle of the large cube formerly described to the sides of the cube six feet distant, and also from the same ball placed in the middle of our large lecture-room to the walls of the room at twenty-six feet distance, the charge sustained upon the ball, in these cases, being solely due to induction through these distances." § 1303. *note.*

(251.) In the course of these inquiries on the phenomena of induction, it further became evident "that the best solid insulators, such as shell-lac, glass, and sulphur, have conductive properties to such an extent that electricity can penetrate them bodily, though always subject to the over-ruling condition of induction;" as, for instance, if a coated plate of glass be charged, and allowed to remain so some time, and then be discharged, an immediate examination will give no evidence of any electricity remaining; but, if it be again examined, after the lapse of a little time, it will appear charged in the same manner, but not in the same *degree*, as before; this effect being due to the return of part of the original

charge, which had penetrated into the glass; and *time* being an element in producing the effect.

(252.) Now, it is well known that a Leyden battery retains a second, and sometimes a third charge, after the original charge has been released; and this effect, which is called the *residual charge*, has been traced by some to the diffusion of electricity over the uncoated surface of the glass; whereas, as appears from Professor Faraday's experiments, it is merely the return of that electricity, which had penetrated beneath the surface of the glass.

(253.) Having considered the effects of induction in cases of *insulation*, he next investigates its influence over *conduction;* and he shows that insulation and conduction are not distinct things, but are the two extremes of the molecular arrangement which induction produces; the one being the condition of those bodies whose particles can retain the polarised state, and the other being the condition of those which cannot. As an illustration that bodies are not *per se* either essentially of the class of insulators or of that of conductors, he instances the discharge of a Leyden jar through a long loop of wire, so bent that two parts, near its extremities, shall approach within a short distance of each other; when, as is well known, by far the larger portion of the electricity will pass in this interval of air. Now, we are in the habit of calling air an insulator, and wire a conductor; but here they evidently change places, proving that their respective properties are only comparative, and that the extension of the conductor gives it the property of an insulator, while the diminution of the insulator gives it the property of a conductor. From these, and other considerations, he is of opinion—

"That insulation and ordinary conduction cannot be properly separated, when we are examining into their nature; that is, into the general law, or laws, under which their phenomena are produced. They appear to me," he adds, "to consist in an action of contiguous particles dependent on the forces developed in electrical excitement; these forces bring the particles into a state of tension or polarity, which constitutes both *induction* and *insulation;* and, being in this state, the continuous particles have a power

or capability of communicating their forces one to the other, by which they are lowered, and discharge occurs. Every body appears to discharge; but the possession of this capability in a *greater or smaller degree*, in different bodies, makes them better or worse conductors, worse or better insulators; and both *induction* and *conduction* appear to be the same in their principle and action, except that in the latter an effect common to both is raised to the highest degree; whereas, in the former, it occurs in the best cases in only an almost insensible quantity." § 1326.

(254.) He then shows how this theory holds good in explaining *disruptive discharge*, or the electric spark, which occurs between two metals, for instance:

"Whilst the induction continues, it is assumed that the particles of the dielectric are in a certain polarised state, the tension of this state rising higher in each particle as the induction is raised to a higher degree, either by approximation of the inducing surfaces, variation of form, increase of the original force, or other means; until at last, the tension of the particles having reached the utmost degree which they can sustain without subversion of the whole arrangement, discharge immediately after takes place." § 1368.

(255.) It is hence very evident that, if any one line of the intervening particles is, from any cause, inferior in sustaining power to the rest, this line will give way first; and, as Professor Faraday shows, "though *all* the particles in the line of induction resist charge, and are associated in their actions so as to give a sum of resisting force, yet when any one is brought up to the overturning point, *all* must give way in the case of a spark between ball and ball."

(256.) As the *distance* between the metals is diminished, there are fewer intervening molecules to oppose the inductive force, and discharge occurs at a lower intensity; again, if the conducting surfaces are *enlarged* with a given charge, the intensity falls; for the inductive action is now diffused over a larger area, any given portion of which possesses a lower amount of force than it did previously. For the same reason, if the conductor is diminished, the inductive action being thus concentrated, the tension or tendency to overcome resistance is proportionately exalted. And hence, when a point is opposed to a charged conductor, the convergence and concentration of *all* the inductive lines on

the point so highly exalts the polarised condition of the extreme particles, that the well-known effects of *discharge* occur. The quantity of electricity required to produce discharge across a *constant* interval of air has been shown by Mr. Harris to be in simple ratio to the density of the air, which is exactly in accordance with the above theory; for instance, when "there are only half the number of dielectric particles in the rarefied atmosphere, so these are brought up to the discharging intensity by half the former quantity of electricity." § 1375. The facility of discharge through a flame or hot air is classed under the head of rarefaction; assisted also by convection arising from the solid particles which are there present.

(257.) The three species of discharge, viz., the *spark*, the *brush*, and the *glow*, are defined, and are shown to be all dependent on the same action.

"The *spark* is consequent upon a discharge or lowering of the polarized inductive state of many dielectric particles, by a particular action of a few of the particles occupying a very small and limited space." § 1406.

"The *brush* is in reality a discharge between a bad or a non-conductor and either a conductor or another non-conductor. Under common circumstances, the brush is a discharge between a conductor and air." § 1434.

"The brush and spark gradually pass into one another. Making a small ball positive by a good electrical machine with a large prime conductor, and approaching a large uninsulated discharging ball towards it, very beautiful variations from the spark to the brush may be obtained." § 1448.

"The form of disruptive discharge, which appears as a *glow*, is very peculiar and beautiful; it seems to depend on a quick and almost continuous charging of the air close to, and in contact with, the conductor." § 1526.

"All the effects show, that the glow is in its nature exactly the same as the luminous part of a brush or ramification, namely, a changing of air; the only difference being, that the glow has a continuous appearance from the constant renewal of the same action in the same place, whereas the ramification is due to a momentary, independent, and intermitting action of the same kind." § 1543.

(258.) It must not be overlooked that in all these forms, it is not the whole charge which causes the discharge, "but merely that small portion of force, which brings the deciding molecule up to its maximum ten-

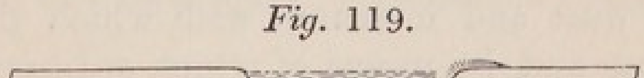
sion;" and that if that small portion alone could pass, the rest of the charge would be inefficient to discharge; but the mere act of a commencing discharge is favourable to itself; and, when once the tottering equilibrium is overthrown, the whole charge pursues a course which it could not otherwise have taken.

(259.) A long series of experiments on the gases led to the conclusion that different gases restrain discharge in very different proportions; and that, in them all, "the different forms of disruptive discharge may be linked together, and gradually traced from one extreme to the other, *i. e.*, from the spark to the glow, or, it may be, to a still further condition, to be called dark discharge;" although each retains a specific character while subject to the general law.

(260.) The *dark discharge* is a curious phenomenon, and we describe it in Professor Faraday's own words:

"Two brass rods, 0·3 of an inch in diameter, entering a glass globe on opposite sides, had their ends brought into contact, and the air about them very much rarefied. A discharge of electricity from the machine was then made through them, and, whilst that was continued, the ends were separated from each other. At the moment of separation a continuous glow came over the end of the negative rod, the positive termination remaining quite dark. As the distance was increased, a purple stream or haze appeared on the end of the positive rod, and proceeded directly outwards towards the negative rod; elongating as the interval was enlarged, but never joining the negative glow, there being always a short dark space between. This space, of about one-sixteenth or one-twentieth of an inch, was apparently invariable in its extent and its position relative to the negative rod; nor did the negative glow vary. Whether the negative end were inductric [actually charged], or inducteous [charged by induction], the same effect was produced. It was strange to see the positive purple haze diminish or lengthen as the ends were separated, and yet this dark space and the negative glow remain unaltered." (*Fig.* 119.) § 1544.

Fig. 119.



"It is quite clear . . . that discharge is taking place across the dark part of the dielectric to an extent quite equal to what occurs in the luminous part. This difference in the result would seem to imply a distinction in the modes by which the two electric forces are brought into equilibrium in the respective parts; and looking upon all the phenomena as giving additional proofs, that it is to the condition of the particles of the dielectric we must refer for the principles of induction and discharge, so it would be of great importance if we could know accurately in what the difference of action in the dark and luminous parts consisted." § 1547.

(261.) In concluding his inquiries on these several forms of discharge, in the course of which he has introduced every modification of experiment that could be of avail, he sums up in the following query:

"Can we not, by a gradual chain of association, carry up discharge from its occurrence in air, through spermaceti and water, to solutions, and then on to chlorides, oxides, and metals, without any essential change in its character; and, at the same time, connecting the insensible conduction of air, through muriatic gas and the dark discharge, with the better conduction of spermaceti, water, and the all but perfect conduction of the metals, associate the phenomena at both extremes? and may it not be, that the retardation and ignition of a wire are effects exactly correspondent in their nature to the retention of charge and spark in air?" § 1561.

(262.) *Convection*, or carrying discharge, is then traced to the same source. As, for instance, if a large electrified body be insulated, and near it a small ball be suspended, the latter is often found to receive by induction a charge of the opposite character; for the inductive action of the hither side of the excited body is in a measure concentrated on the inner side of the small ball, and that portion of it which acts on the ball is exalted, by the mere fact of the ball being there as a limit to the dimensions of the interposed opposing dielectric; and hence the extreme side of the ball is charged to an extent exceeding that of any portion of the greater body, and often to a degree that it discharges to the air, and so becomes oppositely charged to the original body. Under these circumstances, if properly mobile, it is free to approach the exciting body; and, in so doing, becomes similarly charged, and is repelled towards that conductor most favourable to its discharge; and thus represents the floating movable particles of dust and moisture, with which the atmosphere teems, and by means of which ordinary charges are so reduced.

(263.) This theory of contiguous particles involves the consideration of the effect which a vacuum would produce; and, though no perfect vacuum can be obtained for experiment, (indeed, if it could, the solid material bounding it would interfere with the results,) yet the assumption of a vacuum does not appear to

militate against the views here advanced. In illustration of this, Professor Faraday says:

"But assuming that a perfect vacuum were to intervene in the course of the lines of inductive action, it does not follow from this theory that the particles on opposite sides of such a vacuum could not act on each other. Suppose it possible for a positively electrified particle to be in the centre of a vacuum an inch in diameter, nothing in my present views forbids that the particle should act at the distance of half an inch on all the particles forming the inner superficies of the bounding sphere, and with a force consistent with the well-known law of the squares of the distance. But, suppose the sphere of an inch were full of insulating matter, the electrified particle would not then, according to my notion, act directly on the distant particles, but on those in immediate association with it, employing *all* its power in polarizing them; producing in them negative force equal in amount to its own positive force, and directed towards the latter, and positive force of equal amount directed outwards, and acting in the same manner upon the layer of particles next in succession. So that, ultimately, those particles in the surface of a sphere of half an inch radius, which were acted on *directly* when that sphere was a vacuum, will now be acted on *indirectly* as respects the central particle or source of action, *i. e.*, they will be polarised in the same way, and with the same amount of force." § 1616.

(264.) In this very limited sketch of the theory of induction, our object has been to extract the leading features, and point out how actions, apparently so much at variance, may be traced to the self-same law. It will appear from these considerations that the terms *free* and *disguised* electricity, which have been so enlisted into the language of electricians, are misapplied if they are used to designate any difference in the mode or kind of action; for, as Mr. Faraday says:

"When sometimes we make electricity appear where it was not evident before, as upon the outside of a charged jar, when, after insulating it, we touch the inner coating, it is only because we divert more or less of the inductive force from one direction into another; for not the slightest charge is, in such circumstances, impressed upon the character or action of the force." § 1684.

Or, as he elsewhere expresses it:*

"There is no state of static electric force corresponding to the terms of *simulated* or *disguised* or *latent* electricity away from the ordinary principle of inductive action; nor is there any case where the electricity is *more latent* or *more disguised* than when it exists upon the charged conductor of an electrical machine, and is ready to give a powerful spark to any body brought near it."

* Phil. Mag., vol. xxii. p. 203.

(265.) In the course of these researches it was shown that:

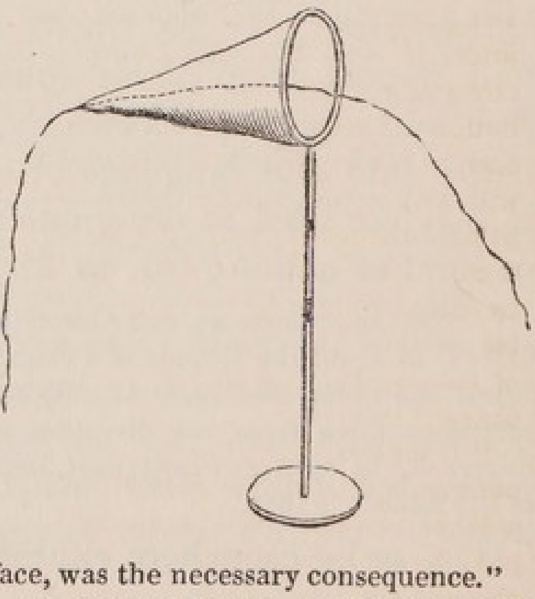
"All charge of conductors is on their surface, because, being essentially inductive, it is there only that the medium capable of sustaining the necessary inductive state begins. If the conductors are hollow, and contain air or any other dielectric, still no *charge* can appear upon that internal surface, because the dielectric there cannot assume the polarized state throughout, in consequence of the opposing actions in different directions." § 1301.

Some very good illustrations of this superficial arrangement of the charge have been given in some of his recent lectures:

"A cylinder of wire-gauze was placed on an insulating stand; a small charge of electricity was communicated to its inner surface, by means of a carrier-ball: a Coulomb's proof plane was now applied to abstract a portion of the charge for testing; the beauty of the experiment consists in this, that no charge can be taken from the inside; that, although there is free and open access between the respective sides, and although the rate at which electricity moves is such as almost to annihilate distances, yet the power of induction is such that it more than counterbalances every other tendency, and retains the charge on the outer surface of the body.

"This permanent residence of a charge on the external surface, without regard to the individual elements of which this surface is made up, was happily illustrated by the following means: An insulating staff (*fig.* 120.), sustained a conical muslin bag, which was stiff enough to preserve its form; the cone was in an horizontal position: when a charge was conveyed to the bag, by means of a carrier-ball, the electricity arranged itself on the outer surface of the cone; the cone was now drawn inside-out by means of a silk thread, so that the surface of muslin, which then formed the inner, now formed the outer superficies. The immediate passage of the charge from one surface of the muslin to the other, in order still to be on the outer surface, was the necessary consequence."

Fig. 120.



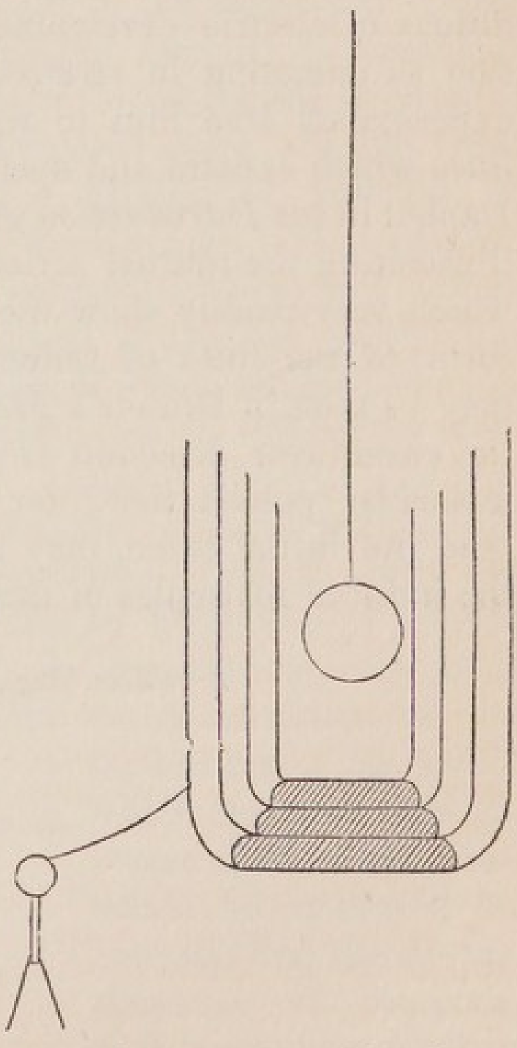
"Again, an ice-pail, standing on an insulating metal-stand was charged, and the electricity was immediately arranged on its outer surface; a series of brass columns, taller than the ice-pail, were placed around it on the metal plane: under these circumstances no electricity could be gathered by the carrier, except from some outer surface of one of these columns; but, when the pail was raised by means of a silk thread (a chain still retaining it in metallic connection), and its upper edge brought above the height of the columns, this edge immediately contained a portion of

the charge, but lost it again, on being depressed below the height of the apex of the columns."*

(266.) Carrying out the same views of induction†, he, in some degree, satisfies the mind as to the effect of the aggregation of isolated electrized particles, such as the vesicles of a cloud may be.

" An ice-pail is insulated and connected with an electroscope: if an electrized carrier-ball is suspended within, the divergence of the gold leaves is equal in amount, whether it is made to act by induction on the metal of the pail, or to communicate its charge to it; whether it is held concentric or eccentric, near the surface or near the bottom. Again, if several pails be placed one within the other, [each] resting on isolating plates of shell-lac, as in *fig.* 121., the action is the same as with one pail; and, whether the charge be in the carrier-ball, or be transferred in succession from one to another of the series of pails, the divergence is the same. Nor is any alteration produced by introducing thick vessels of shell-lac or sulphur between the pails. And further: if, in place of one carrier, several be suspended in either of these systems, each acts independently of the other, [and independently of any charge which one or other of the pails may possess,] and the effect of their united forces is obtained; and whatever changes may be made in the distribution of these respective charges, such as discharging one by contact with either pail, still the same ultimate amount of force is displayed. Similar phenomena are produced by suspending excited pieces of lac within the vessels; except, of course, that they cannot be discharged by contact.

Fig. 121.



" It follows, from the above experiments, that if the space within a large metallic globe were occupied by myriads of charged vesicles or particles, each insulated from its neighbour, the outsides of the globe would be charged by induction with a force equal to the *sum* of all their forces, and would give as long a spark as if the charges themselves were all congregated on the surface of the globe. The link by

* Elec. Mag., vol. i. p. 71.

† Phil. Mag., vol, xxii. p. 200.

which such a globe is connected with a charged cloud, is readily seen; and hence," as Mr. Faraday concludes, "when a charged cloud is over the earth, although its electricity may be diffused over every one of its particles, and no important part of the *inductive* charge be accumulated upon its under surface, yet the induction upon the earth will be as strong as if all that portion of force, which is directed toward the earth, *were* on that surface.'" *

(267.) We leave our readers to trace out, in the mathematical inquiries, which we have given elsewhere, how much in conformity are the results obtained by means so dissimilar. Though we have not had space to give a lengthened detail, the present chapter must not be closed without mention being made that Epirus, Cavendish, Poisson, and others, who have applied mathematical analyses to the elucidation of the several conditions of electric development, have considered induction as operating in *straight* lines; whereas Faraday's experiments lead him to regard it as acting in *curved* lines which expand and open out from each other. Mr. Daniell in his *Introduction* gives two excellent diagrams, illustrating the mutual action of contiguous molecules, which very readily show the rationale of the curvilinear form of the lines of induction. The same diagrams may be seen in Brande's *Manual*. In them we see that the curvilinear direction is a necessary consequence of molecular polarization; for bodies which do not subtend the initial force, may be exposed to the action of the induced molecules of the dielectric.

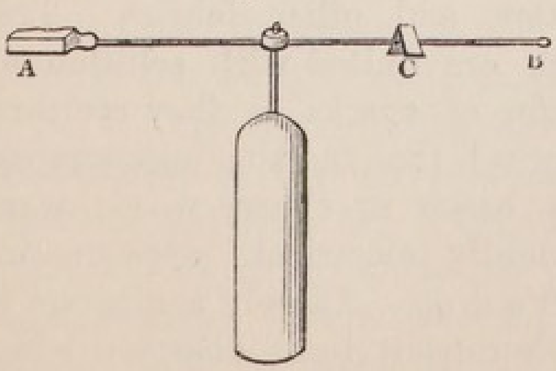
* Elec. Mag., vol. i. p. 66.

CHAP. IX.

SUPPLEMENTARY MEMORANDA.

(268.) We cannot conclude static electricity without adding a few notes on certain phenomena which have not found a place elsewhere. So far as we have yet been able to trace the origin of the power on which we have been engaged, it seems that friction is the influential cause. It has been shown in the passage of the glass along the rubber, and in the passage of the watery particles along the tube of the steam-jet. Other modes of friction, as the forcing mercury by means of a vacuum through the pores of wood, or the driving of air by the ordinary bellows against glass, are but fresh illustrations. So also is the driving of powders of various bodies against the electroscope. But friction seems to be reducible into *renewals of pressure*. Now pressure is another recognised source of electricity. Œpinus found that two plates of glass, which had been pressed together without friction, were differently electrified, on being separated. Isolated discs of silver or copper pressed against a cushion, covered with elastic resin, acquire negative electricity. Iceland spar, and other minerals, become electric by being merely pressed with the fingers. Indeed, it was the observation of this fact which led Haüy to the construction of the instrument (*fig.* 122.), which he terms his *vitreous* electroscope, and which he employed for investigating the electric character of minerals. A B is a needle of silver or brass, having at one end a piece of Iceland spar A; and on the other arm a counterpoise, C. By

Fig. 122.



pressing A with the thumb and finger, the needle, which is insulated by an agate-cup, becomes positively charged. This property is not peculiar to the bodies above named, but appertains to all. When cork and caoutchouc are pressed, the former becomes positive, the latter negative. The vitreous crystalline minerals become positive, when pressed against cork. Fruits, as the orange, pressed against cork, become negative. The conductibility of the bodies, the rapidity of the separation, and the temperature, are all influential in modifying the action. Slow separation produces much less electricity than quick separation. The electricity developed is generally in direct proportion to the pressure, at least up to a certain point. To this source may be traced the light which occurs when two blocks of ice come into contact; and perhaps, also, the familiar case of a spark from the forcible contact and quick separation of the flint and steel.

(269.) In these cases, the *disturbance* of electric equilibrium is caused by the act of *pressure*. The *indication* of the disturbance is obtained by *separation*. The act of contact does not so much disturb the electric equilibrium of the two bodies as *a whole;* but it disturbs that of *each as a portion of a whole*. This leads to the description of those cases in which bodies in a normal state when *whole*, develop electricity when *divided*. Mica, rapidly split, shows a phosphorescent light in the dark; so does the topaz, feldspar, and other crystalline bodies, which are bad conductors. A sheet of very dry paper, when rapidly torn, develops electricity; so does cotton and other fabrics. The waterproof fabrics, which are united with solution of caoutchouc, exhibit a train of sparks as they are torn apart. Mr. Wilson observed that the shavings scraped by glass from very dry beech or cherry wood, were electrical. Light, evidently electrical, appears on breaking a Prince Rupert's drop. Closely analogous to these effects is the phosphorescent light observed when lumps of refined sugar are handled in the dark. Pow-

ders of various bodies acquire the one or the other electricity, when sifted on the plate of the electroscope. This phenomenon is due to the contact or friction on the metal: but there is another series of effects produced, by allowing powders as they fall, fresh-ground from the mill, to be received on insulating discs: under these circumstances, an accumulation of electricity is obtained, which appears mainly due to the separation of the body. We have seen Dr. Faraday explode gunpowder on the lecture table, by a spark thus obtained from very dry coffee. Sulphur, sealing-wax, rosin, and wax have been found electrical when *solid*, if removed from a vessel into which they had been poured when *fluid*; this effect has been traced to friction, for it does not appear to have occurred when they were melted in the vessels, and then allowed to cool.

(270.) *Pyro-electricity* has been applied to that development occurring, on applying heat to certain minerals, of which the tourmaline is the chief. This mineral assumes the form of a rhomboidal prism with one axis, and acquires electrical polarity on the application of heat. In this list are borate of magnesia, a cubical crystal with three axes — topaz, axinite, mesotype, prehnite, calamine, spheene, scholezite, and many other crystals, both natural and artificial: among the latter may be mentioned oxalate of lime, which Mr. Faraday discovered to become so strongly electrical at 300° Fahr., that, when it was stirred with a platinum spatula, it would not be collected; for, whenever it was moved from the sides of the evaporating dish, it flew about it and away from it to the sand-bath.

(271.) An opportunity has not elsewhere occurred of alluding to the extraordinary conducting power of vegetable points. Mr. Pine has noticed that the distance at which a blade of grass, compared with a metallic point, will become luminous, by discharging a prime conductor, is as 14 to 3 or 4. The same is true of the spines on thorns and gooseberry bushes, and also

of the extremities of vegetable buds generally. This action of vegetable points, connected with their unlimited distribution over that portion of the organised creation, conjoined also with observation from other sources, evinces the great influence of electricity over vegetation. As a case in point, the following is given by Mr. Pine: —

"A medical electrician, residing at Maidstone, whose powerful machine was in frequent action during the day, assures me of the following facts: — A narcissus plant, which from previous neglect was in a languishing state, having been placed in his laboratory, soon began to exhibit signs of extraordinary vigour: it grew to the height of about 36 inches, or about *thrice* its ordinary dimensions; flowers retained their colours while the seeds were forming, and at last dropped off without assuming a withered appearance; a Turk's cap lily drooped during the hours of the night, and resumed its vigour with the returning action of the machine."*

This branch of electricity is still open to research. Of earlier writers Nollet was in favour of electrical horticulture; but Igenhouz was against it. Van Marum, Nairne, and others, have experimented on the subject; but no very conclusive results have been obtained.

(272.) While alluding to atmospheric electricity, we take the opportunity of mentioning that other means besides points have been resorted to for collecting it from the atmosphere. Mr. Crosse suspended a very considerable length of wire from tree to tree on his estate; and he only reduced it on account of the depredations to which he was subjected. Mr. Weekes has described a similar arrangement, consisting of a copper wire 365 yards long, suspended between two steeples in the town of Sandwich, and properly insulated. Such an arrangement, under favourable circumstances, is a most extensive source of electricity: —

"When the gathering storm-cloud lingers over the line of wire, tremendous torrents of electric matter, assuming the form of dense sparks, and possessing most astonishing intensity, rush from the terminus of the instrument with loud cracking reports, resembling in general effect the well-known running fire occasioned by the vehement discharge of a multiplicity of small fire-arms. Fluids are rapidly decomposed; metals are brilliantly

* Proceed. Elec. Soc., p. 164.

deflagrated; and large amounts of coated surface repeatedly charged and discharged in the space of a few seconds. When these phenomena obtain, incidental to the hours of darkness, the lightning-flash is seen harmlessly to play in various zig-zag and fantastic shapes, amidst the several contrivances by means of which its power is subdued; thus augmenting the sublimity of a scene, compared to the correct delineation of which, the efforts of language are but imbecile. Again, relinquishing its claims to the terrific and sublime, for features of a more gentle complexion, even the light and feathery aggregations of the summer cloud are found capable of imparting to a pair of delicate gold-leaf pendulums, a test, by which the philosopher assigns a character to inaccessible regions of the atmosphere." *

(273.) In describing the conditions of Leyden charge (232, 233.), it was evident that one or other coating always possesses an excess of charge. As this is a phenomenon of peculiar importance in theoretic investigations, inasmuch as it tends greatly towards discovering the source of the spark, which the outer coating of a system imparts during discharge to other bodies not concerned in the discharge, I prefer adverting to it in the language of authority; and with this view quote Dr. Roget †: —

"It is evident that the quantity of fluid driven out of the lower plate by the action of the fluid in the upper one, can never be quite equal to that of the fluid with which the upper one is itself charged, and the difference will be greater in proportion to the distance of the plates. When they are very close to each other, these quantities approach very near to an equality; and this circumstance it was that misled Franklin into the belief that they were equal."

Considerable light has been thrown on the influence of this state of things by Dr. Riess. ‡ In the course of some investigations on the *striking distance* of a Leyden discharge, he obtained the following generalisations: —

"*The striking distance of the electric battery is entirely independent of the nature of the arc of junction.*

"*The quantity of electricity that disappears during the discharge of the battery at the same striking distance, is sensibly the same whether the wires, with which the circuit is formed, are good or bad conductors.*

"When the battery is discharged by means of a metallic circuit by approaching two balls to each other, *eleven-thirteenths of the total charge disappears when the balls are placed at the striking distance.*"

This fraction, $\frac{11}{13}$, is of course the representation of

* Proceed. Elec. Soc., p. 47.

† Lib. Use. Know. — Electricity, p. 32.

‡ Ann. der Phys. und Chem., No. 5. 1841. Vol. liii.

the particular case before him, and is true of the battery employed, varying for other thicknesses of glass. The $\frac{2}{13}$ remaining behind is termed "the residual charge." Before investigating the influence of this residual, it will be well to explain the state of things during the process of charge; and this is best done in the words of Dr. Riess.

"An electrical battery is in the state of *perfect charge*, when its two coatings contain electricity of the opposite characters, in quantities bearing to each other a determinate ratio, which depends on the thickness and nature of the glass of which the bottles are made. During the *gradual* phenomenon of charge or discharge, this relation is the same at each moment, and the battery passes by on increasing or decreasing series of charges, different in force, but always *equally perfect*; and for each of which there exists a striking distance proportional to the quantity of electricity accumulated. Things are in a different state at the moment when discharge takes place through the circuit. Whilst the electricity passes from the interior to the exterior coating (of which latter the arc of junction must be considered as the prolongation), there *disappears by each of these coatings the same quantity of electricity*; the *relation* between the two quantities of electricity which they contain, cannot, under these circumstances, exist, and the battery thus passes to the condition of *imperfect charge*, which approaches to that on *insulated electrized surface*. But, the apparatus being necessarily supported by foreign bodies, a *change takes place* in its electrical condition during the discharge, inasmuch as the exterior coating *takes from the foreign bodies* the electricity which it requires to re-establish the relation."

These relations may be better understood by an hypothetical case, which I have thus expressed in a paper of mine on the "Difference between Leyden Discharges and Lightning Flashes*:"—

"Let us suppose the ratio between the charge of the two coatings of a given jar to be as 10 : 9, and that 100 of Mr. Harris's units† are thrown on the inner coating; 90, therefore, of such units will be driven off from the outside. Now let the jar be insulated; and it is very evident that the capacity of the outer coating is equivalent to, or it has an attraction for, 90 units: if it is touched by the discharging rod, the upper arm of which being afterwards slowly brought to striking distance of the knob, 90 units may pass, and 10 remain behind: but the presence of this 10 in the interior, will instantly operate in *disturbing the new-created normal condition of the exterior*, and the outer coating will possess 9 *units of free electricity*—electricity possessing the same character as that of the original charge."

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* Proceed. Elec. Soc., p. 484.
† Charges measured by a small jar termed a "Unit-jar."

The jar, under such circumstances, is in a state of *imperfect charge;* and it only acquires the state of *perfect* charge, when the free electricity has been neutralised by communication with conducting bodies. From the conditions which give rise to this free electricity, I have termed it the "induced residual;" and have calculated its value under various relations. I find that if n A represents the charge of the inner coating, A that of the outer, and ϕ the portion constituting the discharge, the "induced residual" will be $(1-\frac{1}{n})\ \phi$. This equation represents the excess of electricity *over and above* what is needed to restore the normal condition of the jar. The whole phenomena bears greatly on lightning discharges; for what is true of the one, is true of the other. Without entering on the extensive bearings of the case, it will suffice to conclude the present chapter with an extract in which I trace out the enormous value of the induced residual of a lightning discharge: —

"An inspection of the equation representing the value of the residual, will show that its amount is great in proportion to the *original excess*, and great in proportion to the quantity constituting *the discharge;* for the value of the co-efficient, $1-\frac{1}{n}$, is great in proportion to the value of the ratio, n; and of ϕ, which represents the discharge itself. Now, I have already given good reasons for believing that n, in reference to a cloud, is very great*; and, therefore, under every circumstance of the discharge, the *co-efficient* will be great. But ϕ is also great; . . . If we connect these considerations with the fact, that a flash of lightning (ϕ) at all times contains an immense amount of electricity, and that n, or the ratio, is always very great, we cannot but perceive that there will be *an immense quantity of free electricity consequent on a lightning flash*."

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* Chiefly on account of the great distance between the coatings, *i. e.* between the cloud and the earth.

BOOK THE THIRD.

VOLTAIC ELECTRICITY.

CHAPTER I.

THEORIES OF VOLTAIC ELECTRICITY.

I. *Contact Theory.*

(274.) When two different metals are brought into contact, it was maintained by Volta that electricity is evolved at their common surface by the decomposition of their natural electricities, the two fluids moving from that surface in opposite directions, the positive fluid being diffused over one metal, and the negative fluid over the other. Thus, if A and B (*fig.* 123.) be two cylinders of different metals, placed in contact at their ends S, then the natural fluid will be decomposed at S, the positive fluid being diffused over B, and the negative fluid over A. This is the fundamental fact of the theory of Volta.

Fig. 123.

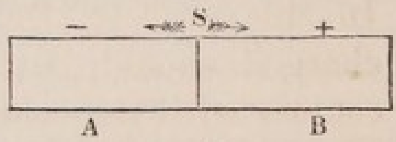
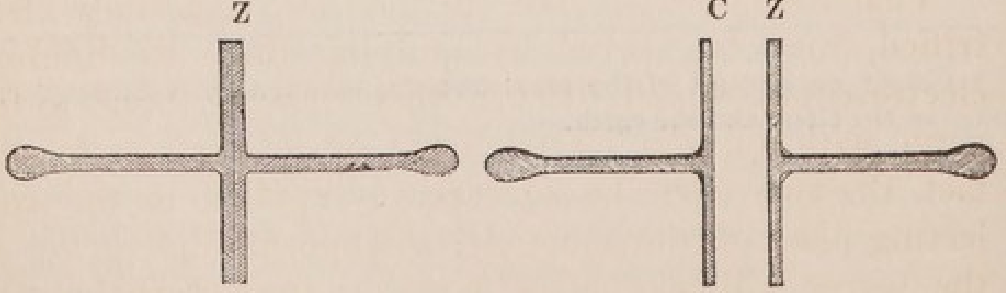


Fig. 124.



The manner in which Volta established this basis of his theory was as follows: Let two discs, C and Z (*fig.* 124.), of different metals — suppose, for example, copper and zinc, — about three inches in diameter, with

perfectly plane surfaces not varnished, and having insulating handles attached to their centres, perpendicular to their surfaces, be provided. Holding them by the insulating handles, let them be brought into contact, and separated, care being taken to move the discs towards and from each other, in a direction exactly perpendicular to their faces, so that no friction shall take place in making or breaking the contact. This being accomplished, the disc Z will be charged with positive, and the disc C with negative, electricity, after the contact. These charges will, however, be too feeble to be rendered directly manifest by the electroscope; but, if either of the discs be applied to the collecting plate of a condensing electroscope, and being afterwards, a second time, brought into contact with the other disc, and then presented again to the collecting plate, and a similar process be continued, the leaves of the electroscope will begin to diverge when they have received the accumulated charge proceeding from a sufficient number of contacts of the discs Z and C. In this process, the disc by which the electroscope is charged should be touched by the finger, before each contact with the other disc, to reduce it to its natural state. After seven or eight contacts, conducted in this manner, a strong charge will be accumulated in the collecting plate of the electroscope; and, on removing the condensing plate, a considerable divergence of the leaves will take place.

That the two discs are, in this case, oppositely electrified, may be proved by applying them to different electroscopes, which will, in that case, be found to diverge with opposite electricities; or if, after each contact, the two discs be successively applied to the collecting plate of the same electroscope, no divergence of the leaves will take place, however numerous the contacts may have been; proving, that the electricity of the one disc has neutralised that of the other.

(275.) The experiment may also be performed in the following manner. Instead of putting one of the

plates of the condenser in communication with the ground, let it be put in communication with the leaves of a second electroscope; and let the disc Z be presented to one plate of the condenser, and the disc C to the other, after each contact, so that the plates of the condenser may receive after such contact the electric charges of the discs respectively. So long as the plates of the condenser are held in contact, these electric charges will be dissimulated, and the electroscopes will not be affected; but when the plates are separated, the fluids will be free to diffuse themselves upon the leaves of the electroscopes, and divergence will immediately ensue. That they are charged with contrary electricities may be proved, by putting the knobs of the two electroscopes in metallic communication; the leaves of both will in that case instantly collapse, the contrary fluids neutralising each other.

(276.) These experiments of Volta's, too faithfully reported in the generality of treatises on galvanism, to the exclusion of others which equally occurred to that philosopher, have been the fertile source of a controversy that has pervaded the arena of electricity from the first promulgation of the fact to the very moment when these observations are being written; indeed, the difference of opinion between the advocates of the "contact," and those of the "chemical" theory, seems fully as great, perhaps greater now, than ever. Could the shade of Volta arise, it would be somewhat surprising to find a fact like this, so associated with the inference he deduced from it, as to have become the rallying point round which a goodly group, calling themselves his disciples, are wont to gather.

The disc experiment, with the effects of the contact of dissimilar metals, is correctly enough described; but it would seem, from the very great importance attached to it, that Volta had either not succeeded in producing electric development, except by the contact of dissimilar metals; or if he had, that he had so thoroughly investigated the matter, as to have found

reason to exclude all else than metallic contact from the theory he laid down.

(277.) That Volta considered the electric effects he obtained as entirely due to contact, and not at all due to chemical action, is abundantly evident from the very title of his letter* to Sir Joseph Banks, — "*On the Electricity excited by the* MERE CONTACT *of conducting substances of different kinds.*" But he was far from confining himself to the contact of metals: even in the very commencing paragraph of his letter he writes of

"Electricity excited by the simple mutual contact of metals of different kinds, and even by *that of other conductors, also differing from each other, whether they be liquid, or containing a certain degree of moisture to which they properly owe their conducting power.*"

If, indeed, we reflect on the matter, it would seem scarcely possible for a philosopher, in the very infancy of a discovery, so far to have carried out a theoretical investigation, as to have attained to such an extreme generalisation, as the annunciation of *metallic contact only* would imply. He had not the means of obtaining such a generalisation; nor, had he the means, would it have been possible for him to have advanced from the foundation stone to the perfect edifice thus suddenly. Such an occurrence would have been almost unprecedented in the history of the sciences. Look, for example, at what has just occurred amongst us in regard to the cause of the electricity of high pressure steam (313—344). From the first experiments of Mr. Armstrong, to the recent researches of Faraday, three or four causes had been assigned; and the minds of those engaged in the experiments were evidently oscillating between this view and that, with the consciousness that they had not yet discovered a sure resting point — they could see the truth dimly at a distance, but could not attain to it. Contradictory effects perpetually rose like clouds before their eager vision, and darkened the prospect which sometimes seemed opening before them. And this was exactly the case with

* Phil. Trans. 1800, Pt. ii. p. 403.

Volta: he saw the analogy between the effects of electricity, and those phenomena observed by Galvani on the muscles of recently killed frogs; and of these effects he thus writes to the editor of the Philosophical and Medical Journal of Leipsic*: —

"At the commencement of the spring of the present year (1793), my attention was particularly directed to electricity, on account of the truly admirable phenomena which the celebrated Galvani, Professor at Bologna, has discovered and described. By these phenomena, he seems to have demonstrated, that there constantly exists, in animals of each species, an electricity of some kind, spontaneously excited by the vital force inherent in the organ, and by the animals themselves; or rather that the electric fluid, when the equilibrium is naturally destroyed, no longer resides in the nerves; but exists in some combined movement, or in the effort it makes to establish itself in some part of the animal, according as it is more or less abundant. . . . . It has not, I say, been ascertained whether these movements and contractions, which, no one can doubt, are to be ascribed to the electric fluid, conveyed from one part to another by the means of a conducting arc, take place because that fluid directs itself by its own energy, or, on the other hand, by the simple force of the organs of the animal towards such or such a part. In the latter case, it may be denominated a true electricity inherent in the animal, as it is asserted by Galvani. Or, again, whether this sometimes happens, as I think I have seen in several instances, because the *metals* employed in the experiments being directly applied to the parts of the animal replete with juices, are enabled, *by themselves*, and *by their own proper virtue*, to *stir*, *excite*, and expel the electric fluid, which was in a state of repose, so as that the organs of the animal merely act passively."

We can very readily imagine Volta following out this his incipient idea of the influence of the contact of dissimilar metals; and we see his faith in its universality greatly shaken by the contradictory effects which would not fail of presenting themselves. Indeed, if nothing beyond the simple fact of electric effects following the contact of the *same* metal with *different* liquids† had occurred, that alone would have added a clause to his theory which would at once detract from its generality. But, without enlarging on the mere consequence of actual facts, it will be best to make a few further extracts from the same letter; and, though

* Wilkinson's Galvanism, vol. i. p. 93.

† Mr. Martens gets over this difficulty by considering the part of the metal in the liquid, and that out, as *two* metals.

we shall see in them expressions almost in direct contradiction of each other, we shall see nothing beyond that which might be anticipated ; viz., illustrations of a mind enriched with the possession of new facts, and labouring to enrol them under some general law ; — labouring, too, not along a smooth and direct path, but along a road wherein obstacles arise at every step.

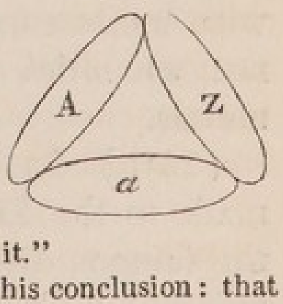
(*a*) " Some time ago, I had occasion to demonstrate, by indubitable experiments, that metallic substances, and charcoal of a good quality, are not only the most perfect conductors of electricity, but even become *exciters by the means of simple contact*. It was already known that metals and charcoal possess the property of transmitting electricity very readily, wherever it is excited ; or, in other words, when it endeavours to re-establish the equilibrium it has lost. But I was afterwards enabled to make the discovery, that the equilibrium of the electric fluid can be destroyed, and *a new electricity created by those substances*. It is in reality by *themselves*, and by their *own virtue*, so far as they act by impelling and forcing the electric fluid to enter into the superficies they touch, or to flow out from thence, that metals and charcoal excite that feeble electricity, which can in no way be discovered by the common electrometers, however carefully they may be made ; but which possesses at the same time a sufficient energy to convulse the nervous fibres and the muscles it encounters, without any friction or other mean, provided these substances be duly applied to water, or to bodies which have imbibed an aqueous humour, such as the nerves and muscles of animals, either living or recently killed."

(*b*) " The *contact* of different conductors, particularly the metallic, including pyrites and other minerals, as well as charcoal, which I call dry conductors, or of the *first class*, with moist conductors, or conductors of the *second class*, agitates or disturbs the electric fluid, or gives it a certain impulse.".......

(*c*) " It is therefore absolutely necessary that two different metals, or conductors of the first class, should be in *immediate contact* with each other, on the one side, while, with their opposite ends, they touch conductors of the second class."....

(*d*) " In *fig.* 125., instead of admitting two different actions, at least, in regard to the magnitude of the power, one where A comes in contact with *a*, and another where Z comes in contact with A also, by which an electric current arises in the direction from Z to A, we might *suppose* only one action at the point where A comes in contact with Z, which impels the fluid in that direction. In *both suppositions*, the result, as may easily be seen, is the same. But though I have reasons for adopting *the first as true rather than the second*, yet the latter represents the proposition with more simplicity, and it may be convenient to adhere to it in the explanation, as it affords a readier view of it."

Fig. 125.



(*e*) " It will be sufficient, for the present, to draw this conclusion: that

in a circle consisting of merely two conductors, however different they may be, their mutual contact can produce no electric stream sufficient to excite sensibility or muscular movement; and that, on the contrary, this effect infallibly follows as often as the chain is formed of three conductors, one of one class, and two different from each other of another class, which come into mutual contact," &c.

(*f*) "The other method of combination, or that of *a metal* placed between *two different moist conductors*, for example, between water on the one side, and an aqueous, saponaceous, or saline fluid on the other, I discovered in the autumn of 1794, . . . and, though I wrote to several correspondents respecting it, that light has not yet been thrown on this new phenomenon, which it seems to deserve."

(*g*) "Some new facts, lately discovered, seem to show that the immediate cause which excites the electric fluid and puts it in motion, whether it be an attractive or repulsive power, is to be ascribed much *rather* to the mutual contact of *two different metals*, than to their contact with *moist conductors*. But though it cannot be denied that in the latter case *there exists an action*, it is proved that it exerts itself in a far more considerable degree when the two metals mutually touch each other. . . . . Though, according to every circumstance, we must admit *some action* of this kind in the *latter contact*, it cannot be denied that the *former* is certainly the most effectual."

(278.) We have marked with italics the passages to which we desire to direct attention. A glance will show the unstable position in which Volta *felt* that any generalising theory he might be disposed to adapt was placed.

In the first extract (*a*), the contact theory, so far as *metals* are concerned, is propounded; in the next (*b* and *c*), the contact of metals with *liquids* is included; in the following (*d*), he seems to think that the contact of the respective metals with the liquid is most likely the exciting cause, but the mere metallic contact is the more simple view of the case; he then (*e* and *f*) alludes to circles of *one* metal and *two* liquids, the explanation of which appears to him buried in mystery; and he finally (*g*) confesses that the contact of metals with moist conductors does produce *some* action, though not *so much* as the mutual contact of dissimilar metals.

(279.) In a communication, subsequently (1801) made to the French National Institute, Volta describes the famous disc experiment (274.); but still retains the opinions he had formerly advanced: he says,—

"The action by which the fluid is excited and put in motion is not produced, as has been falsely supposed, on the contact of the humid substance with the metal, or, *granting this to be the case in a certain degree*, it is unworthy of consideration when *compared* with the action that ensues, as my experiments have fully proved, on the *contact* being established between *different metals*."

And he says, in the next breath, that his pile

"Consists in the simple metallic pair of plates, composed of two different metals, and not, as a great number of philosophers have supposed, in a humid substance applied to a metallic substance, or comprised between two different metals."

(280.) And the only use he chooses to assign to the moisture, is to "establish a reciprocal communication between the metallic pairs of plates;" and, when he adds to the water any ingredient, the effect of which is to increase the electric action, he considered the exaltation was due to the superior conducting power then produced in the water.

In regarding the liquid *merely as a conductor*, he could not fail to reflect whether its place might not be supplied by some solid substance; and he expresses his idea in the following very natural query: —

"Would it not suffice for this purpose to find a solid conductor, either deprived of every force of impulsion, or possessing it in any other point of view, except in the one I have cited, which should be made to supply the place of the humid conductors, between the common pairs of plates of diverse metals?"

(281.) Conceiving, as he does, that the contact of metal with liquid produces an electrical effect to so inconsiderable an amount, he theorises as to whether this effect might not be exalted by the contact of liquid with liquid. He thinks he detects a case in point in the organ of the torpedo; and he imagines a *third* class of bodies, neither metals nor liquids, which are both conductors and *motors*, consisting of "substances drawn from a humour, which, as it coagulates and becomes fixed in a degree imperceptible to our senses, cannot with propriety be denominated a humid substance." And he conceives the electric organ of the torpedo to be a battery, consisting of two heterogeneous substances of the third class, and one of the second.

(282.) In the report of the commission, appointed by the Institute, drawn up by M. Biot, it is recognised that the development of the electric fluid in the disc experiment is independent of any humid conductor; that there is an analogous action between other substances; and, though it may be weak between fluids and metallic substances, there are still several of the former, such as the alkaline sulphurets, which, when combined with the metals, have a very sensible action.

The theory then of Volta is that *contact generally*, but of metals *especially*, produces electricity; but so superficially did he investigate the matter, that while he admits that *some* electric excitation occurs between the liquid and metal of a pile, he does not *include* this as a *motive* cause in the pile, but treats it as though it did not exist. In his favour, it must be remembered that the channel of his thoughts, in the very outset, was not divided between the contact and the chemical theory, but between an electric excitation derived from extraneous causes, and one proper to the animal organisation.

His strong bias, however, to metallic contact, is ever prominent; and to resume the objections of those, who said that *compression*, and even *friction*, both sources of electricity, were involved in the act of contact, and that the mere touch with the moist finger to discharge the discs produced *chemical action* (the proposed explanation of the phenomenon), he introduced the following experiment.

(283.) Let two cylinders, one of zinc and the other of copper, be soldered end to end. Being thus permanently united, the intervention of both friction and compression is removed. The zinc cylinder will be in a permanent state of positive electricity, and the copper cylinder in a permanent state of negative electricity. If either or both be placed in contact with conducting bodies, a stream of positive fluid will pass to the conductor in contact with the zinc, and a stream of negative fluid will pass to the conductor in contact

with the copper. If the copper be put in communication with the earth, and the zinc with an insulated conductor, then the negative fluid propagated at the surface of contact of the two metals being diffused through the earth will be of insensible tension, while the positive fluid diffused over the insulated conductor will acquire the greatest tension which is compatible with the physical principle, whatever it may be, which produces the decomposition of the natural fluid at the surface of contact. To render these phenomena evident, let the zinc Z be held in the hand, so as to communicate by the body with the ground; and let the copper C be applied to the condensing plate of the electroscope, that plate being also copper. If the cylinder, and afterwards the collecting plate, be then removed, the leaves will diverge by the electricity received from the contact. Since, in this method of conducting the experiment, the accumulated effects of a succession of contacts cannot be obtained, the plates of the condenser should be large, so that its condensing power may be considerable.

If the plate of the condenser, being copper, were in this case touched by the zinc, the copper being held in the hand, no effect would be produced on the electroscope. This absence of electricity is explained by the fact that the surface of contact of the copper plate of the condenser and the cylinder of zinc developes electricity, which neutralises that which is developed at the juncture of the zinc and copper cylinders. From the latter point a stream of positive electricity flows to the plate of the condenser. From the former surface an equal stream of negative electricity flows to the condenser. Thus the condenser receives equal charges of positive and negative electricity, which neutralise each other, and no effect is produced on the leaves of the electroscope.

(284.) Were this an orthodox experiment, it would not only come in forcible demonstration that the contact of metals is of itself sufficient to determine a con-

tinued electric development, but it would disclose to us a power differing from all others in nature. Every other power is consumed in the using, and cannot regenerate itself; and hence the repeated failures in the attempt to attain to perpetual motion. But here, according to Volta's notion, would be a force which could never be expended; it would go on, and on, and on, as long as the two metals remained in contact. This, therefore, which is the *experimentum crucis*, — the gauntlet, in fact, which is thrown down before the advocates of the chemical theory, — must be subjected to very rigid investigation ere it can be admitted.

(285.) With respect to the experiment in question, M. Becquérel says * : —

"Chemical actions always giving place to a liberation of electricity, it is necessary to be as much on the guard as possible against effects of this kind, in the phenomena which are under examination. This is effected in some measure by using, in order to collect the electricity, conducting plates formed of an unoxidable metal, because the chemical reaction of the moist finger on the metal is avoided. On the other hand, the moist air exercising a greater or less degree of action upon the metals, according as they are more or less oxidable, we ought also to guard, in like manner, against this. This is accomplished in two ways. The first consists in operating on mineral substances, conductors of electricity, which, having been exposed for ages to the inclemency of the seasons, have not undergone any sensible alteration, as platinum, gold, peroxide of manganese, magnetic oxide of iron, &c.

"The fingers having been washed with distilled water, and being assured that the gold plates or the gilded glass plates do no possess any residual electricity, a piece of blotting paper is placed on one of the plates, and upon it the body which is to be put in contact with that held in the fingers.

"It is immediately found that platinum and gold never give rise to a liberation of electricity by their mutual contact, however great may be the sensibility of the electroscope employed. If, then, Volta discovered any in operating with copper-plates, it must be attributed to the reaction on the copper, of the liquid which adhered to his finger. We have also observed, that there is absence of electrical effects when a plate of gold and another of platinum are plunged, while in connection with a galvanometer, into a liquid which does not attack them. These two facts are worthy of especial notice."

(286.) Indeed, if the original experiment were carefully made, and there really was a long continuation of

* Traite de l'Electricité, t. ii. p. 136.

such effects as those described, it is not easy to see what else than chemical action could be the cause — chemical action on the readily oxidizable metals, copper and zinc, produced by the moisture of the hand. But admitting that the *first act of contact* did cause disturbance of the electric equilibrium, as very possibly it does, it is quite at variance with the known law of electric distribution to find the two characters of electricity repelling each other as designated by the arrows in *fig.* 123.; the known reciprocal action in such cases being mutual attraction. I say, it is in accordance with no known law to find the insulated body A B, *fig.* 123., assume the polarised condition, indicated by the signs + and —, except under the influence of some inducing extraneous cause. The more this experiment is investigated, the more evident does it appear that errors, unsuspected and unnoticed by Volta, entered into it, and effectually exclude it from the place to which he has elevated it.

(287.) To return then to the experiment of the discs: — the mode of manipulating is, *first* to place them in contact, *afterwards* to break contact, and then test them severally. So that, granting that the *act of contact* does disturb electric equilibrium, the evidence of this disturbance is not obtained until *contact is broken*. Now, contact is not broken between the plates of a Voltaic pile in order to continue the action, as we shall see hereafter; and, therefore, whatever weight the contact theory, as propounded by Volta, even with the widest limits may have in explaining an *incipient* action, it fails most effectually in accounting for a *continued* action. And *continuous* action is the essential characteristic of a Voltaic pile.

It is not worth while to suggest the probable influence of temperature in producing *thermo-electricity* in Volta's experiment with the soldered cylinders, as it would not much tend to clear up any doubts which still pervade the contact theory. It will be better to avail ourselves of a few of the more recent researches of

modern philosophy, and see the results which have actually presented themselves.

(288.) M. Peltier took, for condensing plates, a disc of gold and another of platinum; and, having made them communicate by means of a platinum wire, the former became positively electrised, and the latter negatively. He then prepared glass plates, coated with the four metals, platinum, silver, gold, and tin; and by various experiments he was led to infer, that the metals in the natural state of equilibrium possess different quantities of electricity, either positive or negative according to their nature, which no conducting body can remove from them, which are inherent tó their nature; and that it is in virtue of this proper electricity that the two plates of the condenser receive different charges, when a pair of metals is interposed between them; and he believes that this *inherent specific capacity* is the cause of the development of electricity by contact, cases of which he had examined, in which chemical action can scarcely be said to have entered. M. Becquérel seems to recognise, too, this *specific character* of a metal; though he does not draw analogous inferences to M. Peltier.

(289.) M. Karsten describes a long series of experiments, in which he traces the activity of the pile to the contact of the liquid with the metal. He experimented with wires, one end of which was placed in a liquid, and the other on a condenser. A zinc wire gave signs of negative electricity, so also did one of copper. He gives the following new experiment*: —

"A platinum wire, rolled into a spiral, and terminating in a point, was closely enveloped in zinc foil, without, however, being in immediate contact with it; the point was then placed on a small mass of chloride of silver, a substance insoluble in water. Some time after, traces of reduction, which soon ceased to augment, were recognised beneath the point. This effect never took place without the presence of the zinc, nor unless the surface was well cleaned. M. Karsten thence concluded, that the platinum must have extracted from the liquid the negative electricity, and thus the immerged part of the zinc was positive."

The general inferences to which M. Karsten arrived, are:

* Becquérel's Traité, t. v. p. 27.

Metals, perhaps all solid bodies, become positive, on being plunged into a liquid; when the body is partially immersed, the parts acquire contrary electric states; the electro-motive powers of bodies differ with a similar liquid, and hence the action of the pile; when two electromotors are in the same portion of liquid, they acquire comparatively opposite electricities; the two parts, even of the more feebly electrized body are dissimilarly electrized; the electromotive energy of a liquid depends on the facility with which "it renders up its contrary electricities to the same electromotors, with greater or less facility;" ... "the electromotive effects of two metals, forming with a liquid a closed circuit, result from the continued disengagement and recomposition of the contrary electricities in the liquid. These effects are excited by the electromotive relation of the two unequal electromotors toward the liquid; they are favoured by the electromotive relation of the stronger electromotor toward the weaker, and are accelerated by the immediate contact of the two electromotors, inasmuch as they are good conductors of electricity;" the chemical changes are connected with these actions, but are not dependent on them as cause and effect; in a series of pairs, the electricity of each is neutralised and is not transmitted from one to the other.

Though some of the definitions in these deductions consist of only a variation in terms; yet there is, on the whole, a great connection in the main between them and the inferences of Peltier and others.

(290.) M. Peclet's experiments are valuable; a very brief glance at the result of which, is all that we can give*:—

Electricity is developed when the plate of a condenser is touched by another metal, and it is independent of the form or mass of the metal, or the extent, character, or duration of the contact; metals soldered end to end, as in the experiment of Volta (283.), act

* Vide Arch. de l'Electricité, t. i. p. 629—647.

as though they were alone. He determined, in the course of his researches, that "all the phenomena may arise either from the contact of the metals with each other, or from the contact of the metals with the liquids, or from the contact of the liquids with each other, or from these three causes united."

He repeated the disc experiment (274.) very carefully, in the course of which he found, that pressure or friction to which some have attributed the electric effects, if they have any influence at all, *diminish the effect;* since friction, at its maximum, annihilates the effect. He says,

"It is a singular thing that friction, an objection so frequently raised against the experiments I have just related, is without influence, or diminishes the effect when the separation is normal, and entirely opposes the development of electricity, when the separation is tangential."

He found, too, that the effects were great in proportion to the surfaces in contact; and that roughened surfaces were more energetic than those quite smooth. He obtained the following list, in which each metal is positive with regard to those which follow:—zinc, lead, tin, bismuth, antimony, iron, copper, and gold. It was not needful for the discs to be in actual contact; for with a varnish between, and connected by a metallic arc (no matter what the metal was), the effects were the same. With respect to the contact of metals with liquids, the following experiments are most in point:— A platinum crucible, containing diluted sulphuric acid, is placed on the upper plate of a condenser; when a plate of gold, held in the fingers, moistened with distilled water, is dipped into the acid, the gold leaves deviate with negative electricity, which effect, he thinks, cannot but be attributed to the difference of the actions of the fingers and of the acidulated water on the gold. Again, a U tube is filled with alcohol, and, one end being closed with the finger, a metal wire is inserted in the other; silver, gold, or platinum, produce no effects on the condenser; but zinc, tin, and iron do. The effects cannot be due to the action of the alcohol on the fingers, or all

metals would produce the same effect. A solution of potash in the U tube is productive of analogous effects. To use the author's own words—

"It appears to me impossible, after all these experiments, to refuse admitting that there is a production of static electricity, by the contact of certain substances with liquids, without there being any known chemical action, and hence the effects observed can only be attributed to contact."

"I think it is completely demonstrated, that the electricity developed by the pressure and friction of bodies of which one is a bad conductor, is neither derived from molecular derangement, nor from the chemical action of the surrounding medium; that the same applies to the electricity produced by the mutual contact of metals, or of certain metals with certain liquids; and that, in all these instances, the electricity merely results from the simple fact of contact. According to which ideas I consider it very probable, that there is a liberation of electricity in the contact and separation of the molecules of different natures; that, in the first case, there may or may not be chemical action, and, in the second, that the molecules may have been simply placed in contact, or may have been united by a true chemical action, at least this hypothesis satisfies every observed fact."

(291.) M. Martens, a staunch advocate of the contact theory, argues that metallic contact is the only *direct* or immediate cause of the production of the galvanic current in Volta's piles; and that liquids concur in this production indirectly only, not simply as conductors, but as modifiers of the electromotive power of metals; and that chemical action is the effect and not the cause, because electricity is developed in insulated piles before the chemical action consequent on the closed circuit is manifested; that the influence of a liquid on a metal does not depend on its chemical action, because it is often manifested where no such action occurs.* In fact, this author, without intending it, and indeed without being aware of it, evidently maintains similar views with those already advanced; for, while with one breath he denies the influence of liquid contact, with another breath he maintains it.

(292.) From this discussion we have, as yet, been careful to exclude chemical action, which would be anticipating what is to follow, and have introduced a few of the leading features in illustration of the contact theory. We cannot do better, in the present stage of

* Proceed. Elec. Soc. p. 287.

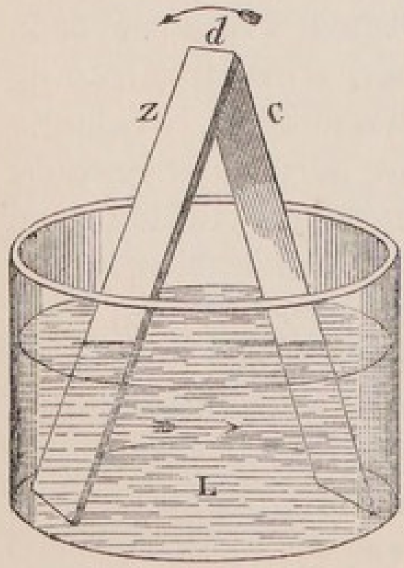
our inquiry, than give Professor Zantedeschi's observations on these several theories, in the truth of which we fully concur*: —

"In fact, it is not enough that the partizans of Volta's theory prove, by experiment, that electricity is developed by the contact of heterogeneous bodies, without there having been previously any sensible change in the nature of these bodies; they must further demonstrate that the chemical phenomena which are manifested in voltaic electromotors, are always an effect of the electric current excited by the juxtaposition of heterogeneous bodies. In like manner, it is not sufficient that the partizans of the chemical theory render it evident that chemical decompositions are accompanied by electrical effects; they must moreover prove that the decompositions succeed the effects; that simple contact can in no case produce electricity, but only permits the manifestation of chemical action, whence alone the electric phenomena of the voltaic pile must be derived. In other words, the partizans of contact must demonstrate that every effective phenomenon of the voltaic apparatus, is simply due to the material contact of heterogeneous bodies; and the partizans of the chemical theory must prove that voltaic electricity is exclusively derived from chemical action. However, this method of procedure has not yet been adopted by any one, and hence it is that the question still remains undecided among philosophers of the two opinions."

II. *Chemical Theory.*

(293.) A very few words will suffice to unfold the principle of the chemical theory. Let *fig.* 126. be a glass vessel containing a liquid L, and a plate of copper C, in contact with a zinc plate Z. When the liquid is *distilled* water, there is scarcely any ELECTRICAL action; when it is *salt* water, the action is increased; but, with *acid* water, it is highly exalted; and, in each case, the course of the positive electricity is that indicated by the arrows. The figure before us represents one pair of a Volta's pile. When *water alone* is used, there is no appreciable CHEMICAL action; when *salt* is added, this action becomes evident; but when *sulphuric acid* is added, it is very greatly increased. The connection of this increase with the increased development of electricity, constitutes the chemical theory. To

Fig. 126.



* Annali Sc. Lomb. Venet., Nov. and Dec. 1841.

use the words of one of its great advocates, M. Becquérel —

"There is no chemical action without a considerable disengagement of electricity.

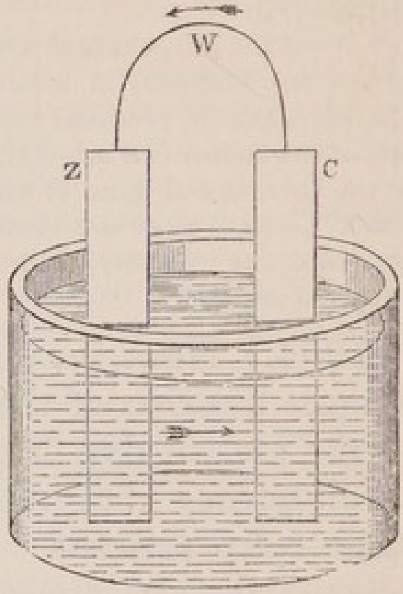
"A voltaic pile, charged with a liquid not acting chemically on either of the two elements of which each body is composed, does not become charged; that is, produces neither current, nor electricity of tension: if one of the elements is attacked, even very feebly, by the liquid, the effects of the current and those of tension immediately follow. If the chemical action becomes more considerable, these actions increase in intensity. In one word, the intensity of electrical effects is in relation to the energy of chemical action." *

(294.) Now, the struction of a voltaic pile by the contact theorists of the old school, and by many indeed of the present day, is one of the most singular cases of inconsistency that the whole history of experimental philosophy presents. They preach one doctrine, and practise the very opposite. They advocate, as their writings show, in no measured terms, the paramount influence of contact—and metallic contact only, many of them; and they never construct an instrument for actual use without availing themselves, as much as possible, of the influence of chemical action, utterly disregarding the extent and character of mere contact, as such. They increase, for instance, the *intensity* of the electric action, by employing a liquid, L (*fig.* 126.), having an increased chemical affinity for the zinc; they augment the *quantity* of electricity, by using a greater depth of liquid. Indeed, so little does metallic contact concern them, that they do not even care to avail themselves of its entire advantage, by allowing the plates to continue in contact at *d*; but very often effect the object by the mere interposition of a wire, W, as in *fig.* 127.; and, what is very remarkable, they see W, this wire, often melted by the passing current; and as the contact made by this wire is to them the efficient cause of the electricity, it is somewhat inconsistent to see the instrument of contact actually destroyed by the very contact itself.

* Compte Rendu, Jan 24. 1842.

(295.) In addition to the above evidence in favour of the chemical theory, it is shown that when chemical action ceases, electrical effects also subside; that, if the chemical action creates a new non-conducting compound which coats the active metal Z, the power of the battery is at once destroyed. These observations will find their illustrations in the sequel.

Fig. 127.



The effects of contact which have been now detailed, have, as we have seen, been assigned by the opponents of that theory, to any other cause than that attributed by the contact theorists. We have, however, seen, that pressure and friction have been excluded by the experiments of M. Peltier: so that the mind is left to determine between contact and chemical action. They, who are attached to the latter doctrine, attribute the facts which we have quoted, to the chemical action of the air, or of objects exterior to the bodies. But they feel at the same time that,

"When two bodies, having affinity for each other, were in contact, without combination occurring (and this evidently is often the case), it might happen that the action of the chemical forces commencing to act, would disturb the equilibrium of the molecules, and set at liberty a very small quantity of electricity, which was not capable of producing continued currents." *

And they append to their theory the probable influence of "either mechanical actions, or finally unperceived causes, which disturb the equilibrium of their molecules." †

(296.) As the modifications of chemical action may be traced throughout all the voltaic arrangements to be described hereafter, it is not necessary, in the present place, to dilate upon the great advantage gained by availing ourselves of its maximum development; it

* Becquérel, Compte Rendu, Jan. 24. 1842.
† De la Rive, vide Becquérel's Traité, t. v. p. 9.

only now concerns us to decide whether electricity can be developed *by contact independently of chemical action.* Experiments on the one hand (against which the only objection has been the *possible* influence of the moist circumambient medium), and admissions on the other, tend greatly towards the affirmation. May not truth lie between? That it may is evidently Faraday's opinion, as the following extracts will show: —

"That the different modes in which electric excitement takes place will some day or other be reduced under one common law, can hardly be doubted; though, for the present, we are bound to admit distinctions. It will be a great point gained when these distinctions are, not removed, but understood." § 1737.

"In such a view of voltaic excitement, the action of the particles may be divided into two parts, that which occurs while the force in a particle of oxygen is rising towards a particle of zinc acting on it, and falling towards the particle of hydrogen with which it is associated (this being the progressive period of the inductive action), and that which occurs when the charge of association takes place, and the particle of oxygen leaves the hydrogen and combines with the zinc. The former appears to be that which produces the current, or if there be no current, produces the state of tension at the termination of the battery; whilst the latter, by terminating for a time the influence of the particles which have been active, allows of others coming into play, and so the effect of current is continued." § 1743.

"Davy refers experimentally to the opposite states which two particles having opposite chemical relations, can assume when they are brought into the close vicinity of each other, but *not* allowed to combine. This, I think, is the first part of the action already described; but, in my opinion, it cannot give rise to a continuous current unless combination take place, so as to allow other particles to act successively in the same manner, and not even then unless one set of the particles be present as an element of an electrolyte: *i. e.* mere quiescent contact alone, without chemical action, does not in such cases produce a *current*." § 1745.

"Still it seems very possible that such a relation may produce a high charge, and thus give rise to excitement by friction. When two bodies are rubbed together to produce electricity in the usual way, one at least must be an insulator. During the act of rubbing, the particles of opposite kinds must be brought more or less closely together, the few which are most favourably circumstanced, being in such close contact as to be short only of that which is consequent upon chemical combination, At such moments they may acquire, by their mutual induction and partial discharge to each other, very exalted opposite states; and when, the moment after, they are by the progress of the rub removed from each other's vicinity, they will retain this state, if both bodies be insulators, and exhibit them upon their complete separation." § 1746.

"All the circumstances attending friction seem to me to favour such a

view. The irregularities of form and pressure will cause that the particles of the two rubbing surfaces will be at very variable distances, only a few at once being in that very close relation, which is probably necessary for the development of the forces; further, those which are nearest at one time will be further removed at another, and others will become the nearest; and so, by continuing the friction, many will in succession be excited. Finally, the lateral direction of the separation in rubbing, seems to me the best fitted to bring many pairs of particles, first of all into that close vicinity necessary for their assuming the opposite states by relation to each other, and then to remove them from each other's influence whilst they retain that state." § 1747.

"It would be easy, on the same view, to explain hypothetically how, if one of the rubbing bodies be a conductor, as the amalgam of an electrical machine, the state of the other, when it comes from under the friction, is (as a mass) exalted; but it would be folly to go far into such speculation, before that already advanced has been confirmed or corrected by fit experimental evidence. . . . ."* § 1748.

III. *Theory of Renewed Contact.*

(297.) The exposition of the existent theories has enabled us, at the same time, to introduce a good series of electrical facts, which are otherwise instructive, independently of the evidence they bring with them of the means by which electric effects have been produced. We have said truth may be balanced between contact and chemical action; and, with this view, have ventured to advance an opinion, as implied in the title of the present section, that *contact may be the prime cause of all electrical action,* and that *the current, consequent on chemical action,* is merely the result of a *succession of contacts,* proceeding from the new particles which succeed the old as they are successively combined. We have no right to urge hypothetical objections to the many carefully conducted experiments, which indicate that the mutual or reciprocal contact of solids or liquids does produce electricity. And if it does so in a few cases, may it not do so in many? May not the successive particles of zinc, which are brought, by the progress of chemical action, into contact with the liquid, be the exact counterpart of the successive particles of glass which pass before the rubber, the renewal being in the one case a chemical, in the

* Exp. Researches, Series xiv.

other a mechanical act. The doctrines of definite equivalents, of specific heat and specific gravity, strongly confirm the opinion deduced from M. Peltier's experiment of the *specific electric capacity* of bodies; and it is then no great concession to admit that, when two particles of different specific capacities come together, there would be a disturbance of electric equilibrium.

The theorists, who talk of *continued* electricity from a *single* contact, advance a proposition with absurdity on the face of it; indeed, their experiments will not bear them out; but if they recognise *one* effect for *each* contact, they not only advance that which every experiment confirms, but they include in this one proposition the whole range of electrical effects, proceeding from whatever source they may.

(298.) The following passage from Mr. Grove's paper on the Gaseous Battery (329.), which has been placed in my hands since the above was written, is very cogent testimony in support of the positions I have advanced.

"If my notion of that [the contact] theory be correct, I am at a loss to know how the action of this battery will be found consistent with it. If, indeed, the contact theory assume contact as the efficient cause of voltaic action, but admit that this can only be circulated by chemical action, I see little difference, save in the mere hypothetical expression, between the contact and chemical theories; any conclusion which would flow from the one, would likewise be deducible from the other; there is no observed sequence of time in the phenomena, the contact or completion of the circuit and the electrolytical action are synchronous. If this be the view of contact theorists, the rival theories are mere disputes about terms. If, however, the contact theory connects with the term contact an idea of force, which does or may produce a voltaic current, independently of chemical action — a force without consumption, I cannot but regard it as inconsistent with the whole tenor of voltaic facts and general experience."

(299.) As it is not the present object to write an elaborate essay on electricity, we are excused from entering very deeply into the illustration of a theory which has only just presented itself to us; we leave it to our readers to test its application to the several forms of electric development, and to apply it by the laws of electric induction, and they may find it very effectual in explaining under one general law a series of phe-

nomena, which have long been meeting in collision and promoting confusion.

This chapter may be concluded by some instances in which the theory is applied: —

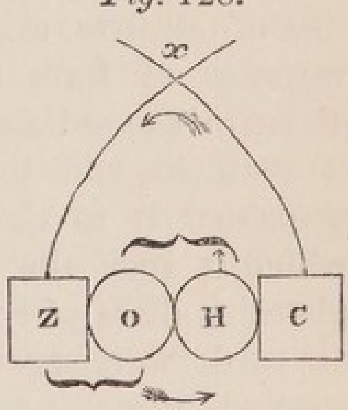
When the glass of an electric machine presses against, or is in contact with, the rubber (for in this view *pressure** and *contact* are all one), a molecular derangement of each two contiguous particles takes place; the respective SPECIFIC quantities of electricity, which were latent before, are now disturbed, and a new arrangement takes place; and the two particles which, when apart, were in a state of electric equilibrium, now, when in contact, have the equilibrium disturbed; and if any means existed of seizing on a single pair of such united elementary particles, they might be found to possess *free* electricity as a whole, just, indeed, as do some of the bodies which we have described, when in contact; or if a single pair were seized and separated, they would individually possess free electricity. In practice, the latter plan is adopted; we move the glass from the rubber, and not only so, we move it *rapidly;* for experience tells us that thus we obtain a maximum effect. According to our theory, a slow rotation would give time for the restoration of equilibrium, a quick rotation would oppose this restoration, and, perhaps, an exceedingly quick motion would oppose the original disturbance. Again, when the pressure of the steam is high, and the contact, therefore, of the particles is very close and rapid, the hydro-electric machine is at its maximum of power.

On the other hand, when the zinc of a voltaic pair is *wetted* by the liquid, *i. e*, when a particle of water is in close contact with a particle of metal, a similar disturbance of equilibrium takes place, and

* It may be right to mention that *pressure* has long been (268.), and continues to be, recognised as one of the sources of electricity, and that, up to a certain point, increased pressure produces increased effects; speedy is of more avail than slow separation, and non-conductibility in one of the bodies, at least, is favourable to the effect.

corresponding effects would attend the examination of the two particles as a *whole* or *individually*. In practice, we cannot, as in the former case, remove the particle of water; but we remove *one* of the elements of which it is composed, viz., hydrogen, and leave the oxygen with the zinc. It does not concern the theory in being unable to penetrate the veil with which the doctrine of chemical equivalents is clouded, it is enough to show, that, if Z and C, *fig.* 128, constitute an elementary voltaic pair, and OH, a particle of water, when the circuit is complete at x, electricity passes between C and Z; the hydrogen H is removed from the oxygen O, which latter unites with Z to form oxide of zinc. In practice the liquid would, in this case, be dilute sulphuric acid; so that as fast as the oxide of zinc is formed, it is dissolved, and fresh particles of water come into *contact*.

Fig. 128.



(300.) Taking this view of electric action, we find that *contact* produces electricity of *tension*, and *chemical action* produces a *current;* and so we see water-batteries of very extended series exhibit electric polarity at the two extremes, *before* the circuit is completed, so as to exhibit electrical attractions and repulsions, and even to afford a spark; but we find them also, on account of their structure, very deficient in all those effects which require *quantity* of electricity, *i.e.*, the constant and renewed supply which is the essential characteristic of a *current*. Powerful chemical agents are introduced in the exciting liquids of a battery, from their power of rapidly evolving the new compound formed by *contact* plus *completion of circuit;* and the rapidity or energy of this evolution, *i. e.*, the reiterated renewals of contact, is the true cause of the powerful action of such combinations.

CHAP. II.

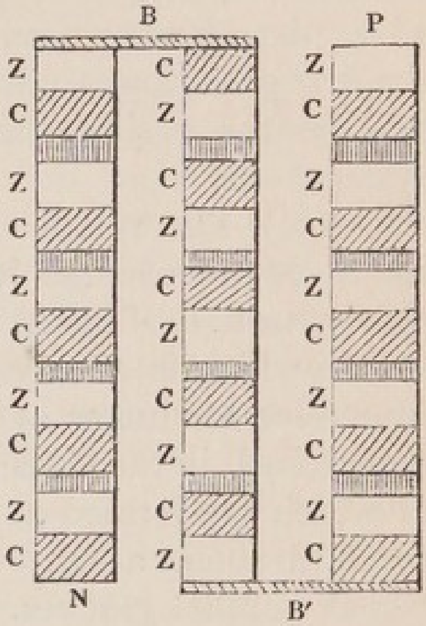
PRACTICAL CONSTRUCTION OF VOLTAIC BATTERIES.

(301.) Having dwelt thus at length on the theories of electric excitement, it remains to describe the varieties of form and arrangement which have been given to the voltaic battery. The earliest form which it assumed, and that in which its illustrious inventor presented it to the world, was the arrangement from which it took the name PILE. A number of circular plates or discs of copper or silver, of zinc, and of cloth or card, were provided, those of cloth or card being steeped in water or a weak saline or acid solution. A PILE is then formed, by placing the discs one over another in the same order — copper, zinc, cloth, — copper, zinc, cloth, — and so on. To keep the pile thus formed steadily in the vertical position, the discs may be placed between three rods of glass fixed in a wooden base and inserted in a similar piece of wood at the top. Two plates of metal are provided at the top and bottom, whence proceed wires by means of which the poles of the pile may be put in metallic communication with any conductors to which it is intended to transmit the electricity. Thus, one of the poles may be put in communication with the ground, and the other with the condenser of an electroscope, if it be desired to observe the tension of the fluid at the pole of the pile; or the two poles may be put in communication with each other through any medium on which the effect of the opposite electricities is to be observed.

(302.) When the number of voltaic elements required is so great that the height and weight of the

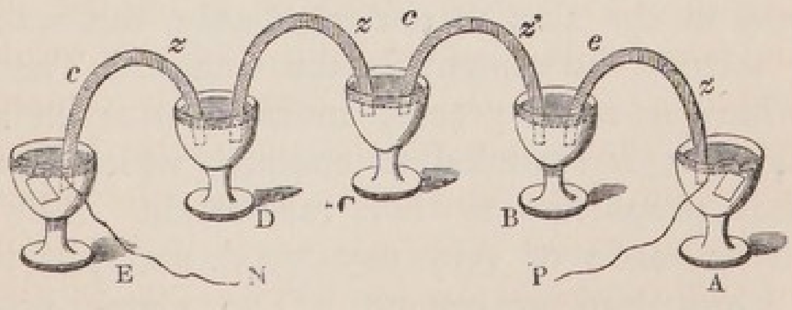
pile would be inconvenient, they may be arranged in two or more piles, connecting their contrary poles by metallic bars, so that the whole system shall have the effect of a single pile. Such an arrangement is represented in *fig.* 129. The positive pole of the first pile, presented upwards, is connected with the negative pole of the second, also presented upwards, by the bar B; and the positive pole of the second pile, presented downwards, is connected with the negative pole of the third pile, also presented downwards, by the bar B′. The negative pole of the system is at N, and the positive pole at P, and the effect of the whole is the same as if the second pile were placed above the first, and the third above the second, so as to form a single pile consisting of three times as many pairs as any one of the three here represented.

Fig. 129.



(303.) The second arrangement proposed by Volta was the *couronne des tasses* (INTROD. (112.)). This

Fig. 130.

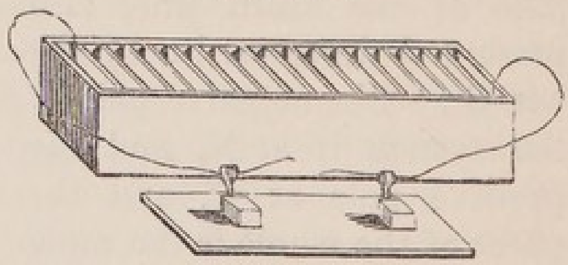


form of voltaic apparatus, represented in *fig.* 130., consists of a series of cups or glasses containing a weak solution of salt or acid. A number of metallic arcs are formed, one half of each being zinc and the other copper, soldered together. The zinc end of one arc is

immersed in the first glass A, and its copper end in the second glass B; the zinc end of the next arc is immersed in the second glass B, and its copper end in the third glass C; and so on to the end of the series, the zinc ends of all the arcs being turned towards the glass A, and the copper ends in the contrary direction. A silver plate, having a wire attached to it, is immersed in the first glass, and a zinc plate in the last. The wire P will be the positive, and N the negative, end of the system.

(304.) The voltaic arrangement invented by Cruickshank is represented in *fig.* 131. It consists of an oblong trough of baked wood (which is a very imperfect conductor of electricity), in the sides of which are formed at equal distances a number of parallel grooves.

Fig. 131.



Rectangular plates of zinc and copper are provided, corresponding in magnitude to the transverse vertical section of the trough, so that they may slide into the grooves.

The zinc plates are made by casting that metal in an iron or brass mould. They may be about the eighth of an inch thick. The copper need not exceed twelve or fourteen ounces to the square foot, and may be soldered to the zinc at one edge only, the other three being secured by cement in the trough. The trough must have as many grooves in its sides as the number of plates it is intended to contain, which should be fewer in proportion to their magnitude. The trough should be made of very dry wood, and put together with white lead or cement. The plates being put before a fire, the trough must be well warmed and placed horizontally on a level table with its bottom downwards; very hot cement is then to be poured into it until the bottom is covered to the depth of a quarter of an inch.

During this process the plates will have become warm, and may then be quickly slid into the grooves and pushed firmly to the bottom, so as to embed themselves securely in the cement. When the cement is sufficiently cool, a slip of thin deal is to be slightly nailed on the upper edge of one of the sides of the trough, so as to overhang the inner surface about a quarter of an inch. The trough being about three quarters of an inch deeper than the diameter of the plates, there will be an interval between their upper edges and the deal slip; and when the side of the trough to which the slip is attached is laid flat upon the table, this interval forms a channel into which very hot cement is to be poured, and it will flow between each pair of plates so as to cement one side of all the cells perfectly. As soon as the channel is quite full of fluid cement, the strip of deal is to be taken off, and the trough inclined so as to allow the superfluous cement to run out. When this is effected, and the cement cool, a slip of deal is to be nailed on the opposite side, and the same process pursued with that side. The apparatus may then be cleaned off, and varnished.*

The intervals between the plates being filled with the liquid conductor, as salt water or dilute sulphuric acid, the apparatus is then prepared for operation. Such an arrangement is called a VOLTAIC BATTERY.

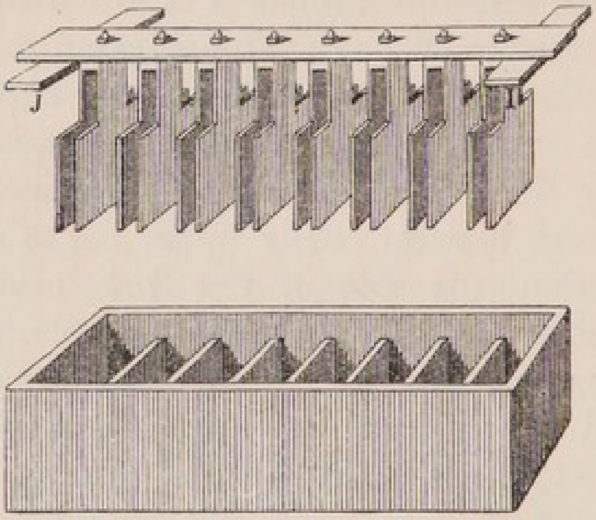
This form of voltaic apparatus, though a great improvement on the pile, is attended with some disadvantages in practice. Besides this, the removal of the liquid from the plates, when it is desired to suspend the action of the battery, is an inconvenient process, especially when the plates are large and the apparatus heavy; also, when the plates, by continued oxidation, require to be cleaned, the process is attended with much trouble.

(305.) An improved arrangement is represented in

* Singer's Elements of Electricity, p. 324.

fig. 132., in which some of these inconveniences are removed. A trough, A B, of baked mahogany, is di-

Fig. 132.



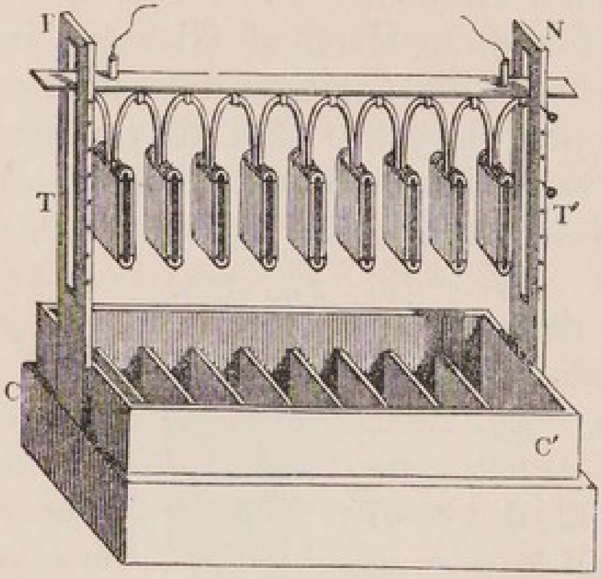
vided by glass partitions into a number of parallel cells; or the trough, with its partitions, may be made of the earthenware called *Wedgewood's ware.* The plates of zinc and copper are soldered together at one point only, at the top, a space being left between the plates of each pair sufficiently wide to admit between them the partitions of the trough. The plates thus united are all attached to a bar of wood C D, by which they may be let into the cells of the trough, or withdrawn from them at pleasure. When they are immersed, the zinc plate of each pair passes into one cell, and the copper plate into the adjacent cell, so that each cell contains a zinc and a copper plate of different pairs. Each trough usually consists of from ten to twelve cells.

One of the advantages attending this arrangement is, that the fluid may remain in the trough while the action of the battery is suspended, by lifting the plates from the cells; and another is, that plates are easily cleaned or replaced when injured or worn.

(306.) It was shown by Dr. Wollaston, that the power of a voltaic battery is always augmented by sur-

rounding the zinc plate of each pair by the copper plate of the succeeding pair, without allowing them, however, to touch. In this case, it is necessary to give the copper plates twice the magnitude of the zinc plates. Such an arrangement is represented in *fig.* 133.

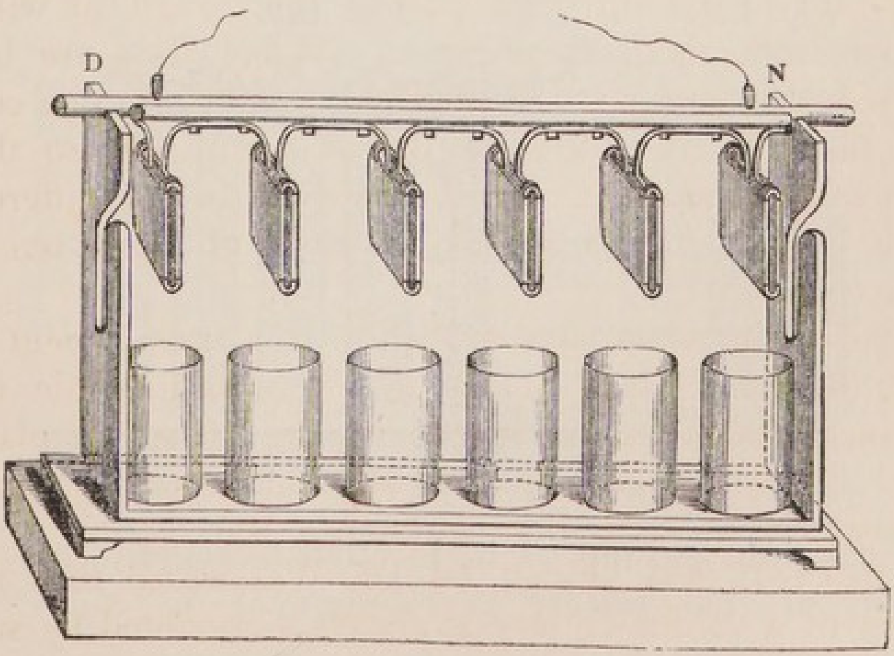
Fig. 133.



Each copper plate is doubled in such a manner as to let the zinc plate of the next pair stand between its folds without touching them.

In batteries of this kind, the trough is sometimes

Fig. 134.



replaced by a series of glass jars, as represented in *fig.* 134., in which the acid solution is more easily changed or discharged.

The same degree of gain would follow if the zinc surrounded the copper, the object being that equal surfaces of metal should face each other, which would occur in either case.

(307.) Mr. John Hart, of Glasgow, improved this form of battery, by adding sides and bottoms to the double copper plates, so that they might themselves form cells to receive the liquid conductor. These cells are formed by cutting the copper in the form represented in *fig.* 135. They are then folded up in the form represented in *fig.* 136., and the seams are grooved. A drop of tin is run into each corner, to render the cells perfectly tight. The zinc plate cast in the usual manner is represented in *fig.* 137., having a piece of screwed brass

Fig. 135.

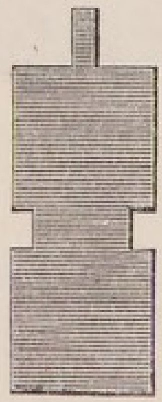


Fig. 136.

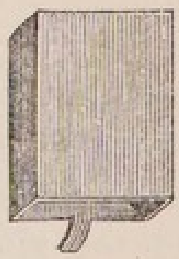


Fig. 137.

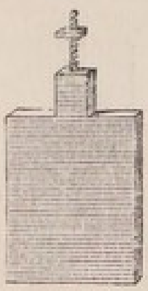
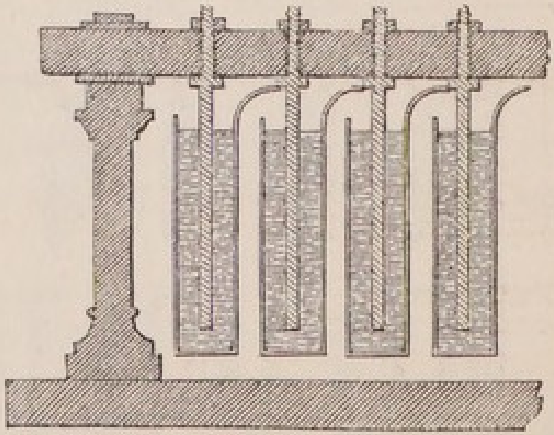


Fig. 138.



wire cast into the top of it, in order to suspend it. A section of the battery is represented in *fig.* 138.,

showing how the copper tail of each cell is connected with the zinc plate of the succeeding one. This connection is rendered complete by means of solder. The zinc plates are kept firm in their places by three small pieces of wood, and all the plates are fixed to a bar of baked wood, previously varnished, by means of screw nuts fitted on to the brass wires. When the battery is about to be used, it is raised from the frame and dipped into a wooden trough lined with lead, into which the acid has been poured; or it may be placed in a leaden trough, and the liquid poured into it, till the cells are filled. When the battery is small, two may be suspended on the same frame.

(308.) The HELICAL BATTERY, constructed under the superintendence of M. POUILLET, for the natural philosophy class of the University of France, has been contrived, with the view of supplying a large *quantity* of electricity in cases where high *tension* is not required.

A vertical side view, or elevation, of this apparatus is

Fig. 139.

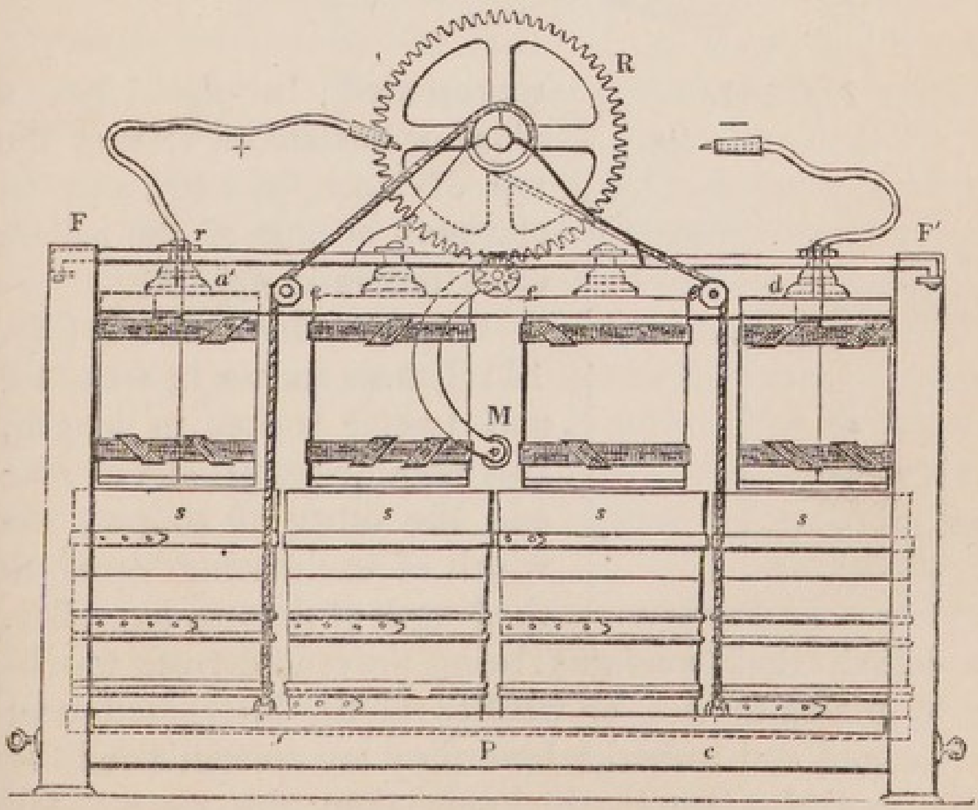


Fig. 140.

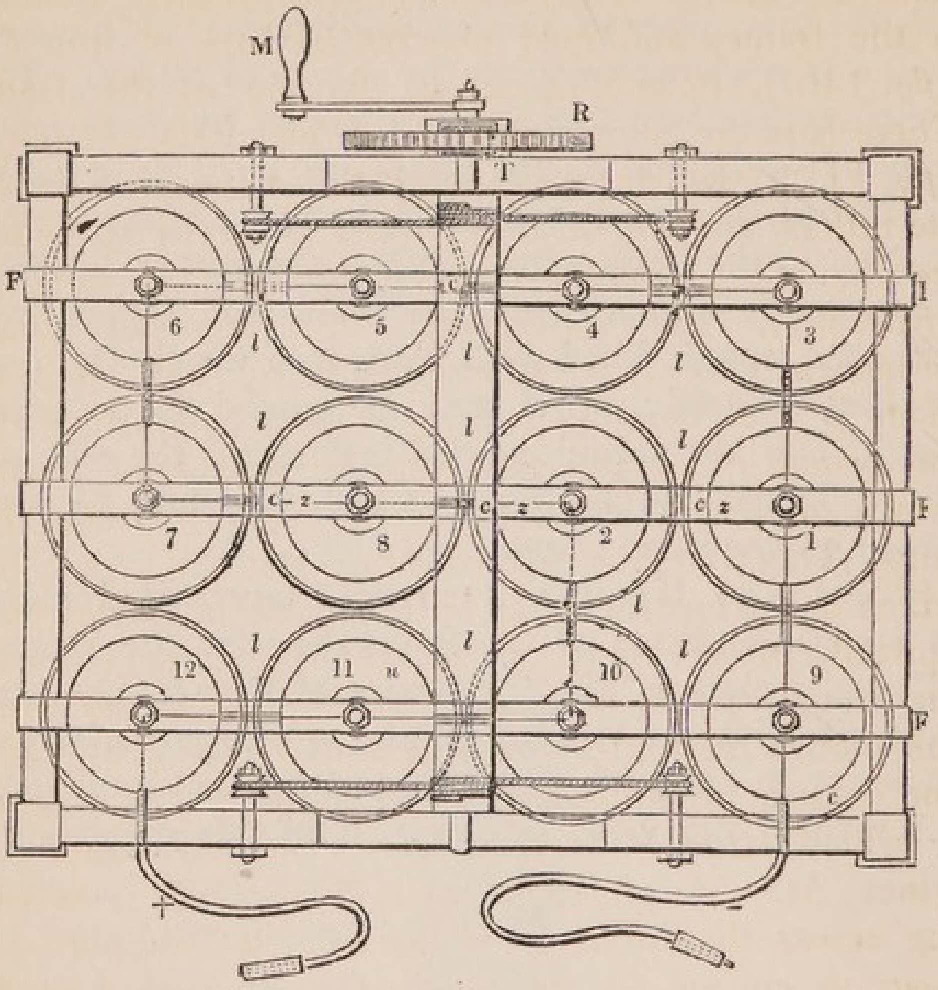
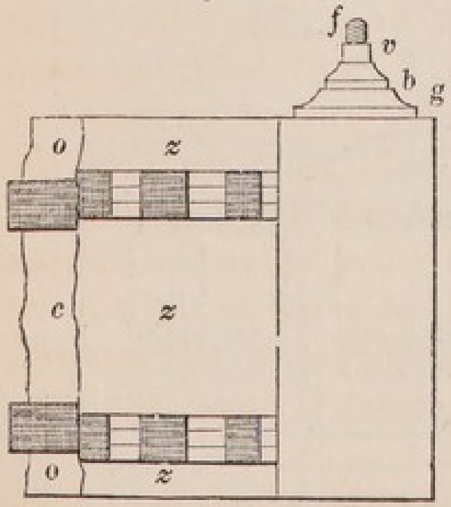


Fig. 141.



represented in *fig.* 139., a plane or horizontal view of the top of it in *fig.* 140., and an elevation of one of the rollers or cylinders in *fig.* 141.

On a wooden roller *b* (*fig.* 141.), three inches in diameter and twelve inches in length, two metallic plates, one of zinc and the other of copper, the width of each being equal to the length of the wooden roller, are coiled, their surfaces being prevented from touching by pieces of list, or woollen cloth, interposed near their edges, and united where they are discontinued, by cords, a little less in thickness than the cloth. On each roller from 50 to 60 square feet of these metallic

plates are coiled. Twelve rollers thus prepared are fixed in the frame, and held together by bars of iron FF′ (*fig.* 140.), extending across the top of the frame. These bars are connected with vertical rods of iron, *f* (*fig.* 141.), which pass through the geometrical axes of the rollers, and which, terminating in screws at the top, are secured to the bars, FF′, by bolts or nuts, *rr* (*fig.* 139.). The voltaic coils thus arranged remain permanently fixed, as represented in *fig.* 139. Beneath them is a rectangular trough, of such magnitude that the system of voltaic coils may be capable of passing into it so as to be immersed in the liquid which it contains. This trough is supported on a stage, P (*fig.* 139.), which is so constructed as to be capable of being raised upwards, preserving its horizontal position, and elevating the trough which it bears. The apparatus by which this motion is effected is represented in (*figs.* 139, 140.), and consists of a toothed wheel R, driven by a pinion *e*, which latter is worked by a common handle, or winch, M. A cylindrical axle, *ll* (*fig.* 140.), extending across the top of the apparatus, and supported in bearings erected on the sides of it, is worked by the great wheel R. On this axle ropes are coiled, which, passing over rollers, *e′e′*, fixed upon the sides of the frame, pass down to the stage P, and being attached to it, are capable of raising or lowering it by means of the wheel and axle. The communications between the different coils of zinc and copper, necessary to produce the voltaic action, are effected by large plates of copper CC. The first of these plates is soldered to the zinc of the first voltaic coil and to the copper of the second; the second, to the zinc of the second coil and the copper of the third, and so on.

(309.) Among the voltaic apparatus which have been rendered most memorable, may be mentioned that of the Royal Institution of Great Britain, with which Davy made his discovery of the decomposition of the alkalies. This consisted of two thousand pairs of plates, each plate presenting thirty-two square inches of surface.

The battery of the Royal Society of London consists of two thousand pairs of square plates, some six inches and some four inches in the side.

The great battery of the Polytechnic School, constructed by order of Napoleon, was composed of six hundred pairs of plates, each plate presenting one hundred and forty square inches of surface, and the whole battery having a surface of about six hundred square feet.

(310.) The helical battery is only an extension of Hare's calorimotor, so called from its power of producing exalted heating effects, and which consisted of eighty coils somewhat similarly arranged, each composed of a sheet of copper 14 in. by 6 in., and one of zinc 9 in. by 6 in.* Mr. Pepys constructed a splendid instrument of the same kind for the London Institution, of a plate of copper and one of zinc, each 50 ft. by 2 ft., exposing in all a surface of 400 ft. They were wound round a rod, horse-hair intervening between them; and when immersed in a tub, they required fifty-five gallons of fluid to excite them.

(311.) Till within the last few years, the above arrangements constituted the chief means of obtaining the various voltaic effects. They all were excited by either salt and water, or various mixtures of sulphuric acid and water, to which nitric acid was often added. In proportion to the extent of the series, or the magnitude of the element, the *first effects* were very brilliant; but the action suffered a rapid decrease, and very soon ceased altogether. Indeed, the more energetic the original effects, the sooner did they cease. These varying effects are due to the chemical changes occurring in each cell, one only of which favours the action, the others opposing it. At the first outset, when the acid solution is strong, every facility is afforded for removing the oxide of zinc as fast as it is produced; and thus the renewed contacts (§ 300.), and renewed chemical actions occur, in very quick succession; but, in proportion as the solution becomes exhausted of its

* Silliman's Journal, vol. iii. p. 105, 1821.

acid, this renewal occurs less rapidly. Again, in proportion as the solution becomes saturated with oxide of zinc, its conducting power is reduced. In the mean time, the hydrogen, which is set free at the other plate, offers a threefold obstruction to the action: 1st, it adheres with great tenacity to the surface of the plate, and thus throws a considerable portion out of action; 2dly, it leaves the cell, and takes away with it its own equivalent of electric action; 3dly, it reduces the zinc from the solution, and deposits it on the copper plate, so as virtually to oppose a zinc plate to a zinc, and of course produce a counter-action.

(312.) And, besides all this, there is a *local action* on the surface of the zinc itself, by which much of that metal is rapidly destroyed, without rendering up any portion of the electric development which causes the destruction; for the zinc of commerce is exceedingly impure, containing abundance of foreign matter, the minute particles of which form, with the particles of zinc itself, an innumerable series of minute elementary pairs, each acting independently of the other, and independently of the plate as opposed to the copper, but all uniting in consuming the zinc, and in throwing portions of it out of action. This local action and its remedy cannot be better illustrated than in the words of Faraday: —

"A dilute sulphuric acid, made by adding about one part by measure of oil of vitriol to thirty parts of water, will act energetically upon a piece of zinc plate in its ordinary and simple state; but, as Mr. Sturgeon has shown *, not at all, or scarcely so, if the surface of the metal has in the first instance been amalgamated; yet the amalgamated zinc will act powerfully with platina as an electromotor, hydrogen being evolved on the surface of the latter metal, as the zinc is oxidized and dissolved. The amalgamation is best effected by sprinkling a few drops of mercury upon the surface of the zinc, the latter being moistened with the dilute acid, and rubbing with the fingers or tow†, so as to extend the liquid metal over the whole of the

* "Recent Exp. Researches &c. p. 74, &c. 1830."

† "The experiment may be made with pure zinc, which, as chemists well know, is but slightly acted upon by dilute sulphuric acid in comparison with ordinary zinc, which, during the action, is subject to an infinity of voltaic actions. See De la Rive on this subject, Bibliothèque Universelle, 1830, p. 391."

surface. Any mercury in excess, forming liquid drops upon the zinc, should be wiped off.*

" When ordinary zinc is acted upon by dilute sulphuric acid, portions of copper, lead, cadmium, or other metals which it may contain, are set free upon its surface; and these, being in contact with the zinc, form small but very active voltaic circles, which cause great destruction of the zinc and evolution of hydrogen, apparently upon the zinc surface, but really upon the surface of those incidental metals. In the same proportion as they serve to discharge or convey the electricity back to the zinc, do they diminish its power of producing an electric current which shall extend to a greater distance across the acid, and be discharged only through the copper or platina plate, which is associated with it for the purpose of forming a voltaic apparatus."†

" All these evils are removed by the employment of an amalgam of zinc in the manner recommended by Mr. Kemp ‡, or the use of the amalgamated zinc plates of Mr. Sturgeon, who has himself suggested and objected to their application in galvanic batteries. . . . ." §

". . . . It is probable that the mercury acts by bringing the surface, in consequence of its fluidity, into one uniform condition, and preventing those differences in character between one spot and another, which are necessary for the formation of the minute voltaic circuits referred to. If any difference does exist, at the first moment, with regard to the proportion of zinc and mercury at one spot on the *surface*, as compared with another, that spot having the least mercury is first acted on, and, by solution of the zinc, is soon placed in the same condition as the other parts, and the whole plate rendered superficially uniform. One part cannot, therefore, act as a discharger to another. . . . . Two excellent and important consequences follow upon this state of the metal. The first is, that the *full equivalent* of electricity is obtained for the oxidation of a certain quantity of zinc; the second, that a battery constructed with the zinc so prepared, and charged with dilute sulphuric acid, is active only whilst the electrodes are connected, and ceases to act or be acted upon by the acid the instant the communication is broken."‖

". . . When an amalgamated zinc and a platina plate, immersed in dilute sulphuric acid, are first connected, the current is very powerful, but instantly sinks very much in force, and in some cases actually falls to only an eighth or a tenth of that first produced. This is due to the acid, which is in contact with the zinc, becoming neutralized by the oxide formed: the continued quick oxidation of the metal being thus prevented. With ordinary zinc, the evolution of gas at its surface tends to mingle all the liquid together, and thus bring fresh acid against the metal, by which the oxide formed there can be removed. With the amalgamated zinc battery, at every cessation of the current, the saline solution against the zinc is gradually diffused amongst the rest of the liquid; and, upon the renewal of contact at the electrodes, the zinc plates are found most

* Exp. Researches, Series vii. § 863. Jan. 1834.
† Ibid. Series viii. § 998. April, 1834.
‡ Jameson's Edinburgh Journal. Oct. 1828.
§ Exp. Researches, Series viii. § 999. April, 1834.
‖ Ibid. § 1000.

favourably circumstanced for the production of a ready and powerful current." *

(313.) The zinc, even when amalgamated, is not protected from one source of local action, viz. the deposition on it of copper dissolved by the solution from off the copper plate. Faraday alludes to it, and says,

"I think it very likely that plates of platina or silver may be used instead of plates of copper with advantage, and that then the evil arising occasionally from solution of the copper, and its precipitation on the zinc (by which the electromotive power of the zinc is much injured), will be avoided." †

Mr. Joule enters more at length into the subject: —

"If a plate of copper be placed in dilute sulphuric acid, it will be gradually dissolved; and, after a certain length of time, the liquid will have acquired a blue tinge, owing to the solution of oxide of copper. If now a plate of amalgamated zinc be placed in voltaic association with the copper, a powerful current will pass along the connecting wire, equal in intensity ‡ to that which would have been produced by a Daniell's cell. But, in the mean time, a part of the copper in solution will have precipitated itself on the amalgamated zinc, causing a local action, which will speedily destroy the plate.

"But if, instead of allowing the copper to remain alone in the acid before the battery is completed, it be placed in the dilute sulphuric acid along with a piece of amalgamated zinc, connected with it by means of a copper wire, the pair thus formed will not, after the immediate effects of immersion are passed away, be as intense as was the former one, but then it will work without local action.

"The due consideration of these facts will enable us to understand why local action is so common an annoyance to those who work with acid batteries, in which copper is employed as a negative element. It will also point out the following means of remedying that defect: —

"1st. Every part of the copper surface, which is immersed in the liquid, should be in sight of the amalgamated zinc. Any part *not* so situated, is not actively engaged in propagating the current, and is consequently liable to enter into solution, and then to be precipitated on the zinc. If we use the Wollaston's arrangement (306.), we should not (as is common) bend the copper about the zinc, but the zinc about the copper.

"2nd. When the copper battery is immersed in its trough, it should be set to work *immediately*, and the current should be allowed to pass with as few intermissions as possible. If we wish to make such a change in our

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* Exp. Researches, Series vii. § 1003.

† Ibid. § 1006.

‡ "It will be proper to observe that throughout this paper I mean by the word "intensity," electro-motive force. It is always proportional to the *quantity* of current multiplied by the resistance of the whole circuit."

apparatus as will occupy any length of time, we should either take the battery out of its trough, or else we should connect its pole by a wire, the conducting power of which is sufficient to occasion a slight effervescence on the copper surfaces.

"By adopting these precautions, I find that I am able to use a copper battery, charged with a strong solution of sulphuric acid, without being annoyed by local action." *

(314.) The energy of the action of a battery depends much on the character of the solution employed, its greater affinity for the zinc, and its less resistance to the transmission of the electric action.

The following table shows the number of equivalents of zinc consumed in each cell, during the decomposition of one equivalent of water by various exciting solutions: —

					eq. of zinc.
(1.)	200 water	+ 4½	sulph. acid	+ 4 nitric acid	= 2·21 †
(2.)	200 —	+ 9	sulph. acid		= 4·66
(3.)	200 —	+ 16	muriatic acid		= 3·8
(4.)	200 —	+ 8	nitric acid		= 1·85
(5.)	200 —	+ 9	sulph. acid	+ 4 nitric acid	= 2·786
(6.)	200 —	+ 9	—	+ 8 —	= 2·26
(7.)	200 —	+ 16	muriatic acid	+ 6 —	= 2·11
(8.)	200 —	+ 16	nitric acid		= 1·82
(9.)	200 —	+ 32	nitric acid		= 2·1
(10.)	200 —	+ 9	sulph. acid	+ 8 nitric acid	= 2·26 ‡

Mr. Joule found 16 measures of water, 3 sulphuric acid, and 1 nitric acid, a good working mixture, which did not annoy him with much local action, and gave him a good quantity of electricity and a tension equal to that of a Daniell's cell. (315.)

An examination of the above table shows that, so far as the zinc is concerned, the second and third mixtures on the list are the *most* extravagant, and the fourth and eighth the *least*. But there is another objection, in an economical point of view, against the use of nitric acid only; it is that a secondary action takes

* Proceed. Elect. Soc. p. 260.

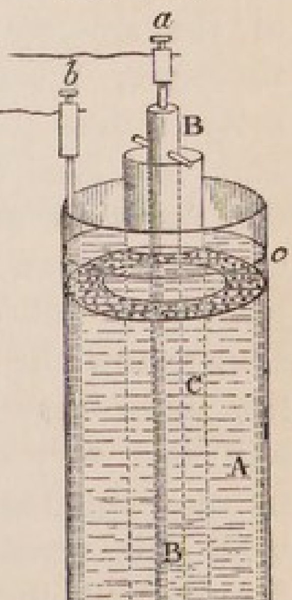
† This charge was after the time of those experiments generally used for ordinary purposes.

‡ Faraday's Researches, 1128. 1137—1141.

place at the copper plate; no hydrogen gas is *evolved* there, as usual, for, in its nascent state, it combines with, and thus consumes, an equivalent portion of the nitric acid, producing ammonia, which is in all cases found where mixtures containing this acid are used. The selection of the first on the list is, therefore, made for good and obvious reasons.

(315.) Our observations have thus far been confined to *one-fluid* batteries, as they are now termed, and a case has just been given of the disappearance of the interfering (310.) hydrogen from the copper plate; the other retarding causes still existing. To Prof. DANIELL of King's College the scientific world are indebted for an arrangement, which, from the provision it contains for removing the several causes that reduce the action of ordinary batteries, has been very appropriately termed the CONSTANT BATTERY. It is first described in the Philosophical Transactions for 1836. A single cell of this battery is represented in *fig.* 142. It consists essentially of a copper-cell A, an amalgamated zinc-rod B, and a porous diaphragm C. The object of the latter is to separate the *two fluids* with which the cell must be excited; it may be constructed, according to circumstances, of paper, animal membrane, plaster of Paris, sail-cloth, or porous earth. The three latter are of most avail for practical purposes. It is furnished with binding screws *a* and *b*, to connect the respective metals with others in a series, or with the subject of experiment. The battery is charged by filling the cell C, which contains the zinc, with a diluted solution of sulphuric acid (one in twenty will do), and the copper vessel A with a saturated solution of sulphate of the oxide of copper, containing a little sulphuric acid. If the zinc is well amalgamated and the appa-

Fig. 142.



ratus in perfect order, *no action will take place* until the circuit is completed by the wires connected with the two screws, when a very powerful action occurs, but unattended with the liberation of hydrogen, so much the characteristic of the one-fluid batteries. But, after continuing the action for a time, the inner surface of the copper cell will be found coated with a layer of new, pure copper; and the copper solution, at the expense of which this metal was deposited, will have become considerably paler. To sustain the strength of the solution, a perforated shelf *c*, is generally contained within the vessel A, which supports a supply of crystals of sulphate of copper to be dissolved in proportion as the metal is reduced. The principles on which this arrangement acts, and which constitute its value, are that the solution of zinc is kept away from the copper; that the hydrogen, instead of escaping, is not even liberated, but, in its nascent state, combines with the oxygen of the dissolved oxide, and reduces (not as in former cases *zinc*, a metal opposed to the continuance of the action, but) *copper* in its purest state, and, therefore, most favourable to the constancy of the action; that the solution of copper is kept from the zinc, and local action is thus prevented. The limits to the duration of the action are the exhaustion of the copper solution, and the saturation of the zinc solution, joined to the consumption of the zinc. We have shown how the strength of the former is maintained; the latter may be changed for very long actions, but will last very well for eight or ten hours or more of uninterrupted action. A very great advantage connected with this arrangement is the absence of all noxious fumes; and, on this account, it is very generally adopted in the application of electricity to the arts.

The size of the cells varies according to circumstances. Mr. Daniell's standard sizes are 20 inches high and $3\frac{1}{2}$ inches in diameter. The most extensive series of these is that possessed by Mr. Gassiot, consisting of 100.

Some idea may be formed of the brilliant effects of such a series from the following data: —

"Titanium was fused into a solid mass; platinum was volatilized; and the flame from charcoal and metallic electrodes was so intense as to render it indispensable that the eyes of those present should be protected by thick screens of black crape. Sixteen feet four inches of platinum wire, No. 20. iron gauge, was ignited to a red heat; and even this length might have apparently been extended had I had a greater quantity of that wire." *

(316.) Mr. Daniell, in some recent researches "on voltaic combinations," † has determined that, for a given zinc rod the amount of action is the same, whatever be the diameter of the copper cylinder A (*fig.* 142.). The resistance to be overcome is *directly* as the distance between the metals, and *inversely* as their common section; *i. e.* $R = \frac{d}{s}$. When a liquid excites two equal-sized plates, the common section is the area of either plate.

"But," as Mr. Daniell says, "how are we to determine the area of the section of the electrolyte, when the surfaces of the generating or conducting plates are not equal? as, for instance, in the case of a rod of zinc placed within a cylinder of copper — is it referable solely to the surface of the conducting plate, or is it limited by the mean of the surface of the two plates?"

By a series of experiments he found that *s*, or the common section, *was* equal to the mean between the two surfaces; and, hence,

"the amount of the current ought to be the same, whatever might be the diameter of the exterior cylinder; for the resistance occasioned by increasing the depth of the electrolyte, that is to say, by increasing the radius of the cylinder, is exactly counterbalanced by the increased conducting power conferred by the increased area of the electrolyte and *vice versâ*."

(317.) A practical advantage derived from this is, that the copper cylinder needs not be contracted in size; for no loss of power accrues on increasing it, whereas a great gain is made by its capacity for containing a good working supply of sulphate solution. As the zinc rod decreases in size by use, a slight abatement of power occurs from the decreased surface and

* Phil. Trans. 1840. part i. p. 187.
† Ibid. 1842. part ii.

the increased distance between the metals. The same law would hold good with a zinc cylinder and a copper rod, were it not for an interfering cause arising from the character assumed by the copper deposit, when reduced on the comparatively limited rod: it appears in "a spongy pulverulent form, which retains the liquid in its pores, which, after the precipitation of all the sulphate of copper which it contained, generated hydrogen, which was equally entangled in it, and produced a strong opposition to the current."

(318.) The "constant battery" has been constructed of all sizes, and of various forms. Solutions of muriate of soda (common salt), or muriate of ammonia, have been used instead of diluted acid about the zinc, which in this case needs not be amalgamated; the zinc has been placed in an earthen jar as the outer metal, with the copper within; sometimes a cylinder of copper has been placed between two cylinders of zinc; in one instance the porous vessel is filled with an amalgam of zinc and mercury (to which little bits of zinc are added as the case may require), and no other solution is needed than the surrounding one of sulphate.—Prof. Wheatstone has used this for telegraphic purposes (511.). An earthenware jar has been covered with wax and coated with plumbago, and copper has been deposited on the plumbago by the electrotype process hereafter to be described (362.), and thus an outer cell has been made.*

(319.) The most extended series of the constant battery, so far as number of cells is concerned, was that employed at Clapham. The form is so simple that any one can construct them, and the cost is not more than a shilling a cell. Mr. Thos. Mason devised it; and first described it in page 13. of the third volume of the Annals of Electricity.

"Each cell of the battery is a vessel of white earthenware A (*fig.* 143.), capable of containing about a half pint. The copper elements C are sheets whose width is equal to the height of the vessel, and whose length

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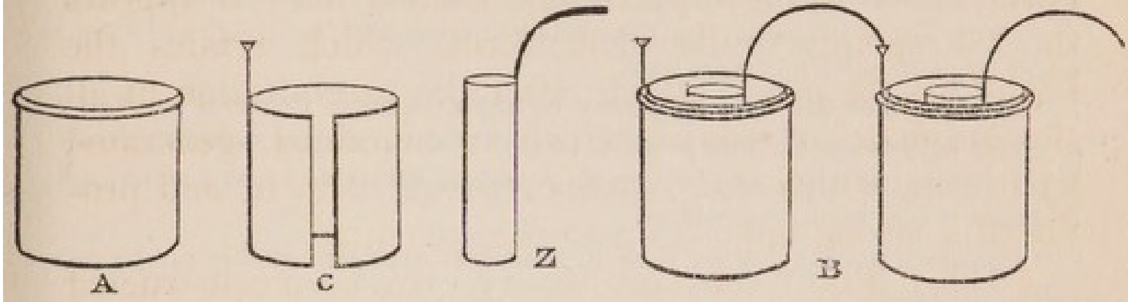
* Vide Elect. Manip. part i. § 57. 13th edition.

is more than equal to the inner circumference; so that, when bent into a cylindrical form, and placed within their respective cells, they arrange

Fig. 143.



themselves closely against the sides. Attached to each is a stout copper wire (diameter one-tenth of an inch), supporting a small brass cup to contain mercury. The zinc elements Z are cylinders two inches external diameter, composed of metal three-sixteenths of an inch in thickness, and each weighing about two pounds. The wires soldered to the zinc are considerably longer than those attached to the copper. B shows two cells in connection.

". . . The ends of the wires within the mercury cups were amalgamated* by touching them with a copper wire, dipped into nitrate of mercury. The coppers, with these their attached wires, being placed in the cells, the cups were filled with mercury. Into each cell was then poured a measured quantity of saturated solution of sulphate of copper (about a quarter of a pint). The ends of their wires having been previously amalgamated, each zinc was rested on the centre of a circular piece of *brown paper*, the circumference of which was carefully collected round the upper edge of the cylinder; if this is done with caution, the paper will lie in very regular folds, and effectually cover the zinc. These cylinders were then filled with a saturated solution of salt and water; and being placed within the copper in the copper solution of their cells, were connected with the neighbouring copper by bending their wires into the mercury cups." †

(320.) Facts *connected with this battery, of which on two occasions, Sept.* 16. *and* 26. 1838, 160 *cells were used; and on a third occasion,* 320 *cells.*

"Two dozen cells (especially if charged with hot solutions), are more than sufficient for all ordinary purposes.

"With a battery consisting of 12 cells with hot solutions, a cubic inch of the mixed gases was released in 27″; it produced a red heat on from 12 to 14 inches of platinum wire, $\frac{1}{100}$ of an inch in diameter, and afforded a very brilliant light from charcoal points.

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* Amalgamation of copper wires for producing close contact was introduced by Mr. Faraday.

† Sometimes the cups are dispensed with, and the respective ends of a single wire are soldered to the zinc and copper.

"Mean decomposing power of each 20 cells of the series = 1 cubic inch mixed gases in 40″.

"Platinum wire $\frac{1}{100}$ of an inch in diameter visibly red by each 20, $3\frac{1}{2}$ to 7 inches.

"When 1 battery or 20 cells were employed, the standard quantity of gases (1 cubic inch) was obtained in 37″; with 6 or 120 pairs, 27″; with 7 or 8, with 140 or 160 pairs, the time was the same 28″, being 1″ *more* than when 20 or 40 pairs *less* were used.

"It seems that the heating power of any number of batteries *combined in series* is the *sum* of their heating powers when *separate*: — If battery 1 heats x inches of wire, and battery 2, y inches, batteries 1 and 2 combined in series would heat $x+y$ inches.

"Platinum wire $\frac{1}{100}$ of an inch in diameter rendered visibly red by 160 cells = 45 inches.

"The length of flame obtained from the charcoal points was $\frac{3}{4}$ of an inch. The end of a steel file was melted by the flame; so also was glass. Zinc turnings were speedily deflagrated, and their oxide was seen floating about the room.

"The battery was separated into 8 batteries of 20 cells each, — a cubic inch of gases was liberated by their united action in 7″. The flame from the charcoal points, instead of $\frac{3}{4}$ of an inch, was reduced to $\frac{1}{8}$. Of the wire $\frac{1}{100}$ of an inch in diameter, 27 inches was the maximum (heated); of the wire $\frac{1}{50}$ of an inch in diameter, 34 inches was obtained as the maximum."*

(321.) A Daniell's arrangement, with bichromate of potassa, substituted for sulphate of copper, constitutes a Leeson's battery. M. Bunsen appears to have been the first to have used chromic acid. Mr. Warrington and Dr. Leeson have each communicated their opinions, in favour of the bichromate, the one to the Chemical the other to the Electrical Society. M. Poggendorff has investigated its action, in hopes of obtaining a constant one-fluid battery, but has only partially succeeded.†

(322.) The next, and most powerful voltaic combination with which we are acquainted, is the Nitric Acid Battery of Prof. Grove, or as it is more generally designated Grove's Battery; a notice of which was first communicated to the French Academy, April 15. 1839, and appeared in the Philosophical Magazine of the May following. It is very instructive to trace the inductive reasoning by which Mr. Grove followed out

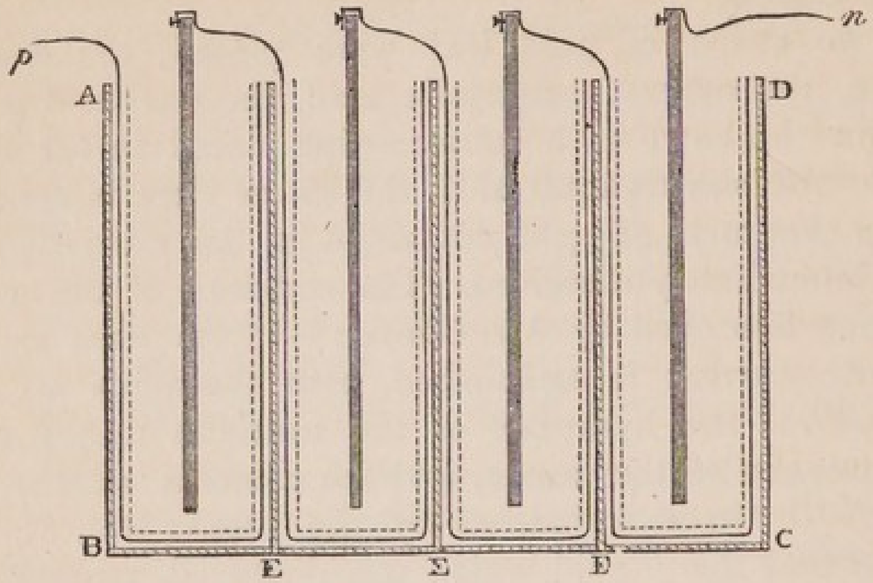
* From Trans. Elect. Soc. p. 57. &c.
† Pogg. Annalen, vol. lvii. p. 101.

an original idea, till it terminated in this very important combination.

Two strips of gold leaf were placed, the one in nitric, the other in muriatic acid, the one acid being within the bowl of a tobacco-pipe placed in the other acid. All was tranquil until the leaves were in contact, when that strip of gold contained in the muriatic acid was immediately dissolved. The *rationale* of the action is thus described by Mr. Grove: — "As soon as the electric current is established, both the acids are decomposed, the hydrogen of the muriatic unites with the oxygen of the nitric, and the chlorine attacks the gold." * On examination by the proper test, it was found that the "gold which was dissolved, represented the *zinc* of an ordinary voltaic combination;" and it hence occurred to Mr. Grove, that, "if gold with two acids gave so powerful an electric current, *à fortiori* the same arrangement, with the substitution of zinc for gold, must form a combination more energetic than any yet known." In confirmation of this idea, a strip of amalgamated zinc 1 inch by $1\frac{1}{4}$ inch, and a cylinder of platinum $\frac{3}{4}$ of an inch high, associated with two acids by means of a pipe-bowl, were found to *decompose acid water*; a similar series of seven decomposed water so energetically as to liberate 1 cubic inch of the mixed gases in two minutes. On repeating the experiment with an arrangement of four pairs, each about 4 inches square, the power equalled the release of 6 cubic inches per minute; it kept 7 inches of platinum wire, $\frac{1}{40}$ of an inch in diameter, at a bright red heat. The annexed *fig.* 144. gives the form of the arrangement. A B C D † is an earthenware trough divided into four cells by the earthenware partitions E, E, E; the *dotted lines* are porous pipeclay diaphragms; the dark line within them is the zinc plate; and the fine line surrounding them, the plate of platinum foil; *p* and *n* are the positive and negative terminal wires. The zinc was excited by

* Phil. Mag. vol. xiv. p. 389. 1839.
† A B = B C = 4 inches.

Fig. 144.



muriatic acid diluted with 2 to $2\frac{1}{2}$ of water, or sulphuric acid with 4 or 5 of water; the platinum, with concentrated nitro-sulphuric acid, consisting of equal measures of nitric and sulphuric acids. The superior energy of this combination over all others is thus explained by Mr. Grove: —

"In the common zinc and copper battery, the resulting power is as the affinity of the anion (in this case *the oxygen*) of the generating electrolyte for zinc, minus its affinity for copper; in the common constant battery, it is as the same affinity, plus that of oxygen for hydrogen, minus that of oxygen for copper; in the combination in question, the same order of positive affinities, minus that of oxygen for azote.* As nitric acid parts with its oxygen more readily than sulphate of copper, resistance is lessened and the power correlatively increased. With regard to the second material question, that of cross precipitation (311.); in the common combination zinc is precipitated on the negative metal, and a powerful opposed force created; in the constant combination copper is precipitated, and the opposition is lessened; in this there is no precipitation, and consequently no counter action." †

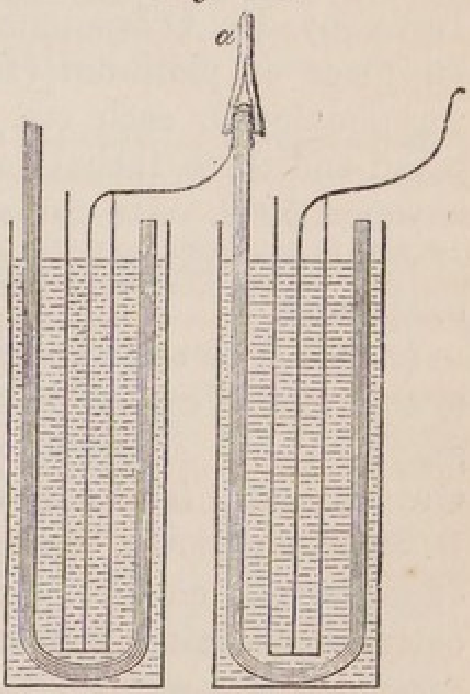
(323.) As this battery works, the nitric acid changes to yellow, green, and blue progressively; and, from commencing without evolution of gas, it after some time gives off nitrous, and finally hydrogen. On March

* Phil. Mag, vol. xv. p. 289. 1839.

† "I have thrown out of the case the resistance to decomposition of the solution in contact with the zinc or generating electrolyte, as common to all the three combinations, respect being had to the other three conditions; the more easy this is of electrolyzation the better."

13. 1840, Mr. Grove illustrated the action of this battery before the members of the Royal Institution, with a series of 50 pairs, each 4 inches by 2 inches. When he grouped together 8 series of 5 pairs each, he obtained 110 cubic inches of gas per minute: a sheet of platinum 12 inches by 1 inch was made incandescent. When the 50 pairs were arranged in a single series, the charcoal points gave "a voluminous flame $1\frac{1}{4}$ inch long," which exhibited the magnetic properties of the voltaic arc spoken of by Davy.* Still more recently (Jan. 20. 1841), in a lecture before the members of the London Institution, Mr. Grove manipulated with 100 cells of the same size, being the most powerful battery ever seen.† In this case he obtained an arc of light four inches long, and other effects in similar proportion. The structure of the battery had been somewhat modified before these cells were prepared; and the arrangement then employed, is now, for several reasons, that generally adopted. The cells are not, as in *fig.* 144., all made in groups of four; but are each distinct, as in *fig.* 145.; and the zinc is made the surrounding, instead of the inner, metal. This arrangement economizes the platinum, and also the nitric acid. Mr. Grove tells me that a series of four in good order, will give a cubic inch of the gases for every square inch of platinum in each cell.

Fig. 145.



Mr. Gassiot, who cultivates the science of electricity with the greatest enthusiasm, possesses a series of 100 Grove's batteries. To avoid the effects of the nitrous

* Phil. Mag. vol. xvi. p. 338. 1840. † Ibid. vol. xviii. p. 234. 1841.

fumes, which, as we have mentioned, are given off after a certain time, he encloses the cells in a box. At a *soirée* held at Clapham, April 26. 1842, he first used this battery entire. The vapours were carried off by a tube passing into the outer atmosphere from the lid of the box. Never before did so brilliant a light shine upon so brilliant an assembly. Such exalted effects of ignition and combustion are unequalled. — We have ourselves used at the lecture table a dozen cells of Grove's, fitted, according to Mr. Gassiot's plan, in a small box; and have obtained all the amount of effect required, without the least annoyance from fumes. Contact between the zinc of one cell and the platinum of the succeeding, is effected by means of a cleft piece of wood (*a, fig.* 145.), by which means the interfering effects, resulting from the action of the acid on the copper binding-screws, are avoided. The most costly of nitric acid batteries in existence is one constructed in India by Dr. O'Shaughnessy, consisting of 48 cells. In place of platinum (for local reasons merely) gold was employed, each cell containing a slip half an inch broad and three inches long. The gold of the battery is worth 500*l*. He finds a mixture of two by weight of sulphuric acid to one of saltpetre, as serviceable as nitric acid.

(324.) The expense of platinum has induced several to recommend carbon, in the various forms of plumbago, graphite, and charcoal, as the negative element of a Grove's cell. The idea originated with Mr. Cooper *: B. Silliman, jun. †, and Mr. Bunsen ‡, have likewise experimented on the subject. On account of the difficulty of procuring carbon of the proper character and form, the idea seems for a time to have been abandoned. Mr. Silliman feels their difficulty, but does not *describe* the preparation of the mixture he substituted: —

"The plumbago here employed, is the artificial mixture made at the

* Phil. Mag. Jan. 1840, p. 35. † Silliman's Journ. Jan. 1843, p. 180.
‡ Pogg. Ann. vol. lv. p. 265. Elec. Mag. vol. i. p. 16.

crucible works, and crouded into moulds of the proper shape, and baked.* The difficulty of procuring suitable cylinders of native plumbago, arises not from a want of the abundance of material, but from the occurrence of numerous natural joints, even in that which seems externally quite sound, which cause them to fall to pieces under the saw. . . . It is not supposed that plumbago is quite equal to platina for the negative element."

(325.) The following is Mr. Bunsen's mode of preparing the carbon : —

"For this purpose a mixture of coke (baked as well as possible) and of pitcoal, reduced to a fine powder, is subjected to a red heat. If the mass thus obtained is too friable, which is commonly the case when poor pit-coal is used, the proportion of the latter relative to the coke must be increased. If, on the other hand, the pit-coal is superior, the resulting mass cracks, and presents nothing but disjointed fragments. But when once the proper proportion is found, the operation can no longer fail. The mixture is heated over a moderate charcoal fire, in sheet-iron moulds, which are able to stand ten or a dozen operations, without being deteriorated. Should the diameter of these moulds exceed five or six inches, it is rare that a carbon is obtained completely exempt from fissures. But it may easily be obtained under the form of hollow cylinders, of the largest dimensions, by introducing within the iron mould a cylindrical wooden box, and filling with the mixture the interval existing between the two walls. The very great change of volume, which the carbon undergoes during this operation, does not allow of the box being replaced by an empty cylinder of sheet-iron.

"The carbon obtained by this means has doubtless already a tolerably solid structure; but its great porosity renders its employment altogether impossible. To render it as compact as it ought to be, and to give it a consistency which scarcely yields to the hardest stones, it is plunged, before the second operation, into a concentrated solution of sugar, made, if we please, with the coarsest refuse of sugar; it is then dried until the sugar has acquired a solid consistence in the mould. The carbon does not acquire conductibility and electro-motive force until it has been exposed for several hours to the action of a very intense white heat, in a covered vessel, capable of resisting fire, filled with pieces of charcoal, an operation which can very readily be accomplished in an ordinary potter's furnace. The carbon prepared by this method is perfectly homogeneous, — very slightly porous; it does not in the least degree lose its colour; it rings; has a metallic appearance; and is so solid that a hollow cylinder, weighing six ounces, and three lines thick, can fall on wood, from a height of six or eight feet, without breaking. The best mode of procuring carbon discs is to take pieces of carbon of a cubical form, and to divide them with the saw into discs one line thick, which are afterwards polished on a plate of grey stone." †

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* To be obtained of J. W. Ingall, Taunton, U.S.
† Vide Elec. Mag. No. i. p. 17.

He describes an arrangement, which he says is "perfectly equal to that of a Grove's battery." He makes hollow cylinders of carbon, and fills them with nitric acid, which he allows to remain until they become saturated. He then pours away the nitric acid, and places them in their saturated condition as the negative element of a series, using no diaphragm, and only one liquid, viz. acid water. — Platinum, however, is in the long run decidedly preferable to carbon; as experience will soon teach.

(326.) The chemico-mechanical battery, called after its inventor SMEE'S BATTERY, is an instrument of much practical importance. We have said (311.), that the adhesion of the liberated hydrogen greatly interferes with the action of a voltaic power. Having noticed the property which *rough* surfaces possess of evolving the hydrogen, and *smooth* surfaces of favouring its adhesion, Mr. Smee has taken advantage of this principle to its fullest extent, and has constructed a zinc and platinum battery, in which the negative element is either silver or platinum (generally the former for practical purposes), covered with the finely divided black powder of platinum. This process, which he calls "*Platinization*," is thus conducted: —

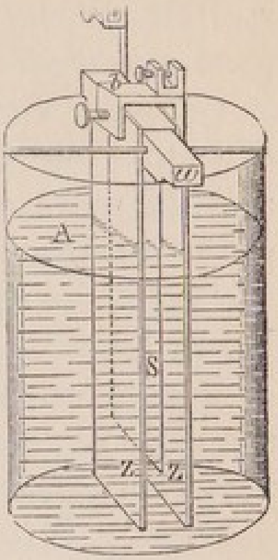
"The metal to be prepared should be of a thickness sufficient to carry the current of electricity, and should be roughened, either by sand-paper, as in the case of platinum or palladium, or, when silver is employed, by brushing it over with a little strong nitric acid, so that a frosted appearance is obtained. The silver is then washed and placed in a vessel with dilute sulphuric acid, to which a few drops of nitro-muriate of platinum are added. A porous tube is then placed in this vessel, with [water and] a few drops of diluted sulphuric acid; into this the zinc is put. Contact being made, the platinum will, in a few seconds, be thrown down upon the surface of the silver, as a black metallic powder. The operation is now completed, and the platinized metal ready for use. However iron, when thus prepared, is as effectual as silver, and may be sometimes employed with advantage. With this metal all that is required is to rub a little nitro-muriate of platinum over it, and an immediate deposit of the black powder takes place." *

A single cell of Smee's battery is generally arranged

* Electro-Metallurgy, p. 24. 2d edition.

as in *fig.* 146. A, an earthenware cell containing the acid solution (1 sulph. acid + 7 water); *w*, a bar of wood to which the platinized plate S is fixed: ZZ, two zinc plates, secured to the bar *w* by the binding screw *b*. Connections are made by means of small binding-screws as in the figure. When a series is used, they are generally arranged to suit the porcelain trough of a Wollaston's battery (*fig.* 132.) "The characteristic of this battery," says Mr. Smee, "is the great quantity of electricity produced, and its simplicity; moreover, it requires very little trouble in the manipulation." It is peculiar for the great hissing produced by the rapid evolution of the hydrogen, and this is a very convenient indication of the amount of the action going on. — The dense atmosphere of hydrogen arising between the plates, induced Mr. Grove to recommend platinized gauze on each side a zinc plate, and so arranged that the gas should pass through the gauze. By this means the plates could be more closely approximated.*

Fig. 146.



(327.) The following is Mr. Smee's approximation to the relative *cost* of working the three batteries last mentioned: he says,

"In mine, it is the cost of the zinc dissolved by the acid; zinc + acid + a local action. In the constant battery, it is zinc + acid + sulphate of copper + much local action. Each cell of this, to do any given amount of work, would cost about twice as much as mine. In Grove's battery, it is zinc + acid + nitric acid, reduced by the hydrogen + nitric acid combined with ammonia formed during the action of the battery + extensive waste of the zinc = about three times as much as mine."†

(328.) In juxtaposition to this, we must place the relative *powers* of the respective arrangements, from a table drawn up by Mr. Grove.‡

Nitric acid battery with sulphuric acid 1 + water 5,

* Proceed. Elec. Soc. p. 117. † Electro-Metallurgy, p. 31.
‡ Proceed. Elec. Soc. p. 114.

(specific gravity 1·17.) on the zinc side; and nitric acid specific gravity 1·34 + 0·2 concentrated sulphuric acid, gave *seventy-five* degrees of a galvanometer.

Constant battery with saturated solution of sulphate of copper + 0·2 sulphuric acid on the copper side, and the same acid solution as before on the zinc side, gave *sixty-four* degrees.

Chemico-mechanical battery with the same acid solution 1 acid + 5 water, gave *fifty-nine* degrees.

The relative value of the greater arcs is far beyond the ratio of their angles; but this belongs to another part of the work. (503.)

(329.) When describing the nitric acid battery Mr. Grove has remarked,

"There is still, however, another imaginary voltaic circle, which would be superior to any of these; it is one of three elements — two metals, or substances having the electrical properties of the metals, and an electrolyte; of these two substances the positive should be analogous to zinc, but the negative should possess a strong affinity for the cation of the electrolyte, and unite energetically with it, as it separates in a nascent state, or rather, should of itself be able to tear it from its associated anion; such a substance is, I may say, at present unknown: the nearest illustration I can give is mercury when associated with zinc and a cuperous solution; the peroxide of lead of Professor Schœnbein with zinc and an electrolyte, may serve as another. In a circuit of this description, we should have actually the sum of affinities instead of their difference, and I can conceive no more powerful hydro-electric arrangement."*

(330.) Schœnbein's battery, in which powdered peroxide of lead is used instead of nitric acid, is described by De la Rive.† The peroxide is rammed round the platinum, in the porous cell; it serves as an electromotor and a depolarizer. The hydrogen, instead of being liberated, combines with one portion of the oxygen of the oxide, converting the peroxide into a protoxide. The same effect has been produced by using platinum plates in Grove's arrangement, on which peroxide of lead has previously been deposited. Peroxide batteries are very powerful.

(331.) Mr. Grove has pursued his original ideas (329.), and arrived at the results which he thus expresses:—

* Phil. Mag. vol. xv. p. 290. 1839.

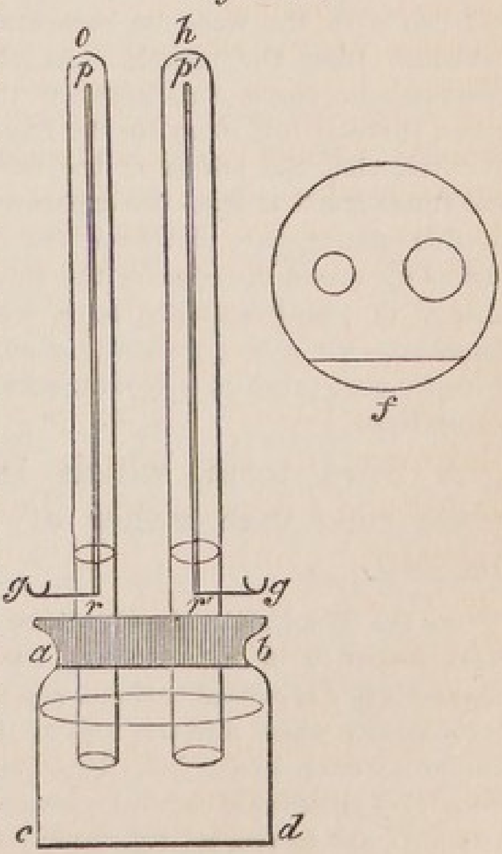
† Arch. de l'Elect. vol. iii. p. 112.

"Chlorine, in its voltaic relations, may be considered as the converse of zinc, both decomposing water, but the one liberating oxygen, the other hydrogen; thus a tube of the *gas battery*, charged with chlorine, and having acidulated water as an electrolyte and zinc as a positive element, forms a combination of which one pair will decompose water. I have tried to render this combination practically useful, by charging the negative cell of a diaphragm battery with peroxide of manganese and muriatic acid; but the supply of chlorine thus obtained is insufficient for quantitative voltaic effects, though the intensity is great."*

(332.) The gas battery alluded to in the above extract, is a purely philosophical instrument, and is entirely the result of inductive reasoning. In regard to power, it is in direct contrast to the nitric acid battery; but in theoretical interest it has not its equal. It is somewhat remarkable, that these two instruments, occupying the extreme positions in the scale, should both have been added to science by the same philosopher—Professor Grove.

This instrument was first made known in the Phil. Mag. for December 1842; and an experimental investigation of it was read before the Royal Society, May 11th, 1843.†

Fig. 147.



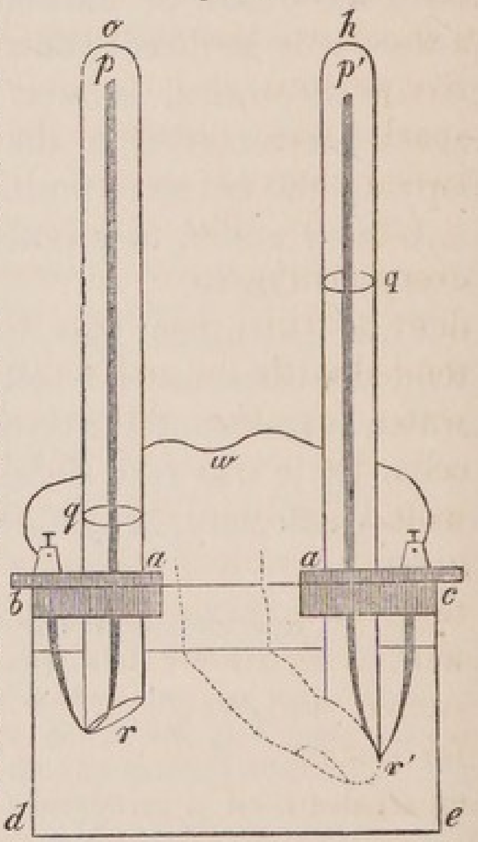
"*Fig.* 147. represents the first form given to it; *a b c d* is a wide-mouthed glass jar, into which a wooden plug, *a b*, fits tightly by means of attached pieces of cork; this wooden cover is perforated to receive the tubes *o h*, of which the size is such that the content of *h* shall be double that of *o*, and which are firmly cemented into it; the wooden cover is shown in plan in figure *f*; the piece *f* is capable of being detached at pleasure, in order to introduce a tube for charging the apparatus with gas; *p r*, *p′ r′* are strips of well-platinized platinum foil, slightly curved like a cheese-scoop, to keep them erect and in the centre

* Phil. Trans. 1843, part ii. p. 103. † Ibid. p. 91

of the tube, and rivetted or welded to stout platinum wires, which are hermetically sealed into the glass, and terminate in brass mercury cups at *g, g*. This form of battery is charged by inverting it so as to fill the tubes with liquid; on reinversion, the tubes may be charged with gas from a crooked tube and bladder. The apparatus is represented as charged and ready for use."

This form is useful; because, by merely inverting the instrument, the tubes can be filled with liquid previously to charging them with gas; so that the fingers need not touch the liquid, and give rise to interference in the action. — The second form which follows (*fig.* 148.), has the advantages not possessed by the other, of permitting either tube with its contents to be removed —

Fig. 148.



"*b c d e* is a parallelopiped glass or stoneware vessel; the tubes are cemented into pieces of wood, *a b*, *a c*, and can with the wood be separately detached from the trough. At the aperture, or space *a a*, between the tubes, there is just room for the finger to enter, close the orifice of the tube, and thus detach it from the apparatus. In this figure the platinum foil is turned up round the edge of the tube, instead of being attached to a wire sealed into the glass; and instead of a mercury cup, there is a binding-screw connection."

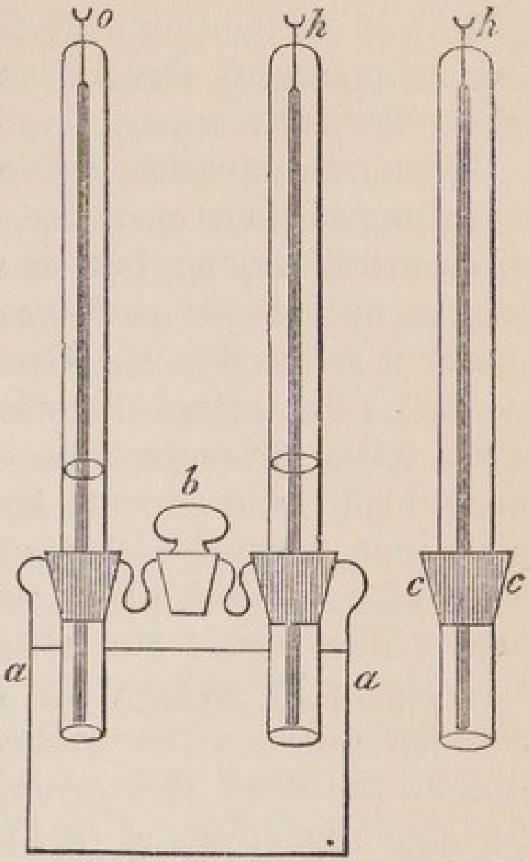
A third form, which is in all respects more advantageous than either of the preceding, is given in *fig.* 149.

"*aa* is a Woulfe's bottle with three necks; in the centre neck is fitted a glass stopper *b*; in the other two, the tubes *o h*, fit accurately by means of glass collars, *c c*, welded to them, and ground on the outside; the platinum is hermetically sealed into the tops of the tubes, which may be charged in a similar manner in fig. 147. By immersing this apparatus in the water-trough [of pneumatic chemistry] each tube with the gas it contains may be detached and examined separately; but its principal advantage is, that, by slightly greasing the stopper and collars, it may be made perfectly air-tight."

(333.) The battery is charged by filling the vessel

and the tubes with diluted sulphuric acid, and then filling the tubes *o* and *h* respectively with *oxygen* and *hydrogen* gas. If *four* such cells, or, for quicker action, several cells, be connected in series—the *o* tube of one with the *h* tube of the other — water may be decomposed. With fifty pairs, a shock was passed through five persons, and a brilliant spark was obtained between charcoal points.

Fig. 149.



(334.) The action of every arrangement antecedent to this, has been attended with the analysis of water in the generating cells, the oxygen of which would combine with the zinc, and the hydrogen would be given off, unless otherwise disposed of. In the gas battery, the very converse takes place; its action is associated with a synthetical effect, by which the gases are consumed and water is produced. A particle of oxygen, for instance, when the circuit is closed, unites with the equivalent of hydrogen in the particle of water in contact with it; the oxygen of this particle of water unites with the hydrogen of the next particle; and so on to the end of the series, when the last particle of oxygen, finding itself in contact with the hydrogen of the tube *h*, unites with an equivalent, and thus an equivalent of water is formed at the expense of an element of hydrogen from one tube, and one of oxygen from another: and this goes on throughout the series till all the gases are consumed: and, when interfering actions are deducted, it is found that the gas consumed in each cell exactly equals the gas released in the decomposition cell; or, in other words, that the water

composed in each cell of the gas battery, is exactly equal to that *decomposed* by its action. The "platinization" (326.) of the platinum, is for the purpose of increasing the points of contact, and obtaining the advantage of capillary attraction for wetting the platinum.

Other combinations of gases avail in producing, according to their character, a greater or less amount of electrical action; but, as an account of them would lead us out of the path we are pursuing, the curious reader is referred to Mr. Grove's original paper.

(335.) The water battery is in principle the same as all other voltaic arrangements. In its best form, which is undoubtedly that adopted by Mr. Gassiot, it consists of glass cells, covered with varnish of shell-lac, resting on slips of varnished glass, on trays sustained by glass legs. The metals are cylinders of zinc and copper, kept apart by string; the exciting liquid is pure or distilled water. The ordinary voltaic actions are not sought for from this arrangement: it is constructed for obtaining effects of tension, like those from ordinary electricity; and on this account a long series is used, and the cells are insulated in the best manner possible; though, from the great presence of moisture, the insulation, under the most favourable circumstances, is very imperfect.

The most celebrated water batteries are those of Mr. Crosse, extending to 1600 pairs; and that of Mr. Gassiot amounting to 3520.

The poles of the water battery give evidence of electric tension *before the circuit is completed*, — a spark passes *before contact*; gold-leaves from the respective poles are mutually attractive *before contact*; either pole is active on an uninsulated body, without the direct influence of the other pole, because the insulation is always very imperfect. When contact is made, the ordinary effects of the voltaic battery occur. If the circuit has been completed, and is then broken, the divergence of gold leaves or other indications of tension, are *gradual*; perhaps, on account of the time

required by pure water to remove the fresh-formed oxide from the zinc plates. It must not be supposed that any of the above effects are peculiar to the water battery; they are rather to be regarded as the actions of an insulated battery of a long series of cells: they have been observed, under one or other modification, in the other batteries. They are beautiful illustrations of the identity of the electricities; and they are, in my opinion, strong confirmations of the identity of the exciting causes (297.) of electricity generally.

(336.) In illustration of the extent of series required for producing the exalted effects of tension, the following extracts are given: —

"30 Pairs afford a slight spark, sufficient to pierce the cuticle of the lip, the hand making the communication being wetted: 130 pairs open the gold leaves of an electrometer about ½ inch: 250 pairs cause the leaves to strike their sides: 400 pairs give a very peceptible stream of electricity to the dry hand making the connection between the poles, the light being very visible: 500 pairs occasion that part of the dry skin which is brought in contact, to be slightly cauterised, more especially at the negative side: 1200 pairs give a *constant small stream* of the fluids between two wires, or two pieces of tin-foil, placed the one-hundredth of an inch apart, such wires or pieces of foil *not having been previously brought into contact;* a pith-ball, ¼ of an inch in diameter, suspended by a silk thread, will constantly vibrate between the opposite poles: 1100 pairs will produce this latter effect." *

"Sir Humphry Davy, in his Elements of Chemistry (p. 152.) says, a bright spark was produced of one-thirtieth or one-fortieth of an inch in the open air, and in vacuo nearly ½ an inch, by using 2000 of Dr. Wollaston's plates.

"Mr. Children informs us, that with 1250 pairs the spark was capable of passing through a distance of one-fiftieth of an inch." †

"Prof. Daniell had a water battery consisting of 1024 pairs; attractions as well as repulsions, when the electrodes terminate in slips of gold-leaf, are plainly perceptible; a minute but distinct spark is seen on completing the circuit, but with the *battery alone the spark could not be obtained* through the space of one five-thousandth of an inch.

"I was induced to prepare 100 [large cells of a Daniell's battery] (315.); I also excited 100 of the smaller cells already described (319.); *but neither with these two powerful batteries combined*, or separate, could any appearance of a spark be observed until contact was made, and the circuit completed. ‡

(337.) It must have been noticed in the course of

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* Crosse, Trans. Elec. Soc. p. 119. † "Phil. Trans. 1809."
‡ Gassiot, Phil. Trans. 1840, part i.

these descriptions, that the action of the several forms of battery has never been attended with the *liberation of oxygen ;* this element has always been required for combination with the active metal. Indeed, the relative affinities of these two elements are the availing cause of the action. There is, however, one arrangement in which this affinity is not included and the oxygen is set free : it is M. Becquérel's Oxygen-Gas Battery, thus described : —

"Some years ago I described an electro-chemical apparatus, by the aid of which oxygen gas might be obtained in considerable abundance, and in a short space of time. This apparatus, which serves as a type to constant batteries, consists of a vessel filled with nitric acid, in which is placed a glass tube, closed at bottom with clay that is retained by means of a piece of linen properly tied, and filled with a concentrated solution of potash ; and of two plates of platinum immersed, one in the acid, the other in the potash, and connected by means of a platinum wire, the ends of which are twisted together. As soon as connection is made, abundance of oxygen gas is liberated on the plate contained in the solution of potash ; this effect is due to the action of the current that arises from the combination of the acid with the potash, which action is exalted in proportion as the tamping of clay is thinner. Plaster, mixed for the purpose, may be substituted for clay."

"In this apparatus the nitric acid, and probably the water, are decomposed; the results of the decomposition are, oxygen in the tube where the potash is, and nitrous acid around the platinum plate which is in the nitric acid. If the decomposition of water contained in a separate vessel is desired, we have only to replace the platinum plate immersed in the zinc, by a plate of zinc, and to attach to this a platinum wire, at the end of which is fixed another plate of platinum; and also to place another plate at the free end of the second wire. Water is decomposed as soon as the two plates are immersed in it: the plate connected with the metal, which is in the potash, is the negative, the other the positive pole; the liberation of gas on each is abundant.

"What occurs when zinc is substituted for platinum is, that the former. being oxidized by the reaction of the alkaline solution upon it, assumes the negative electrical condition; moreover, by the reaction of the acid on the alkaline solution, the latter acquires negative electricity, which it transmits to the zinc plate; so that when the circuit is closed, the current resulting from the reaction of the two liquids on each other, is added to that derived from the oxidation of the zinc ; but as this double effect is produced without the intervention of a new pair, and consequently without there being a new alternation, it follows that the current has a more energetic decomposing force than in the former case ; and thus water is abundantly decomposed in a vessel separated from the apparatus, although forming part of the circuit." *

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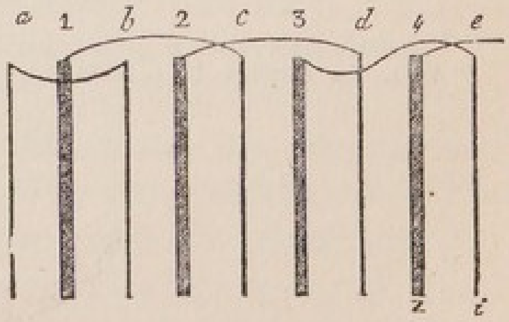
* Compte Rendu, July 4th, 1843. Elec. Mag. October 1st, 1843.

(338.) Professor Schœnbein takes advantage of a peculiar property termed by him *passivity*, which in 1836 he discovered in iron under certain circumstances — especially on being immersed in nitric acid, — a power of becoming indifferent with respect to oxygen, and acquiring very much the character of platinum in its voltaic relation. He, therefore, makes a diaphragm battery * of passive iron and zinc, and excites it like the nitric acid battery; he also excites, in the same way, a diaphragm battery, consisting of active and passive iron. With a series of five of the former, the zinc outer cylinders being ten inches by nine inches in diameter, forty cubic inches of gases were released per minute. This form of battery does not appear to have been much adopted. Is it not, that the passive iron is destroyed, when the nitric acid, on which its character depends, is converted by electrolysis into nitrous acid?

(339.) Mr. Martyn Roberts, who had discovered in 1838 the superior efficacy of iron over copper in voltaic combinations, has lately used it in constructing a common acid battery; and has considerably improved upon a mechanical adjustment introduced by Mr. Young, so as to obtain the action of both sides of both plates.

"Let the numbers and *z* (*fig.* 150.) represent the zinc, and the letters and *i* the iron plates; let *a* and *b* be joined together, and stand free as a double terminal plate or pole, having, of course, a wire proceeding from them as a conductor; then join 1 to *c*; 2 to *d*; 3 to *e*; and so on, terminating the other end of the battery by a positive plate, but having both its surfaces opposed to a negative plate, as is the condition of 4.

Fig. 150.



"In a battery of this construction there is no cross play of electricity, because two plates intervene between every positive plate and the negative plate in metallic connection with it. Its power is very great, in consequence of the closeness of the plates to one another; indeed, I have found it superior to a battery of the

* Vide Arch. de l'Electr. vol. i. p. 286. Proceed. Elec. Soc. p. 529.

same metallic surface, fitted with cells and double plates on Wollaston's plan. It is very compact; I have one of 20 pairs only eight inches long." *

The above battery was prepared for igniting wire for the purpose of blasting. Mr. Roberts has also described † a *swinging* battery, which is only in action when in actual use.

(340.) Professor Poggendorff increases the power of one-fluid batteries, by using amalgamated zinc, and subjecting the copper plates to any of the following processes: —

"1st To heat in air until the colours, which form at the commencement, are no longer visible; 2dly, To plunge it into nitric acid, and then to wash it in water; 3dly, To cause the precipitation of a layer of copper, in a reddish-brown powder, similar to that which is obtained on the surface of the copper plates of a Daniell's battery, excited by a diluted solution of sulphate of copper containing free acid; 4thly, To form this same layer on the plates of copper, by plunging them into diluted nitric acid, and then placing them in the circuit of one of Saxton's magneto-electric machines." ‡

M. de la Rive traces the increased power of this arrangement to the fact, that the hydrogen developed is engaged in reducing the oxide on the negative plate, and hence does not interfere in the action. §

Other forms of battery, not included in this list, are modifications of one or other of those before us. We pass on now to a more detailed notice of the effects of voltaic electricity, the mention of several of which has necessarily been anticipated, in order to make the description of each battery understood.

* Proceed. Elec. Soc. p. 358.
† Mech. Mag. 1843.
‡ Ann. der Phys. t. li. p. 384.
§ Arch. de l'Elec. vol. i. p. 93

CHAPTER III.

VOLTAIC EFFECTS.

(341.) MR. FARADAY mentions eight effects as common to several developments of electricity, each of which is modified according to the source whence the electricity is obtained. They are — Physiological Effects — Attraction and Repulsion — Magnetic Deflection — Magnets made — Spark — Discharge by Hot Air — Heating Power — True Chemical Action.*

A few words in addition to what is to be gathered throughout the treatise, will suffice for all but the last two.

(342.) The *Physiological Effects* or *electric* shock, produced by the voltaic discharge, vary according to the size and character of the battery; the shock is obtained by grasping a metal body in each hand and touching the ends of the series: a hot burning sensation is felt at times, while contact is maintained. Other things being the same, it is acute according to the length of the series, and dense or violent according to the size of the plates. Voltaic electricity, in the eyes of early empyrics, was regarded as a means which might terminate in being the "universal panacea," and many strange notions pervaded their prejudiced and partial minds. We must refer our readers to Wilkinson's Galvanism; and those, who are interested in further investigating the medical reputation of this agent, can consult M. Coudret's "Recherches sur l'Electricité Animale," and the medical journals of the passing day, also Becquérel's treatise. They will find that it

* Exp. Researches, Series iii. § 360.

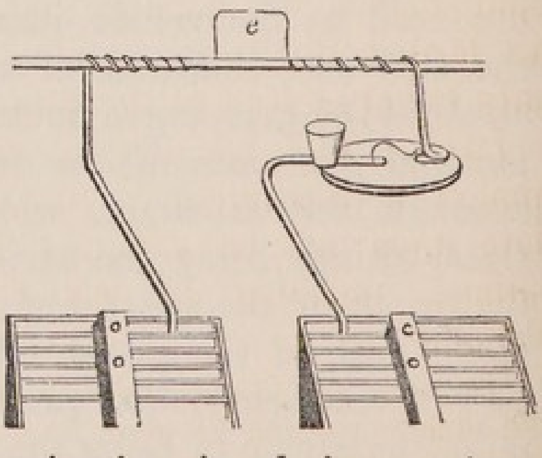
is recognised to a certain extent by the profession, and that, especially in nervous diseases, it is applied with frequent success. These observations are equally applicable to all the electricities.

Attraction and Repulsion have been already mentioned (335.), as the indications of the tension of the ends of a voltaic pile.

Magnetic Deflections and *Magnets made* belong more appropriately to another branch of electricity to be described hereafter (electro-magnetism); we have occasionally (328.), however, had a glimpse at them already.

(343.) *The Spark*, as we have seen, is not obtained *before contact*, except with very extended series; but, after contact has once been made, the terminal wires may gradually be separated, until a considerable length of flame is obtained. (320.) This long flame is, in fact, one form of the *Discharge through hot air*.

Fig. 151.



Professor Faraday demonstrated that heated air will uninsulate a charge, which air in its ordinary condition will insulate, by the arrangement shown in *fig.* 151. Proceeding from the respective ends of a Wollaston's series of twenty pairs, were two copper wires, twisted round a glass rod, and terminating in platinum wires, the ends of which formed a rectangle, as in the figure; but the points were not quite in contact at *e*. The arrangement at the right hand wire is a decomposing apparatus, to indicate the passage of the current. Things being in this condition, no evidence of decomposition was visible, but as soon as a spirit lamp was applied at *e*, so as to heat the air between the platinum points, the current immediately passed and decompo-

sition occurred, which ceased when the lamp was removed.*

(344.) *The heating power* of voltaic electricity has been frequently alluded to; it is manifested in cases where *resistance* is offered to the transmission of a current, as where a thin wire, especially of platinum (a bad conductor), is interposed in the circuit. In this case a greater or less length of a thicker or a thinner wire is elevated to a degree varying with the character of the voltaic arrangements. The thicker the wire, the less is its temperature elevated; the thinner it is, *within certain limits*, the greater is its temperature changed; but if too thin, it will either not be rendered even red-hot, by a series which would fuse a thicker wire; or if it *is* heated, a much less length can affected than with a thicker wire; as for instance, with a series of 160 cells of the constant battery, we were unable to heat platinum wire $\frac{1}{50}$ of an inch in diameter, but heated sixty inches of $\frac{1}{100}$ of an inch in diameter; with the same battery arranged in eight groups of twenty each, we heated thirty-four inches of the thicker wire and only twenty-seven of the thinner.†

(345.) The ignition of wire has frequently been quoted in illustration of the action of a battery; these data must not be accepted but with certain qualifications, included in the following observations of Faraday:—

"The same quantity of electricity which, passed in a given time, can heat an inch of platina wire of a certain diameter red-hot, can also heat a hundred, a thousand, or any length of the same wire to the same degree, provided the cooling circumstances are the same for every part in all cases. This I have proved by the volta-electrometer. I found that, whether half an inch or eight inches were retained at one constant temperature of dull redness, equal quantities of water were decomposed in equal times. When the half inch was used, only the centre portion of wire was ignited. A fine wire may even be used as a rough but ready regulator of a voltaic current; for, if it be made part of the circuit, and the larger wires communicating with it be shifted nearer to or further apart, so as to keep the portion of wire in the circuit sensibly at the same temperature, the current passing through it will be nearly uniform."‡

* Exp. Researches, Series iii. §§ 271, 272.

† Trans. Elec. Soc. p. 69.

‡ Exp. Researches, Series vii. § 853. *note.*

From this it would appear, that a given indication of heat manifested by any length, great or small, of a given wire, evidences the passage of a given *quantity* of electricity. The *size* of wire heated is, therefore, regulated by the quantity of electricity, or comparative size of the generating pairs. But the *length* of such sized wire is due to the comparative number in the series, being, indeed, the power to overcome the resistance of a greater or less length of the interposed fine wire, the *quantity* of passing electricity being the same. The following table is drawn up from the results of experiments with 160 cells of the constant battery. It is entitled to greater confidence from having been constructed from data obtained for another purpose, and collected only on account of the striking coincidences which induced the suggestion of the law already quoted. (*320.*)

" Batteries	8	7	6	5	4	3	2	1	Calculated.	Observed.
	3½	+ 4½	..	..	..	..	..	..	8	12
	3½	+ 4½	+ 6	..	..	..	..	..	14	14
	3½	+ 4½	+ 6	+ 6½	..	..	..	..	20½	20
	3½	+ 4½	+ 6	+ 6½	+ 7	..	..	..	27½	27½
	3½	+ 4½	+ 6	+ 6½	+ 7	+ 5	..	..	32½	34
	3½	+ 4½	+ 6	+ 6½	+ 7	+ 5	+ 5	..	37½	39
	3½	+ 4½	+ 6	+ 6½	+ 7	+ 5	+ 5	+ 4	41½	45 *

The eight batteries of twenty each are numbered; beneath each number is the length of wire ignited by that battery when used alone; the column marked "observed," is the length ignited with two or more batteries in series; the column marked "calculated," is obtained by adding the individual lengths together of the separate batteries. The coincidence between the two columns is remarkable, and seems to show that, "if the mean heating power of each *one* battery be z inches, the heating power of any number n united, would be n *times* z inches.

(346.) For measuring minute elevations in the temperature of wires interposed in the path of small quantities of electricity, Mr. Snow Harris has constructed a very delicate instrument, known as "Harris's thermo-

* Trans. Elec. Soc. p. 63. † Phil. Trans. 1827, p. 18.

electrometer."* It consists of a large glass bulb, connected with a spirit bulb and attached thermometer tube: a platinum wire passes through the large bulb; and (by a recent addition) a silver wire passes, without touching, at right angles to this. When a minute quantity of electricity, as, for instance, the shock from a torpedo, is passed through either wire, the heat expands the air and causes the spirit to rise in the tube.

(347.) The *heating power* of electricity has been successfully employed in place of the common fuse, for blasting on land, and under water. A fine wire is passed through a charge of gunpowder, and its ends are connected with the stout terminal wires, proceeding from the voltaic arrangement. When the circuit is completed, the fine wire is ignited and the powder explodes. The experiments of Mr. Roberts, and the recent experiments of General Pasley, by which the wreck of the Royal George has been removed, and those by which the cliff at Dover has been thrown down, are fresh in the memory of our readers.

TRUE CHEMICAL ACTION.

(348.) The *chemical action* of voltaic electricity, both that which occurs in the respective cells of the series, and that which is produced in an experimental vessel placed in the circuit, is its most important feature. It has been impossible to describe the battery without repeatedly adverting to this property, and therefore many of the leading facts which should be included here, have been anticipated. It remains now to trace out those actions more closely.

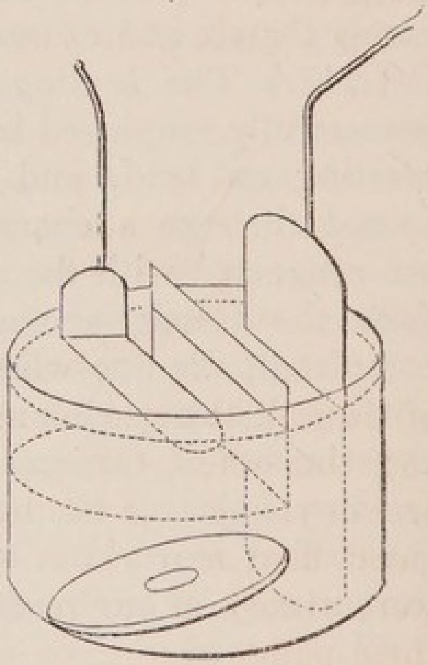
The theory of Grotthus, who appears to have been the first to recognise the production of a series of decomposition and recomposition, along the whole line of the decomposed liquid, has been given in the INTRODUCTION †; but he included in this theory the idea that the poles,

* Phil. Trans. 1827, p. 18.

† Vol. I. p. 135.

i. e. the metallic terminations, respectively had an *attraction* for oxygen on the one hand, and hydrogen on the other; over-looking a very obvious objection, that these very poles which were assumed to have the power of extracting oxygen from combination, had not the power of retaining it when liberated.

Fig. 152.



(349.) The error of his position is rendered evident by the famous experiment of Faraday, given in *fig.* 152. A glass basin had a division of mica fixed across the upper part, so as to descend one inch and a half below the edge; solution of sulphate of magnesia was carefully poured in till it rose a little above the edge of the mica; a platinum plate connected with one end of a voltaic battery, was placed in the right hand division, with a block of glass resting against it, in such a manner as to direct any gas, which might be given off, away from the left hand division. Into the left hand division was poured distilled water, in such a manner as to preclude mixing, until the liquid on each side rose nearly to the top of the vessel; a platinum plate connected with the other pole of the battery, was then placed in the left hand division, when the whole presented the appearance in the figure. The action had not continued long before a sensible portion of the sulphate of magnesia was decomposed, and the magnesia made its appearance, *not at the metal pole*, but at the surface, indicated by the dotted lines, where the sulphate solution ended, and the distilled water began; in fact, at *a water pole*, or more properly speaking, at the *termination of the sulphate solution*.*

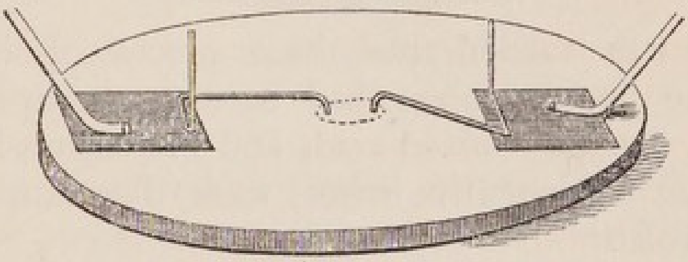
(350.) Not only did he succeed in eliminating the

* Exp. Researches, Series v. § 494.

elements of a compound thus against a boundary of *water*, he has also effected it against *air* in another series of researches, when he was tracing out the identity of the electricities,— when demonstrating, as in the following experiment, that the electricity from the ordinary machine gives cases of *true polar decomposition.*

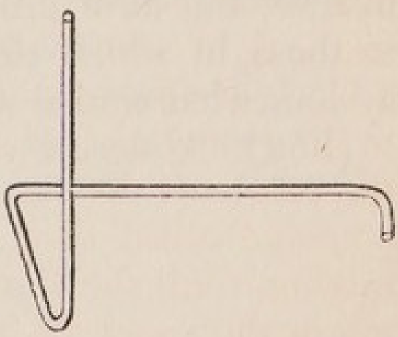
On a glass plate (*fig.* 153.), were placed two pieces

Fig. 153.



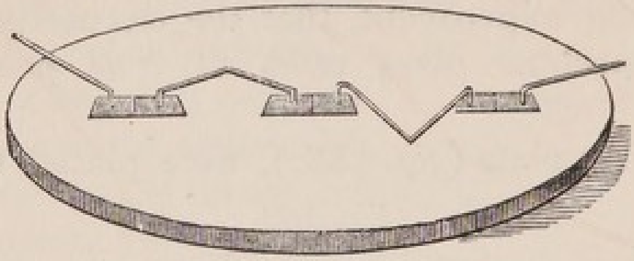
of tin foil, the one connected with the prime conductor, and the other with a good discharging train, by wires or wet string. Two pieces of platinum wire were provided, bent as in *fig.* 154. These were placed, as in *fig.* 153, with their points resting on a drop of sulphate of copper, shown by the dotted lines; or upon a piece of filtering paper containing sulphate of indigo in muriatic acid, or iodide of potassium in starch; or upon a piece of litmus paper containing solution of common salt or of sulphate of soda; or upon turmeric paper containing sulphate of soda. In all these cases the solutions were decomposed: in the 1st, metallic copper coated the end of the negative wire; in the 2nd, the indigo was bleached by the chlorine evolved about the positive wire; in the 3rd, iodine was liberated at the positive wire, forming the blue iodide of starch; in the 4th, the litmus paper was reddened by the acid evolved at the positive wire, or, when muriatic acid was used, was bleached by the chlorine; in the 5th, the turmeric paper was reddened at the negative wire by the alkali there liberated.

Fig. 154.



The experiment was extended, by placing a series of compound pieces of litmus and turmeric paper, moistened with sulphate of soda, as in *fig.* 155: when the

Fig. 155.

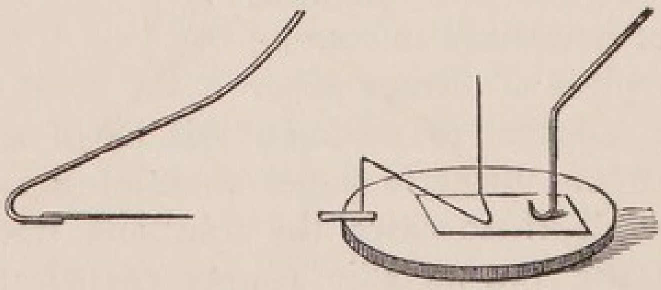


machine was turned, the three pieces of litmus on which the positive wires had been made to rest, were reddened by the evolved acid, and the turmeric papers, supporting the negative wires, were discoloured by the evolved alkali.

(351.) The above experiments, which very plainly show the *identity of voltaic with frictional electricity*, are, it is true, but cases of decomposition with *metal* terminations. We could not omit them from this treatise, and have introduced them *here*, as preliminary to those in which elements were released against *air*, by somewhat similar arrangements.

(352). A piece of tin-foil, on a glass-plate (*fig.* 156.),

Fig. 156.

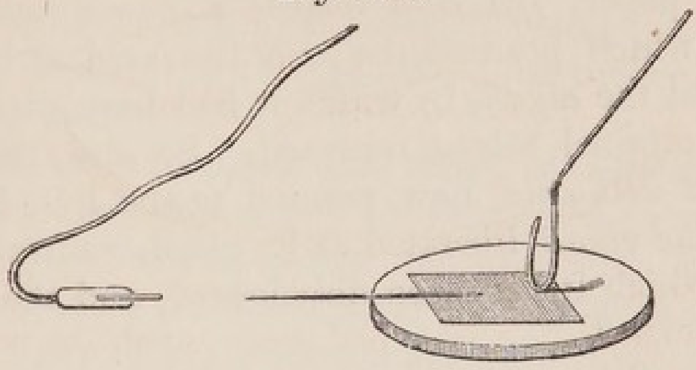


was connected, as before, with the prime conductor of the machine; the bent wire (*fig.* 154.), was placed on the tin-foil, with its point resting on a piece of turmeric paper, moistened with sulphate of soda; opposite to, and about two inches from the turmeric paper, was a metallic point connected with a discharging train. After forty-eight or fifty turns of the machine, the end of the turmeric, in contact with the air (that which is

at the left hand in the figure), was deeply coloured by the presence of free alkali.

Again: the arrangement was reversed, as in *fig* 157.,

Fig. 157.

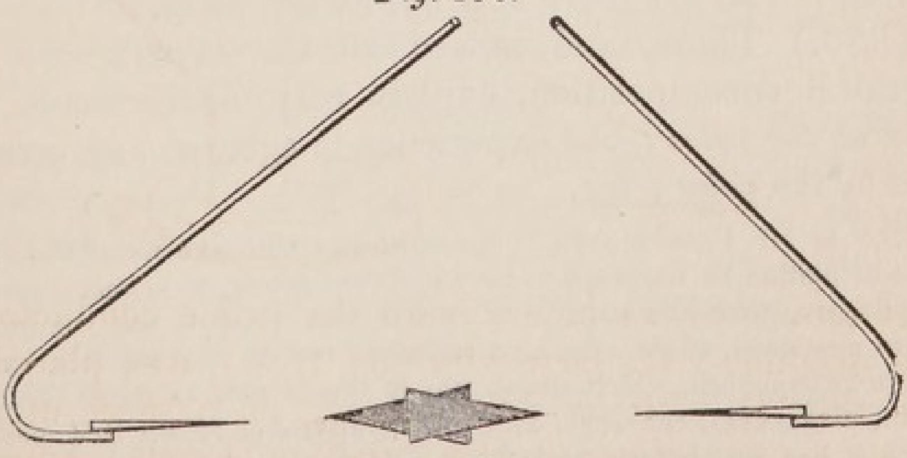


so that the pointed wire should rest on the tin-foil, and the paper which, in this experiment was litmus moistened with sulphate of soda, rest on the end of the discharging train. After a very few turns, the end of the litmus in contact with the air, was discoloured by acid.

In these three cases, the solutions were terminated at one end by *metal*, and at the other by *air*.

Arrangements were now made, in which there was no metallic communication with the decomposing solution, as in *fig*. 158., where a piece of the moistened

Fig. 158.

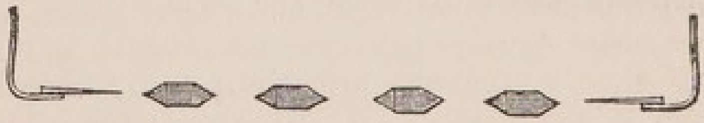


turmeric and another of the litmus paper are supported on wax between, and at about half an inch distant from two needle points, one proceeding from the prime conductor, the other from the discharging train. The litmus paper which points to the right, became reddened

with the *acid*, and the turmeric was simultaneously reddened with the *alkali*. On turning the paper conductor round, so that the relative position of its points was inverted, the natural colour was restored. The turmeric paper, *red with alkali*, now pointed to the right, in which position the *acid* liberated at its point, neutralized the *alkali*, by which it had been discoloured, and the original colour returned. So also, the litmus paper, *red with acid*, now pointed to the left, in which position the *alkali* liberated at its point, neutralized the *acid* by which it had been discoloured, and the original colour returned.

Finally. Four such compound conductors, as those in the last experiment, were placed, as in *fig.* 159.; and the respective ends of each pair gave similar evidence of the elimination of the elements against the *air;*

Fig. 159.



i. e. "against the electrified boundary surfaces:"—in fact, "they indicate at once an internal action of the parts suffering decomposition, and appear to show that the power, which is effectual in separating the elements, is exerted there and not at the poles." *

(353.) These, and indeed all the experiments on chemical decomposition, explain why the elements *appear at the poles;* but experience is against any *attraction by the poles;* for,

"If," as Mr. Faraday says, "in accordance with the usual theory, a piece of platina be supposed to have sufficient power to attract a particle of hydrogen, from the particle of oxygen with which it was the instant before combined, there seems no sufficient reason, nor any fact, except that to be explained, which shows why it should not, as those of gravitation, magnetism, cohesion, chemical affinity, &c. *retain* that particle which it had just before taken from a distance and from previous combination. Yet it does not do so, but allows it to escape freely." § 536

As, for instance, the magnesia liberated in the experiment with a water-boundary (349.), after being freed

* Faraday, § 471.

from a much more powerful attraction in an opposite direction, is not in the least degree affected by the pole, which has been said to *attract it*. And, the pole which has power, as the theory would have it, to attract *gold from combination*, has no power to attract free *particles of gold* floating in the liquid. The theory, therefore, confutes itself.

(354.) From these and other considerations Professor Faraday laid down the principles on which electro-chemical decomposition depends, with more clearness and more in accordance with general observation than did any of his predecessors. He says: —

"The evolved substances are *expelled* from the decomposing mass, not *drawn out by an attraction*." § 537.

"It appears to me that the effect is produced by an *internal corpuscular action*, exerted according to the direction of the electric current; and that it is due to a force either *superadded to*, or *giving direction to the ordinary chemical affinity* of the bodies present." § 518.

"I conceive the effects to arise from forces which are *internal*, relative to the matter under decomposition, and not *external*, as they might be considered, if directly dependent upon the poles. I suppose that the effects are due to a modification, by the electric current, of the chemical affinity of the particles through or by which that current is passing, giving them thē power of acting more forcibly in one direction than in another, and consequently making them travel by a series of successive decompositions and recompositions in opposite directions, and finally causing their expulsion or exclusion at the boundaries of the body under decomposition, in the direction of the current. . . . . I do not believe that a substance can be transferred in the electric current, beyond the point where it ceases to find particles with which it can combine." § 524.

(355.) The poles, according to this view, being "only the doors or ways by which the electric current passes into and out of the decomposing body," he proposes to banish this term, which, in some sense, involves the ideas of attraction and repulsion, and to substitute for it the word *electrode*.* The propriety of this term is recognised, by its being now very generally adopted among electricians.

(356.) In describing the gas battery (333.), mention was made of the exact correspondence between the chemical changes occurring in each cell of the bat-

* From ἤλεκτρον and ὁδὸς, *a way*.

tery, and those manifested in the decomposing apparatus. This law was thus laid down by Faraday: —

"*The chemical power of a current of electricity is in direct proportion to the absolute quantity of electricity which passes;*" and "*the amount of electro-chemical action is also a constant quantity,* i. e. *would always be equivalent to a standard chemical effect founded upon ordinary chemical affinity.*" §§ 783. 505.

(357.) This led to the construction of the volta-electrometer, or voltameter, as an actual measurer of the electricity passing. One form of this instrument is given in *fig.* 160. It consists of a glass bottle with two necks, into one of which is fitted a graduated glass tube. Two wires, terminating within in platinum plates, are hermetically sealed in the tube, their projecting ends serving for connection with the battery. The vessel being filled with acidulated water, and the stopper placed in, is inverted, so that the air is expelled from the tubes, while the liquid is substituted. On placing it the circuit, oxygen gas is given off at one electrode, and hydrogen at the other; and for every *nine* grains of water decomposed, *eight* grains of oxygen and *one* of hydrogen are liberated; and *thirty-two* grains of zinc are consumed in each cell. The voltameter is made in various forms, either for collecting the gases separately or combined: in all cases the electrodes must be either gold or platinum, or the oxygen would combine with them, as we have seen it combine with zinc in the various generating cells. *Fig.* 161. is another form of the instrument.

Fig. 160.

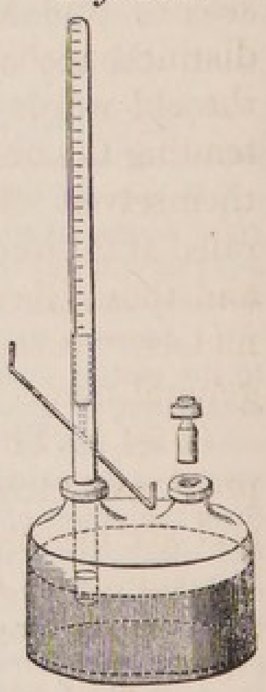
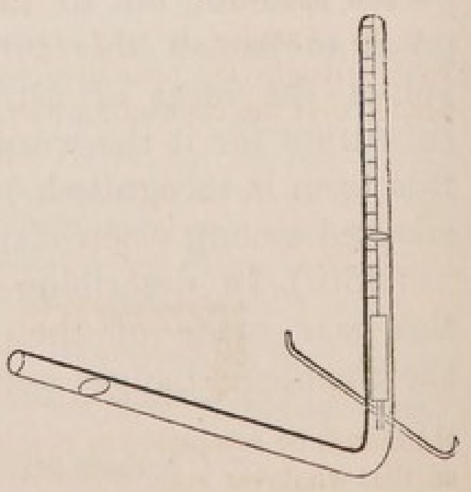


Fig. 161.



(358.) From λύω, to loosen, Professor Faraday has named decomposable bodies "*Electrolytes;*" and the act of decomposition, "*Electrolyzation.*"

He has also called the boundary where the current enters an electrolyte, the "*anode*,"* and that where it leaves the electrolyte the "*cathode*."† In the single cell (*fig.* 142.) the zinc plate is in contact with the anode, and the copper with the cathode; in the voltameter the plate where oxygen is given off impinges on the anode, and that where hydrogen is liberated on the cathode. Many electricians at home and abroad, either intentionally or through misapprehension, had acquired the habit of applying these terms to the electrodes or metal plates *themselves*; and Mr. Grove, finding the inconvenience of no distinctive character being given to the electrodes, unless the old words positive and negative, determined on extending the original application of the terms to the metals themselves. Professor Faraday called those bodies liberated at the *anode*, as oxygen, chlorine, iodine, "*anions*;" and those liberated at the *cathode*, as hydrogen and the metals, "*cathions*;" and to all of each class he gives the general name "*ions*." ‡

(359.) These explanations will render intelligible previous extracts wherein these words were introduced, and are necessary for the comprehension of the following summary of certain ascertained facts relating to the chemical action of the voltaic current:—

"1. A single *ion*, *i. e.*, one not in combination with another, will have no tendency to pass to either of the electrodes, and will be perfectly indifferent to the passing current §, unless it be itself a compound of more elementary *ions*, and so subject to actual decomposition.

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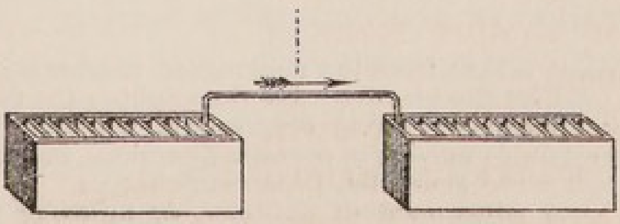
* *ανω, upwards.* † *κατα, downwards.* ‡ *ιων, going.*

§ Mr. Faraday is very particular in defining a current. If two voltaic troughs are connected, as in *fig.* 162., with a magnetic needle suspended over the connecting wire, no effect will occur to the needle, until

Fig. 162.



the circuit be completed by connecting the other ends with another wire, so that whatever state the wire may possess, antecedent to the circuit's

"2. If one *ion* be combined in right proportions with another strongly opposed to it in its ordinary chemical relations, *i. e.*, if an *anion* be combined with a *cathion*, then both will travel, the one to the *anode*, the other to the *cathode*, of the decomposing body.

"3. If, therefore, an *ion* pass towards one of the electrodes, another *ion* must also be passing simultaneously to the other electrode, although from secondary action it may not make its appearance.

"4. A body decomposable directly by the electric current, *i. e.* an *electrolyte*, must consist of two *ions*, and must also render them up during the act of decomposition.

"5. There is but one *electrolyte* composed of the same two elementary *ions*; at least, such appears to be the fact, dependent upon a law that *only single electro-chemical equivalents of elementary ions can go to the electrodes and not multiples.*

"6. A body not decomposible when alone, as boracic acid, is not directly decomposible by the electric current, when in combination. It may act as an *ion*, going wholly to the *anode* or *cathode*; but does not yield up its elements, except occasionally by a secondary action. . . . .

"7. The nature of the substance of which the electrode is formed, provided it be a conductor, causes no difference in the electro-decomposition, either in kind or degree: but it seriously influences, by secondary action, the state in which the *ions* finally appear. Advantage may be taken of this principle in combining and collecting such *ions*, as if evolved in their free state, would be unmanageable.

"8. A substance which, being used as an electrode, can combine with the *ion* evolved against it, is also, I believe, an *ion*, and combines in such cases in the quantity represented by its electro-chemical equivalent. . . . .

"9. Compound *ions* are necessarily composed of electro-chemical equivalents of simple *ions*. For instance, sulphuric acid, boracic acid, phosphoric acid are *ions*, but not *electrolytes*, *i. e.*, not composed of electro-chemical equivalents of simple *ions*.

"10. Electro-chemical equivalents are always consistent; *i. e.*, the same number which represents the equivalent of a substance A, when it is separating from a substance B, will also represent A, when separating from a third substance C. Thus, eight is the electro-chemical equivalent of oxygen, whether separating from hydrogen, tin, or lead. . . . .

"11. Electro-chemical equivalents co ncide and are the same with ordinary chemical equivalents." *

These laws are just as applicable to the actions going on in the several cells of the battery, as to the decom-

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being completed, it differs from the subsequent condition; and the latter alone appears to affect the magnet. He thus defines the two states: —

"By *current* I mean any thing progressive, whether it be a fluid of electricity, or two fluids moving in opposite directions, or merely vibrations, or, speaking still more generally, progressive forces. By *arrangement* I understand a local adjustment of particles, or fluids, or forces, not progressive." § 283.

* Exp. Researches, Series vii. §§ 826—836.

posing cell; for the *liquid* throughout the series is undergoing *electrolysis*.

Professor Faraday has established many other important facts, as, that as solid *electrolytes* are liquified, they acquire the power of *conduction* and *decomposition;* that water is not, as some have thought, essential in an electrolyte; that compounds formed by a powerful affinity, as water, are more easily decomposed than those dependent on weak affinities, as glass; that the electricity which decomposes, and that evolved by the decomposition of a certain quantity of matter, are alike, being each the representative of the actual quantity of electricity, or electric power, belonging to different bodies; that metallic contact is not necessary for the production of the voltaic current; that the forces termed chemical affinity and electricity are one and the same; that an electrolyte is essential to a voltaic circuit. These several deductions will find their illustrations in many of the voltaic arrangements which have been described. We must now proceed to explain the *secondary actions* alluded to in Nos. 3., 6., and 7., which will greatly assist in comprehending the *rationale* of the application of electrolysis in the arts.

(360.) If acid water is included in a voltaic circuit by means of electrodes of platinum, it is decomposed, and the two elements, oxygen and hydrogon, are given off at the respective plates; and the anode always gives off oxygen, and the cathode hydrogen. This liberation of the gases is termed a primary result. But if the anode be of copper instead of platinum, the case is altered; for the oxygen, instead of being given off, combines in its nascent state with the copper, and forms an oxide of that metal, soluble in the acid water; so that hydrogen is obtained at the cathode as before, and sulphate of copper is formed at the anode. Again, if the sulphate of copper is allowed to accumulate in the liquid, the cathode will soon cease to give off gas; for the nascent hydrogen will combine with the oxygen of the metallic oxide in solution, and the metal will be set free. These

are illustrations of the two kinds of secondary action; in the one case, the liberated element combines with the electrode and consumes it; in the other, it combines with an element previously combined with another and in solution, and sets free the other. (372.) Instances of these secondary actions are most abundant, and may be traced in every voltaic arrangement except Grove's gas battery. They are of great avail in practice; for we are often enabled to associate their action with that of the voltaic current, and produce decompositions at a small expense of generating power.

ELECTRO-METALLURGY, ETC.

(361.) This reduction of metal by secondary action is no new thing in electro-chemistry; but the idea of reducing metal in *different forms*, and of a *definite character*, is of comparatively recent date; and it is jointly due to Prof. Jacobi, of St. Petersburg, and to Mr. Spencer, of this country. By the former, the art was termed the "*Galvano-plastic;*" and in England it had received from Mr. Bachhoffner the name of "*Electrotype.*" Mr. Smee, one of the earliest writers on the subject, termed it "*Electro-metallurgy;*" and, from its very varied and extensive application in working the metals, in conditions to which the words *plastic* and *type* are most assuredly inapplicable, we are now inclined to adopt the latter designation.

The electro-metallurgic operations divide themselves into two classes: — 1st, those which are effected at the *cathode* (358); 2d, those which are affected at the *anode*; and the latter are sub-divided into erosion and deposition.

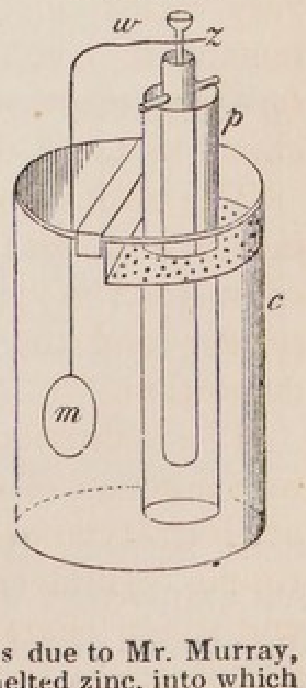
The reduction of metals from their solution is seen in the action of a Daniell's battery; and before the idea of electrotype occurred, films of metal deposited on the copper cylinder, would peel off and present the lines and other characteristics of the original surface: but the hint was lost on many of us. It was but to keep

the action in proper order, and provide suitable surfaces to collect the metal upon; and an art, now practised by every schoolboy, was introduced.

(362.) The simplest form of experiment is to copy a seal. A wax impression is *very* slightly moistened with alcohol; and black lead* is rubbed over it with a stiff brush, by which means a conducting surface is given to it. A piece of copper wire is then warmed and pressed into the margin of the wax, care being taken to complete with black lead the conducting connection between the wire and the impression. To the other end of the wire is attached a piece of zinc, about two inches square. The wire is bent so that the zinc and the seal come face to face; and the zinc end is placed in a water-tight card diaphragm, containing salt water. The card is placed in a glass of saturated solution of sulphate of copper; and, after remaining twelve or more hours, a thick mass of metallic copper will be found on the seal; which copper, when removed, will present a faithful copy of the seal, in its minutest detail.

In the same manner, wax moulds of medals, or plaster medallions are treated. A more convenient arrangement is given in *fig.* 163., where *z* is a rod of zinc, *p* a porous clay diaphragm, *c* a cell of glass or earthenware, *w* a copper wire connected to the zinc by a binding screw, and *m* the seal or mould. The zinc may be used, if unamalgamated, with salt and water; or, if amalgamated (312.), with acid water. The latter is the better, because the crystallization of the salt in the pores of the diaphragm is apt to disintegrate it; and for other reasons.

Fig. 163.

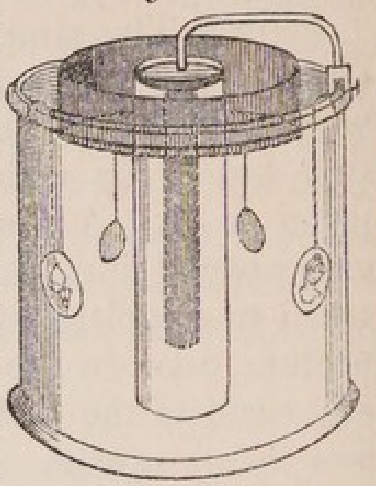


Another form, in which several moulds can be introduced at once, is

* The application of black lead for this purpose is due to Mr. Murray, of Regent Street. At Elkington s they have found melted zinc, into which a few pieces of iron have been placed, when powdered, advantageous to mix with the plumbago.

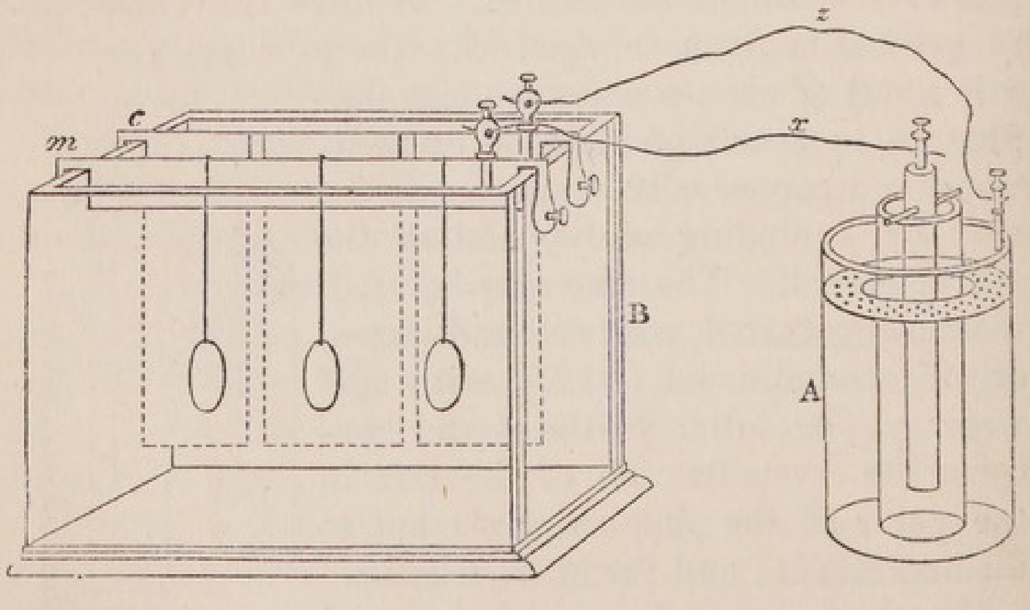
given in *fig.* 164. In this case, the zinc rod is connected with a rim of metal about the upper edge of the cell, on which the moulds are suspended. The action is maintained by supplying the copper solution with crystals of the sulphate, which are generally placed on shelves introduced for the purpose. It is only while the due adjustment between the size of the elements (of which the mould is one), and the strength of the solution, is maintained that the "reguline" metal, as Mr. Smee has termed it, is deposited.

Fig. 164.



(363.) In practice, on account of some inconveniences connected with the management of the single cell, as the above arrangements are termed, two cells are often employed; one for generating the electricity, which may be a Daniell (315.), a Smee (326.), or other constant arrangement; and another for a working cell. *Fig.* 165. represents such an arrangement. A is a con-

Fig. 165.

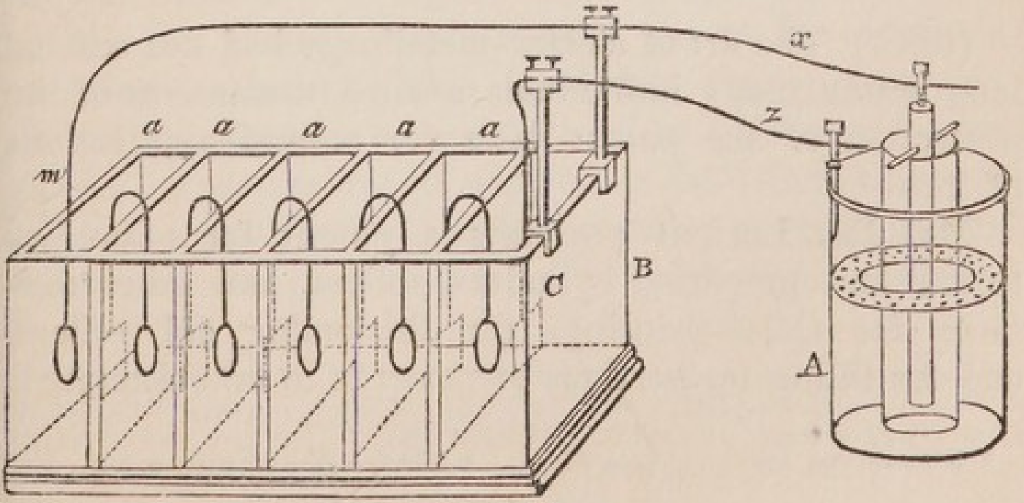


stant battery, B the decomposition cell, *m* a metal rod for supporting the moulds, *c* a similar rod for supporting copper plates; the wire *x* connects the moulds with the zinc of the battery, the wire *z* connects the copper

plates with the copper of the battery. The cell B contains a mixture of *one* part sulphuric acid, *two* parts saturated solution of sulphate of copper, and *six* or *eight* or *more* parts of water, according to circumstances. The actions, which take place with such an arrangement, have been already described (360.); copper is *consumed* from the plates *c* by union with the oxygen liberated there, and copper is *deposited* on the moulds *m*, by the secondary action of the nascent hydrogen; and this consumption and deposition are exactly equal; so that, so far as this action is concerned, the solution is in the same condition at the *end*, as at the *beginning* of the experiment. Had platinum plates been used instead of copper *c*, the deposition would have occurred at the expense of the solution, which would soon have been exhausted; and, in that case, one generating cell would not have done the work. It will be seen in the arrangement before us, that the cell B offers very little resistance to the current; for the affinity of the oxygen for the copper is of the same character, though less in degree, and exerted in the same direction as the affinity of the oxygen for the zinc in the generating cell A.

(364.) Taking advantage of this feeble resistance, we have been in the habit of accomplishing a series of as many as *six* depositions of metal, by means of *one* generating cell. *Fig.* 166., by which this is effected, will be understood at a glance. The reduction of six equivalents of copper is thus obtained at the expense of

Fig. 166.



but one equivalent of zinc; or for every $32\frac{1}{2}$ grains of zinc consumed, $6 \times 31.6 = 189.6$ grains of copper are obtained. The solutions, in the cells *a*, are to be more diluted than when only one operation is going on.

(365.) The following observations will show how the generating power and the work must be adjusted, in order to ensure the "reguline" deposits, which we just now mentioned (362).

"If the battery is *too large*, or the copper-plate in the decomposition cell is *too large*, or if the mould is *too small*, *hydrogen*, as well as copper, will be released, and the deposit will be the dark powder, a dull red, a violet, or a black powder. The same will occur if the solution in the decomposition cell contains too *much* acid, or too *little* sulphate of copper.

"If the battery is *too small*, or the copper-plate in the decomposition cell *too small*, or if the mould is *too large*, or if the decomposition cell contains too *little* acid, or too *much* sulphate of copper, or if the weather be too *cold*, the copper will be deposited *very* slowly, and will present a dull-red exterior, or be of a very brittle texture, or will be thrown down in a crystalline form.*

These principles are embodied by Mr. Smee into the following laws: —

"Law I. — The metals are invariably thrown down as a black powder, when the current of electricity is so strong in relation to the strength of the solution, that hydrogen is evolved from the negative plate of the decomposition cell.

"Law II. — Every metal is thrown down in a crystalline state, when there is no evolution of gas from the negative plate, or no tendency thereto.

"Law III. — Metals are reduced in the reguline state, when the quantity of electricity in relation to the strength of the solution is insufficient to cause the production of hydrogen on the negative plate in the decomposition trough, and yet the quantity of electricity very nearly suffices to induce that phenomenon." †

(366.) The art of electro-metallurgy had not existed long before many individuals availed themselves of the protection of the patent laws for several applications of it: —

Mr. Jas. Lockett possesses a patent for manufacturing and preparing cylinders, rollers, and other surfaces for calico-printing, for thickening old rollers, and for filling up portions of patterns to be obliterated.

* Electrotype Manip., §§ 63, 64. † Electro-Metallurgy, p. 115., &c.

Mr. William Tudor Mabley has a patent for producing printing or embossing cylinders or blocks, from designs executed in parts,—for joining disconnected metallic plates into one connected surface,—for adding to the surface of a plate, in order to extend the design, —for producing designs in relief, by depositing copper on a plate which has previously been prepared by covering with varnish, tracing the design through the varnish, and covering the whole with *plumbago*,—or on a lithographic stone similarly treated,—or on a design, punched on sheet-lead,—for producing sets of plates for printing in colours,—for making button-dies, and dies for embossing,—for mounting seals and tools,—and for making seals.

Mr. Alex. Jones has a patent for making pipes, boilers, stew-pans and other vessels of copper by depositing the metal on moulds of clay, wax, plaster, &c., or on metals which melt at a lower temperature than copper;—also for joining pieces together to form vessels.

Mr. Ed. Palmer has a patent for producing printing surfaces, which are popularly known as "Electro-tints:" a painting is made with some kind of varnish on a copper plate; the whole is black-leaded, and a copper deposit is thrown down, which, when removed, is printed from.*

Mr. Islam Baggs has a patent for improvements in printing, whereby colours are given to fabrics by electrolytic action.

Mr. Ed. Palmer has a second patent for producing printing surfaces. This he terms "Glyphography." A smooth copper plate, after being blackened by sulphuret of potassium to enable the draftsman to see his work, is coated with a certain etching ground, through which the design is traced. The high lights are now

* Prof. von Kobell of Munich, on making such a plate, examines the proof: if too faint, he deposits copper on the plate, and thus obtains a mould, to which he can make the necessary corrections; he then deposits again and obtains a fresh plate.

built up with non-conducting materials to prevent their printing: the whole is made conductive, and an electro-copper plate is formed on it: this is soldered on a block of wood and used as a wood-cut, and is called an *electro-glyphographic* cast. Or the plate, after etching, has a plaster cast taken from it: from this the high lights are cut out; it is then oiled, and a second cast is taken, from which a stereotype copy is to be made. This is called a *stereo-glyphographic* cast.

Dr. Leeson has a patent for improvements in the art of depositing and manufacturing articles by electric agency.

(367.) But, besides the operations we have here described of depositing metals on moulds or other prepared surfaces, from which the metal is to be subsequently removed, there are cases in which the metal is to remain where it is deposited. Gilding and plating are of this class.

The solutions employed are the auro-cyanide and the argento-cyanide of potassium, best made by dissolving neutral chloride of gold, or cyanide of silver respectively in pure cyanide of potassium — the sulphates of gold or silver — and the carbonate of silver. The operation is conducted in the same manner as for the deposition of copper. Many precautions are necessary to ensure adhesion between the surfaces, &c., into the detail of which we cannot now enter.

The patentees for these applications, in order, are G. and H. Elkington, J. S. Woolrich, and Ed. Tuck.

Of course, the same operations, properly regulated, are of equal avail in the deposition of other metals: and we have first on the list of patentees, James Shore, for coating or covering manufactured articles composed of wrought or cast iron, lead and copper and its alloys, with copper or nickel; and Messrs. Elkington for electro-zincing, by which means they protect iron from the effects of oxidation, consequent on exposure to the atmosphere. Their process, if we may judge from the specimens, promises to be very advantageous. The

sulphate of zinc in solution is employed by the patentees. The same gentlemen have recently obtained a patent for producing metallic cloth, or rather cloth with a metallic coating on one side. They prepare it for various purposes, among which are roofing, packing, &c. Electro-coppering from a cyanide solution is also patented. The only other patent of which I am aware is one possessed by Mr. Ogilthorpe Barrett, for the precipitation of metals.

(368.) Such of our readers as are curious to know the many electro-metallurgic processes, both at home and abroad, which are not patented, may consult some of the treatises on the art.* De la Rive was the first to obtain a deposit of gold, but his process was not available in practice. M. de Ruolz has experimented to some extent on gilding and plating; so has M. Becquérel. Basket-work, fruits, leaves, flowers, the grasses, and even insects,—also busts, statues, and medallions, have in turn received coatings of copper and other metals; indeed, the whole detail of the art, and its many ramifications, give it an unusual degree of interest. Daguerréotype plates have been made by this means: yes, and even Daguerréotype pictures have been *copied*. For the sake of contrast, in order to show the universal interest in the art, we may mention, on the one hand, that we were lately in conversation with one of the watchmen on the Great Western Railway, who had with him several very excellent electrotype impressions, which were the product of his leisure hours; and, on the other hand, that His Imperial Highness the Duke of Leuchtenberg has not only experimented on it, but has added to its applications that modification termed by M. Jacobi, Galvanography, which consists in writing on a metallic surface with varnish, and then allowing copper to deposit and *grow over* the lines, so that a plate fit for printing is obtained.

* Vide Jacobi's Galvano-Plastic, translated by Sturgeon, Smee's Electro-Metallurgy, and Walker's Electro-type Manipulation.

But we must now pass on to describe the effects which occur at the anode, or place where the electricity enters the decomposition cell.

(369.) With few exceptions, we have noticed the very general destruction of the anode or positive metal in the several voltaic arrangements. It is prevented by using platinum (360.) or gold, in cases where oxygen is the liberated element; but even these metals are destroyed, when a compound containing chlorine (322.) is acted on. Hence has originated "electro-etching," an art for which Messrs. T. Spencer and J. Wilson have a patent. It includes etching on iron and steel by a solution of common salt; on silver by sulphate of soda or sulphate of silver; on gold, by hydrochloric acid; on copper, by sulphate of copper, and on metals generally. The process is extremely simple. To a polished copper plate, for instance, is affixed a wire, the back of the plate is varnished, and the face is covered with etching ground;—the design is traced through the etching ground by a fine point;—the plate is then suspended in a decomposition cell, B (*fig.* 165.), on the rod *c*, which is in connection with the copper of the battery; on the rod *m*, facing the prepared plate, is suspended an equal sized piece of copper. The oxygen, liberated by electrolysis, having access to the exposed parts of the plate only, combines with those portions of the copper, and in a few minutes (ten perhaps) the plate is etched;—the fine parts are now stopped out with Brunswick black, and the operation is renewed;—the half-tints are then stopped out, and a few minutes' more action completes the etching.

Mr. Grove, by following out the principles of electric affinity, has even etched Daguerréotype plates. The dark and light portions of these pictures are respectively *silver* and *mercury*. Not finding an electrolyte whose element would act on one of these metals, and not on the other, he selected dilute hydrochloric acid, the chlorine of which has a *greater* affinity for silver than for mercury. After a very brief action, the

original design assumes the appearance of a sienna-coloured drawing, from the film of oxy-chloride formed: on washing the film away with ammonia, and rinsing in distilled water, a perfect etching is discovered, from which faint prints may be obtained.*

Another mode of etching, in which the design is obtained in relief, is due to the Duke of Leuchtenberg:—he makes a sketch as before (368.), with varnish, on a copper plate; he then connects the plate as the anode in the decomposition cell, and thus erodes all the uncovered metal, leaving of course those portions in relief which are protected by the varnish.

(370.) We have yet another feature to notice of the action at the anode; it is the *deposition on it*, under certain circumstances, *of a metallic peroxide*. When a polished steel plate in a saturated solution of acetate of lead is made the positive pole of a series of two or three, and a pointed wire from the negative end of the series is held over and near the plate, metallic lead is liberated on the wire, as in previous experiments, and a brilliant series of coloured rings make their appearance on the plate. By varied mechanical adjustments, such as using metal patterns instead of points and discs, with interposed patterns cut in card, the colours may be arranged into various figures; these are called "metallo-chromes." †

If *small* steel plates are used, and larger metal discs are opposed to them, a single tint may be given to each plate; and, by regulating the duration of the experiment, and the distance between the plates, a gradation of tinted plates may be produced. This is called "Nobili's Chromatic Scale." The first tint is produced in about *two* seconds. There is very great difficulty in the actual manipulation; for, from the varying circumstances of the experiment, and its extreme delicacy, the production of too high or too low a

* Proceed. Elec. Soc. p. 94.

† Vide Nobili, Scient. Memoirs, art. v. vol. i.; Gassiot, Proceed. Elec. Soc. 4to. p. 190.; Electrotype Manip. part ii. p. 43.

tint is a common occurrence. We have ourselves succeeded indifferently well conjointly with Mr. Gassiot, in producing a series of about *forty* tints.

"The colours commenced with what Nobili terms silver blond, being the colour of very light hair, and progress on with darker gradations to fawn colour; and thence through violet shades to indigoes and blues. . . . From the blue, the tints pass through pale blue to yellow; thence through orange to lake; thence through bluish lake to green and greenish orange; thence through rose orange to greenish violet and green; and thence through reddish yellow to rose lake, which constitutes the highest or 44th colour of Nobili's chromatic scale." *

The above extract from Mr. Gassiot's paper will give some idea of the beauty of these productions. It is somewhat surprising that experiments of such exceeding brilliancy are not more frequently repeated. From the year 1829, when Nobili first described them, till they were successfully revived by Mr. Gassiot in 1839, they had been little noticed; and ever since that time, there have been few who have attempted them.

The colours in these experiments arise from thin films of peroxide of lead, deposited on the plate; and are thus far analogous to the colours of a soap bubble, or the celebrated Newton's rings. The peroxide is the effect of electrolysis: — the oxygen liberated finds in the solution a *protoxide* of lead †, for which it has a great affinity, and uniting with this, the *peroxide* of the deposit is formed.

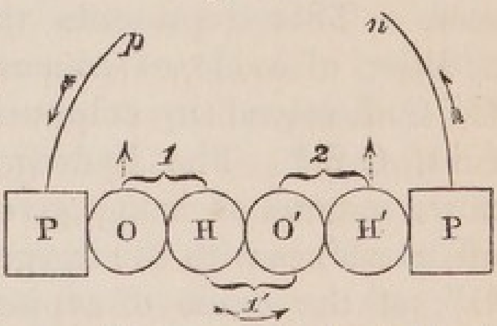
(371.) M. Becquérel has turned these affinities to practical account in some very recent researches. ‡ Guided by the fact that peroxides are not affected by atmospheric influences, he was induced to apply them as protecting coatings to metals, especially to iron, exposed to atmospheric action. He has employed the peroxide of lead, and the peroxide of iron; the former, obtained from a solution of protoxide of lead in caustic potash, the latter from protoxide of iron in ammonia.

* Proceed. Elec. Soc. p. 191. 4to.
† Acetate of lead being protoxide of lead, in acetic acid.
‡ Compte Rendu, July 3. 1843.

It is not well to electrolyze these solutions for *practical* purposes in the same manner as when Nobili's films are obtained; because the extraction of *metal* at one electrode, and *oxide of metal* at the other, would soon exhaust the solution. It is therefore placed in a porous tube within a vessel containing dilute nitric acid:— a platinum plate in the acid is connected with the negative end of a constant pair, and the object to be coated, which is placed in the metallic solution, is connected with the positive end;—if, instead of nitric acid, in the outer vessel, there is an alkaline solution, minus the metal, the same effects may be obtained, but it requires a series of generating pairs.

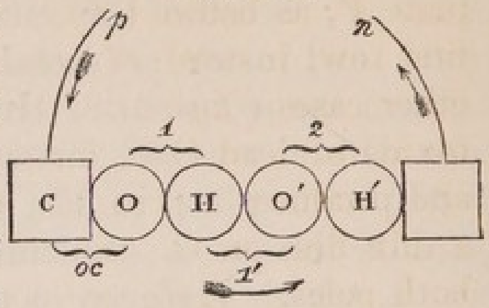
(372.) We are induced here to give four diagrams to illustrate these various electro-metallurgic operations, and, with them, electrolytic actions generally. *Fig.* 167. represents two platinum electrodes P P connected respectively by the wires *p*, *n*, with the positive and negative ends of a voltaic series. Between them are two particles of water, each particle consisting, as is well known, of an equivalent O of oxygen, and an equivalent H of hydrogen. Before the current passes, these elements exist together as water, as shown by the links (1) and (2); but, when the current passes, the element O of the first particle (1) of water is liberated, and ascends, in the direction of the dotted arrow, as gas: the element H of the said first particle (1) combines with the element O′ of the second particle (2), still producing a particle of water (1′), as represented by the lower link: the hydrogen H′ of the second particle is thus liberated, and ascends in the direction of the dotted arrow, in the form of gas: nothing is here lost, but, in place of two molecules of water, there remains but one molecule, and enough of the two gases to make another molecule.

Fig. 167.



If an oxidizable metal, as copper, C (*fig.* 168.), is made the positive pole or anode, the oxygen is not set free; but, from the affinity existing between nascent oxygen and copper, combination takes place and a molecule (*o, c*) of oxide of copper is produced. This in fact is the principle of electro-etching.

Fig. 168.



If a metallic solution, as sulphate of copper, is used, neither oxygen nor hydrogen is set free. To the former diagram, other things remaining the same, I have now added (*fig.* 169.) a second row of molecules (of which, to avoid confusion, part only is expressed), and also a third row. This represents the addition of oxide of copper; O″ C dissolved in sulphuric acid, O S.* The hydrogen now, instead of being given off, combines with the oxygen O″, of the oxide of copper, as shown by a thick line, and the copper C′ is liberated and deposited on the plate P. This is the principle of the reduction of metals by electrolysis. It is here seen that C′ is taken *out* of the solution; but the action illustrated in *fig.* 168. simultaneously prevails; and C being taken *in*, the strength remains unimpaired (363.). If C were platinum, of course it would not combine.

Fig. 169.

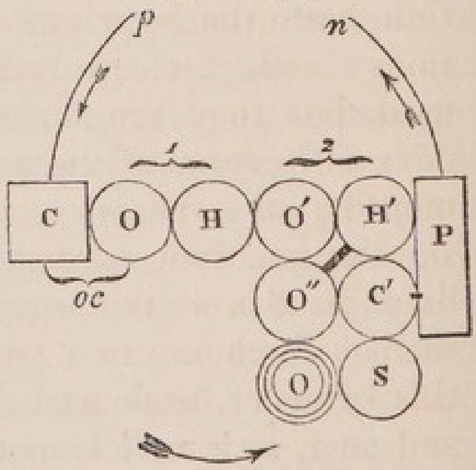
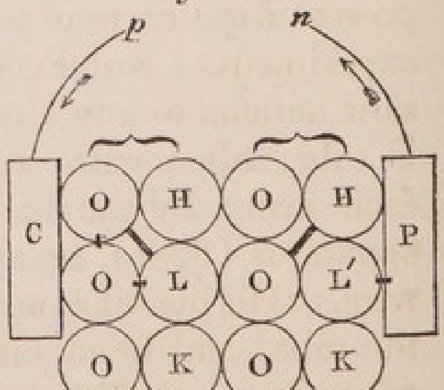


Fig. 170.



Lastly, in *fig.* 170. the first row represents molecules of water; the second protoxide

* The triple circle is to show that sulphuric acid is 1 S+3 O.

of lead O L, dissolved in O K, oxide of potassium or caustic potash: in this case metal L′ is deposited on plate P, as before (*fig.* 169.); but the oxygen O in the first row, instead of combining with the copper as in other cases (*figs.* 168, 169.), combines with the protoxide of lead O L, for which it has a greater affinity, and produces a peroxide, O O L, which is deposited in a thin film on C. In this case metal is abstracted at both poles. Here we have the metallo-chromes, and Becquérel's experiments.

SLOW ACTIONS.

(373.) This universal power of electro-chemical action has even been employed in producing crystallizations; and, for this purpose, very feeble actions are used, but they are continued, not merely for hours or days as in some of the cases before us, but for weeks or months, or even, in some instances, years: by which slow action, time is given to the several crystalline products to assume the isomorphous characters peculiar to each. Bucholz, in 1807, made some experiments on this subject: he poured a metallic solution into a glass; and on it he carefully poured distilled or acid water, so that no mixture should occur: he plunged a plate of copper into the vessel, and one end became coated with reduced metal after several hours immersion.* In the present day this would be called an electro-metallurgical experiment. But Becquérel is the first to have carried slow actions to any extent:—He took, for instance, a U tube, filled with metallic solution, having a wire in each arm: by the feeble current of a thermo-electric apparatus (534.), he deposited copper on the negative wire. He placed a tamping of asbestus in the bend of the tube, and filled one arm with solution of sulphate of copper, and the other with salt water. He connected them with an arc of copper wire. After a time, on

* Annales de Ch. et de Ph. t. lxvi. p. 166.

one end of the wire metallic copper appeared; on the other, octohedral crystals of the double chloride of copper and sodium.* Similar double chlorides of other metals were obtained in like manner. On substituting sal ammoniac for sea-salt, the crystals were double chlorides of *ammonia* and the metals. In like manner were double iodides obtained. A test tube was partly filled with deutoxide of copper, and on it was poured solution of nitrate of copper; a copper plate was then thrust to the bottom of the tube. In a fortnight, red, transparent octahedral crystals of protoxide of copper † were found on the lower portion of the plate. With sub-acetate of lead, a plate of lead, and litharge, protoxide of lead was obtained in dodecahedral crystals with pentagonal faces, or in silky filaments. With a U tube, containing hydrochloric acid and silver in one arm, connected with carbon in the other, octohedral crystals of chloride of silver, similar to those found in nature, appeared on the silver. Chlorides of other metals were obtained by similar means. The bend of a U tube was tamped with moist clay; into one arm was poured hyposulphite of potash, and into the other nitrate of silver, which were connected by silver wire. Metallic silver appeared on the end contained in the nitrate; and, on the other, there were produced, in the early stages of the action, prismatic crystals of the double hyposulphite of silver and potash; and afterward, beautiful octohedral crystals of sulphuret of silver. Other sulphurets were obtained by like means, as were also iodurets. In reference to these experiments, after mentioning the *regular action of electrolysis*, which we have seen in all the forms of voltaic apparatus, M. Becquérel says: —

"*That* is what takes place wherever the force of the battery is sufficient to effect the decomposition of both solutions. But, if it can only decompose one of them, then the elements of this are transported into the others,

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* Common salt being chloride of *sodium*.

† Mr. John Davy, without being aware of these experiments, had also obtained the same protoxide.

where they generally produce modifications, which lead to the formation of new compounds." *

(374.) He now examines other cases of slow action: —Two vessels, one containing solution of sulphate of copper, and the other alcoholic solution of sulpho-carbonate of potash, are connected by a U tube filled with clay moistened by nitrate of potash:—a piece of copper in the sulphate is connected with a piece of lead in the other vessel. On the copper plate metallic copper is precipitated; on the sides of the other vessel, neutral carbonate of potash crystallizes; on the lead, &c. double sulpho-carbonate of lead and potash in acicular crystals, carbonate of lead, and probably sulphate of potash and sulphate of lead; and finally, a deposit of sulphur in octohedral crystals with rhomboidal faces. In acting on organic compounds, hydrated carbonate of lime was formed from lime dissolved in syrup. Solution of proto-chloride of iron was placed in one arm of a U tube, and chloride of sodium in the other; in the former was a piece of zinc, connected with a piece of platinum in the latter: small crystals of iron were after a time deposited on the platinum. Zirconium was reduced from an hydro-chlorate containing a little iron; the first results were an alloy. Glucinum and oxide of titanium were also reduced. Magnesium was reduced with difficulty.

He also obtained sulphurets by another method:— Sulphuret of mercury was placed in a test tube, and on it was poured a solution of chloride of magnesium. A piece of metal was thrust to the bottom of the tube, and the apparatus hermetically sealed. After six weeks' action, the lower portion of the tube was covered with regular tetrahedral crystals of pure *sulphuret of lead*.

(375.) By some such molecular charges as are evidenced in these slow actions, M. Becquérel believes that the carbon is transferred during the conversion of iron into steel; and, as he expected, on connecting the

* Traité de l'Electricité, &c., vol. i. p. 337.

respective ends of a test instrument with the iron and the carbon, during the progress of this operation, he detected a powerful electric action from the iron to the carbon: and in like manner he believes the changes in the essential character of rocks to be brought about.

(376.) The arrangement for producing *arragonite* is more complex than those above. A U tube, filled with moist clay, connects a closed vessel containing chloride of calcium, with another containing saturated solution of carbonate of lime in carbonic acid; and a third vessel generates carbonic acid to keep the second supplied. The negative pole of a water battery of thirty pairs is placed in the second vessel, and the positive in the first. After twenty days, crystals of carbonate of lime appeared in the second vessel: they were not rhombohedral, like the primitive carbonate of lime; but were quadrangular prisms, with the usual characteristics of arragonite.

(377.) The character of this treatise does not permit the introduction of the actually chemical, though doubtless essentially electrical experiments, by which M. Caigniard Latour obtained silicates; we can only mention how M. Becquérel proceeded electrically. He placed a silicate and an aluminate of copper in a test tube, and filled it with a solution of sea-salt; he thrust in an iron wire: after a time rectangular-faced crystals, characteristic of a silicate or a sub-silicate of alumina appeared on the inner surface of the tube. Again, he placed a saturated solution of silex in hydrochloric acid of commerce in one tube, and salt water in another, with zinc in the latter, and platinum in the former. And the proper connections being made, he obtained first an alloy of silicium and iron (for the acid of commerce contains a little iron), and then almost pure silicium.

(378.) Unacquainted with these experiments, our countryman, Mr. Crosse, was pursuing similar investigations, and by somewhat varied adjustments he obtained the same general results. From a cavern near

Broomfield, the top of which is studded with crystals of arragonite and carbonate of lime, he took some water, and found it to contain about ten grains of carbonate of lime, and a little sulphate, per pint. After electrolyzing this for ten days with 100 pairs of the water-battery, he obtained rhomboidal crystals of sulphate of lime; and in three or four weeks the negative wire was covered with them. The same electrolysis was performed in the dark with thirty-nine pairs, and the negative wire was twisted round calcareous stone; in six weeks the negative wire was covered, and, in eight months, thickly encrusted, with similar crystals. He allowed the water, in another experiment, to fall drop by drop, on a piece of brick, which he electrolyzed with 100 pairs of the watery battery: in four or five months, carbonate of lime, in a more or less crystalline form, and very fine prismatic crystals of arragonite, were found on the brick: the latter were on the side toward the positive pole, the former on that toward the negative. In like manner, he operated with eleven large cells of the water-battery, on acid fluo-silicate. After six weeks, the lead from the acid occupied the end of the negative wire, and little crystals of silica the extremity of the lead. In two or three months there was perceived at the bottom of the vessel, a six-sided prism terminated by a pyramid, and in all respects like quartz. Solution of silicate of potash was acted on for several weeks by 160 cells of the water-battery, when fifteen or sixteen hexagonal crystals were obtained. A piece of schist was suspended by platinum wire in a similar solution: hexagonal masses of gelatinous silica appeared around the positive wire; and they were followed by a formation of chalcedony.

"Mr. Crosse has formed with voltaic apparatus of high tensions, — calcareous spar, arragonite, quartz, protoxide of copper, arseniate of copper, blue and green carbonates, phosphate and sulphuret of copper, carbonate of lead, sulphuret of silver, rough carbonate of zinc, chalcedony, oxide of tin, yellow oxide of lead, sulphurets of antimony and zinc, black oxide of iron, sulphuret of iron, and crystallized sulphur."*

* Becquérel, vol. v. p. 291.

Mr. Crosse found that crystals of carbonate of lime were obtained from lime-water in *ten* days in the light, but in *six* in the dark. He is in possession of a large and beautiful tree of crystallized and arborescent silver formed in the dark in fifteen months, with twenty cells of the water-battery. He once formed a stalactite of well-crystallized arragonite, half an inch in length.*

(379.) More recently he has published some further results. By placing zinc ingots, covered with resinous coatings, in metallic solutions of copper, silver, or lead, he obtained in a few weeks crystals of the metals at the expense of the zinc, to which the acid gradually had penetrated. By burying zinc or other easily oxidizable metals in plaster of Paris, and boiling it in sulphate of copper, he obtained perfect octohedral crystals of metallic copper. Iron was imbedded in plaster, over which was strewed dry sulphate of silver: after a fortnight's constant boiling, the plaster was found interspersed with crystals or arborescent forms of silver, *quite insulated.* Pipe-clay was kneaded into a common basin, and in it were imbedded a piece of limestone, and a sea-shell; the clay was covered with a mixture of decomposing sulphuret of iron and river-sand, in which was placed another sea-shell. A pint of water was poured in; and during one year and three days, while the experiment lasted, about a pint more was added. The basin was kept in the dark. On examination, the limestone was covered with well-defined crystals of *sulphate of lime*, in rhomboids and prisms: a few similar crystals were on each of the shells. This change of *carbonate* into sulphate of lime was just in accordance with some natural phenomena, which had given rise to these experiments. A common red brick, resting on two half bricks, was placed in an earthen pan, filled with spring water, which contained a little chlorine; platinum wires connected the respective ends of the brick

* Trans. Elec. Soc. p. 121.

with a sulphate of copper battery of nine pairs; the upper surface of the brick was half an inch above the water. At the end of a year the experiment was terminated. The positive end of the brick was easily removed; but the negative required some force to detach it from the half-brick, and it was found cemented by snow-white crystals of *arragonite,* fifty times more abundant than they had been found in any preceding case; among them were some exquisitely formed crystals of carbonate of lime in cubes, rhomboids, and six-sided prisms. At the other end of the brick were a few small crystals, of another kind apparently. At the bottom of the pan was a quantity of white carbonate of lime, in minute crystals, which also surrounded the sides of the vessel. In this experiment the lime is obtained from the brick by the presence of the small quantity of chlorine, which serves over and over again. In a saucer, containing concentrated solution of nitrate of potassa, was placed a flat polished piece of white marble, on which was a common sovereign; a piece of platinum wire, from the positive end of a series of eight pairs of Daniell's, rested on the coin, and was retained there by a glass rod pressing on it; the marble was connected with the negative pole. The nitric acid liberated from the potassa, soon attacked the marble near the coin, which, in three days, was embedded in the marble; and, when removed, left a tolerable impression. If a very minute quantity of hydro-chloric acid be in the solution, and the lower end of the glass rod be ground, it will be very fairly gilded in a few days. A piece of clay slate, in a dish of spring water, was connected with the negative end of eight Daniell's, and a piece of limestone with the positive: after two months, the positive wire had eaten into the limestone, and the negative wire was covered with crystalline carbonate of lime, which, on general inspection, appeared like a grove of translucent fir-trees, but when closely examined, the branches were found to consist of rhomboids growing out of each other. The carbonates of

strontia and baryta, the sulphate of baryta and quartz, were obtained by similar means.

We cannot close this division of our subject better than with M. Crosse's opinion of these slow, but long-continued actions: —

"Now, although subterraneous electric currents are supposed by Mr. Robert Fox, and by others, with good reason, to be constantly traversing metallic and other lodes, and to have occasioned the crystalline and other deposits therein, this would by no means account for the far more numerous and extensively disseminated variety of insulated crystalline bodies found in all parts of the globe. It would be absurd to suppose that a separate electric current of any extent belongs to each of these lodes, or even to each separate stratum in which they are found. If this were the fact, we should have electric currents crossing each other in all directions, alike complicated in their origin and effects. We have, however, as it seems to me, no necessity for travelling so far out of the way, as the *local electric action existing between dissimilar bodies*, with the addition of water and a porous medium between the two opposing substances or solutions, or substance and solution, as the case may be, is quite sufficient to account for the origin of such insulated crystalline matters." *

(380.) There is an intimate connection between these slow molecular actions and the varied phenomena of phosphorescence; but the investigation of this branch of electricity would require more space than could be fairly allotted to it; it is therefore better only to allude to it here, and refer those who would investigate the phenomena to Becquérel's fourth and fifth volumes, and to some recent experiments by Mr. Pollock.†

ASSAYING BY VOLTAIC MEANS.

(381.) A very interesting application of electro-chemical action is in assaying. Mr. Martyn Roberts, many years ago, practised it in the mining districts of this country; M. Becquérel has long practised it in France. A quotation from Mr. Roberts, and another from M. Becquérel, will explain two means of effecting this: —

"If in an ore, containing iron, copper, silver, — metals, whose affinities for oxygen stand in the order in which I have placed them, — we wish to ascertain, first, the quantity of silver, and afterwards that of copper in the

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* Proceed. Elec. Soc., p. 322. † Ibid., p. 537.

sample, dissolve the ore, and make a galvanic pair of silver as a negative, and copper as a positive plate; then immerse it in a measured quantity of the solution: the silver only is thrown down, because copper cannot throw down copper; and copper, as a positive plate, will not throw down iron, because the acid in which the ore is dissolved, already holds the iron in solution with greater force than the affinity of the acid for copper, — the positive pole. Having thus assayed for silver: into another measured portion of the ore in solution, immerse a galvanic pair of iron as a positive plate, and either copper or silver as a negative; copper only is now thrown down, as iron cannot throw down iron." *

Practically, for assaying copper ores, Mr. Roberts would now construct a single-cell apparatus of a cylinder of iron and one of copper: the iron plate is in dilute muriatic acid, contained in the porous cell, and the copper plate in the surrounding solution of the ore in nitro-muriatic acid; the gain of the copper, in weight, gives the value of the ore. M. Becquérel's mode of extracting gold from a mixed ore will illustrate his process generally.

"Let us commence upon a solution of gold and copper in aqua regia. The solution, which has been rendered as neutral as possible, is poured into the diaphragm (p. 329. *fig*. 142.), and this is placed in a vessel containing a solution of copper of the same degree of concentration, and in which a plate of copper is immersed; in the other is a plate of platinum; the two plates are placed in connection. The copper is immediately attacked with the formation of proto-chloride; the electric current, which is developed, has an intensity sufficient to decompose the chloride of gold, and not the chloride of copper. . . . .

"If we desire to extract the gold from a solution of lead, copper, iron, and gold, a solution of the three former must be prepared in the same proportions, so as to have very nearly the same density, and the experiment must be conducted as before, operating with a pair of platinum and copper. . . . .

"To extract the copper without touching the other metals, the solution of the three mteals must be replaced by another containing lead and iron. Thus, by operating with a pair of lead and platinum, or iron and platinum, the copper would be obtained." †

(382.) These are both cases of *quantitative* analysis; one object of the French philosopher in using, to excite the positive element, a similar solution to the other, *minus* the metal to be extracted, is, that he may avoid the effects of endosmose, — the passage of the liquids from one cell to the other. The method of *qualitative*

* Proceed. Elec. Soc., p. 511.

† Vide Proceed. Elec. Soc., p. 450. Compte Rendu, Jan. 24. 1842.

analysis practised by M. Becquérel, as early as 1823 * is this : —

" We may detect very small quantities of copper in gold, and even determine whether one specimen of gold contains more alloy than another: in fact, let us take a spoon of perfectly pure gold ; and solder it to a platinum wire which is immersed into one of the mercury cups, in which the extremities of the wire of the galvanometer terminate ; let us then place in the spoon some nitric acid, free from nitrous gas, and plunge in it the piece of gold, held in platinum nippers [connected with the other end of the galvanometric wire] : should the piece of gold contain copper, its action on the nitric acid determines a current from the gold spoon to the nippers," &c.

(383.) One more practical illustration of the influence of electro-chemistry in the arts of life, ere we close, unwillingly, this chapter : —

" Tin, as we know, precipitates copper from its solutions ; and neverthe- ess tin is precipitated from its solutions, in the action of tinning pins. If the pins are introduced into a solution containing tin, a mixture of one part of subtartrate of potassa, two of alum, two of sea-salt, and a certain quantity of water, the pins never become tinned, however long a time they may be left immersed in the solution ; but if a *piece of tin* is placed in the solution so as to touch the pins, they are immedietely tinned : the pins, which are not touched by the tin, are not tinned. To explain the effect produced, it must be remarked that the tin which is immersed, suffers a feeble chemical action from the solution, in consequence of which the metal becomes negative and the solution positive ; in making contact with the brass pins, they become the negative element of the voltaic pair, the energy of which is sufficient to determine the precipitation of the tin, which is, in common cases, easily reduced by the employment of the single pair." †

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* Ann. de Chim. t. xxiv. p. 347. 1823.
† Becquérel's Traité, vol. iii. p. 348.

CHAP. IV.

DRY PILES.

(384.) THE term DRY PILE was intended originally to express a voltaic pile, of which all the elements were solid; and the advantages of such an instrument, if it could be discovered, were so apparent that the attention of electricians was directed to it at an early period in the history of Voltaic discovery. If a pile composed of solid elements (thought they) could but be discovered, neither evaporation nor chemical action could take place; the electricity due to the contact of heterogeneous bodies, according to Volta's theory, would be continually evolved; and as the bodies evolving it would suffer no change, the qnantity and intensity of the electricity supplied by the instrument would be absolutely uniform and invariable.

(385.) The earlier attempts at the construction of dry piles have been already noticed (INTROD. (183.)). The instrument invented by DE LUC, and improved by ZAMBONI, is prepared by soaking thick writing paper in milk, honey, or some analogous animal fluid, and attaching to its surface by common paste or gum a thin leaf of zinc or tin. The other side of the paper is coated with peroxide of manganese, in a minute state of subdivision, applied with a cork. A number of leaves of this paper are then laid over one another, the sides similarly coated being presented upwards, and discs are cut by pressing on them a circular cutter about an inch in diameter, each action of the cutter supplying as many superposed discs as there are leaves of paper. Several thousands of these discs, thus obtained and laid over each other, are pressed into a close and compact

column by means of a screw, and the surface of the column is then thickly coated with gum-lac to prevent the humidity from being dissipated.

386.) The sources of the disengagement of electricity in this pile are various and complicated. Besides what may arise from the contact of heterogeneous substances, chemical action intervenes in several ways. The organic matter acts upon the zinc as well as upon the peroxide of manganese, reducing the latter to a lower state of oxidation.

Zamboni examined the effects produced on the electricity of the pile by soaking the paper to which the tin leaf was pasted in different liquids, and found that, according as the state of the other side of the paper was changed, the poles of the pile were thrown to different ends. If the paper be soaked in oil, the poles are in a direction contrary to that which they assume when a coating of manganese is used. On the other hand, when the paper is soaked in honey, in an alkaline solution, a solution of the sulphate of zinc, or half curdled milk, the poles have the same position as when they are coated with manganese.

No sensible shock is received from a pile of two thousand pairs, although the tension at the poles is sufficient to produce a sensible effect on the proof plane, and a condenser applied to one of the poles will, in a few moments, give sparks an inch in length, and a Leyden battery may receive from it a charge.

The conducting power of the vapour suspended in the atmosphere, carrying away a portion of the electricity of these piles from their poles, produces a continual variation in the tension of the electricity at these points.

Zamboni found that the energy of the pile was greater in summer than in winter, whether measured by the tension of the electricity at the poles, or the rate at which the fluids were produced and propagated. M. Donné compared the tension with the height of the barometer, but could discover no relation between them.

He found the tension the same in a vacuum as under the pressure of the atmosphere.

The most useful purpose to which the dry pile has been applied, is to augment the sensibility of the electroscope. The manner of applying it to this instrument has been explained in p. 28.

(387.) It is known that electricity may be developed on a plate of a single metal, by causing one surface of the plate to be acted on chemically, in a degree or manner different from the other surface. This may be effected by merely rendering one surface smooth and the other rough. This expedient is said to have been resorted to in the construction of a voltaic battery with one metal, without any liquid element. From sixty to eighty plates of zinc, of four square inches of surface, are made clean and polished on one side, the other remaining rough as it comes from the mould. These are fixed in a wooden trough parallel to each other, their polished surfaces all turned towards the same end of the trough, and with an open space between the successive plates of from the tenth to the twentieth part of an inch. These intermediate spaces are filled by thin plates of atmospheric air. If one extremity of this apparatus be put in communication with the ground, and the other with an electroscope, the latter will receive a very sensible charge.

(388.) We can regard the dry pile in no other light than as an extended voltaic series. The moisture, which is essential to its activity, is in the condition of any thing but freedom of motion ; so that the renewal of contact by the presence of fresh particles, which seems essential in all developments of electricity, exists in the lowest degree ; and then again the feeble chemical actions existing between elements under circumstances so unfavourable, all conspire in producing the small quantity of electricity for which these instruments are remarkable ; while the great length of series produces the high tension of the poles. It is only recently that chemical decomposition has been obtained

by the dry pile. Mr. Gassiot prepared 10,000 Zamboni's discs; and by carefully directing the electricity through hydriodate of potassium on a slip of glass, he obtained the development of iodine on the wire connected with the oxide of manganese end of the series. He could not obtain heating effects on Harris's thermo-electroscope, unless he allowed the charge to pass in sparks.

The idea of obtaining an *actually dry pile* seems now to be abandoned: it would be a case of power without consumption, force without motion: the most enthusiastic for the old form of the contact theory could only have hoped for the discovery, through having overlooked the fact that *change of place* is included, in every case in which electricity is developed; the change being in some instances evident to the eye, in others evident to the mind.

BOOK THE FOURTH.

ON MAGNETISM.

(389.) We are not in a condition to examine the action of voltaic currents on magnets, or their mutual action on each other, constituting as it does the important source of electro-magnetism, until the phenomena of magnetism itself have been explained. Without reiterating what has been already advanced in the Introduction (p. 191.), respecting the directive power of magnetic needles, and their dip or deviation from the horizontal plane, let us at once seek an insight into the characteristics of magnetism, by examining what takes place in some of the processes of magnetization which are there described, as well as in others to be mentioned as we go on: and, for this purpose, we commence with the principle which presents itself in all electrical phenomena, as antecedent to every development — Induction.

If a line be drawn on a table, and on its length be placed a bar-magnet and a bar of soft iron, in the vicinity of each other, the iron bar will instantly acquire magnetic virtue. If its ends be called A and B, and A be contiguous to the south end of the magnet, B will acquire southern polarity, and A northern. The shorter the interval between the magnet and the iron, the more powerful will be the effect. The most favourable condition of the experiment is, the actual contact of the two bodies; and, under these circumstances, there is a strong attraction between the magnet and the iron. It is thus seen, that in magnetic phenomena, like electrical, the condition of charge is preceded by the act of induction; and that the attraction in this

case, which is *apparently* between a magnet and a piece of iron, is *actually* between two magnets, presenting to each other opposite poles. Now, when the iron is removed from its vicinity to the magnet, it loses its magnetic power just as speedily as it acquired it.

(390.) If, however, the experiment be repeated with a small bar of steel, in place of the iron bar, the steel will take a longer time in acquiring the magnetic virtue; but, unlike the iron, it will *retain* the power, more or less unimpaired, for years. The harder the steel, the more permanent is the effect. Without theorizing much upon the difference in the molecular structure of the various kinds of iron and steel, let it suffice to recognise this marked difference in their conduct in respect to magnetism. Steel may be looked upon as a compound of iron + carbon; and the carbon may, in some sense indeed must, operate in resisting the *reception* of magnetic charge, and in resisting its *separation*.

(391.) There are cases of retentive magnetism, in which the place of carbon is otherwise supplied; one may be selected, which occurred to M. Becquérel, during his experiments on slow voltaic action (374.) :—

"In the negative tube I placed a solution of protochloride of iron, and in the other a solution of chloride of sodium. In the latter I simply place a zinc plate, and in the other a platinum plate, in mutual connection. At the end of a certain time, *iron* is deposited on the negative plate in very *small crystals*, the grouping of which on the plate presents a glittering appearance. Sometimes the crystals are so near each other, that one might fancy the metal had been poured on the plate. These plates possess *magnetic polarity*, which in the outset arises from the *action of the current*, and afterwards from the *solution of continuity*, which exists between all the parts of the deposited layer, — *which solution supplies the place of the carbon in steel.*"*

A somewhat similar illustration may be gathered from Dr. Knight's method of forming artificial magnets with an iron paste : —

"Having provided himself with a large quantity of clean filings of iron, Dr. Knight put them into a tub that was rather more than a third full of

* Traité, t. i. p. 344.

clean water; he then, with great labour, worked the filings to and fro for many hours together, that the friction between the filings of iron by this treatment might break off such small parts as would remain suspended in the water for some time . . . The water being by this treatment rendered very muddy, he poured it into a clean earthen vessel: when the water had stood long enough to become clean, he poured it out carefully, without disturbing such of the iron sediment as still remained, which was now reduced to an almost impalpable powder. This powder was afterwards removed into another vessel, in order to dry it. . . . . The next thing to be done was to make a paste of it; for this purpose he had recourse to linseed oil. . . . . This paste was then put upon wood, or sometimes upon tiles, in order to bake or dry it before a moderate fire. . . . When that was done, and the several baked pieces were become cold, he *gave them their magnetic virtue*, by placing them between the extreme ends of his magazine of artificial magnets for a few seconds or more, as he saw occasion. By this method the virtue they acquired was such that, when any one of these pieces was held between any of his best ten-guinea bars, with its poles purposely inverted, it immediately, of itself, turned about to recover its natural direction, which *the force of these very powerful bars was not sufficient to counteract.*" *

A more forcible case may be taken from Dr. de Haldat's experiments: —

"The magnetic force may be communicated to a mass, composed of molecules of iron, independent of each other, and contained in a copper tube, and polarity may be given to it . . . these independent molecules may be mixed with a powdered substance, which is not sensibly susceptible of acquiring magnetic virtue; and that even five parts of powdered quartz for one of iron may be introduced, without destroying the magnetism of the mixture, which still *preserves its polarity*. It is readily seen that magnets composed in this manner of independent molecules, can *preserve their polarity* only as long as the molecules which compose them *preserve their respective situation*. And, in fact, by vibrating the tube with sufficient force to *change their relations*, *polarity is destroyed*. These facts prove that the magnetic force resides in the *intimate molecules*; for *protoxide of iron*, being employed in the same way as the filings, gives the same result." †

(392.) Thus much on the probable *insulating influences*, so to speak, which *resist* the impartation of magnetism, but *retain* it when imparted. An obvious question here arises; — if these resistances can be overcome in *one* direction, so that steel *gains* magnetic

* Phil. Trans. vol. lxix. p. 51. — Note: Ingenhouz made paste magnets with iron dust, or which was better, load-stone dust, and a mixture of cheese and quicklime.

† Ann. de Chim. t. xlii. Elec. Mag. vol. i. p. 150.

virtue, how is it that they are not similarly overcome in the *other* direction, so that the steel shall *lose* its magnetic power, when the exciting cause is *removed?* The solution of this question will lead to a further exposition of magnetic phenomena. Take a bar magnet, and apply to its south end the point of a sewing-needle; a very brief contact will suffice to produce permanent magnetism, and directive power,—the point of the needle, when freely suspended, turning to the north. Now, we may assume R to represent the molecular resistance, which the needle opposed to the reception of its present magnetic condition; and it is evident that the magnet had *power, x, to overcome this resistance.* When the magnet is removed, the resistance R is to be overcome, before the virtue is lost. But, when the needle is freely suspended, there is not only no force present to overcome R; but there is actually a force, weaker, indeed, than the original force *x*, but exerted in the same direction, with therefore a tendency to resist the loss of magnetism. This force is the *polarity of the earth.*

(393.) Since the *north* end* of the needle has a certain directive power, it follows that the force which *attracts* it must correspond to the *south* end of a magnet. So, in the sequel, wherever the north magnetic pole of the earth is spoken of, it must be remembered, that it possesses south magnetic polarity. But we have seen (390.) that the south end of a magnet increases rather than diminishes the contiguous north polarity of a needle; and thus is magnetism retained, so far as the influence of the earth is concerned.

(394.) But the case would be widely altered, if the *north* end of the magnet were now applied to the *north* end of the magnetized needle. In this case the direction

* The word pole is often ambiguous in magnetic nomenclature; for, if we talk of the north magnetic pole of a *needle*, and the north magnetic pole of the earth, the language would indicate *points endowed with the same virtue;* whereas, the north pole of the earth, and that of the needle, are *endowed with the opposite virtue*, for they *attract* each other. It is often better to use the word *end*, when speaking of a needle or magnet.

of the power x, coincides with that of the resistance R, and it would be free to act: first, it would overcome the resistance to *de*-magnetization R, and *destroy* the magnetism of the needle; secondly, it would overcome the same resistance R, to *re*-magnetization, and would magnetize the needle, so that its point should now be a *south end*.

(395.) We are thus prepared to see the use of pieces of soft iron, termed *keepers*, which we are taught to apply to magnets when out of use. *Fig.* 171. represents

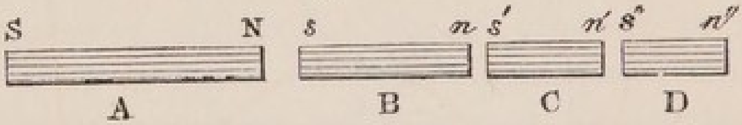
Fig. 171.

two bar magnets, with two pieces of soft iron, A, B. The end N of the upper magnet and the end S′ of the lower, are jointly occupied in producing a south end s, and a north end n, in the soft iron bar A; while the end S of the upper, and the end N′ of the lower, are producing in the bar B a north end n', and a south end s'. The whole system is, therefore, according to the illustrations we have given, favourable to the retention and even exaltation of the magnetic power of each magnet. The arrows represent the general direction of the action. The same sort of thing occurs with the keeper of a horse-shoe magnet. We are hence led to see the mischief which would occur if the bars were misplaced, so that their ends n and n', should be in the same direction; here would be counter-actions, each operating to reduce the other: and, as we have just seen (394.) in the case of a large and small magnet, the weaker has a tendency to give way. These considerations will also show why magnets, placed away without regard to their direction, have a tendency to lose power:

and this is one cause of the loss of power in magnets; for if the weak, though distant, action of the *north* pole of the earth be allowed to act on the *south* end of the needle, a gradual demagnetizing action is going on.

(396.) The mode of magnetizing which we have introduced (389, 390.), does very well on a small scale, and for short bars or needles, but not for longer bars. In *fig.* 172., let A be the magnet, and B, C, and D the

Fig. 172.



longer bar, or, which comes to the same, three portions of a bar, broken after magnetization; the nearer part will be the more powerful magnet; and the pole *s* will be more powerful than the pole n''; the neutral point not being equidistant from the extremities; so that if these pieces constituted one bar, the magnetized intensities of the two ends would differ; and thus constitute one imperfect magnet. The fact, too, that a bar thus broken exhibits in *each* piece *both* polarities, shows that a magnet in reality consists of a succession of poles, produced along its length, of which the north are always one way directed, and the south, the other; and the nearer poles to the source of power are necessarily more powerful than the more distant. This may be rendered further evident by placing a bar magnet beneath a sheet of paper, and sprinkling iron-filings over the paper; a few gentle taps will produce an arrangement of the filings into a certain succession of curves known as the "magnetic curves" (*fig.* 173.). Were the magnetism of each particle *utterly absorbed*, and, as it were, *latent*, by its action on the next succeeding, some such arrangement as those shown in *fig.* 174. might occur—a radiating or rectilineal arrangement, as the case might be; but, as the position assumed by each line of particles is that represented in *fig.* 173., it is very evident that the consecutive magnetic polarities are not in this sense *latent*; but that they ex-

Fig. 173.

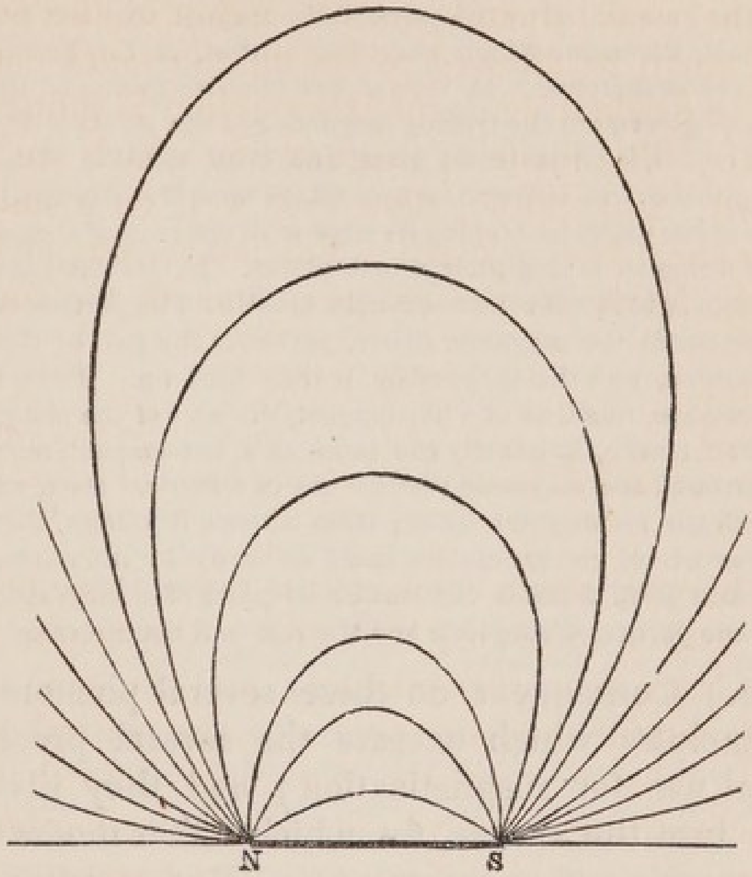
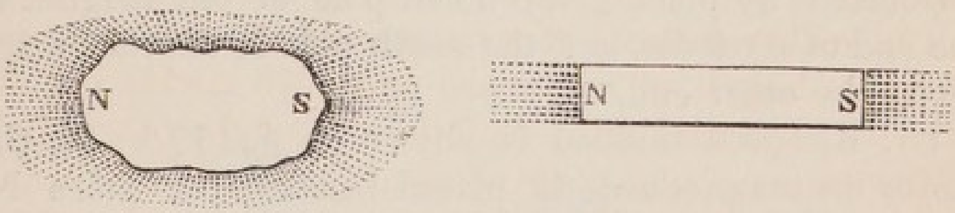


Fig. 174.



ercise, through their whole course, the repulsive power of similar polarities, evidenced by the *recession* of the curves from either N. or S., with respect to each other.

(397.) This *isolation*, so to speak, and *independence* of the polarity of each particle is aptly illustrated in Dr. de Haldat's magnetic pictures :—

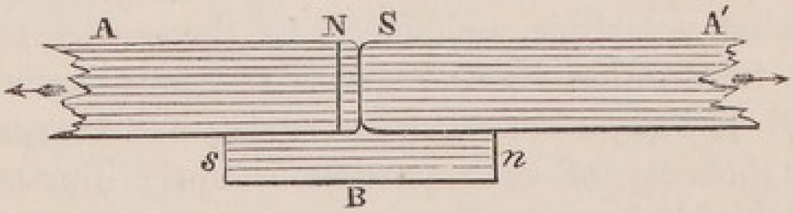
"For this purpose he employs plates of steel, from eight to twelve inches square, and from one-twentieth to one-eighth of an inch thick. The plates are of that kind of steel, which is used for the manufacture of cuirasses... Figures of any kind may be traced on the surface of the steel plate, either by one magnet or several combined, and the best form for this purpose is that in which the poles are rounded. In this way we may write upon a steel plate the name of a friend, or sketch a flower or a figure, with the

extremity of a magnet . . . . . and if we shake steel filings upon the plate out of a gauze bag, the filings will arrange themselves in the empty spaces between the lines traced by the poles of the magnet, and will represent, in vacant steel, the name which has been written, or the flower or figure which has been sketched. M. Haldat has likewise produced these curves by interposing between the tracing magnets and the steel plates, solid non-magnetic bodies, such as cords, glass, and even metallic plates that are not ferruginous. . . In sifting the iron filings upon the steel plate, a gentle vibration of the plate, by tapping its edge with the ring of a small key, will assist the filings in taking their proper places. M. Haldat has found that the magnetic figures will continue for six months. The portion of the metal which surrounds the magnetic figure, performs the part of the *armature* of a load-stone, and the magnetism is thus kept up. If the figure be a simple rectangle, like that of a bar-magnet, the state of the plate, examined with a small needle, is exactly the same as a bar-magnet, and the parts which surround the magnetic portion are in a neutral state, as if unconnected with the rectangular space; from whence it follows, that the *magnetic virtue* which communicates itself so easily by influence, ceases to communicate itself *between the continuous parts* of a magnetizable body, of which one portion is magnetic and the rest in a neutral state."*

(398.) Consequent on these several phenomena are the principles which actuate the several processes in practical use for magnetization; and they give us an insight into the causes, for which other modes are superior to that of mere contact. But it may be first mentioned that mere contact, when employed, is best performed by placing the north pole of one magnet at one end of a needle, and the south pole of another magnet at the other end.

Dr. Knight's method is shown in *fig.* 175. B, the bar to be magnetized, is placed beneath the poles N,

Fig. 175.



S, (which are in contact over its centre,) of two bar magnets, A, A′: the magnets are drawn apart in the directions of the arrows; the process is repeated several times on *each* side of B. Dr. Scoresby, as the result

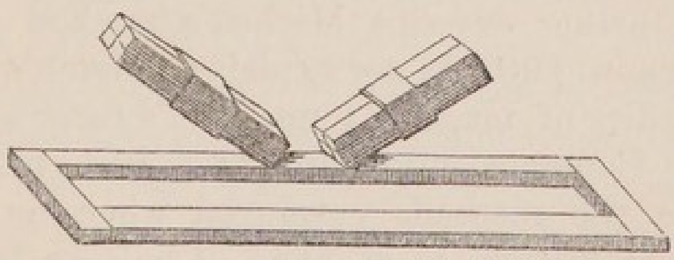
* Brewster's Magnetism, p. 91—94.

of his recent very extensive experiments on magnetism, varies the process thus:—

"For the magnetizing of *thin plates* of all descriptions and dimensions, up to the measure in length and breadth of the magnets employed in the operation, the process ultimately adopted, being a process most simple, rapid, and effective—was a modification of that of Dr. Knight. (INT. § 204.) For, by a change in the arrangement according to the description usually given of Dr. Knight's method, a most important practical advantage is gained. This change mainly consists in placing the plate or bar to be magnetized *above* instead of *beneath* the magnets employed in the operation, by which very great facility is given to the performance of the requisite manipulations, and for the maximum development of the magnetic condition.

"A pair of powerful bar magnets (single bars tempered or made hard throughout), of equal length and breadth, at least with those dimensions of the plates to be magnetized, are placed in a straight line, with their opposite poles very near each other, but not in contact. The plate to be magnetized is laid flat upon the magnets, so as to extend equally over the surface of both. The bars are then drawn asunder till the plate just rests with its extremities in contact with the extreme poles of the two magnets, and then it is slid off sideways and removed to some distance, preserving the parallelism of its position with that of the magnets till these are restored to the proximity with which the operation commenced. The process is repeated with the other side of the plate in contact with the magnets; and in the case of thin small plates, such as I have adopted for the needles of sea-compasses, the condition of saturation is usually found to be obtained. Generally, however, to secure the maximum more satisfactorily, the plates are subjected to four strokes of the magnets, two on each side; and, in hard short bars, six or eight strokes are usually given, partly on the edges as well as on the flat sides. This process, for the convenience of reference, is distinguished as the method KS."*

Fig. 176.



(399.) Duhamel, finding with others that Knight's process was inapplicable to large bars, arranged two bars to be magnetized into the parallelogram *fig.* 176., by means of two pieces of soft iron: he then rubbed each bar in succession with two magnets, or two bundles of magnets, inclined to it at an angle of 45°, as in the figure, by separating the magnets from each other.

* Magnetical Investigations, Part i. p. 12.

Æpinus improved on this, by using previously magnetized steel bars, instead of the pieces of soft iron; and separating the poles of the inclined magnets by a piece of wood, he drew them unitedly backwards and forwards on each side of each bar in succession.

Dr. Scoresby's modification of this process may be safely taken as the result of much experience: —

"For the magnetizing of *large bars* in pairs, I have found no process so efficient, or so convenient and rapid in operation, as that of Æpinus, the developing power consisting of a large compound horse-shoe magnet. But this method I found modified to much advantage (as originally suggested to me by a practical magnetician), and with a very striking influence on the ultimate power, especially in large massive hard bars, by passing the horse-shoe magnet employed in the process *round the whole parallelogram of steel bars and iron conductors in the same direction* (terminating at the middle of one of the bars), instead of limiting the manipulations to the extent of the steel bars separately from end to end. . . It is important, however, that the passage of the magnet should be made smoothly and without hitchings, the effecting of which with any degree of certainty requires the surfaces of the bars to be slightly oiled. This process is distinguished as the method ÆS." *

Barlow's square of nine bars on each side, with four little pieces of soft iron to complete the corners, and a magnet carried twelve times round the figure, is a similar process to the above.

These two methods being efficacious for all practical purposes *when a source of magnetism is at hand*, we need not further describe Michell's method of *double touch* (INTROD. § 205.); nor explain Coulomb's *fixed* and *double* bundles of magnets; nor Biot's *battery* of magnets; nor Canton's union process. But, before proceeding to the methods employed when no artificial source of magnetism is at hand, it will be instructive to point out that, in the methods now before us, the *sum of the action of both poles* is obtained on the interval of the steel bar, which is, from time to time, between them; in Knight's plan there is but *one*, and that an *increasing* interval; in Duhamel's and Æpinus's plan, the interval is *constant*, and each part of the

* Magnetical Investigations, Part i. p. 13.

bar is in succession included in it. Thus the source of power is applied to every portion of the molecular particles, and the intensity of the two ends corresponds.

(400.) As the magnetism of the earth possesses *directive* power, it may readily be expected to be endowed with *inductive* power; for they are part and parcel of one thing; and to be a source, less in degree perhaps, but of the same character, whence magnetism may be obtained, in the absence of artificial means. We see this illustrated in the property possessed by certain species of iron ore,—or oxide of iron, termed by some writers the *oxidum ferroso-ferricum*. It is abundantly found at Roslagen, in Sweden; and on being taken from the mine where it has lain for ages exposed to the influence of the earth's magnetism, it is itself found endowed with permanent magnetic power. It is, in fact, the LOADSTONE.

(401.) Before attempting to construct magnets by the inductive power of the earth, the direction or situation of the resultant of the earth's power must be sought, in order that we may avail ourselves of it under the most favourable circumstances. In using the artificial magnet (389.), the body to be magnetized was placed in the position which it would retain after it had become a magnet, in preference to any other,—to which it would return if suspended and free to move. The direction, then, which is assumed by a compass-needle, under the influence of the earth's magnetism, is that most favourable to obtaining the maximum magnetizing effect. But what is this direction? For on the solution of that question depends the determination of the most favourable position. Being more accustomed to regard the magnetic needle as an instrument peculiarly characterized by its tendency to assume a position on the magnetic meridian, that is to say, nearly north and south, we require to be reminded that, if the needle is in every respect free, it has another tendency, namely, to deviate from the horizontal position, and allow its north end to drop very considerably. If

for instance, a needle, perfectly well poised so far as weight of metal is concerned, be placed in the magnetic meridian, and balanced, as in *fig.* 177., the northern end

Fig. 177.

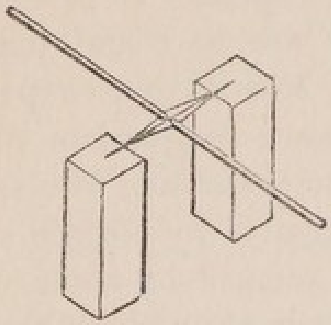
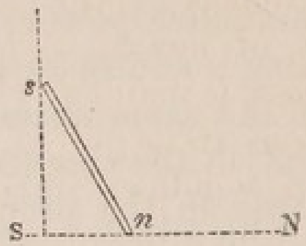
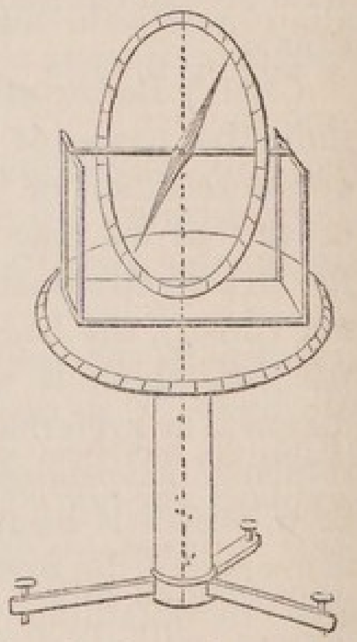


Fig. 178.



will point toward the earth, and assume the position which is called the "dip." In *fig.* 178. if S N represents an horizontal line in the magnetic meridian, and S *s* a perpendicular to it, *s n* will be the direction of the dip for London, the angle S *n s* being at present about 70°. Then, again, the needle does not point exactly to the north; but to about 24° west of north. Combining these two data, we learn that the position of the resultant of the earth's magnetism is in the direction of 24° W. of N., and at an angle of 70° from the horizontal line. *Fig.* 179. represents a dipping-needle.

Fig. 179.



(402.) Just, then, as a piece of soft iron becomes magnetic when placed in a line with the pole of an artificial magnet (389.), so will an iron bar become magnetized when placed in the line of direction of the dip. If a small poised compass-needle is placed on a table, and the operator stands with the needle between him and the magnetic north, and holding near the needle a bar of iron in an almost perpendicular position (for 70° is not far from 90°), the *lower* end of the iron will acquire *north* polarity from the natural south polarity of the

earth's magnetism in this hemisphere, and will attract the south end of the needle ; if the iron be so held that the needle can test the condition of its *upper* end, it will be found possessed of *south* polarity. The intensity of the action is modified on account of the distance of the source of power. If iron possessing some degree of hardness, is maintained in this position for a long period, it retains its acquired power : and hence it is that the bars of windows and other pieces of iron, as the fire-irons, which have occupied a vertical position for many years, are found to have become permanent magnets. But there are means for facilitating the process, so that even steel can be magnetized, and that, too, in a very short space of time.

(403.) Let a needle be fixed in the magnetic meridian by silk threads, or, otherwise, against the edge of a table ; then hold a long iron bar, or a poker, above, and another below it, as in *fig.* 180.; then move the bars in contrary directions to the position shown in *fig.* 181. ; repeat this several times, and the needle will be magnetized. Enough has been said to explain the *rationale* of this process, as also of those which follow. The letters will further explain.

Fig. 180.

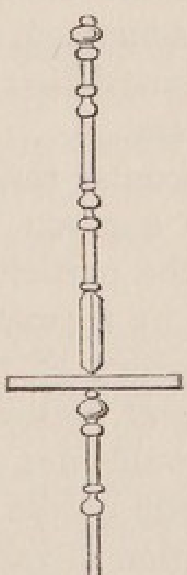
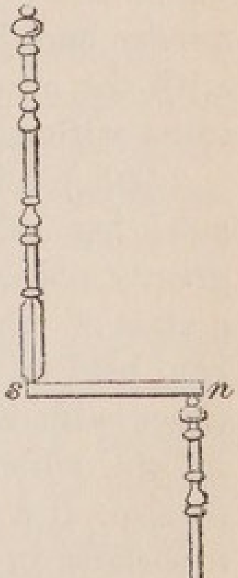


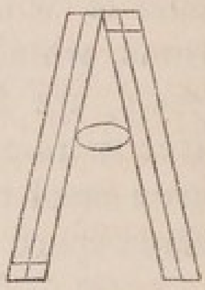
Fig. 181.



(404.) Canton's process is as follows : — He sets out with six bars of soft and six bars of hard steel, and two bars of soft iron ; or, in lieu thereof, the poker and tongs. To avoid mistakes he marks one end of each bar. He magnetizes in succession four of the soft bars, by tying each in turn, with its marked end downwards, to the poker

placed in the position of the dip, and rubbing it with the tongs (held vertically), from its lower end upwards, about ten times on each side. He then lays the *two* unmagnetized bars parallel, and completes a parallelogram, as in Duhamel's method (399.), by two short pieces of soft iron: he places together the four magnetized bars, with the marked poles arranged as in *fig.* 182., thus constituting a system analogous to the horse-shoe employed by Dr. Scoresby: and with this he imparts a certain amount of magnetism to the two bars included in the parallelogram. The bars of the system are made in succession to form the sides of the parallelogram; and after each pair has been thus magnetized, a considerable power will have been accumulated. The six soft bars thus magnetized are now arranged into a system of two bundles of three each, and are used to magnetize two pairs of the harder bars: the *soft* bars are then laid aside; and the four *harder* bars just magnetized, are used and interchanged with the other two hard bars, until the whole are saturated with magnetism.

Fig. 182.



(405.) The molecular resistance, R (392.), which a steel bar offers to a given magnetizing power x, is greatly reduced if the particles of metal are thrown into a state of vibration by a smart blow; and hence a steel bar, held in the position of the dip and struck several times with a hammer, will exhibit an amount of magnetism which it would not otherwise have acquired; so also, if a magnetic needle is thrown on a stone floor, especially in a position at variance with its directive tendency, its power will be reduced. In investigating these phenomena, Dr. Scoresby found that a certain amount of magnetism was obtained, if the lower end of the bar rested on *stone;* but a much greater amount of it rested on iron. He finally adopted the following process: —

"I procured two bars of soft steel, thirty inches long and an inch broad; also six other flat bars of soft steel, eight inches long and half an inch

broad, and a large bar of soft iron. The large steel and iron bars were not, however, necessary, as common pokers answer the purpose very well; but I was desirous to accelerate the process by the use of substances capable of aiding the development of the magnetical properties in steel. The large iron bar was first hammered in a vertical position; it was then laid on the ground with its acquired south pole towards the south, and upon this end of it the large steel bars were rested while they were hammered; they were also hammered upon each other. On the summit of one of the large steel bars, each of the small bars, held also vertically, was hammered in succession, and in a few minutes they all had acquired considerable lifting powers. Two of the smaller bars, connected by two short pieces of iron in the form of a parallelogram, were now rubbed with the other four bars, in the manner of Canton (404.). These were then changed for two others, and these again for the last two. After treating each pair of bars in this way for a number of times, and changing them whenever the manipulations had been continued for about a minute, the whole of the bars were at length found to be magnetized to saturation, each pair readily lifting about eight ounces." *

(406.) It is needless to repeat these various directions in their application to bars of a horseshoe form: a keeper placed on a single horseshoe, or two horseshoes placed end to end, will constitute the parallelogram (399.).

Though not strictly belonging to this branch of the science, it may be mentioned that M. Aimé magnetized a steel bar, while red-hot, by means of an electro-magnet (506.), and, while under the influence of the magnet, he quenched it in cold water: the results were satisfactory to him.†

(407.) Next to a knowledge of the means best fitted for magnetizing steel, is an acquaintance with the comparative magnetic value, both in respect to *capacity* and *tenacity*, of different kinds of steel. The investigations of Dr. Scoresby were directed to both these points, but more especially to the latter. He writes: —

"Tenaciousness or fixidity, which is a grand element in good magnetic instruments, especially in sea-compasses, has heretofore been comparatively little attended to in their construction; the great point generally aimed at having been to obtain, in the first instance, high magnetic energy. And thus the needles of *compasses*, in which *permanency* of power is of very high consideration, have generally been constructed on a principle incom-

* Phil. Trans. 1822, part ii. † Ann. de Chim. t. lvii. p. 442.

patible with the attainment of this most important property. For not only may needles or bars on the ordinary construction and temper, exhibit, in many cases, an effective energy at the first; but even a perfectly soft or untempered bar of good steel, of a certain limited mass, will have a very considerable capacity for magnetism, and so much apparent strength as to yield an efficient power for a compass needle, after being removed from all extraneous aids for the retaining of the power. But, in such a needle, the magnetic condition, as is well known, will be comparatively transient; and, indeed, so unfixed in its character that the mere proximity of another magnet may be sufficient to neutralize or even reverse its polarity."*

He has showed beyond all dispute, "that the degree of hardness and that of tenaciousness are co-relative;" and the magnetic powers of bars, similar in all respects excepting as to thickness, *are not proportional* to their respective masses; but that the ratio of augmentation of power diminishes as the thickness increases. These data are deduced from the tabulated results, on page 409.†

The results are here given of experiments with four sets of steel bars, each bar being six inches long and half an inch broad; each set contained five bars, numbered in the table according to their thicknesses, which were respectively $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$, $\frac{1}{32}$ of an inch. The first set H were of the hardest steel; the second set T, of a steel tempered at blue; the third set E, of steel tempered at *the ends* only, according to a custom prevalent among manufacturers; and the fourth set of very soft steel. Column I. gives the number corresponding to the thickness of each; Col. II., the weight of each; Col. III. the deviation of a compass needle as each was placed (after being magnetized by the K S process (398.), at twice its length, or twelve inches from the centre of the needle, and in the magnetic east and west; Col. IV., the tangent representing the angle of deviation, which collateral experiments had shown to be *equivalent to the power* for the time being; *i. e. to the magnetic capacity;* Col. V., the reduced deviation, which is taken after the magnetized needle has been laid with similar poles in

* Mag. Invest. Part i. p. 25. † Ibid. p. 57.

No.	Weight of Bars in Grains.	Highest Power.		Reduced Power by Test Bar H.		Tenaciousness.	
		Mean Deviation.	Tangent.	Deviation.	Tangent.	Difference of Tangents.	Loss per Cent.
I.	II.	III.	IV.	V.	VI.	VII.	VIII.
HARD SERIES, H.							
I.	2950	38°·20′	791				
II.	1404	31 ·50	621	28·15	537	84	13·5
III.	786	27 ·13	514	23·54	443	71	13·8
IV.	340	14 ·15	254	1·5	19	235	92·5
V.	175	10 ·0	176	9·8	161	15	8·5
TEMPERED SERIES, T.							
I.	3018	31·50	621	22·30	414	207	33·3
II.	1535	27·10	513	18·0	325	188	36·6
III.	710	22·0	404	9·43	171	233	57·7
IV.	318	17·5	307	6·16	110	197	64·1
V.	160	10·48	191	2·3	36	155	81·1
TEMPERED AT THE ENDS, E.							
I.	3030	24·30	456	10·22	183	273	59·9
II.	1518	19·50	361	6·32	112	249	68·1
	1417	27·15	515	16·52	303	212	41·1
III.	670	18·13	329	3·32	59	270	82·2
IV.	314	14·40	262	3·6	54	208	79·5
V.	158	11·5	196	1·3	18	178	90·8
SOFT THROUGHOUT, S.							
I.	2853	18·50	341	3·37	63	278	81·5
II.	1393	16·32	297	0·45	13	284	95·6
III.	713	15·8	270	−1·35	−28	298	110·4
IV.	317	11·30	203	−3·22	−59	262	129·1
V.	167	9·13	162	−2·50	−49	211	130·0

contact, on a powerful TEST-MAGNET of hard steel, six inches long by half an inch square; Col. VI. the tangent of this lesser angle, equivalent to the then power of the bar; Col. VII., difference of the tangents, or *loss of power*; Col. VIII. loss per cent. of power, on *relative tenacity*.

A few observations on this table will be of practical utility. That needles have not magnetic *capacity* in the ratio of their bulk, may be gathered from each series. Take, for instance, Col. IV. of series T., representing the ultimate power *, or *magnetic capacity*, of five tempered needles, differing only in that each one in the series is double the thickness of the preceding; and it will be found that each falls far short of being of double the power of its successor, and very far short of the multiple in power of the last. The powers, to be in proportion to masses, reckoning from the thinnest, would stand 3056, 1528, 764, 382, 191, instead of as they are found in the table.

A deduction from these experiments is: —

"That thoroughly hard steel, indeed, is susceptible of less power than tempered or soft steel when first magnetized *to a very limited extent of mass*, is apparently the fact: but, as a general proposition, it is most erroneous; for in all masses above the weight of 130 grains (that is, of the form and length here under consideration) *perfectly hard* steel appears to be superior in capacity to soft steel; in masses above 250 grains weight, superior to bars tempered only at the ends; and above 400 grains, superior to any of the kinds of tempering with which it has been compared." p. 63.

The tenacity per cent. is in every respect in favour of the hardest steel. No. IV. in the hard series is evidently not a specimen of the character given to it, which fact is disclosed by its enormous loss of $92\frac{1}{2}$ per cent.—Magnetism may hence, under proper circumstances, be used in the arts; and, as such, Dr. Scoresby proposes it as a means of testing the character of steel instruments. Before leaving this subject we may mention that in all cases those needles are to be considered the best for practical purposes, "in which the product of the forces of the original power and the reduced power is the greatest,"— *i. e.* The product of Col. IV.* multiplied by that of Col. VI.

(408.) The application of the test bar will have shown how magnets are deteriorated when placed in bundles; and this holds good in needles: but the de-

* The needles were in all cases magnetized to saturation, as was shown by their gaining nothing on being subjected to the more powerful process ÆS (399.).

terioration is far less, when slips of paper, wood, or cardboard intervene; and hence advantage can be taken of the comparatively superior capacity of thin bars, by uniting them into a bundle with intervening diaphragms, so as to build up a thick bar. Dr. Scoresby, at the last meeting* of the British Association, stated that "from the experiments already made, he would have no difficulty in constructing a magnet of a ton weight; and, by means of his peculiar test (which he exhibited to the section) of rendering every bar effective."†

The *form* given to small needles is generally that preferred by Coulomb, a flat bar, tapering at its extremities; but for ships' compasses such bars as those examined by Scoresby are employed. Cylindric forms are also occasionally given; so is the rhombus, and the pierced rhombus. Captain Kater preferred the latter. The prismatic or parallelopiped form is given to the motive magnets in observatories. Needles are balanced on pivots entering an agate or garnet cap. Some needles have card vanes, to check the vibrations.

DIRECTIVE PROPERTY OF THE NEEDLE.

(409.) It is time now to advert to the directive property of needles properly suspended; it has already (401.) been stated that, with us at London, the north end of a needle now points about 24° west of north; but it is not so every where; at Boston, U. S., for instance, it points $5\frac{1}{2}$° west of north. It may be remembered, for instance, that Columbus had well nigh lost the honour of being the discoverer of America, from this very cause; for, as he voyaged onwards, he found the needle, instead of being true to the pole as the poets have it, gradually deviating more and more to the north-west. We can scarcely wonder at the mariners wishing him to return, being, as they were,

* August 21. 1843, at Cork.

† Other modes of combining magnets, and a fund of information on "Practical Magnetics," will be found in the 2d Part of Dr. Scoresby's book which has appeared during the progress of these sheets through the press.

under the apprehension that the virtue of the compass was gone. This leads us to the important subject on which philosophers in all quarters are now engaged, viz. the declination* of the needle, *i.e.* its deviation from the terrestrial meridian.

(410.) First. There is a given declination, or deviation from the true north, or a given direction of the needle, proper to each spot of the earth. This declination is, therefore, influenced by *place, i. e.* by change of latitude or longitude, or both. It is found by experience, that this relative declination bears no regular ratio to the change in latitude and longitude, but is governed by other laws; and so irregular is the rate of variation, that it is not easy to foresee the precise effect of a change of place; so that nothing but actual observation avails for the construction of tables showing the declination in different places; or, at least, no calculations can be confided in, unless well confirmed by observation. Navigators and travellers in former days, and with them philosophers at the present moment, have accumulated their various observations; and, from these data, have been constructed magnetic charts which should present, at one view, the declination of the needle for all parts of the globe. Dr. Halley, Messrs. Mountain and Dodson, Professor Hansteen, and Dr. Barlow, have successively published such charts, so also has Captain Duperrey; and as his charts are of very recent date, we take them for our illustrations.

(411.) Plate I. represents a chart of the world on which are laid down magnetic *meridians* and *parallels*. The former of which alone concern the matter now in hand: —

"The magnetic meridians, as M. Duperrey considers them, are not hypothetical lines; they result from the direction of the magnetic needle in each point of the globe. Suppose that we set out from any given point, and that, journeying always according to the direction of the magnetic

* This is frequently called, by English writers, the *variation* of the needle; I have preferred the French term *declination*, which is equally, or perhaps more, appropriate, and the more especially, as there are effects of variation in this declination (412.) that could not consistently be termed variation of the variation; for the word would here have two meanings.

needle, at first toward the north pole, then toward the south pole, we collect all the points through which we may have passed, the curve which unites them all, will form a magnetic meridian. If another point of departure, near the former, is taken, and a magnetic meridian is traced in the same manner, this meridian will meet the former in two points, situated one toward the north pole, the other toward the south. By tracing on the globe a number of these meridians, and taking the points of intersection of two neighbouring meridians, we always obtain in each hemisphere, a closed curve, resulting from the reunion of all the points of intersection; it is natural to admit that the magnetic pole of each hemisphere is to to be found in the centre of the area included by these curves." *

To determine the declination by this chart it is merely necessary to find the latitude and longitude of the place, and to observe the *direction* of the vicinal magnetic meridian; and this shows the point toward which the needle is directed, and hence its declination. The place of the north magnetic pole is here 70° north latitude, and 100° west longitude; that of the south, about 76° south latitude, and 135° east longitude. Plate II. is a bird's eye view of the polar regions, again showing the directions and convergence of these meridians. It is instructive to examine these plates, and see how seldom the magnetic meridian is parallel to the meridian of longitude. Plate III. is a magnetic map of the hemisphere containing both the magnetic poles.

(412.) It may be imagined that the amount of information necessary to construct such charts as these, is immense; because the consecutive portions of every line must be laid down almost from actual observation; and as may be imagined, observations have not in all cases been made with that rigid accuracy that is desirable. But, if all these difficulties were surmounted, and a perfect chart were produced, this chart would be of only temporary utility; for there is a *variation of the declination;* the declination is *not always the same at the same place*, but undergoes *secular, annual, mensual, diurnal,* and also *irregular* changes.

The *secular* change is a progressive alteration ob-

* Becquérel, Traité, vol. vii. p. 429.

served in the magnetic needle during a series of years, as may be seen in the following table:—

Table of the Secular Variation in the Declination of the Needle at London.

A. D.	Observed by	Declination.
1576.	Norman -	11° 15′ E. of N.
1580.	Burroughs -	11 17 —*
1622.	Gunter -	6 12 —
1634.	Gellibrand -	4 5 —
1657. } 1662. }	- - -	0 0 Due North.
1666.	- - -	0 34 W. of N.
1670.	- - -	2 6 —
1672.	- - -	2 30 —
1700.	- - -	9 40 —
1720.	- - -	13 0 —
1740.	- - -	16 10 —
1760.	- - -	19 30 —
1774.	- - -	22 20 —
1778.	Phil. Trans. -	22 11 —
1790.	- - -	23 39 —
1800.	- - -	24 36 —
1806.	- - -	24 8 —
1813.	Col. Beaufoy	24 20 17″ —
1815.	- Ditto. -	27° 18′† —
1816.	- - -	24 17 9 —
1820.	- - -	24 11 7 —
1823.	- - -	24 9 40 —
1831.	- - -	24 0 0 —

This table shows that the direction of the needle, during the early periods of observation, was deviating more and more to the E. of N. until 1580, when the declination gradually decreased, and from 1657 to 1662, it pointed due north. It then acquired a west declination, which increased until 1815, when it commenced returning as before. The variation per annum in the declination is as irregular as the declination itself.

* Maximum *east* declination. † Maximum *west* declination.

"It appears from the table given by Mr. Gilpin *, that the annual change in the variation [declination] has diminished in each successive period, since the beginning of the last century. In the preceding century, that is from 1622 to 1692, the annual change was about 10′; from 1723 to 1773, it was about 8′; from 1787 to 1795, about 5′; from that time to 1802, only 1′·2; in 1818 it was reduced to Zero." †

A table of variations at Paris, collected by Arago ‡, shows that the dates of the two maxima correspond with those of London. A similar progressive variation is traced in observations made at the Cape of Good Hope.

(413.) The *mensual* change is an alteration in the direction, according to the season of the year, by which the needle, during the months between the vernal equinox and the summer solstice, retrogrades toward the east; and during the remaining nine months pursues its general tendency towards the west.

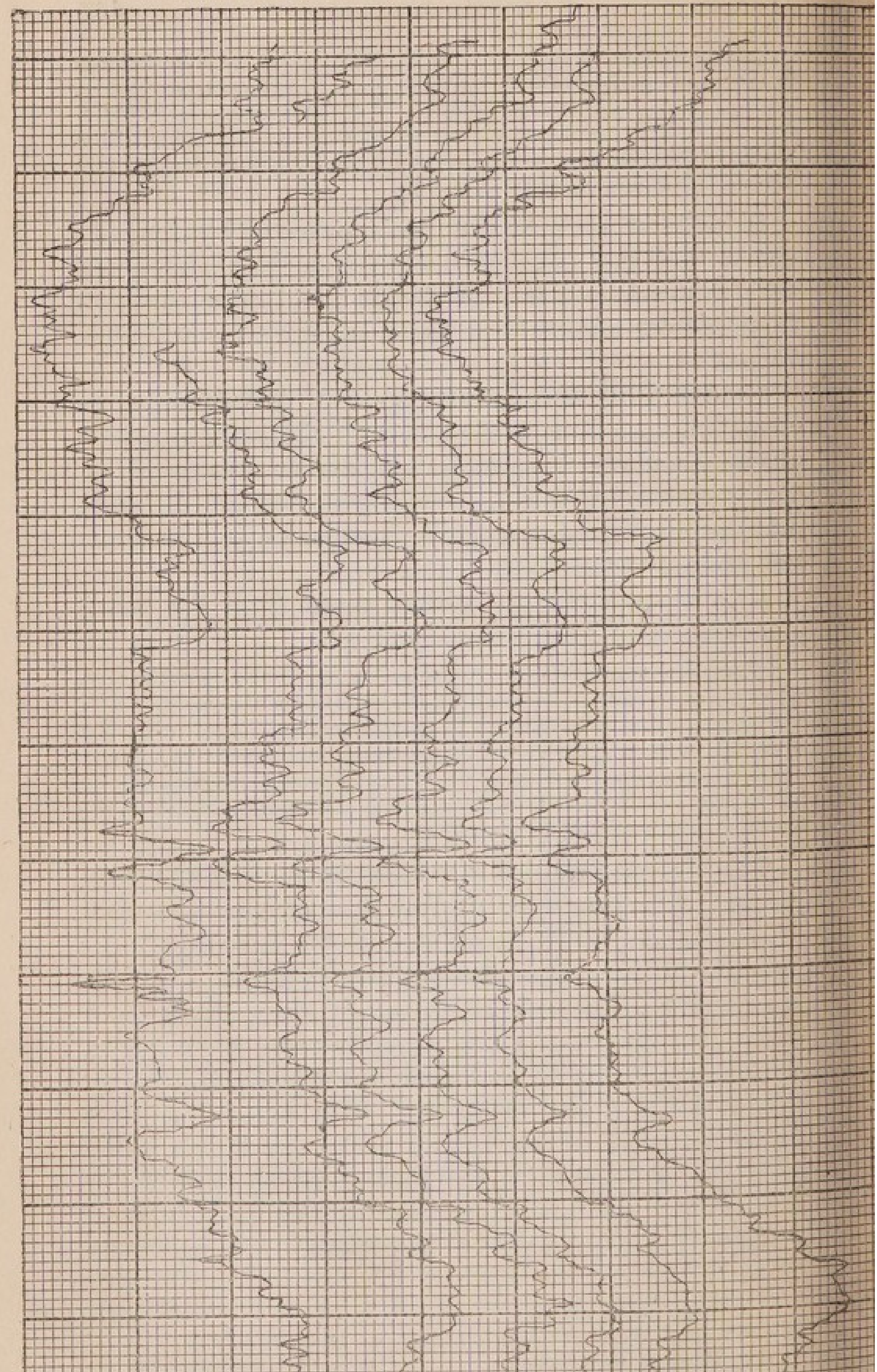
The *diurnal* change is thus given from the recent observations of Professor Lloyd:—

"The mean daily curve of the changes of declination for the entire year, exhibits a small easterly movement of the north end of the magnet, during the morning hours, which reaches its maximum about 7 A.M. After that hour, the north end moves rapidly westward, and reaches its extreme westerly position at 1 h. 10 m. P.M. It then returns to the eastward, but less rapidly, the easterly deviation becoming a maximum about 10 P.M.; the mean daily range = 9·3 minutes." §

The diurnal variation of which the above is the *mean* amount, differs according to the time of year and place of observation. MM. Gauss and Weber have been indefatigable in their researches on these subjects. *Fig.* 183. is a graphic delineation of six sets of observations made under their directions, simultaneously every five minutes, on August 17. 1836, at Upsal, the Hague, Göttingen, Berlin, Leipsic, and Munich. The horizontal lines define intervals of two hours each, the lowest being midnight of August 16, the highest being midnight of August 17.: the curved lines indicate the proportion of deviation for each place in succession. Though there

* "Phil. Trans. 1806."
† Roget, Library of Useful Knowledge. Magnetism, p. 29.
‡ Annuaire, pour 1830.
§ Athenæum.

Fig. 183.



is a great difference in many cases, in the *amount* of the deviation at any given time, there is a very marked coincidence in its *direction*, as is evident from the general resemblance to each other of the set of curves.

(414.) Besides these comparatively regular variations, there are others of an *irregular* character, which are due to adscititious causes, present only under peculiar circumstances. Chief among these disturbing causes is the aurora borealis, during the prevalence of which the needle is considerably disturbed. M. Becquérel says,—

"Generally, the declination increases before the aurora, and often even until the phenomenon has attained a certain degree of intensity; then the great oscillations commence; afterward the needle returns toward the east very regularly: it passes beyond its normal position, which, providing no new aurora disturbs its progress, it regains again, although not until some hours have elapsed."

Earthquakes and volcanic eruptions are also said to disturb the needle.

(415.) There are also *local* variations dependent on the vicinity of magnets or of bodies susceptible of magnetism, which, unless recognised or removed, will prevail to make the compass-needle, even with all the advantages to be derived from these tables and charts, a very faithless index. I allude especially to the presence of vicinal iron. We have seen that iron, in its *normal* condition, acts upon the needle; much more does it act if it is itself a magnet: but we have seen that magnetism is induced, more or less, into all iron by the action of the earth (402.); and hence vicinal iron is doubly influential in interfering with the correct action of the needle. On this account the greatest pains are taken to banish iron from magnetic observatories. But in ships, where so much depends on the fidelity of the needle, and which nevertheless contain so fertile a cause of disturbance in their bolts, water-tanks, guns, shot, stores, and engines, other means are adopted. The disturbing cause cannot be *removed*, it is, therefore, *recognised and estimated.*

Mr. Wales, who sailed with Captain Cook, was the

first to notice that the *needle* varied, as the *course* varied. Mr. Downie was the first to detect the cause; he said he was "convinced that the quantity and vicinity of iron in most ships, have an effect in attracting the needle." Captain Flinders went further, and found that "when the ship's head was on the *east* side of the meridian, the differences were mostly *one* way; and, when on the *west* side, they were the *contrary*." He observed that, in the *northern* hemisphere, the *north* end of the needle was drawn *forward*. The effects can be understood, from the principles elsewhere (402.) laid down, to be these: —

"Every distinct piece of iron in the ship becomes a magnet, with its south pole upwards. But, since the binnacle is placed very far aft, it follows that almost the whole of these temporary magnets are between it and the head of the vessel; and, as they have each their south pole upwards, the united force of all inevitably tends to draw the *north* end of the needle toward the head." *

(416.) As the deviation of the needle, by local causes, is often very great, means were sought for correcting it, which led to the construction of "Barlow's correcting plate."

"It occurred to him, that, if a large mass of metal A, at distance A B, produced a certain deviation, a smaller mass C, at a less distance C B would produce the same; and that if C were in the line, which joined A and B, the tangent of the needle's deviation would be doubled. But, as the tangents of small arcs are nearly in proportion to the arcs themselves, we shall not be far from the truth if we consider the arcs themselves as being doubled.

"It was, therefore, requisite to work the vessel round to each point of the compass, and to observe what effect the ship's iron had on the needle in the different positions,—and so to determine the planes of no variation, and hence the direction of the resultant line A B. Having found this, it was next requisite to determine *on shore* (by repeated trials) at what distance the smaller mass C should be placed, in order to produce the same amount of deviation as was produced by the iron in the vessel. And, having obtained this, the mass C was to be placed in the line A B, at the distance B C, and adjusted so that the line might pass through the pivot of the needle and the centre of attraction of both A and C. It was then removed, and only used to correct observations, as follows:—

"Let the compass indicate that the vessel's head is 5° N of E; then place C in the line of direction, at the previously determined distance; and, if the compass should declare the vessel's head to be 8° N. of E., the additional 3° in the amount will be due to C. But, since C has the same

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* Ann. of Elec. vol. iii. p. 3. Walker on the Effects of Iron.

effect as A, the deviation produced by A is 3°; deduct this from 5°, then the remaining 2° N. of E. is the ship's true position." *

The mass C, is Mr. Barlow's correcting plate, or magnetic compensator; and consists of two plates of iron, about a foot in diameter, and of such thickness that a square foot will weigh three pounds; the iron plates are separated by card or thin board.—The amount of local disturbance has been found to vary from 5° to 15°; for such angles, especially the smaller of them, the ratio of tangents is applicable, and, therefore, also, is the correcting plate. For correct observation, the following formula is given,

$$\tan. x = \frac{1 + \sqrt{1 - 8 \tan. a^2}}{4 \tan. a},$$

where x is the angle of deviation produced by the ship, and a that produced by the plate. For iron ships in which the deviation is 50° or 60°, Mr. Barlow has adopted a plan of compensating by means of a magnet. M. Poisson, by mathematical analysis, has also devised a means of correcting the effects of local action.

(417.) The *dip of the needle*, which the French term INCLINATION, is in like manner subject to variation, dependent also on *place*, *time*, and *local* circumstances. In London, as we have said, the dip is about 70°, at New York it is about 73°. Over the magnetic poles shown on the Plates I., II., and III., the dip is 90°, *i. e.*, the needle assumes a vertical position; in certain places the dip is 0°, *i. e.*, the needle hangs horizontally; the line intersecting these latter places, is termed the *magnetic equator;* it may be seen in Plates I. and III.; it cuts the earth's equator in two places, in longitude 10° E. and in longitude 170° W. The lines, whose general direction is E. and W., and which are somewhat symmetrical with the magnetic equator, are the *magnetic parallels*. They are drawn through the places of equal dip; they possess, as do also the correspond-

* Ann. of Elec. vol. iii. p. 5. The effects of local action.

ing meridians, certain properties, which are, at the present moment, being investigated by M. Duperrey.

There is no need to go into the various modifications of periodical variation in the dip; let it suffice to give here a table of the secular variation for London:—

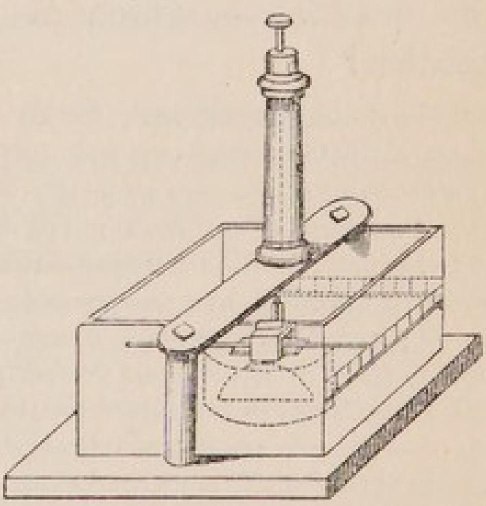
A. D.	Dip.	Observed by
1720	74° 42′	Graham.
1773	72° 19′	Heberden.
1780	72° 8′	Gilpin.
1790	71° 53′	——
1800	70° 35′	——
1818	70° 34′	Kater.
1821	70° 3′	Sabine.
1828	69° 47′	——
1830	69° 38′	Kater.

(418.) The *intensity* of the magnetism of the earth varies also with place and time. The intensity is the power of the earth to bring an oscillating needle to a state of rest; and it is in proportion to the squares of the number of oscillations per second. In general terms, the intensity may be said to increase from the equator to the poles. Much of our information on this subject is due to Humbolt, Sabine, Lloyd, Forbes, Gauss, and Duperrey. The latter can speak for himself in the charts of isodynamic curves, published by him, Plates IV. and V. With the exception of the inter-tropical regions over the southern hemisphere, these charts correspond pretty nearly with those of Hansteen. A needle placed on any curve here delineated in the direction of E. W., will give the same number of oscillations per minute. He has not laid down the position of the magnetic poles; because the isodynamic lines are not sufficiently exact to give him the means of determining it accurately. It is, of course, somewhere within the two extreme curves. In addition to the isodynamic curves, laid down by Duperrey, M. Becquérel has added to Plate IV. the isothermal curves, or curves of *equal heat* from M. Berghaus' Atlas. These are marked by discontinuous lines.

The *intensity*, like the *dip* and *direction*, is subject to change, modified as they are by time and place; and is in some measure influenced by the motion of the sun. The daily range is greatest in July, and least in December.

(419.) The instruments required for these observations are of extreme delicacy, and require considerable experience in using. We pass by these to describe the instrument by which Coulomb establishes the fact which we just advanced, that the square of the vibrations per second indicates the magnetic intensity, as that of the pendulum vibrations do the intensity of gravity. Fig. 184. is Coulomb's torsion balance. The needle is suspended by silk fibre, in a metal stirrup, the lower part of which bears a vane, shown by the semi-circular series of dotted lines, moving in a vessel of water, so as to afford a resistance, by means of which the oscillations shall be limited. The instrument is used by twisting the fibre, and observing the deviation it produces on the needle; whence the force of torsion is found proportionate to the sine of the angle. He compares various needles, by placing them in turns in the instrument.

Fig. 184.



(420.) But magnetism is not confined, as we have hitherto regarded it, to ferruginous bodies only, it has a kind of universal existence. *Nickel* holds the next rank to iron in magnetic capacity; but brass, cobalt, zinc, copper, bismuth, antimony, and their various ores, and also the unmetallic ores, are susceptible. Cavallo found that the ruby, chrysolite, emerald, garnet, and mica attracted the needle; even the flesh and the blood act similarly. In proof that this property is not due to the presence of minute particles of iron, as some have suggested, M. de Haldat has operated upon an immense number

both of organic and inorganic bodies which do not contain an atom of iron. Coulomb obtained magnetic effects from needles of gold, silver, lead, copper, and tin. Lebaillif obtained them from platinum, nickel, cobalt, bismuth, antimony; Sœbeck, Pouillet, and Dove also have devoted their attention to this matter. The magnetic power, in all these cases, is of very low intensity; but we are now about to enter on a branch of electricity, namely, electro-magnetism, which will give us the means, if not of making magnets of the other metals, at least, of making them act precisely as if they were magnets. We may conclude this chapter with an extract from Dr. Scoresby's book, to which allusion has already been made (408.), being a general reply to the question — which is the best steel for magnetic needles?

"We should recommend, for all *large* or *massive* SINGLE MAGNETS of the straight bar form — the best *cast steel*, made quite hard; for STRAIGHT-BAR COMPOUND MAGNETS generally, the same steel and hardness; for compound magnets of my BUSK-PLATE description, the best cast steel hardened to the utmost in oil; for HORSE-SHOE MAGNETS, if *single*, cast steel, annealed from file hardness, at a temperature of about 550°, or shear-steel a little reduced; and for COMPOUND HORSE-SHOE magnets, cast steel annealed at 480° to 500°, or shear-steel perfectly hard; for COMPASS NEEDLES, if *single* and *heavy* (such as are suited for stormy weather), hard cast steel; if *light*, or of *moderate weight*, whether single or compound, best cast steel, annealed at 500° or 550°, or hard shear-steel, or hard cast steel from Bradford iron; and for VERY LIGHT NEEDLES, or other small magnets, the best cast steel annealed, as with advantage it may be, at the heat of boiling oil.

"In all these cases, the steel, whatever be the denomination, should be the produce of the best qualities of foreign iron, except in the instance of cast steel for compass needles of a light description, when steel from the best Bradford iron might, it appears, be advantageously employed." *

And now, having investigated the properties of electric currents and of magnets as distinct, we are prepared to examine the phenomena attendant on their mutual action.

* Magnetic Inves part ii. p. 281.

BOOK THE FIFTH.

ELECTRO-MAGNETISM.

CHAPTER I.

ANALYSIS OF THE MUTUAL ACTION OF AN ELECTRIC CURRENT AND A MAGNETIC NEEDLE.

(421.) If the only or the chief applications of the voltaic battery consisted in the exhibition of electrical effects similar to those produced by the ordinary electrical machine, such as charging insulated conductors or condensers with either species of electricity, charging the Leyden jar or battery, or showing the effects of sudden and violent derangements of the electrical equilibrium of conductors, the investigation of its properties would belong more correctly to ELECTRO-STATICS; and, considered as a physical agent, it would rank immeasurably below all the common electrical machines. But although, by the electricity proceeding from the pile, all the effects explained in the first part of this work may be reproduced, modified only in degree, these form so small and comparatively unimportant a part of the vast powers of that instrument, that they are regarded with no other interest than as supplying the most satisfactory means of establishing the identity of common and voltaic electricity.

If the extremities of a continuous metallic wire of any length, and arranged in any desired form, be put in communication with the poles of a voltaic battery, a *current* will pass along the wire; and so long as the

connection is maintained, the wire will give several evidences of its not being in its natural state.

1st. Let any part of the wire be reduced in thickness until it attains a certain degree of tenuity: its temperature will then be observed to rise. This is an effect which would also be produced by free electricity passing along it.

2d. Let the wire be still further attenuated, or let the power of the battery be augmented: the thin part of the wire will now become red hot; and by still further attenuating the wire, or augmenting the power of the battery, the metal will be fused. These are also effects of free electricity passing along it.

3d. Let a magnetic needle, freely suspended, be brought near to any part of the wire, however distant from the poles of the battery: the needle will be immediately deflected from its direction; and this deflection will increase in quantity as the needle is brought nearer to the wire; and it takes place in one direction or the other, according to the side of the wire to which it is presented. This deflection of the magnetic needle is another effect which is produced by the passage of free electricity.

The system of two streams thus passing in opposite directions on any conductor is called an *electric* or *voltaic current*.

When the *direction of a current* is referred to, that of the *positive* stream alone is indicated. Thus every current is said to run from the positive to the negative end of the wire.

(422.) These electric currents are fed by the electricity continually disengaged by the voltaic action of the pile, and their intensities or electro-motive force will depend, therefore, on the power of production and propagation of the pile.

The voltaic battery may be regarded as a generator of electricity, as the boiler of a steam-engine is the generator of the elastic vapour from which that machine derives its efficacy; and as the power of a

steam-engine, whatever be the particular form or magnitude of the machine, must ultimately depend on the rate at which the boiler can supply steam to the engine, the power of a voltaic current must, in like manner, depend on the quantity of electricity which the battery can supply in a given time to the conductor of the current.

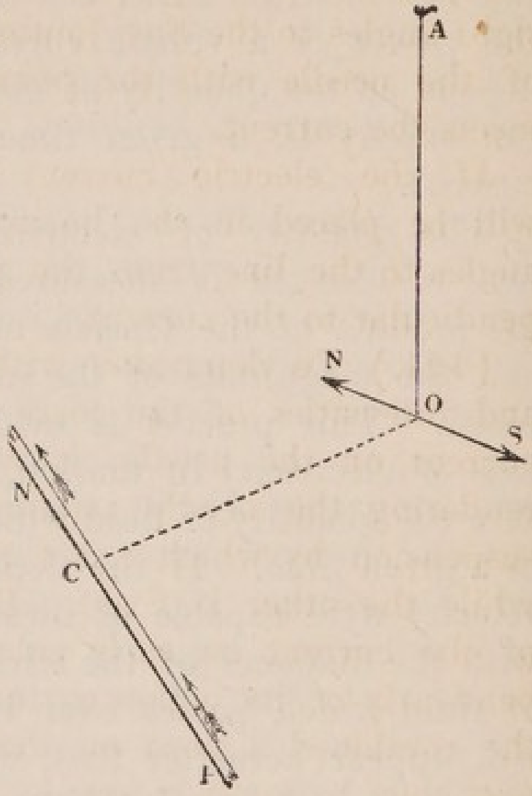
The quantity of electricity with which any surface is charged is measured in ELECTRO-STATICS by the product of the tension or depth of the electricity, and the magnitude of the surface on which it is diffused. This process is evidently inapplicable to the case of electricity in motion, and cannot serve to measure the quantity of fluid which passes over a conductor in a given time. If the depth of the current and its velocity were capable of measurement, these, combined with the diameter of the wire, would give the quantity of fluid which passes over it in a given time; but it will appear hereafter that, when the current is transmitted through certain substances, it will produce effects on them which, being always proportional to the actual quantity of electricity engaged in their production, and being themselves capable of accurate numerical estimation, supply means of measuring electricity in motion susceptible of as much accuracy as attends the application of Coulomb's electrometer to electricity in repose.

(423.) The most important property of electric currents, and that by which their theory has been brought to light, arises from their relation to the magnetic needle. Between an electric current and a magnetic needle there is exercised a mutual action, in virtue of which the needle and the conductor of the current receive, under various circumstances of position and distance, certain definite motions, which it is the province of observation and analysis to investigate and explain.

To ascertain the influence of an electric current on a magnetic needle, let us first suppose the needle to be freely suspended by a slender fibre of raw silk,

A O (*fig.* 185.), attached to its centre of gravity, O, so that it shall be capable, so far as relates to its gravity, of resting indifferently in any position in which it is placed, whether horizontally or at any other inclination to the vertical line. We shall, also, suppose in the present case, and in the following paragraphs of the present chapter, that the needle is *astatic;* that is, independent of the influence of terrestrial magnetism, so that it will not, like ordinary magnetized needles, settle itself in the direction of the magnetic meridian. The methods of rendering a needle astatic will be explained hereafter. It will be sufficient, for the present, to assume that the needle has magnetic poles, but no disposition to take any particular direction in virtue of the earth's magnetism.

Fig. 185.



Let P N be the wire conducting an electric current running from P towards N. This current will, when brought sufficiently near the needle NS, cause the latter to change its position, and to place itself in a certain direction, thus determined:—Let a line C O be drawn from the point of suspension of the needle, O, perpendicular to the current, and let this line meet the current at C. Through C O suppose a plane to pass perpendicular to the current. The needle N S will take a position in this latter plane perpendicular to C O.

Hence it appears, that an electric current, placed near a magnetic needle freely suspended, will exert a force or a system of forces on the needle which

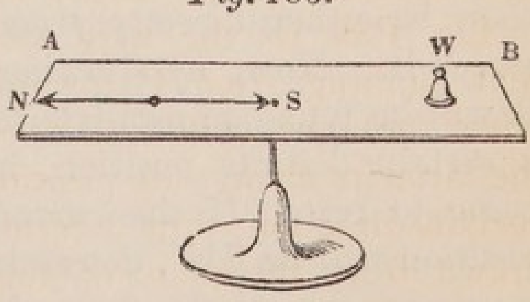
will cause it to assume a position in which the line passing through its poles and point of suspension shall be in a plane perpendicular to the current, and at right angles to the line joining the point of suspension of the needle with the point where the latter plane meets the current.

If the electric current be vertical, the needle will be placed in the horizontal plane, and at right angles to the line from the point of suspension, perpendicular to the current.

(424.) To determine with precision the directions and intensities of the force or forces exerted by the current on the needle, it will be necessary, besides rendering the needle astatic, to adopt some mode of suspension by which either pole may be free to move while the other is fixed. By such means, the action of the current on each pole may be observed independently of its action on the other, and the result of the combined actions on the poles when both are free may then be easily inferred.

This object may be attained by the following arrangement: — Let an oblong strip of card or pasteboard, A B (*fig.* 186.), be supported at its centre of gravity on a pivot, so as to be capable of revolving in the horizontal plane. On this card a magnetic needle may be placed, so that the pivot or centre of motion may coincide with either pole, or have any required position between or beyond the poles. The card may be balanced, so as to preserve its horizontal position, by the adjustment of a movable counterpoise. A magnetic needle may thus be arranged, so as to be capable of revolving in an horizontal plane round any proposed point as a centre of motion.

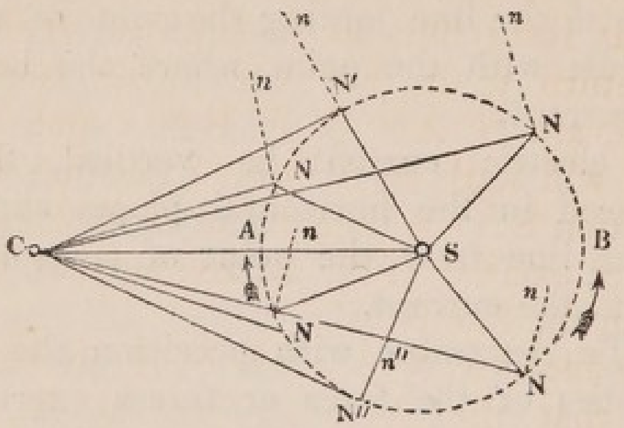
Fig. 186.



(425.) Let the needle be first placed with one of its

poles, the south pole, S (*fig.* 187.), for example, over

Fig. 187.



the pivot, so that the action of the current on the north pole N alone shall take effect. Let the wire conducting the current be perpendicular to the plane of the paper, penetrating it at a point C, and the motion of the needle must then be confined to the plane of the paper. Let the circle described by the north pole of the needle round the pivot be A N B, the wire being outside this circle.

To ascertain the direction in which the force exerted by the current on the pole N of the needle acts, it is only necessary to find the position in which the needle will remain at rest; for the direction of the force must then be either directly *from* the pivot, or directly *towards* it. Now, by allowing the needle to play freely, it will be found to oscillate for a time on each side of a certain definite position, in which at length it will come to rest. If the current *ascend* on the wire, this position will be SN′, determined by a line CN′, drawn touching the circle from C. The force, therefore, exerted by C on N′ must be in the direction N′*n*′; for although a force in the contrary direction N′S would also be consistent with the equilibrium of the needle in the position N′S, yet, on the slightest disturbance from that position, the pole of the needle would depart from it; whereas, in the present case, it is found to return to it.

If the other tangent C N″ to the circle be drawn from the same point C, and the needle be placed in the position S N″, it will maintain that position so long as it is kept at rest; but, on the slightest disturbance, it will not return to it, but will sweep round, either through the arc N″A N′ or N″B N′; and, after some oscillations, will settle in its former position S N′.

The position S N″ is then one of *instable equilibrium*, and the force exerted at N″ by the current is directed *towards* S in the line N″*n*″.

Since the angles C N′ S and C N″ S are right angles, it appears that the force exerted by an ascending current at C on the north pole N of a magnetic needle, is in a direction perpendicular to the line drawn from the current to the needle, and turned to the left of that line as viewed from the current.

If the pole N be placed any where in the arc N″ A N′, it will be moved by the action of the current towards N′, as indicated by the arrow.

For let a line C N be drawn to the pole from the current, according to what has just been proved, the action of the current will be in the direction *n*, or perpendicular to C N, and to the left of it as viewed from C. Such a force will evidently cause the pole N to move towards N′.

If the pole N be placed any where in the arc N″ B N′, the force of the current acting still perpendicular to C N in the direction N *n*, will cause the pole N to move towards N′.

Hence it is apparent that wherever the pole N may be placed, except at the point N″ of instable equilibrium, it will move towards N′, and will oscillate from one side to the other of that point in the manner of a pendulum, until it is brought to rest at that point by friction and the resistance of the air. The position S N′ is therefore a position of stable equilibrium.

If the current *descend* upon the wire, the point N″ will be that of stable, and N′ that of instable, equilibrium. Hence it appears that in this case the force

of the current must act to the right of the line drawn to the pole. The motions of the needle in every part of the circle will therefore be contrary to those which it had in the former case. It will now oscillate on each side of the point N″.

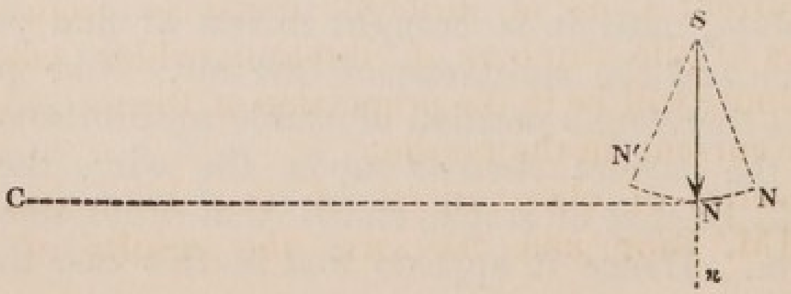
If the north pole N of the needle be placed over the pivot, the south pole S being alone subject to the action of the current, the effects when the current ascends will be the same as in the former cases they were when it descended, and *vice versâ*.

(426.) To assist the imagination and the memory in conceiving and retaining the conditions which determine the direction of the force exerted by an electric current on the poles of a magnetic needle, let the person of the observer be supposed to be the conductor of the current, with a descending current running from his head to his feet, and let his face be supposed to be always turned to the north pole of the needle; the general tendency of the north pole will be toward the right; and its exact direction will always be at right angles to the line drawn from the observer to the pole in any given position: as the current or the observed pole is reversed, the direction is reversed also; but a *downward* current moving a *north* pole to the *right* hand is a convenient form for impressing the proposition on the mind.

(427.) Having explained the conditions which will in every case determine the *direction* of the forces exerted by a current on the poles of a magnetic needle, it will next be necessary to consider those which affect the *intensity* of these forces.

Let S N (*fig.* 188.) be a magnetic needle, rendered

Fig. 188.



astatic and supported on its south pole S. Let C be the section of a wire perpendicular to the paper placed in a line C N, at right angles to S N, and having a descending electric current passing along it. The pole N will then be solicited by a force in the direction N *n*, the intensity of which it is required to measure. If the needle be drawn through a small arc N N′, on either side of its position of equilibrium, and liberated, it will oscillate like a pendulum; and when the arc N N′ is small compared with the distance C N, and the angle N S N′ also small, it may be assumed that the force exerted on the pole of the needle in every part of its arc of vibration has the same intensity, and is directed in lines every where sensibly parallel to S N *n*. This being the case, the needle is in all respects analogous to a common pendulum, and the intensity of the force which keeps it in vibration may be deduced from observing its rate of vibration in the same manner and by the same principles as those by which the intensity of the force of terrestrial gravity is deduced from observing the rate of vibration of a common pendulum.

If the distance of the current C from N be varied, it will be found that as C approaches N the vibration of the needle will be more rapid, and as C is removed to greater distances it will be slower. It is evident, therefore, that the force exerted by the current on the pole of the needle increases in some proportion as its distance from the needle is diminished.

But it is proved in mechanics, that the intensity of the force which keeps a pendulum in vibration is, in the same proportion as the square of the number of vibrations of the pendulum in a given time. If the vibrations, therefore, of the needle be observed when the current C is at different distances from it, the squares of the numbers of vibrations which take place per minute will be in the proportion of the forces exerted by the current on the needle.

A series of observations of this kind was made by MM. Biot and Savart, the results of which

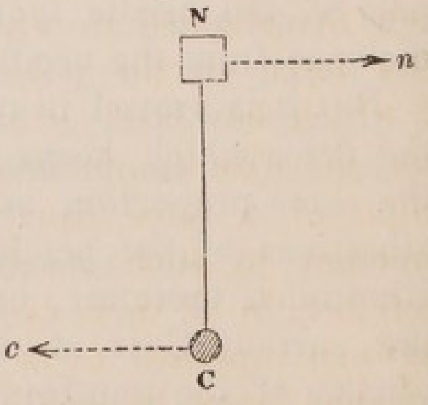
prove that *the force which the current exercises on the pole of the needle increases in the same ratio as the distance of the current from the pole of the needle is diminished.*

In the experiments from which this law was deduced, the length of the wire conducting the current was considerable; and the total action of the current must be regarded as composed of the separate actions of every part of it, these several parts being at different distances from the pole of the needle. M. LAPLACE submitted the result of the experiments of MM. BIOT and SAVART to analytical investigation, and proved from them that each elementary portion of the current must exercise an action on the pole of the needle, the intensity of which is inversely as the square of the distance.

(428.) It is natural, however, to infer, that the action of the current on the magnet must be attended with a corresponding and equal reaction of the magnetic poles on the current; so that if the wire conducting the current were moveable, and either pole of the magnet fixed, the latter would act on the wire, and produce effects equal and contrary to those which the wire, being fixed, produced on the magnet. Experience accordingly confirms this inference.

If N (*fig.* 189.) be the north pole of a magnet, and C represent the section of the conductor of a descending electric current of which the direction is perpendicular to the plane of the paper, it has been shown that the force exerted by C on N is in the direction of the line N *n*, at right angles to C N, and to the *right* of an observer who views N from C. Now, the reaction of N on C would produce a force, C *c*, in the contrary direction, C *c* to the *left* of the same observer, or to the *right* of an observer who views C from N. If, then, the conductor which car-

Fig. 189.



ries the current be moveable, and the magnet be fixed, the pole N will exert a force on C which will urge C in the direction C *c*.

If the pole of the magnet which acts on a descending current be the south pole, the current will be urged by a force directed to the *left* of an observer who looks at the pole from the current.

An ascending current is affected by the north pole of the magnet in the same manner as that in which a descending current is affected by the south pole; and it is affected by the south pole in the same manner as a descending current is affected by the north pole.

(429.) Hence, in general, if the person of an observer of the north end of a needle represent a wire carrying a descending current, he will himself be urged to the left by the action of the magnetic pole or the current; and *vice versâ*, when conditions are reversed.

(430.) If the current be capable of moving in a circle, of which the magnet is the centre, it will move direct when the pole is N and the current descending, or the pole S and the current ascending; and retrograde when the pole is N and the current ascending, or the pole S and the current descending.

The reciprocity of the action of the conductor of the current and the poles of the magnet involves the consequence, that, in all the cases which have been investigated in which the conducting wire exercises force on the poles of the needle, the resultant of which has been determined in intensity and direction, the wire conducting the current is subject to the action of a force equal in intensity and opposite in direction to such resultant. The results obtained, therefore, in all these cases, where the conducting wire has been supposed to be fixed, and the magnetic needle movable, may be applied, *mutatis mutandis*, to the cases in which the magnet is fixed, and the conductor of the current moveable.

CHAP. II.

EXPERIMENTAL ILLUSTRATIONS OF THE MUTUAL INFLUENCE OF MAGNETS AND RECTILINEAR ELECTRIC CURRENTS.

(431.) WHEN the reciprocal influence of magnets and electric currents was unfolded by the researches of Oersted; and the laws which govern it explained by Ampère, the practical ingenuity of philosophers and philosophical instrument makers was stimulated to contrive methods for the experimental illustration of these laws. The fruit of their labours has been a vast variety of illustrative apparatus new to the cabinets of physics, many of which present features of so much interest, that, although they sometimes differ from each other in little more than mere form, they cannot properly be passed over without particular notice in this work.

The object aimed at in these instruments is to exhibit the rotation of a magnet round a current, or of a current round a magnet, or of each at the same time round the other. The general principles which have served as the guide in the invention of such apparatus are those which have been explained in the preceding chapter

Several varieties of instruments, which are now about to be described, may be briefly stated as follows: — If the north pole N of a magnet and a descending current D mutually act on each other, each will have a tendency to move round the other with *direct rotation*. If the pole of the magnet or the direction of the current be changed, the rotation will be retrograde; but if both the pole of the magnet and the direction of the current be changed, the direction of the rotation will

remain unaltered. The rotation of each round the other, in every possible case, will be as follows: S expressing the south pole and A an ascending current—

$$\left.\begin{matrix} N, D \\ S, A \end{matrix}\right\} \textit{Direct rotation.}$$

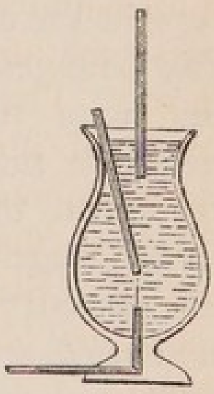
$$\left.\begin{matrix} N, A \\ S, D \end{matrix}\right\} \textit{Retrograde rotation.}$$

We shall classify these instruments according to the particular manner in which they exhibit the action of the electric and magnetic forces.

(432.) *To cause either pole of a magnet to revolve round a fixed electric current as a centre.*

A glass vessel (*fig.* 190.) is nearly filled with mercury, and an electric current is made to pass through the mercury by means of a wire, from one end of a constant cell (315.) dripping into the mercury, and another wire, connected with the other end, passing into the mercury, through the sole of the instrument. A magnet is retained, by a piece of silk attached to the lower end, in such a manner that one pole shall be above the surface. The ends of these wires are amalgamated to insure contact. If, now the current is descending, and the exposed pole is the north of the magnet, it will revolve with direct rotation.

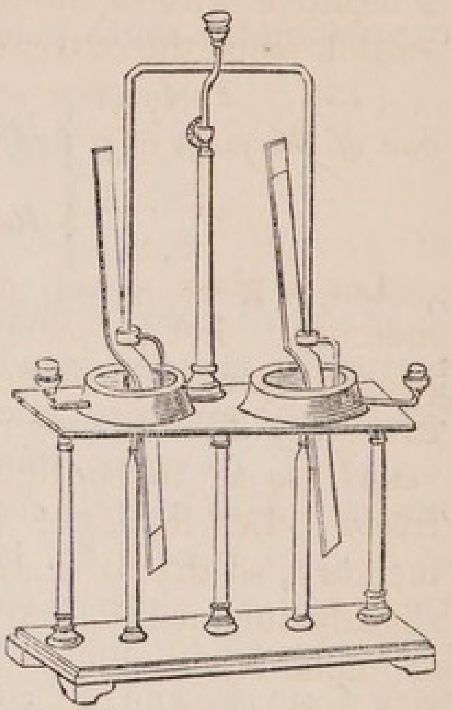
Fig. 190.



In the following arrangement the resistance of the mercury is avoided:—

Let two bar magnets be bent into the form shown in *fig.* 191., so that a small portion at the middle of their length shall be horizontal, while the remainder is vertical. Under the horizontal part of each let an agate cap be fixed, by which the magnet may be supported on a vertical pivot; and on the upper surface of the horizontal part let a small cup, to contain mercury, be fixed. Let the two magnets thus constructed be arranged in a frame, the pivots supporting them so as to allow them to revolve. In order to steady

Fig. 191.



the motion of the magnets, they are provided with wire loops on the lower parts, which embrace the wire supporting the pivot, and prevent the magnets swerving from the vertical position. A small circular canal containing mercury surrounds each magnet a little below the rectangular bend, and is supported on the stage. A bent wire, pointed and amalgamated at the end, passes from each small cup of mercury, and dips into the mercury in the circular canal. By this arrangement the point of the wire moves in contact with the mercury in the canal, while the magnet revolves on the pivot; and this wire forms one electric communication between the mercury in the cup and the mercury in the circular canal. The cups are connected with a cup at the top by a rectangular wire, supported on a central pillar, and having its points in the mercury contained in the cups. From the sides of the circular canals wires project, which also terminate in small cups.

If the cups be all filled with mercury, and the positive wire of a voltaic battery be dipped in the upper one, and wires connected with the negative pole in the two lower, descending currents will be conducted to these cups, and will pass away by the negative wires. If the north pole of one magnet and the south pole of the other be uppermost, the former will revolve on its pivot with a direct, and the latter with a retrograde, motion. If the north poles of both be uppermost, both will turn with a direct motion; and if the south poles be uppermost, with a retrograde motion.

If positive wires be brought to the lower cups, and a negative wire to the upper, the rotations will be reversed, since the currents will then ascend.

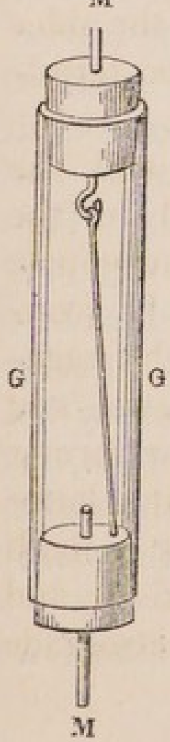
(433.) *To cause a moveable current to revolve round one of the poles of a magnet, the latter being fixed.*

First Method.

Let a glass vessel, *fig.* 192., be nearly filled with mercury. Let a metallic wire be suspended by a ring or hook at its upper extremity directly over the centre of the vessel, so as to be capable of revolving freely. Let its lower end float on the mercury, so that it shall rest in a position slightly inclined to the vertical. A rod of metal enters the bottom of the vessel, and is in contact with a fixed magnet occupying the centre. When one of the poles of a battery is put in communication with the mobile wire, and the other with the fixed wire, a current will pass along through the mercury. If the current descend, and the north pole of the magnet be uppermost, the rotation will be *direct;* otherwise it will be *retrograde.*

Fig. 192.

Fig. 193.



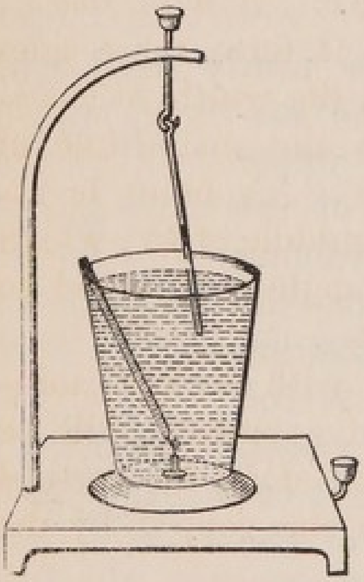
Let G G, *fig.* 193, be a glass tube, in the lower end of which is inserted a cork, through which a rod M of soft iron is passed. The upper end is also stopped with a cork, through which a wire passes, whence is suspended, within the tube, a wire, in the same manner as in the first method. A little mercury is poured into the tube on which the lower end of the wire floats. The pole of a powerful magnet being applied to M, this rod becomes magnetic by induction; and when a current is transmitted through the wire, the latter will revolve rapidly round M, even when the current is feeble.

Mr. Faraday, to whom is due this and the

first method, constructed an apparatus of this kind, which was put in operation by a voltaic arrangement, consisting of only two plates of the magnitude of a square inch.

(434.) By combining the method *fig.* 192., with that already described, *fig.* 190., for producing the revolution of a magnet round a fixed current, Mr. Faraday exhibited both phenomena at the same time. This apparatus is represented in *fig.* 194.

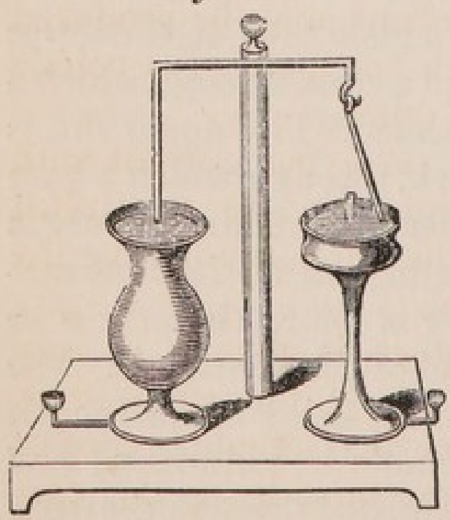
Fig. 194.



One mercurial cup, communicates with the mercury in the vessel, by a wire rod bent at right angles. This mercury being in contact with the mobile rod, the current is continued along, and thence down the fixed vertical rod to the vessel, in which a magnet is suspended. The current is conducted from the mercury by another rectangular rod to another cup.

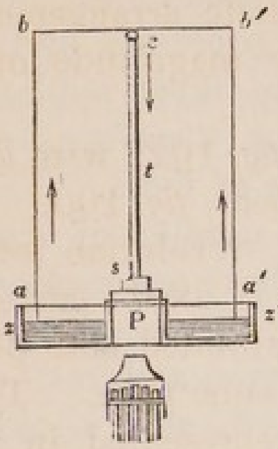
When the cups are put in communication with the poles of a voltaic apparatus, the wire revolves round the magnet fixed in the centre of the vessel, and the magnet in the vessel revolves round the wire hanging over the centre of that vessel. The directions of these rotatory motions are determined, as before, by the principles already stated; or two vessels may be employed, as in *fig.* 195., in the one which is at the right hand in the figure, the *wire* rotates, and in the other the magnet does.

Fig. 195.



(435.) Let zz' (*fig.* 196.) represent a section of a

Fig. 196.



circular trough of zinc, having an opening in the centre, in which is soldered a smaller circular vessel, P, of copper, surmounted by a vertical rod, *t*, of copper, terminated at the upper extremity by a mercurial cup, *c*. A wire, *abb′a′*, is bent so as to form three sides of a rectangle, the width, *bb′*, corresponding to the magnitude of the trough *zz′*. A point is attached to the middle of *bb′*, which rests in the cup *c*, so that the rectangle is balanced on *t*, and capable of revolving round it.

If the trough *zz′* be now filled with an acid solution, voltaic action will ensue, and a current will be established proceeding from the acid along the vertical sides of the wire, and returning to the copper by the vertical rod *t*.

If the pole of a magnet be now applied under the centre of the copper vessel, P, it will act upon the ascending vertical currents, *ab*, *a′b′*, and will cause the wires to revolve with a *direct* or *retrograde* motion, according as the pole applied is the south or north pole.

If the circular trough be composed of glass and filled with mercury, the same effects may be produced by connecting the mercury with one pole of a voltaic battery, and the cup *c* with the other.

The points of contact of the revolving current with the fluid in the circular trough may be multiplied by attaching the points *a a′* of the wires conducting the current to a small hoop of metal.

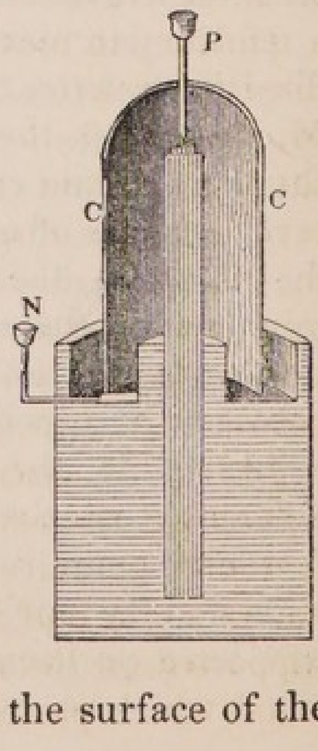
When the pole of the magnet is placed at any point within the circle described by the wires *a a′*, different from the centre, or on the circumference of that circle, or, finally, any where outside it, the currents will be subject to movements of oscillation, and will have positions of stable and instable equilibrium

similar to those which a magnet assumes when acted on by a current in corresponding positions. These phenomena may be investigated by processes and formulæ similar, *mutatis mutandis*, to those applied in the preceding chapter; and it will not, therefore, be necessary here to enter into an analysis of them.

(436.) It is evident, that if any number of rectangular circuits of wire, such as that represented in *fig.* 196., were so united that the cross pieces $b b'$ should be common to all the currents, and rest on a common pivot, the vertical parts, $a b$, $a' b'$, would lie in a cylindrical surface, of which t would be the axis, and the current, instead of passing along two of those vertical wires, would be shared among all of them. Now this state of things will not be changed if, instead of a number of independent rectangular circuits of wire, a cylindrical surface of metal be substituted, its lower edge dipping in the fluid contained in the circular trough. The case is the same whether the cylinder be suspended by one wire, as in *fig.* 196., or be completed above, as in *fig.* 197.

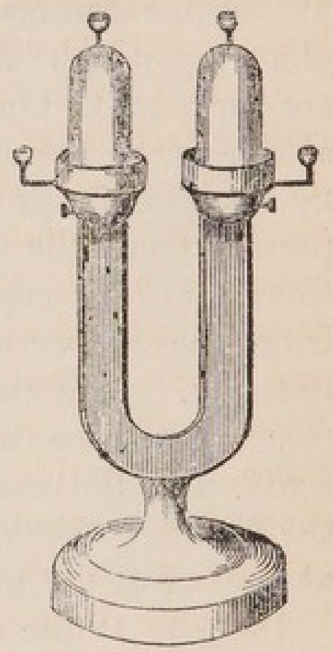
Such an arrangement is represented in *fig.* 197. A bar magnet is fixed upright, in a solid stand which has a cavity adapted to receive it. In this stand is formed a circular trough which is filled with mercury so as to surround the magnet. A light hollow cylinder, CC, of copper, is suspended on a point resting in an agate cup placed on the top of the magnet, and having a vertical wire proceeding from it which terminates in a small mercurial cup, P, at the top. Another wire connects the mercury in the trough with another small mercurial cup, N. When the cups P and N are put in connection with the poles of a voltaic apparatus, the currents passing upon the surface of the

Fig. 197.



copper cylinder are acted on by the pole of the magnet in its centre, and a motion of rotation is imparted to the cylinder, the direction of which will be determined as usual by the direction of the currents and the name of the magnetic pole.

Fig. 198.

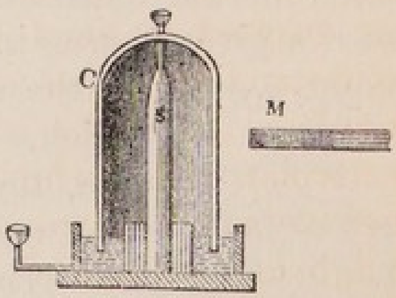


A double apparatus of this kind, erected on the two poles of a horseshoe magnet, is represented in *fig.* 198. The rotations of the copper cylinders will be in opposite directions if the currents be both descending or both ascending, but in the same direction if one current ascend while the other descends.

The wooden circular troughs are in this case fixed upon the arms of the magnet, and made fast by adjusting screws.

(437.) It is very obvious that a magnet M, *fig.* 199., applied *exterior* to the cylinder is far less efficacious than one in the *interior:* for, as the descending currents in C have all a tendency to move in the same direction *relative to the magnet* M, not *relative to the centre* S, the more distant currents would revolve in one direction round S, and the nearer currents in the other direction; as the latter, from their proximity, are most acted on, they will determine the direction; and the amount of motion will be the difference between the two forces.

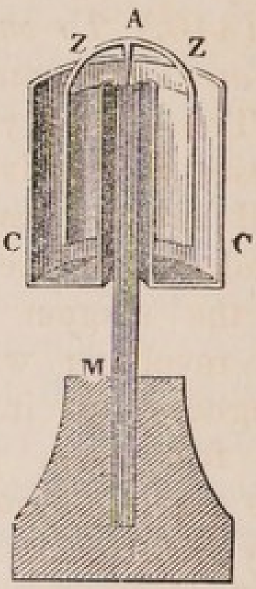
Fig. 199



(438.) M. Ampère adopted the following method of exhibiting the revolution of a current round a magnet. A double cylinder of copper, CC, *fig.* 200., about two inches and a half in diameter and the same in height, is supported on the end of a bar magnet, M, by a plate of metal which passes across the upper orifice of the inner

cylinder. A light cylinder of zinc, Z Z, supported by a wire arch, A, is introduced between the inner and outer cylinders of copper, a steel point attached to the wire arch resting upon the arched plate by which the copper cylinders are supported. On introducing diluted acid between the copper cylinders, voltaic action is produced, the current passing from the zinc to the acid, and thence to the copper, and ascending from the copper through the pivot to the zinc. The zinc being in this case free to revolve while the copper is fixed, and the current descending on the former, the rotation will be direct or retrograde according as the pole of the magnet is north or south.

Fig. 200.



(439.) If the copper were free to revolve as well as the zinc, it would turn in the contrary direction, since the current ascends upon it while it descends upon the zinc. This effect is exhibited by a modification introduced in the apparatus by Mr. J. Marsh, who substituted a pivot resting in a cup at the top of the magnet, for the metallic arch by which, in the former case, the copper vessel was supported. This arrangement is shown in *fig.* 201.

Fig. 201.

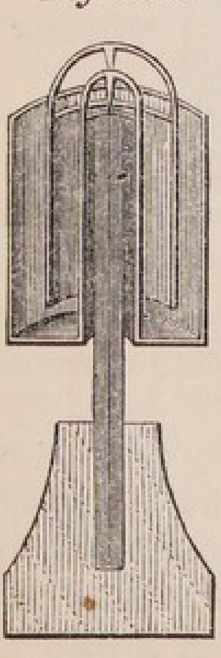
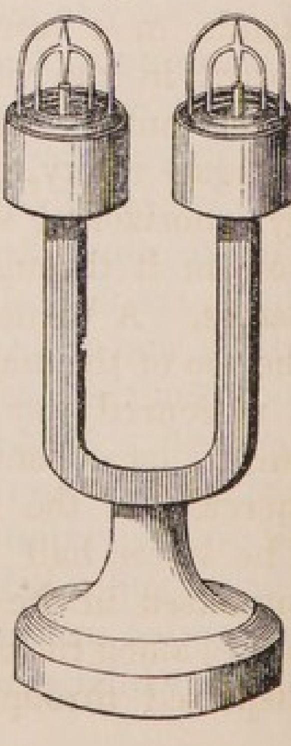


Fig. 202.



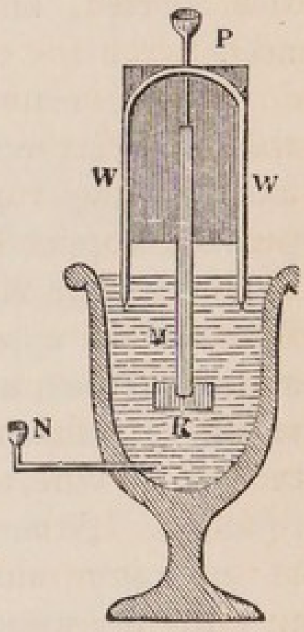
The effect of opposite magnetic poles may be exhibited by using a horse-shoe magnet as represented in *fig.* 202., each pole supporting similar vessels of zinc and copper suspended on pivots in the same manner. The

motions on the two arms of the magnet will be in contrary directions.

(440.) *To cause a magnet to turn on its own axis by an electric current transmitted parallel to it.*

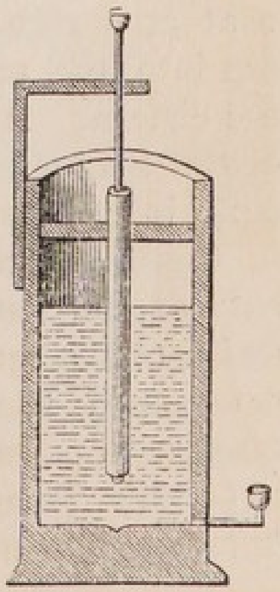
The tendency of the conductor on which a current passes to revolve round the magnet will not the less exist, though the conductor of the current be so fixed to the magnet as to be incapable of revolving without carrying the magnet with it. The magnet may in fact form part and parcel of the moving system, without causing any variation in the results. In *fig.* 203. the magnet M is sunk by a platinum weight P; its upper end being fixed to the copper cylinder W W, a current passing from P to N causes the cylinder to rotate, which carries with it the magnet.

Fig. 203.



(441.) Since the magnetic bar is itself a conductor of electricity, it is not necessary, in the exhibition of this effect, to introduce any other conductor for the current. In the apparatus in *fig.* 204., the magnet stands in a vessel of mercury, supported in the vertical position at the lower end by a steel point resting in an agate cavity, and at the upper part by a horizontal slip of wood having a hole in it through which the magnet passes. A vertical wire proceeds from the top of the magnet and terminates in a mercurial cup, while another mercurial cup communicates with the mercury at the bottom of the vessel. The lower half of the magnet being immersed in the mercury, the current passes along the upper half, and is there dispersed through the mercury so as

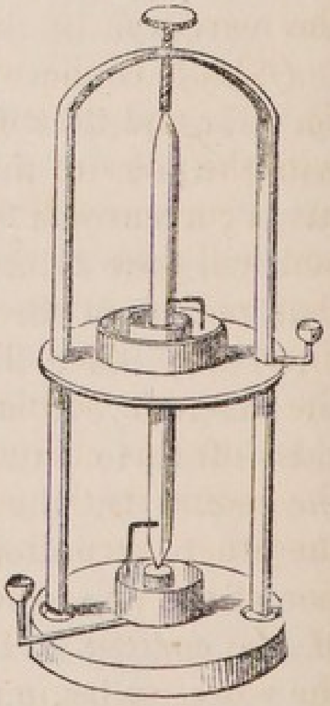
Fig. 204.



not to affect the lower part in any sensible degree. When the cups are put in communication with a voltaic apparatus, and a current transmitted along the part of the magnet above the mercury, a motion of rotation of the magnet will commence, the direction of which will depend, as usual, on the direction of the current, and on the magnetic pole on which it acts.

A more convenient apparatus for the exhibition of this effect is represented in *fig.* 205., where a magnetic bar is supported in the vertical position between pivots, which play in agate cavities. A stage is supported by the frame of the apparatus at the middle of the magnet, on which a circular canal containing mercury is sustained, by which the magnet is surrounded. A similar circular trough of mercury surrounds the lower end of the magnet. Two mercurial cups communicate metallically with the mercury in these troughs respectively. A small wire, pointed and amalgamated at its end, is fixed to the middle of the magnet, immediately above the cistern, and is bent at a right angle, so as just to dip into the mercury contained in the cistern. Another wire is attached to the lower end of the magnet, dipping in like manner into the mercury in the lower cistern. When the cups are put in communication with a voltaic apparatus, the lower half of the magnet only is traversed by the current, and a rotation takes place, the direction of which is determined in the same manner as in the former cases.

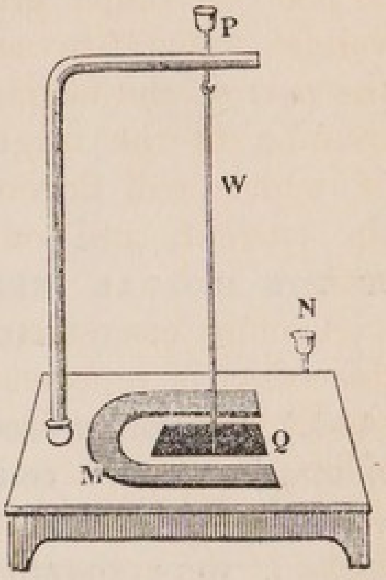
Fig. 205.



(442.) *To apply the electro-motive force of a current to turn a wheel upon its axle.*

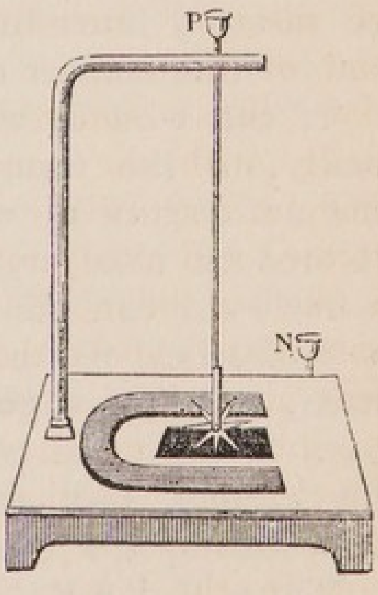
When the wire W, *fig.* 206., conveys a descending current from P, to be carried off by N from a trough of mercury Q, placed *between* the poles of a horse-shoe magnet, of which the more distant shall be a south pole, the wire will be urged toward Q; but the nearer or north pole, being on a different side of the wire, will urge it in the same direction, so that it will be repeatedly tossed out of the mercury.

Fig. 206.



(443.) If the wire W terminate in a radiated wheel *fig.* 207., and the cups P and N be put in communication with the poles of a voltaic apparatus, a current will traverse the rod and will pass to the mercury by that radius of the wheel which dips into it. The poles of the magnet, acting on opposite sides of this current, will impel the radius in the one direction or the other, according to the position of the poles and the direction of the current. This will cause the wheel to begin to revolve, and as fast as one radius emerges from the mercury another enters it, and so the electric action and consequent motion is continued.

Fig. 207.



It is not necessary that the wheel should be radiated. If it be a uniform disc of metal, the edge of which touches the surface of the mercury, as suggested by Mr. Sturgeon, the same effects are produced, and they may be explained in the same manner.

CHAP. III.

OF THE MUTUAL INFLUENCE OF MAGNETS AND CIRCULATING CURRENTS.

(444.) In the preceding analysis and experimental illustrations, the conductors of the electric currents whose properties in relation to magnets have been examined, were supposed to be rectilinear. The wire which conducts a current may, however, be bent into any desired form, and the effects produced by the action of its different parts on a magnet, as well as those which it may suffer from the action of the magnet, may be deduced immediately from principles on which the action of rectilinear currents is determined.

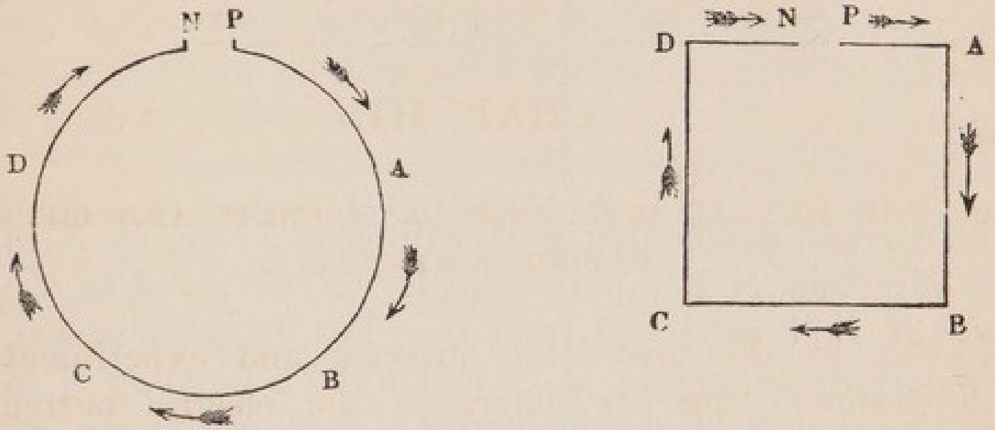
If the wire by which a current is traversed, being bent into the form of any geometrical figure, have the extremities at which the current enters and leaves it brought close together, the current is usually called a *closed current*. As, however, a current cannot traverse a geometrical figure which, like a circle, returns into itself, some space, however small, being necessarily left open between the points of entrance and departure of the current, such arrangements may be more properly expressed by the term *circulating currents*.

Thus, if PABCDN (*fig.* 208.) be a geometrical figure complete except at the space between N and P, and the point P be put in communication with the positive, and N with the negative, pole of a voltaic battery, an electric current will pass round the figure in the direction of the arrows entering it at P and leaving it at N. Such a current is a *circulating current*.

(445.) If a circulating current be viewed on opposite sides of the figure formed by the wire con-

ductor, it will appear to circulate in opposite directions; the current, as viewed on one side, circulating as the

Fig. 208.



hands of a watch, or *direct*, and, as viewed on the other side, in a direction contrary to the hands of a watch, or retrograde. As it will be frequently necessary to refer to these opposite sides of circulating currents, being distinguished from each other by specific electro-magnetic properties, we shall call that side on which the circulation of the current appears direct, the FRONT of the current; and that on which it appears retrograde, the BACK of the current.

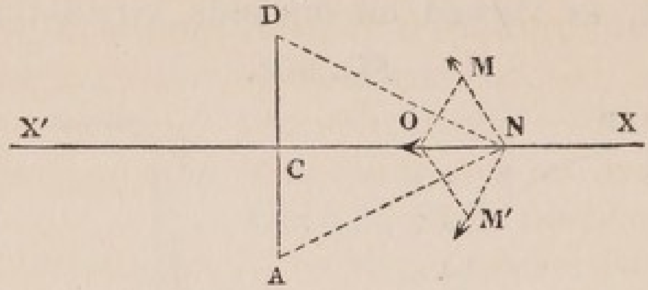
If a circulating current be a geometrical figure which has a *centre* that is a point round which every part of the current is symmetrically disposed, a straight line passing through this centre, perpendicular to the plane of the current, may be called the AXIS of the current.

(446.) *To determine the mutual influence of a circular circulating current, and a magnetic pole placed any where in its axis.*

Let the axis X′ C X′ of the current be supposed to coincide with the paper, and the plane of the current therefore to be perpendicular to it, C being the centre, A the point where the current ascends, and D the point where it descends. It is evident, therefore, that O will be at the *front* of the current.

First. Let us suppose that a north magnetic pole, N (*fig*. 209.), is placed on the axis in front of the current.

Fig. 209.

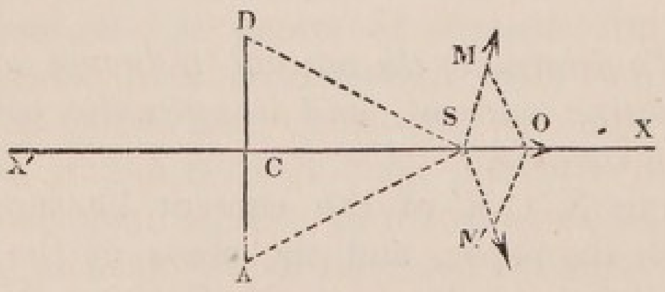


The current, descending at D, will exert a force on N in the direction N M′, perpendicular to D N, and to the right of D N as viewed from D. For the same reason, the current ascending at A will exert a force on N in the direction N M, perpendicular to A N, and to the left of A N as viewed from A. The two forces being equal may be represented by the equal lines N M′ and N M; and their resultant will be the diagonal N O, which is therefore a force directed along the axis *towards* the centre of the current.

If the plane of the paper be imagined to turn round the line X′ X′ as an axis, the same conclusions will follow in every position which it can assume. Hence every part of the circular current exercises an *attractive* force on a northern magnetic pole, placed any where upon its axis *in front* of it.

Secondly. Let us suppose that a south magnetic pole,

Fig. 210.



S (*fig*. 210.), is placed in the same position. In that case the action of D on S is directed to the left of D S, and the action of A to the right of A S. These forces, being equal, may be represented by S M and S M′; and their resultant will be S O, directed *from* the centre C.

If the plane of the paper be imagined, as before, to revolve round the line X X′, the same will be true of all points of the current through which it will pass; and it therefore follows that the current exercises a *repulsive* force on the *south* pole of a magnet placed on its axis in *front* of it.

By the same reasoning it will evidently follow, that a north magnetic pole will be repelled, and a south magnetic pole attracted, when placed on the axis C X′, and to the *back* of the current.

Since the magnet exerts upon the current an action equal and contrary to that which the current exerts on the magnet, it follows, that the pole N placed in front attracts, and placed at the back repels, the current, and that the pole S has in the same positions contrary effects.

(447.) Such are the general effects as to the *direction* of the resultant of the electro-magnetic forces developed by a circular current acting on a magnetic pole placed in its axis. But it is necessary, also, to determine the manner in which the *intensity* of such force varies with the change of position of the magnetic pole on the axis.

To accomplish this, it must be remembered that each small portion of a current exerts a force on the pole of a magnet which is the same at equal distances, and varies inversely as the square of the distance. Since, in the present case, the magnetic pole, in any of its supposed positions, is at the same distance from all parts of the current, the forces which all the elements of the current exert upon it at any distance are equal. Let the force which the unit of length of the current exerts at the unit of distance be i; the force which the whole circular current will exert at the same distance will be $2ri\pi$, where r is the radius of the current, and π the ratio of the circumference of a circle to its diameter. The force which the current would exercise at the distance D will then be $\frac{2ri\pi}{D^2}$.

But since this force is inclined at an angle to the axis of the current whose cosine is $\frac{r}{D}$, we shall have

$$R = \frac{2r^2 i\pi}{D^3}.$$

Hence the intensity of the attraction or repulsion of a current of the same intensity, on a magnetic pole of the same magnetic intensity, varies *directly as the square of the diameter of the current, and inversely as the third power of the distance of the magnetic pole from the conductor of the current.*

(448.) It follows, therefore, in general, that the north pole of a magnet placed before a circular current and on its axis attracts, and is attracted by, the current, and when placed behind the current on its axis repels, and is repelled by, the current; and the south magnetic pole produces and suffers contrary effects; and the intensity of such attraction or repulsion varies directly as the square of the diameter of the current, and inversely as the third power of the distance of the pole from it.

It follows, therefore, that a circular current possesses the attractive and repulsive properties of a magnet in reference to magnets, the *front* of the current having the properties of a *south*, and the *back* of a *north*, magnetic pole.

(449.) If a series of circular currents could be produced with a common axis, and the fronts presented all in the same direction, their planes being very near each other, the forces which they would exercise on any magnetic pole presented to them would be combined, and the effects proportionally augmented.

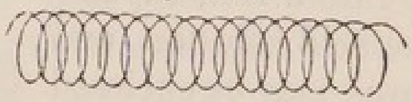
Fig. 211.

This may be accomplished by bending the wire which conducts the current into a spiral, as represented in *fig.* 211., which may be considered as very nearly

identical with a system of concentric circles. Each circle will exert a force on any magnetic pole placed in the axis of the spiral, which will be attractive or repulsive according to the name of the pole, and according to the side of the spiral at which it is placed.

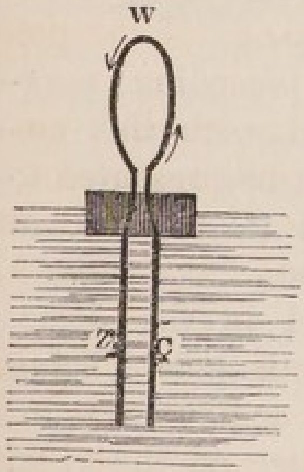
Or it may be accomplished still more conveniently by reducing the conducting wire to the form of a helix, as represented in *fig.* 212., the successive coils of which may be regarded as circles whose planes are nearly parallel, and whose centres lie on the straight line parallel to those planes.

Fig. 212.



(450.) The magnetic properties of a circular current may be illustrated by a simple and ingenious apparatus imagined by M. de la Rive. Let Z and C (*fig.* 213.) be a pair of zinc and copper plates, attached to a cork of sufficient magnitude to float the apparatus on an acid solution. Each of the plates is about two inches in length and half an inch in breadth. A piece of copper wire, W, wrapped with silk thread, is attached to the plate C, and, passing upwards through the cork, is bent into the form of a circle of about an inch in diameter, so that the other end returns through the cork, and is soldered to the upper edge of the zinc plate Z. Voltaic action is thus produced, the positive fluid passing from the copper to the zinc, and from the zinc through the acid solution to the copper. The direction of the electric current is therefore expressed by the arrows. The copper will be on the right, and the zinc on the left, of an observer who looks towards the *back* of the current.

Fig. 213.

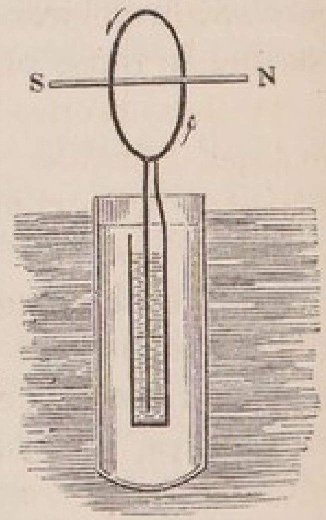


The susceptibility of this instrument may be increased

by coiling the wire several times round the circle before it is soldered to the zinc, each circular coil exercising the same electro-magnetic force; and the effect of the whole being as many times greater than that of a single coil as there are coils forming the ring. The silk with which the wire is wrapped prevents the electricity from passing laterally from coil to coil.

(451.) This apparatus may be otherwise constructed. Let the copper plate be doubled, so as to surround the zinc plate, as in Wollaston's method of constructing the voltaic battery (306). It may thus be formed into a cell, capable of containing the acid solution, and the whole apparatus may be enclosed in a glass tube, and floated on water or any other liquid, as represented in *fig.* 214. This modification of De la Rive's contrivance was suggested by Mr. Marsh.

Fig. 214.



(452.) All the consequences which have been deduced in the preceding paragraphs may be experimentally verified with this apparatus. If the pole of a bar magnet be presented to the ring, attraction or repulsion will take place, in accordance with the conditions explained.

If a thin magnetic bar be placed in the direction of the axis of the ring, the south pole S being in front of the current, and the middle or neutral point of the magnet coinciding with the centre of the ring, both poles of the magnet will repel, and be repelled by, the ring; and, as both poles are equally distant from the ring, these repulsive forces will be equal. The ring and magnet will, therefore, be in equilibrium.

(453.) *The mutual effect of the current and the magnet when the centre or neutral point of the magnet does not coincide with the centre of the current.*

When the north pole is in front of the current, the middle of the magnet is attracted to the centre of the

current, on whichever side of the centre it may be placed; and when the south pole is in front of the current, the middle of the magnet is repelled by the centre of the current, on whichever side of the centre it may be placed.

Since the action of the magnet on the current is equal and opposite to that of the current on the magnet, it follows that the current is attracted towards, or repelled from, the middle of the magnet according as the north pole of the magnet is before or behind the current.

It has been shown, that when the centre of the magnet coincides with that of the current, the system will be in equilibrium. If, in this case, the north pole be before the current, the centres will immediately return to their position, if any external force disturbs them from it; for, whatever the derangement may be, the centres of the magnet and the current will attract each other. But if the south pole be before the current, mutual repulsion will follow any disturbance of position, and the centres will depart from the position of equilibrum. The former is therefore a position of stable, and the latter of instable, equilibrium.

(454.) These properties may be experimentally illustrated and verified by M. De la Rive's apparatus (represented in *figs.* 305, 306.), by placing a magnetic bar in the axis of the current with its neutral point at different distances from, and at different sides of, the centre of the ring.

A curious effect may be observed when the circular current is repelled in either direction from the centre of the magnet. In that case, the wire ring will recede with a gradually retarded motion, owing to the rapidly diminishing intensity of the force by which the resistance of the fluid in which it floats is overcome. It will at length come nearly to rest, when it will turn slowly on its vertical diameter, and, having made half a revolution so as to reverse the direction of its plane, its front being turned towards the direction in

which the south pole of the magnetic bar is pointed, it will obey the attractive force directed to the centre of the magnet, and will move to that centre with an accelerated motion, when it will ultimately come to rest in a state of stable equilibrium.

This effect is easily accounted for. When the ring is repelled from the centre of the bar, its front must face to that side towards which the south pole of the magnet is directed. The forces exerted by the poles of the magnet on the circumference of the ring will then be all directed *inwards*, or towards the axis of the ring; and as the ring recedes from the magnet, the direction of these forces becomes inclined at a less and less angle to the plane of the ring, so that relatively to them the ring approaches to a state of instable equilibrium. In this state it would continue if absolutely undisturbed by any external action. To such action, however inconsiderable, it is always exposed in practical processes, and consequently, its position being slightly disturbed, it does not return to it, but, turning half round, takes that position relatively to the same forces which corresponds to stable equilibrium, and in which, also, it is attracted towards, instead of being repelled from, the centre of the magnet.

(455.) Helices, or screws, are of two kinds; those of which the thread turns in the direction of the hand of a watch (as represented in *fig.* 215.) are called *right-*

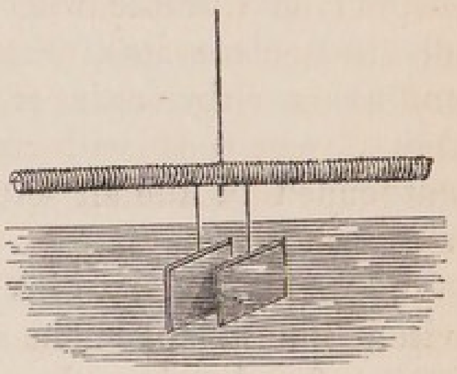
Fig. 215. *Fig.* 216.

handed, and those of which the thread turns in the contrary direction (as represented in *fig.* 216.) are called *left-handed.*

(456.) If an electric current traverse the thread of a right-handed helix, its front will be turned towards that end at which it enters; and if it traverse the thread of a left-handed helix, its back will be turned to that end at which it enters.

Hence, when a current traverses a right-handed helix, the extremity at which it enters has the magnetic properties of a south pole, and the extremity at which it leaves the helix has the properties of a north pole. When it traverses a left-handed helix, the extremity at which it enters has the properties of a north pole, and that at which it leaves the helix has the properties of a south pole.

Fig. 217.



(457.) Such a helix was arranged by Vanden Boss, so that, as the zinc and copper plates (*fig.* 217.) were immersed in acid water, the system should be suspended by a thread and free to move. In all cases it placed itself on the magnetic meridian.

(458.) If a magnetic needle be placed with its poles in the axis of a helix through which an electric current passes, its north pole will be attracted towards the positive end of the current, and its south pole towards the negative end, when the helix is right-handed; and its north pole will be attracted towards the negative end, and its south pole towards the positive end, when the helix is left-handed.

If a magnetic needle, placed in the centre of the axis of a helix, has its north pole presented towards the front of the current, its poles will be both equally attracted towards the centre of the axis of the helix, and the equilibrium of the needle will be instable. On the least disturbance of position, it will reverse the direction of its poles.

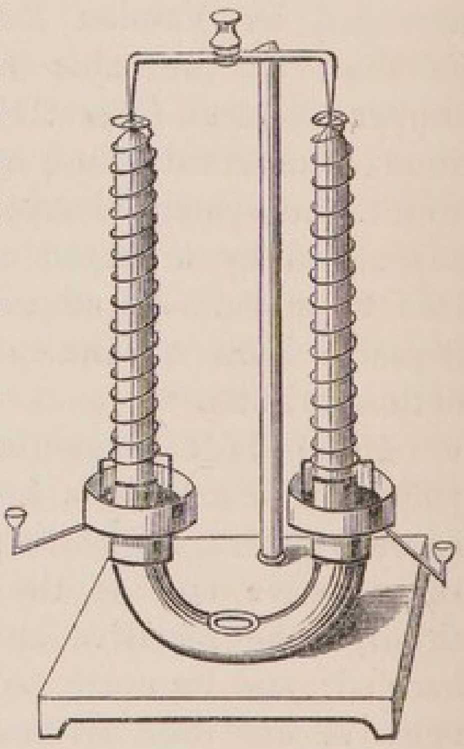
If the south pole be presented towards the front of the current under like circumstances, both poles will be equally repelled from the centre of the helix, and the equilibrium of the needle will be stable.

If the needle be placed any where in the axis of the helix, with its south pole directed before

the current, it will move towards the centre of the helix, and will come to rest when its centre coincides with the centre of the helix.

When the needle is sufficiently light, and the helical current sufficiently powerful, a curious effect may be observed if the needle be placed within the spires of the helix, so as to rest on the lower parts of the wire. The moment the connection is made with the battery, the needle will start up and place itself in the middle of the axis of the helix, where it will remain suspended in the air without any visible support.

Fig. 218.



(459.) Mr. Watkins devised the arrangement (*fig.* 218.) for showing the rotation of helices. The cup at the top of the cross bar is connected with one end of a battery, and the other two cups with the other end. The rotations occur in the usual way.

CHAP. IV.

OF THE INFLUENCE OF TERRESTRIAL MAGNETISM ON ELECTRIC CURRENTS.

(460.) The mutual influence of magnets and electric currents, and the laws which govern it, being ascertained, it is natural to inquire what effect the globe of the earth itself produces upon these currents in virtue of its magnetic polarity.

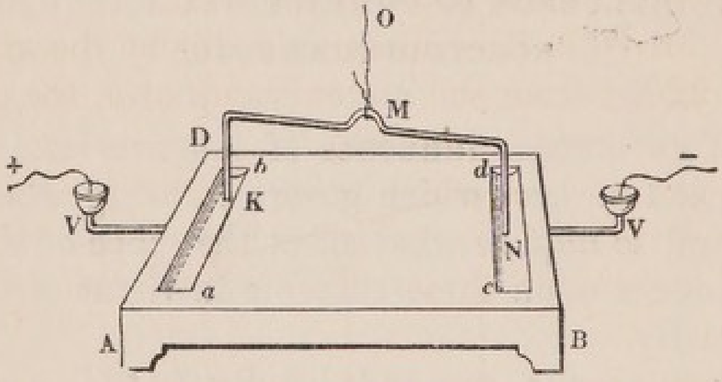
We have seen a suspended helix (457.) act, in all respects like a magnet; but before analyzing that action, which, by another train of circumstances, has presented itself to us, let us see the conditions under which a finite rectilineal current is placed with respect to the earth's magnetism. The earth may be regarded as an immense globe, having a powerful magnet in the axis; consequently, as experience tells us, a magnetic needle in our latitude, being unequally acted on by the two poles of this large magnet, will not remain parallel to the axis of the earth, but assume a position according to the resultant of the forces; which with us becomes nearly *perpendicular* (401.); let us consider it for the present, as if it were perpendicular; and in that direction must we look for the resultant magnetic force, which is to act upon our rectilineal wire.

Now, lying with our face to the earth, a current passing, as before (426.), from head to foot, and acted on by a south pole (for such is the north magnetism of the earth) (393.), any direction we may take, while looking toward the earth, will indicate that the current represented by our body, has a rendency to move *toward our right hand.* Lying from north to south, the direction would be *east;* lying east to west, it would be *south;*

lying south to north, it would be *west*; lying west to east it would be *north*; and so on for the intermediate points.

(461.) This effect of terrestrial magnetism on an horizontal current was observed by Mr. Faraday with the apparatus represented in *fig.* 219., which consists of a

Fig. 219.



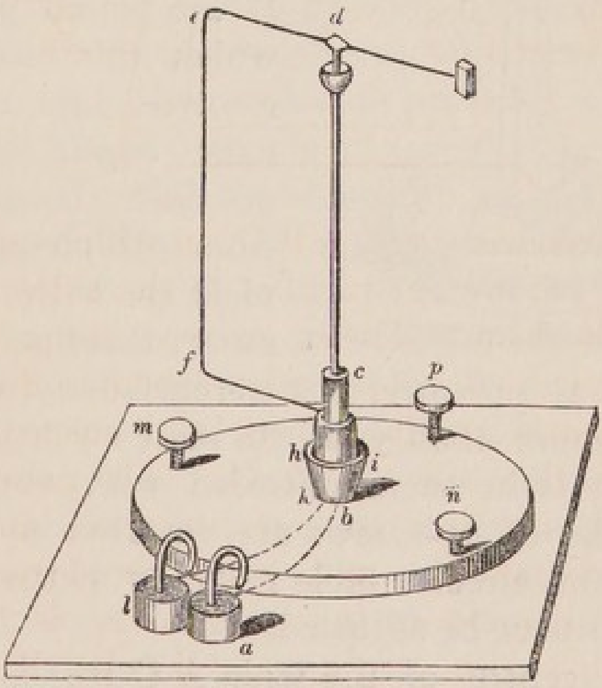
rectangular wooden stage, A B D, in which two straight grooves, *ab*, *cd*, are cut parallel to the sides, and about half an inch deep. These grooves being filled with mercury, a piece of copper wire, about a foot long, is bent downwards at the points, and suspended at the middle by a fine silk thread, O. The points of these wires, which dip into the mercury, are amalgamated to prevent oxidation, and preserve perfect metallic contact. The mercury in the grooves is in metallic communication with two mercurial cups, V and V, by which the apparatus may be put in communication with a voltaic battery. A current will thus pass from the groove *a b* through the wire, to the groove *c d*. When this takes place, the wire will be moved parallel to itself, and will continue so to move until the points are stopped by the ends of the grooves, or until the weight of the wire, acting like a pendulum, balances the tendency of the current to move in obedience to the earth's magnetism. The wire M may be made to resume all the positions just given (460.), and the experiment will show that the direction, in which it is urged, is in exact conformity with the theory.

(462.) Now, if the direction of the dip were exactly

perpendicular, the earth's magnetism could have no influence on a *vertical* current; for it would be in the line of the dip. But as the north end of a needle dips about 70°, and not 90°, the direction of the magnetic force is always somewhat *in front* of an observer looking toward the north; and hence a descending current has a tendency to move toward the east; and an ascending one to move towards the west.

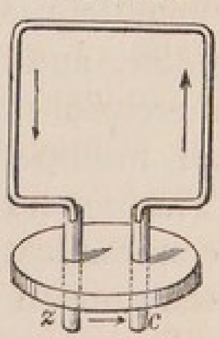
(463.) M. De la Rive illustrated this by the arrangement, *fig.* 220.; from the mercury cup at *a*, the current

Fig. 220.



ascends at *b*, the vertical rod, which is insulated by a glass tube *c*; it traverses the wire rectangle, *d, e, f,* to a ring which terminates in a mercury cup *h*. Thence it reaches the battery by *l*: *m, n, p,* are adjusting screws.

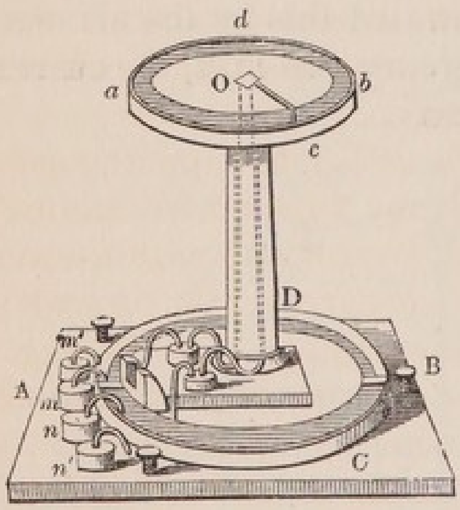
Fig. 221.



The apparatus (*fig.* 221.) was devised by M. De la Rive, sen.; it consists of a small piece of zinc and one of copper, connected by a rectangular wire, and floating on a cork in acid water. In this case an ascending and a descending current are mutually acted on, and the system will face (445.) the south.

(464.) Among the various apparatus which have been contrived to illustrate experimentally the effect of the earth's magnetism on rectilinear currents, as well as various other electro-magnetic phenomena, one of the most useful is due to M. Auguste De la Rive, and is represented in *fig.* 222. A circular table of wood A B, is supported on a platform, and is surrounded near its edge by a groove which is filled with mercury, forming a circular canal. At A and B are placed partitions by which this canal may be resolved into two semicircular canals, the mercury of each being separated from all metallic communication with that of the other, these partitions being removable at pleasure. A mercurial cup, *m*, is in metallic communication with the mercury in A D B; and another, *n*, is in communication with the mercury in A C B. Levelling-screws are inserted in the platform on which this circular table rests, by which its horizontal position may be adjusted.

Fig. 222.



In the centre of the table A C B D is a pillar, on which another circular table, *a c b d*, of less diameter, is supported, and which also has formed upon it a circular canal of mercury, resolved in like manner into semicircles by partitions at *a* and *b*, removable at pleasure. A concave screw is formed at *o*, in the top of a metallic rod, which is carried vertically through the pillar, and which is in metallic communication with a mercurial cup, *m'*, by means of a wire extending from an intermediate cup standing near the vertical pillar. The mercury in the superior canal is in like manner in communication with a mercurial cup, *n'*. A hinge is constructed on the inferior table, by which the vertical pillar may be stooped through a certain angle to dis-

charge the mercury from the superior canal; a motion which is permitted by the intermediate cups placed on the inferior table, without permanently breaking the communications between the cups *m′ n′*, and the conductors which are carried through the pillar.

By these arrangements it is always possible to put the mercury in either semicircle of the lower canal, the central screw O, of the superior table and the mercury in the canal on the latter, in communication with either pole of a voltaic battery, and to change or invert such communications at pleasure.

A small metallic point (*fig.* 223.), to support a cone or cap by which any apparatus is required to be suspended, is provided with a screw adapted to the concave screw formed at O; and a hollow cup or cone having a similar screw is also provided to support any point by which a conductor is to be suspended. Either of these pieces can, at will, be screwed upon O.

Fig. 223.

When the apparatus is placed for observations on terrestrial magnetism, the vertical plane passing through the partitions A and B should have an azimuth between that of the magnetic meridian and a perpendicular to it.

If the cup be screwed upon the conductor O, and the rectangular wire *e f g h i k l* (*fig.* 224.) be suspended upon it, the parts *g f* and *i k* being vertical and terminating in fine platinum points *f e* and *k l*, these

Fig. 224.

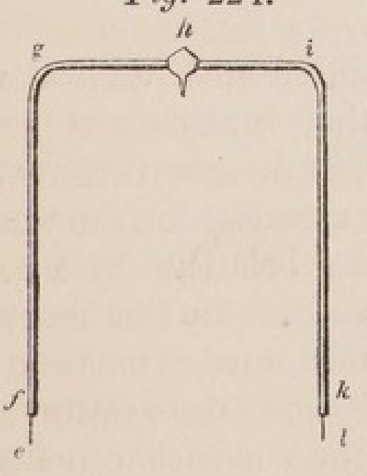
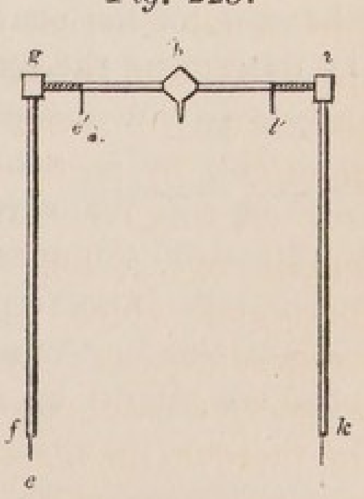


Fig. 225.



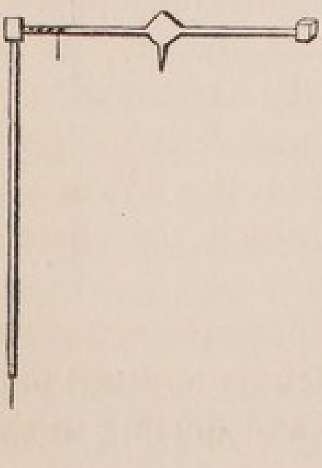
points will dip in the mercury in the two semicircular troughs formed in the inferior table. If the cups *m* and *n* be now put in communication with the poles of a voltaic battery, the current will be transmitted from one semicircular trough to the other, through the rectangular wire *f g h i k*, and this wire will immediately settle itself in a plane at right angles to the magnetic meridian.

To determine the share which each part of the current has in producing this effect, let each of the three sides of the retangular wire be successively suppressed. To suppress the horizontal part *g i*, let the arrangement represented in *fig.* 225. be substituted, in which *g i* is a glass tube. The wires *f g* and *k i* are connected with fine platinum wires rolled round the tube, and presenting points *e′* and *l′* downwards, so as to dip into the superior canal.

The partitions *a* and *b* being removed from the superior canal, the current will pass up through one vertical wire, and down through the other, being diffused horizontally through the mercury of the superior canal, instead of passing, as before, along the horizontal wire which connected the vertical wires. Under these circumstances the system will place itself, as before, at right angles to the magnetic meridian, the *ascending* current being on the *west*, and the *descending* current on the *east*, of the centre O.

To determine the force exerted on each vertical wire separately, the arrangement represented in *fig.* 226., in which a single vertical wire attached to a horizontal glass tube, and balanced by a counterpoise, is used. In this case, the current may be made, at pleasure, to ascend or descend by connecting the inferior or superior canal with the positive pole of the battery. If the partitions be removed from both canals, it will be found that

Fig. 226.

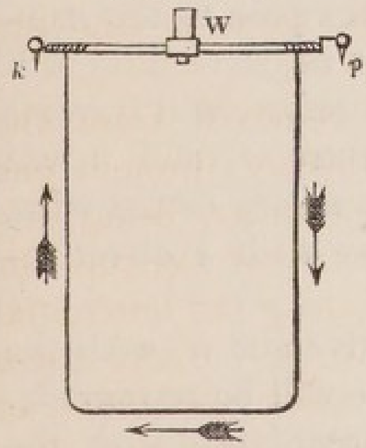


the wire will revolve until it settles towards the magnetic *west* when the current *ascends*, and towards the magnetic *east* when it *descends*.

If the arrangement (*fig.* 225.) be used, and the connexions be so made that the current shall either ascend or descend in both vertical branches, the wire will rest indifferently in any position; for both branches having an equal tendency to turn to the west or the east, according as the current ascends or descends, these tendencies counteract each other, and the wire is in a state of indifference as to the azimuth which it will assume.

(465.) To illustrate by experiment the effect of the earth's magnetism on an horizontal current, let the arrangement represented in *fig.* 227. be suspended in two mercurial cups, placed on the same level by means of the platinum points, *p n*. When the apparatus is thus suspended, the knob, W, acts as a counterweight above the points of suspension, so that the centre of gravity of the whole is brought very nearly to coincide with the horizontal line joining the points of support. The current on the two vertical wires, being in contrary directions, produces opposite forces, which counteract each other, or, at least, can produce no other effect than giving a tendency to the apparatus to revolve on the vertical line through W, which is resisted by the supports. The only part of the current, therefore, which can affect the position of the apparatus, is that which traverses the horizontal wire at the bottom. It is accordingly found that the rectangle declines from the vertical plane to the left of the current, looking in the direction in which the current moves.

Fig. 227.



The experiment may be varied by interchanging the poles of the voltaic battery with which *p* and *n* communicate, in which case the current will decline to the

contrary side of the vertical plane through the points of support.

The action of the earth's magnetism on an horizontal current may be shown in a much more striking manner by the aid of the apparatus of M. De la Rive (*fig.* 222.).

Let W O p (*fig.* 228) be an horizontal wire, having a point at O to rest in the central cup screwed upon the superior table of the apparatus; and let the weight, W, counterpoise the wire, O p. Let the point p dip into the superior circular canal, while the point O rests in the central cup. The partitions *a* and *b* being removed, let *n′* be put in communication with the positive, and *m′* with the negative, pole of a voltaic battery. The positive fluid will thus pass to the mercury in the superior canal, while the negative fluid will pass to the point O. The current, therefore, will traverse the wire from the point p to the centre O, and it will produce a force constantly at right angles to the wire, which will cause the wire to revolve with a *direct* rotation.

Fig. 228.

If *m′* be connected with the positive and *n′* with the negative pole, the rotation of the wire will be retrograde.

These results are evidently in accordance with the principles previously established.

(466.) M. Ampère, to whom many useful and beautiful electro-magnetic instruments of illustration are due, has contrived an apparatus by which the effects of the earth's magnetism, and other electro-magnetic principles, are experimentally verified.

Two vertical copper rods, V V′ (*fig.* 229.), are fixed in a stage of wood, T T′, the upper parts being bent at right angles, and terminated in two mercurial cups, *y y′*, one below the other in the same vertical line, as represented in the figure. The horizontal parts of these rods are protected from lateral electric communication by a coating of gum-lac, or by silk rolling. Two small cavities, *r r′*, are formed in the stage T T′, and near them

are two mercurial cups, *s s′*, which are in metallic communication with the vertical rods V V′. The cavities, *r r′*, being filled with mercury, are put in communication with the poles of a voltaic battery; *r* with the positive, and *r′* with the negative, pole. A movable metallic communication is provided, by means of which *r* may be connected with *s*, and *r′* with *s′*; or this relation may, at pleasure, be reversed, and *r* may be connected with *s′*, and *r′* with *s*. By such means the mercurial cups, *y* and *y′*, may be put in connexion with the poles of the battery, and the connexion inverted at pleasure.

Let a copper wire be formed into a rectangle (*fig.* 230.) terminated by steel points, corresponding in position to the cups *y y′*, so that one of these points may rest upon a small surface of glass fixed in the bottom of one of the cups, while the other point dips in the mercury

Fig. 229.

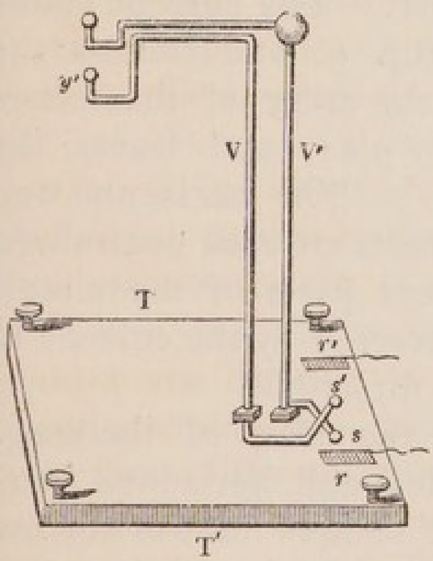
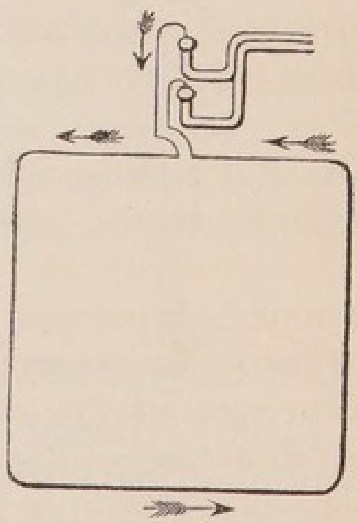


Fig. 230.



in the other. The voltaic circuit is thus completed; and if *y* be supposed to be connected with the positive pole of the battery, the current will circulate on the rectangle in the direction represented by the arrows.

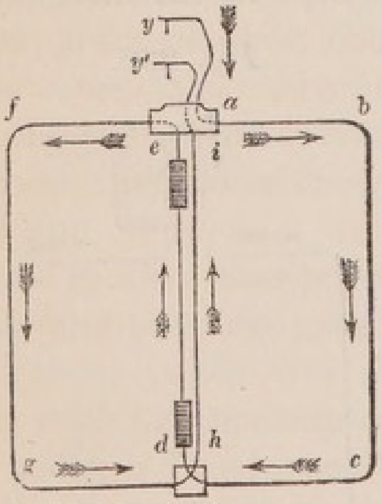
When the current is thus established, the rectangle will be observed to turn on its support, and to vibrate on one side and the other of a certain azimuth, in which it will

at length settle. This azimuth will be at right angles to the magnetic meridian, and the side of the rectangle on which the current descends will be turned towards the east

If the direction of the current be inverted by interchanging the connexion of the cups $y\,y'$ with the poles of the voltaic battery, the current will descend on the side of the rectangle on which it before ascended, and *vice versâ*. The rectangle will then immediately turn half round, still presenting the descending current to the east.

(467.) In order to determine electro-magnetic effects independent of the influence of the magnetism of the earth, it is necessary to be able to obtain an *astatic* current, or one on which the effects of the terrestrial magnetism equilibrate with each other.

Fig. 231.



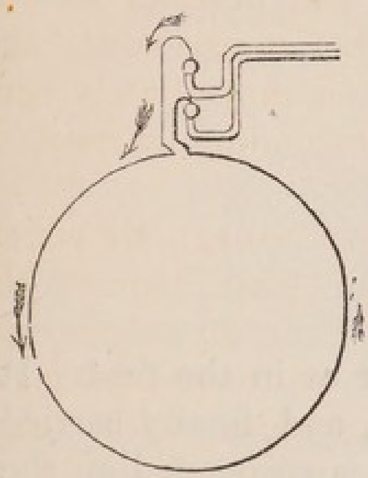
Such a system is represented in *fig.* 231. The current enters by the cup y, and follows the wire in the order of the letters $a\ b\ c\ d\ e\ f\ g\ h\ i$, and leaves the wire at y'. The horizontal and vertical parts are each neutralised by different parts of the circuit being traversed by the current in contrary directions.

(468.) Having determined the effect of the magnetism of the earth upon vertical and horizontal currents, its influence on currents oblique to the horizon can be inferred from a principle which will be established when the mutual influences of currents on each other is investigated (489.). By this principle, the well-known theorem of the composition and resolution of forces is extended to currents; and it is shown, that any oblique current is equivalent to the vertical and horizontal currents of which it is the diagonal. All currents and parts of currents, whatever be their form or position, may therefore be resolved into equivalent

systems of horizontal and vertical currents, the effects of which are determined on the principles already explained.

(469.) A circular or any other circulating current (*fig.* 232.) of a curvilinear form, suspended as the rectangular current was in *fig.* 230., will also, under the influence of the earth's magnetism, assume a position at right angles to the magnetic meridian, the side on which the current descends being turned towards the east. For each element of the current, so small as to be regarded as a straight line, being resolved into its vertical and horizontal components, the sum of the latter in one direction will be equal to their sum in the contrary direction, and the earth's influences on them will neutralise each other. The sum of the vertical elements descending will be on one side of the vertical axis of the figure, and the sum of the vertical elements ascending on the other. The effect of the earth's magnetism will be to turn the former to the magnetic east, and the latter to the magnetic west.

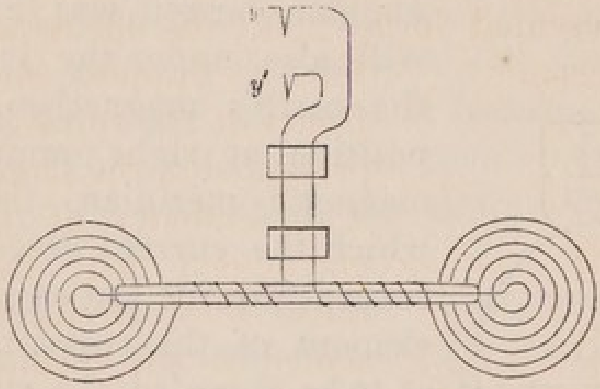
Fig. 232.



(470.) In the preceding cases, the vertical line on which the current is capable of revolving divides it symmetrically, the descending parts of the current on one side of the axis being similar and equal to the ascending parts on the other side of it. Where the axis does not pass through the centre of the current, the position of equilibrium is in every case determined by means of the same general principles. An arrangement is represented in *fig.* 233., consisting of two spirits formed by the same wire, and presenting their fronts towards the same side. From the point of suspension *y*, the wire is carried down vertically to a glass tube on which it is coiled, and at the extremity of which it

forms a spiral. It is then carried from the centre of the spiral through the axis of the tube to the other extremity, where it is formed into another spiral, the

Fig. 233.



direction of the coils being the same as in the first. It is then again coiled round the tube, and finally carried up to the point y'. The apparatus is suspended on the cups y y' (*fig.* 229.), and is free to revolve round a vertical line through y y'.

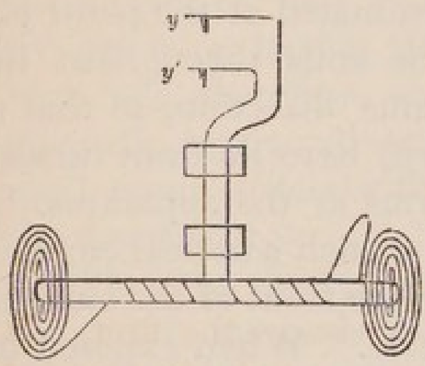
According to what has been already established, a current transmitted through these spirals would have a tendency to present its front towards the south, and its back towards the north, pole of a magnet under the influence of which it is placed; and as the two spirals are equally distant from the axes y, y', if they be affected by equal forces they will be equally effective in giving to the apparatus that position which is in accordance with this principle. Now, since the northern magnetic pole of the earth is endowed with the properties of the south pole of a common magnet, it follows that these currents should present their front to the magnetic north, and therefore take a position at right angles to the magnetic meridian; and such in fact they will be found by experiment to do.

(471.) If the two spirals were coiled in contrary directions, the fronts of the currents would be presented towards opposite sides of the apparatus, and the earth's magnetism would exercise contrary effects upon them. The apparatus would, in this case, be found to have

no polarity, and would rest indifferently in any azimuth.

(472.) If the spirals, instead of being formed in the vertical plane passing through the axis of the tube, be formed in planes perpendicular to the axis of the tube as represented in *fig.* 234., the effects will be different.

Fig. 234.

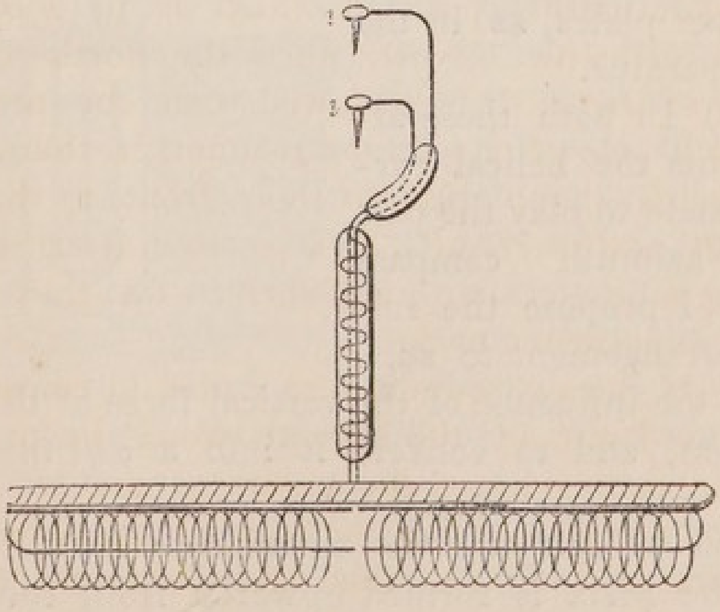


Suppose, first, that the fronts of the spiral currents are presented in the same direction. The tendency of the earth's magnetism will then be to cause these fronts to be presented to the magnetic south, and therefore to throw the axis of the tube into the magnetic meridian. Experiment will, accordingly, verify this consequence.

If the spirals be coiled in opposite directions, the fronts of the currents will be turned in opposite directions; and the effects of the earth's magnetism on the currents, being mutually opposed, will counteract each other, and the apparatus will have no polarity.

(473.) An apparatus is represented in *fig.* 235., consisting of a helix suspended at the middle point of

Fig. 235.

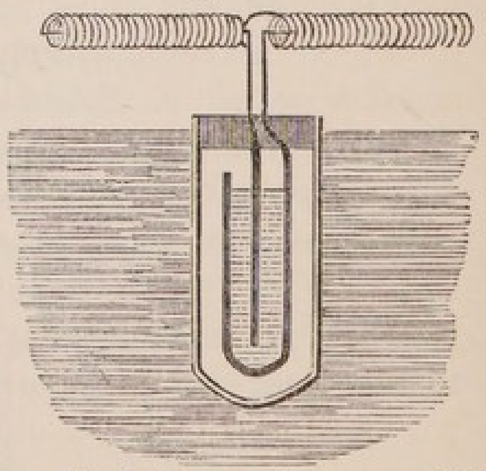


its axis, so as to be capable of revolving on a vertical line passing through that point and assuming any azimuth. The wire is carried downwards from the point *y*, and coiled helically from the centre to one end of the horizontal rod, from which it is carried through the axis of the helix to the other end, from which it is again helically coiled till it reaches the centre, whence it is again carried upwards and terminated at the point *y′*. The helix thus formed has the coils throughout its whole length turned in the same direction, so that a current transmitted through it will have its front turned in the same direction on both arms of the apparatus.

It has been shown (449.) that such a helical current has all the properties of a magnet, the front of the current possessing those of the south pole. When exposed to the influence of the earth's magnetism, it ought, therefore, to present a front to the magnetic south ; and such will be found to be the case, the axis of the spiral placing itself in the magnetic meridian.

(474.) The apparatus just described is suspended by Ampère's contrivance (*fig.* 229.). Another method of supporting it has been suggested by M. De la Rive, and is represented in *fig.* 236., and is analogous to the apparatus represented in *fig.* 217. The current is supplied by a single pair of zinc and copper plates, as in the latter apparatus.

Fig. 236.



(475.) In both these arrangements the helical current is made to play the part of an azimuth compass needle. I propose the following arrangement to submit it to the influence of the vertical force of the earth's magnetism, and to convert it into a *dipping* helical current.

Instead of carrying the extremities of the wire of which the helix is formed upwards from the middle

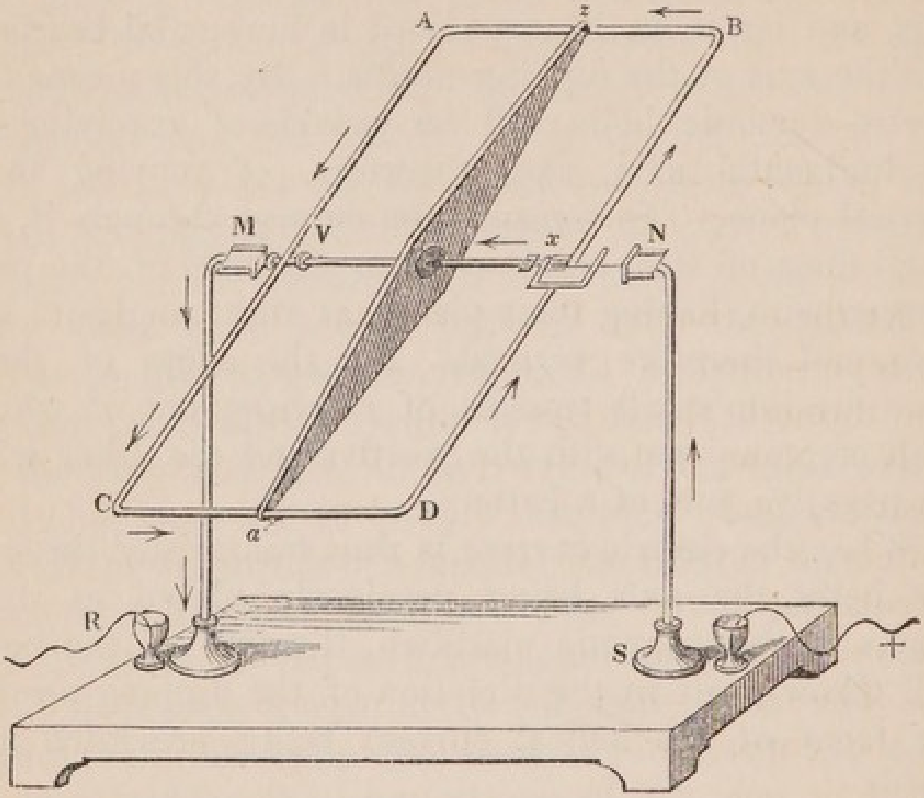
of the axis, let them merely project laterally from its sides, forming a right angle with the direction of the axis, and let them be supported in horizontal bearings like the axis of the dipping-needle. By this means the electro-dynamic helix will be capable of revolving on an horizontal axis, and, therefore, of moving in a vertical plane. To transmit the current through it, let small discs of steel be attached to the ends of the projecting wire, having their planes at right angles to the wire, and therefore vertical. Let the edges of these discs dip into small troughs of mercury, one of which shall communicate with the positive and the other with the negative pole of a battery.

When the electric current is thus transmitted through the helix, the axis being previously placed at right angles to the magnetic meridian, the axis of the helix will throw itself in the direction of the dipping-needle, the front of the helical current being presented upwards

(476.) Analogous to this, is the electro-dynamic rectangle (represented in *fig.* 237.) contrived by Ampère, which consists of a rectangle, A B C D, formed of brass rods, the construction of which will be understood by observing the direction of the arrows. The current passes from the positive mercurial cup through the pillar S N, then through a steel pivot, placed upon a metallic plate, N. It then traverses the rectangle A B C D, as indicated by the arrows ; from whence it passes along the tube x V, which serves as the axis of the apparatus, whence it passes by a second steel pivot to the plate M, and finally to the negative cup R. The apparatus being placed with its axis x V at right angles to the magnetic meridian, a little mercury is put on the plates M and N, to establish more effectually their contact with the pivots. The lozenge a z is formed of light wood, and serves to maintain the rectangle in its proper form.

The moment the voltaic current is established through the apparatus, the rectangle begins to oscillate, and

Fig. 237.



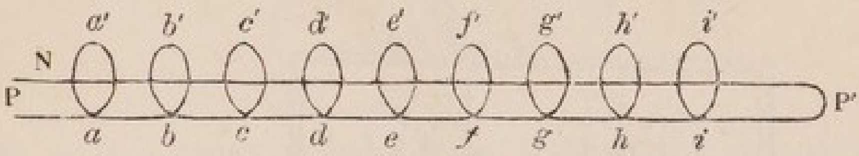
at length comes to rest in the plane of the magnetic equator.

(477.) The electro-magnetic helix is only a particular example of a much more general arrangement imagined by M. Ampère, and denominated by him a Sole′noid.

Let a copper wire (*fig.* 238.) be wrapped with silk, so that, when any two parts of it are brought into contact, the electricity which traverses the wire may not pass laterally from the one part of the wire to the other. With this wire let an apparatus be prepared in the following manner:—From the extremity P, the wire proceeds in a straight line to the point a, where it is bent into the form of a geometrical figure of any desired species, having its plane at right angles to P a. We shall suppose, for example, that this figure is a circle, $a a'$. From a, let the wire again be conducted in a straight line to b, where it is to be formed into another circle, $b b'$, equal and parallel to $a a'$, and so that the wire in forming it may be bent in the same direction. From b it is

again carried in a straight line to *c*, where another equal and parallel circle, *c c′*, is formed; and so on.

Fig. 238.

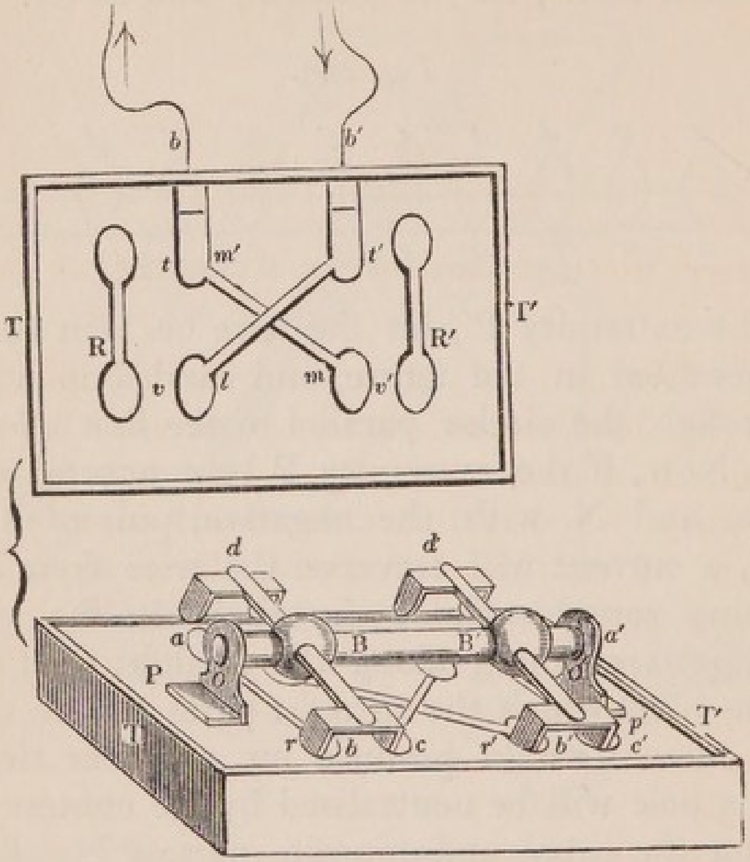


At the extremity P′, let the wire be bent backwards as represented in the figure, and carried in a straight line through the circles parallel to the line *a b c d*, &c. to N. Now, if the extremity P be connected with the positive, and N with the negative, pole of a voltaic battery, a current will traverse the wire from P to N, circulating round each of the circles in the same direction, and returning along the straight part P′N to N. The effect which the straight parts *a b*, *b c*, *c d*, &c. of the current would produce on, or suffer from, any magnetic pole will be neutralised by the contrary effects attending the equal and opposite part, P′N, of the returning current. The whole effect, therefore, which attends the apparatus must be due to the circulation of the current in the circles. Now, as this circulation takes place in all the circles in the same direction, the front of the current is every where presented towards the same end of the apparatus; and, from what has been established respecting circulating currents generally, it is evident that this apparatus will have, in reference to magnets in general, and to the magnetism of the earth, the same polarity and attractive and repulsive properties as a bar magnet, the end to which the front of the currents is presented being the south pole.

The same would be true whatever might be the figure, *a a′*, *b b′*, &c., of which the solénoid might be formed.

(478.) An instrument of much utility in these inquiries is that represented in *fig.* 239., which, from its being used to alter the direction of the current, has been termed an *Electrepeter*. The form here given is that devised by

Fig. 239.



Ampère: other and less complex arrangements have been introduced; but all are on the same principle. The lower portion of the figure represents the complete instrument; the upper, the instrument with the bar BB and its appendages removed. If R′R be troughs of mercury, connected with the two ends of a battery, and *v′v*, *t′t*, cavities also filled with mercury, and connected by the metal cross pieces *m*, *l*, which are insulated from each other; and *b′b* two wires conveying the current to any electro-dynamic apparatus, the direction of the current will depend on whether *v′* or *t′* is connected with R′. When the metal rods, *d d′*, turning in the insulating pillar, B, B′, are in the position represented in the figure, and the positive wire of the battery is in R′, the current coming in the direction of the arrows, will pass through the apparatus in one direction; but when the position of the cross pieces is reversed, the direction of the current changes: this alteration can evidently be made most readily and repeatedly

CHAP. V.

OF THE MUTUAL ACTION OF ELECTRIC CURRENTS.

(479.) THE mutual attractions and repulsions exhibited by insulated conductors, charged with the electric fluids in a state of repose, would naturally suggest the inquiry, whether the same fluids in motion, or in the form of continued currents, have any analogous reciprocal action; and the fact, that such currents affect, and are affected by, magnets in a peculiar manner, suggests the probable mode in which their reciprocal action, if they have any, may be developed. These views conducted AMPÈRE, the founder of this part of electro-dynamics, to the discovery of a class of phenomena new to physical inquiries, and surrounded by circumstances, and conducive of consequences, of the most profound and general importance.

The forms and limits of voltaic currents being infinitely various, the investigation of the laws of their mutual action can be clearly traced out only by resolving them into classes, taking the most simple in the first instances.

Electric currents may, then, be divided into *rectilinear* and *curvilinear*.

Rectilinear currents may be divided into those which are of limited length, which we shall call *terminated currents*, and those which may be regarded as unlimited, which we shall call *indefinite currents*.

The straight line in which a rectilinear current is propagated we shall call the *line of the current*, and the direction along that line in which the current moves we shall call the *direction of the current*. Thus, if a current be propagated along a straight wire,

Fig. 240.

A B (*fig.* 240.), the line A B is the *line of the current;* and if the positive pole of the battery be connected with A, the *direction of the current* is from A to B.

It is necessary to remember, that the *line of a current* is not sufficient to determine the current, since, on the same line, the current may have either of two contrary *directions.* Both the *line of the current* and the *direction of the current* are necessary for its exact determination.

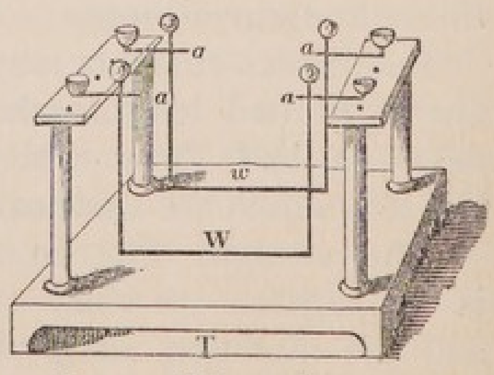
The *intensity* of a current is measured by the quantity of the effect it produces under given circumstances. Thus, if one current exerts on a given magnetic pole, at a given distance, twice the attraction which another current traversing the same conductor exerts on the same magnetic pole at the same distance and in the same position, then the *intensity* of the one current is double the intensity of the other.

Proposition I.

(480.) *To determine experimentally the mutual action of two parallel currents.*

A table of wood, T (*fig.* 241.) supports four vertical wooden columns, on which are sustained two cross-pieces of board, pierced with a row of small holes to receive the stems of mercurial cups. Two cups are placed on each board at equal distances asunder. From the wire stems of the cups, copper wires, *a a′* are conducted at right angles, and, being bent twice perpendicularly, are made to communicate between the cups as represented in the figure. All parts of the wires, W and *w*, are parallel, and they are rendered more free to turn on

Fig. 241.



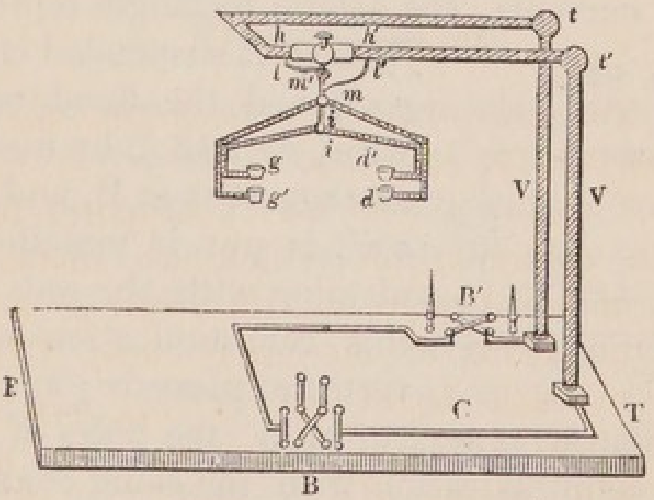
the horizontal axes, $a\,a'$, by counter-weights fixed on them above those axes. Thus placed, each of the wires is at liberty to approach to, or recede from, the other, in obedience to the action of any force capable of overcoming the very small preponderance given to the lower part of each wire, and the friction of the axes $a\,a'$ on the horizontal bearings.

First: Let two *parallel* currents be transmitted *in the same direction* along the wires, and mutual attraction will be immediately manifested by the wires approaching each other.

Secondly: Let two currents pass in *parallel* and *in contrary directions*, and mutual repulsion will be immediately manifested by the wires receding from each other.

(481.) The same phenomenon was exhibited by Ampère, by means of an apparatus represented in *fig.* 242., which was also used to illustrate various

Fig. 242.



other properties of currents. On a wooden stage two vertical rods of copper, V V′, are fixed, connected with copper horizontal rods, $t\,h$ and $t'\,h'$, the extremities of which are inserted in a small cylinder of ivory, $h\,h'$, by which the escape of the fluid from one column to the other is prevented. Two mercurial cups, $m\,m'$, are placed in the vertical line between h and h', and are

connected with the copper rods by the wires $l\,m'$ and $l'\,m$.

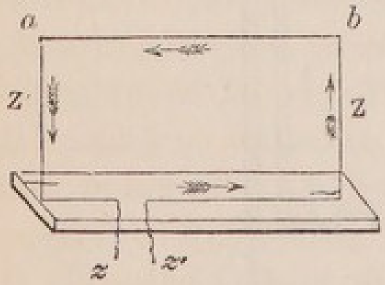
Four other mercurial cups, $g\,g'$ and $d\,d'$, are placed, two on the right and two on the left of this vertical. A small rod, $m'\,i'$, which supports the cup m', is divided at i' into two branches, one leading to the superior cup d', and the other to the inferior cup g'. A tubular rod, $m\,i$, supporting the cup m, is separated from the rod $m'\,i'$ by means of a tube of glass in which the latter is enclosed; and this rod is likewise divided at i into two branches, one terminating in the superior cup g, and the other in the inferior cup d.

The wires $l\,m'$ and $l'\,m$, communicating between the rods V V′ and the cups $m\,m'$, may be removed or inverted at pleasure.

The arrangements at B and B′ are similar to those already described in *fig.* 239., and are intended to supply the means of inverting at pleasure the poles of the battery with which the rods V and V′ are put in connexion.

To demonstrate with this apparatus the mutual action of parallel currents, the astatic rectangle represented in *fig.* 231. is suspended on the cups $g\,g'$; and the fixed rectangular wire (*fig.* 243.), by means of the arrangement at B, and the wires $z\,z'$, is put in metallic communication with the rods VV′, and this communication may be inverted at pleasure; and by means of the similar arrangement at B′ the poles of a battery are put in communication with the same column.

Fig. 243.



Let us suppose, first, that the connexions at B and B′ are so made that the current ascends the column V, passes from l to m' into the cup g', from whence it ascends the two external vertical sides of the rectangle (*fig.* 231.), and descends the two internal vertical sides. After circulating the rectangle, it leaves it at the cup g, from whence it passes to m and l', and, traversing the rods $l'\,t'$, descends the rod V′ and arrives at B, where it

enters the fixed rectangle at z, and, after circulating round it, issues from it at z' and passes round the arrangement of rods on the table to B′, where finally it passes to the negative pole of the pile.

The vertical side, Z, of the fixed rectangle, and the external vertical sides of the moveable rectangle, are traversed by currents, which, whatever be the position of the latter rectangle, are parallel and in the same direction, since they both ascend. A mutual attraction will be manifested by the approach of the external wires of the rectangle (*fig.* 231.) towards Z.

By inverting the connexion of the fixed rectangle with the arrangement at B′, the directions of the current on Z will be reversed, and the apparatus will illustrate the repulsion of parallel and opposite currents.

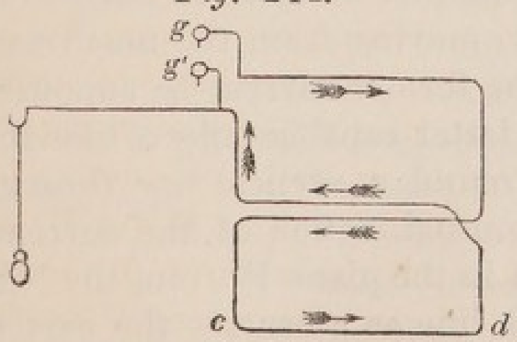
Hence in general it may be inferred, that *parallel rectilinear currents mutually attract when they have the same direction, and mutually repel when they have opposite directions.*

Proposition II.

(482.) *To determine experimentally the mutual action of two rectilinear currents which are not parallel.*

For this purpose, let the astatic arrangement represented in *fig.* 244. be suspended on the cups gg' (*fig.* 242.) and let the fixed rectangle (*fig.* 243.) be applied as before, the lowest horizontal side, $c\,d$, of the one being *above* the highest horizontal side, $a\,b$, of the other. When thus arranged and suspended, the system (*fig.* 244.) will be free to revolve round a vertical axis, $g\,g'$, the weight of the wire being balanced by a counter-weight.

Fig. 244.



Supposing the connexions with the battery to be made so that the current shall enter at g, and leave the

movable system at g', it will have the direction $c\,d$ in the lowest horizontal side. Let the connexions of the fixed rectangle (*fig.* 243.) at B be so made that the current in the highest horizontal side shall pass from b to a.

If the movable system be so placed that its plane shall make any proposed angle with the plane of the fixed system, the moment the connexion with the battery is made, the movable system will begin to turn on its axis, the end d, towards which the current moves in the lowest side of the movable system, turning towards the end a, towards which the current moves in the fixed system; and this motion will continue until these parts of the current become parallel and in the same direction, when the system will come to rest.

(483.) It appears therefore that *when two rectilinear currents, placed in any manner in space, act upon each other, their mutual forces are such as tend to bring their lines parallel in such a manner that their directions in these lines when brought to parallelism shall be the same;* and since, when they are thus parallel and in the same direction, they will attract each other, it follows *that the mutual action of any two electric currents, however they may be directed, has a tendency to bring them both to the same line, and to the same direction upon that line.* To render this more clear, we shall suppose a current upon a horizontal plane, P, moving from north to south, and another on another horizontal plane, P′, above the former, moving from the north-east to the south-west. If the former current be supposed to be immovable, and the latter capable only of moving in the horizontal plane round a vertical line through both currents, then the mutual action of the currents will cause that which runs in the plane P′ from the NE. to turn round the vertical line as a centre, the part to the NE. turning towards the north, and the part to the SW. towards the south. The current will come to rest when it takes the position, from north to south, parallel to the fixed current. If in this position it be capable of moving parallel to itself, in the plane of the meri-

dian, it will descend upon the fixed current, and ultimately coalesce with it.

(484.) If the currents be in the same plane, their lines will intersect, and by their mutual action they will turn round their point of intersection until they coalesce in a common line and a common direction.

These several effects are expressed by AMPÈRE in the following general theorem:—

If two rectilinear currents in the same plane, and not parallel, be both directed towards, *or both directed* from, *their point of intersection, they will attract each other, and, if capable of moving round that point, will coalesce. If one be directed towards, and the other from, their point of intersection, they will mutually repel.*

If two currents be not in the same plane, a line may always be drawn, intersecting them, and perpendicular to both. They will mutually attract if they both move towards, *or both move* from, *this line, but will mutually repel if, while one moves* towards, *the other moves* from *it.*

(485.) If A B and A′ B′, (*fig.* 245.) be the lines of two currents directed from A to B and from A′ to B′, and O their point of intersection, then O B will attract and be attracted by O B′, and O A will attract and be attracted by OA.′ Also OA will repel and be repelled by O B′, and O B will repel and be repelled by O A′. The same will be true if the current A B, instead of being on the plane of the paper, were raised to any height above it, the point O being then the end or projection of a common perpendicular to the two currents. As in *fig.* 246., where A B, if free to move, while C D is fixed, would take the position *a b*, parallel to C D; or if C D were free, and

Fig. 245.

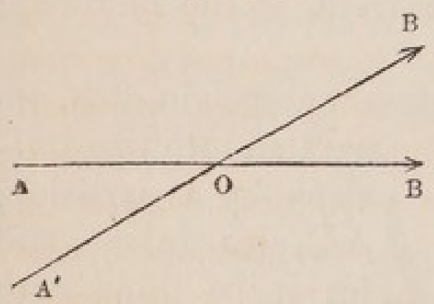
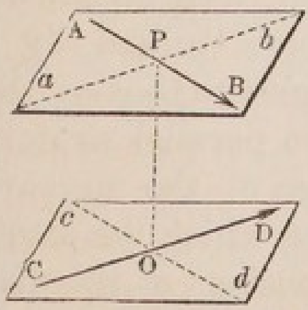


Fig. 246.



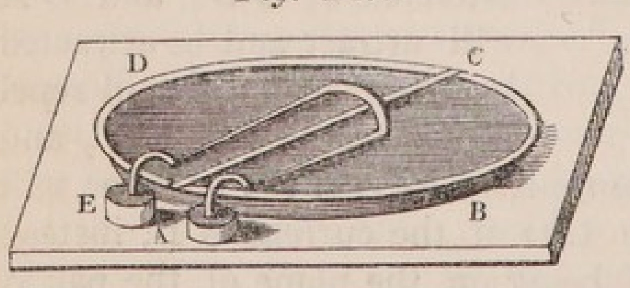
A B fixed, C D would take the position *c d:* if both were free, they would take some position parallel to each other; and, if still further free, they would approach and coalesce, according to Proposition I. Hence it follows, that if the direction of either of two currents be reversed, their mutual attraction or repulsion will be also reversed; but if the direction of both be reversed, their mutual attraction or repulsion will remain unaltered.

(486.) Different parts of the same current exercise on each other a repulsive force. This will follow immediately as a consequence of the general principle which has been just established. Since a repulsive action takes place between O A and O B′, and such action is independent of the magnitude of the angle AOB′, it will still take place, however great that angle may be, and will therefore obtain when the angle OAB′ becomes equal to 180°, that is, when O B′ forms the continuation of A O, or coalesces with O B. Hence, between O A and O B there exists a mutually repulsive action.

(487.) Independently of this demonstration, M. Ampère has reduced the repulsive action of different parts of the same rectilinear current to the following experimental proof: —

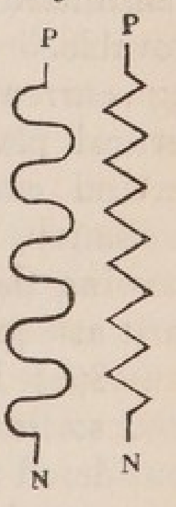
Let A B C D (*fig.* 247.) be a glass or porcelain dish, separated into two divisions by a partition, A C, also of glass; and let it be filled with mercury on both sides of A C. Let a wire wrapped with silk be formed into two parallel pieces, united by a semicircle whose plane is at right angles to that of the straight parallel parts, and let these two parallel straight parts be placed floating on the surface of the mercury at each side of the partition A C, over which the semicircle passes. The mercury in the divisions of the dish is in metallic communication with the mercurial cups,

Fig. 247.



E and F, placed in the direction of the straight arms of the floating conductor. When the cups E and F are put in connexion with the poles of a voltaic battery, a current will pass from the positive cup to the end of the floating conductor, from that along the arm of the conductor, then across the partition by the semicircle, then along the other floating arm, and from thence through the mercury to the negative cup. There is thus on each side of the partition a rectilinear current, one part of which passes upon the mercury, and the other part upon the straight arm of the floating conductor. When the current is thus established, the floating conductor will be repelled to the remote side of the dish. This repulsion is effected by that part of the straight current which passes upon the mercury acting on that part which passes along the wire.

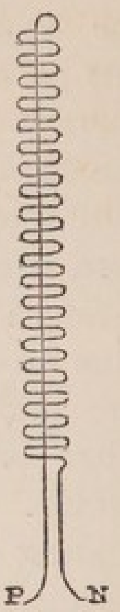
Fig. 248.



(488.) If a current, instead of following a rectilinear course, deviate alternately to the right and to the left of it, either by following a sinuous or a zigzag course (as in *fig.* 248.), or, in fine, if its lateral deviations be irregular in any manner, the action which it will exercise on any rectilinear current in its neighbourhood will be the same as if it were itself a rectilinear current extending from P to N.

This proposition may be demonstrated experimentally by forming, with a copper wire wrapped with silk, a sinuous conductor, and carrying the wire back in a rectilinear direction along the middle of the sinuous part, as represented in *fig.* 249. If the extremities P and N be so connected with the apparatus (*fig.* 242.) at B, that the current shall ascend by the straight part of the wire, and descend by the sinuous part, the system being fixed, no effect will be produced by it on a movable astatic current suspended in the cups *g g′*. Hence it appears that the descending sinuous

Fig. 249.



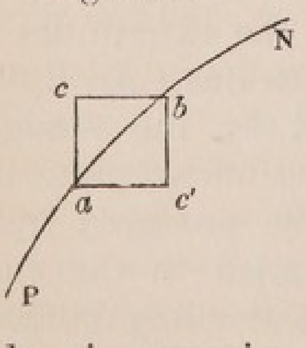
current exactly counteracts the effect of the ascending rectilinear current. If the connexion of P and N with B be inverted, and the ascending current pass along the sinuous and the descending current along the rectilinear wire, the same neutralisation of effects will take place.

It follows from this, that a sinuous and straight current, whose general directions agree, exert the same attraction or repulsion on other currents.

This was demonstrated by Ampère in a still more direct manner. A straight and a sinuous wire were suspended vertically near each other, a descending current being transmitted along each of them, and both being immovable. A movable vertical and straight ascending current was placed between them, and in the vertical plane passing through them. This movable vertical current was *repelled by both*, and, after some oscillation, settled itself exactly midway between them, showing that the two currents exerted equal repulsions on it at equal distances.

(489.) It follows from this, that any part of a current, so limited in extent that every point of it may be considered at the same distance from any other current or magnetic pole on which its attraction or repulsion is exerted, may be considered as equivalent to two currents at right angles, of which the part of the given current is the base. Thus, the part *a b* (*fig.* 250.), of the current P N is equivalent to two small currents, *a c* and *a c′*, at right angles to each other. Thus the well-known theorem of the composition and resolution of force is equally applicable to electric currents, so long as the intensity of their action throughout the part under consideration remains the same.

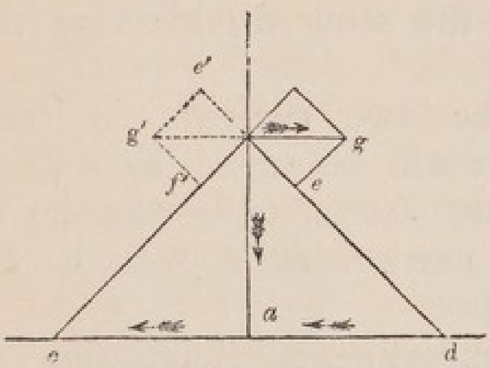
Fig. 250.



Hence it follows, also, that if a current be represented by one side of a small rectilinear figure of any kind, it will be equivalent to a number of currents represented by all the other sides of the figure.

(490.) A finite rectilinear current, *a b* (*fig.* 251.), which is perpendicular to an indefinite rectilinear current, *c d*, lying all at the same side of it, will be acted on by a force tending to move it parallel to itself, either in the direction of the indefinite current, or in the contrary direction, according to the relative directions of the two currents.

Fig. 251.



If the finite current does not meet the indefinite current, let its line of direction be produced till it meets it at *a*. Take any two points, *c* and *d*, on the indefinite current at equal distances from *a*, and draw the lines *c b* and *d b* to any point on the finite current.

First Case. Let the finite current be directed *towards* the indefinite current. Hence the point *b* will be attracted by *d* and repelled by *c* (485.); and since $d\,b = c\,b$, the attraction will be equal to the repulsion. Let the equal lines *b e* and *b f* represent this attraction and repulsion. By completing the rectangle, the diagonal *b g* will represent the resultant of these forces, and this line *b g* is parallel to *c d*, and the resultant is contrary in direction to the indefinite current.

The same may be proved of the action of all points on the indefinite current on the point *b*, and the sum of all these resultants will be the total action of the indefinite current on *b*.

The same may be proved respecting the action of the definite current on all the points of the indefinite current.

Hence the current *a b* will be urged by a system of

forces acting at all its points parallel to *c d*, and in a contrary direction.

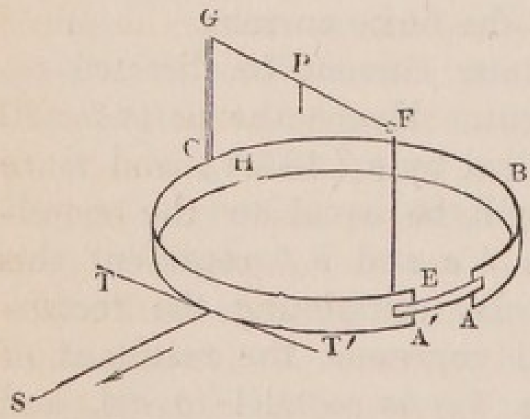
Second Case. Let the finite current be directed *from* the indefinite current. The point *b* will then be attracted by *c* and repelled by *d*, and the resultant *b g′* will be contrary to its former direction.

Hence the current *a b* will be urged by a system of forces parallel to *cd*, and in the same direction as the indefinite current.

Since the action of the two currents is reciprocal, the indefinite current will be urged by a force in its line of direction either according or contrary to its direction as the finite current runs *from* or *towards* it.

(491.) The following experimental illustration of these actions was due to M. Savary. Let A B C E F G (*fig.* 252.) be a movable conductor, consisting of a narrow strip of copper bent into the form of a hoop, and united at its ends by a piece of ivory, A A′. To A′ is attached a copper wire, which is bent into a rectangular form, E F G, and is attached at G to another piece of ivory, G H, by which it is connected with the copper hoop on the opposite side. A fine steel point is placed at P, over the centre of the copper hoop, by means of which the conductor may be suspended so as to be capable of revolving on a vertical line passing through P.

Fig. 252.



An apparatus is represented in *fig.* 253., consisting of a circular trough of copper formed of two concentric cylinders attached to a base of wood, in the axis of which is a vertical rod of metal, supporting a small capsule intended to receive the pivot of any movable

conductor, which may be placed upon it. The apparatus is represented in section in *fig.* 253., and in plan in *fig.* 254.

Let the conductor, represented in *fig.* 252., be now placed with the point P resting in the capsule, *s* (*fig.* 253.). The circular trough being filled with acidulated water, the edge of the copper hoop will dip into it. If the rod *t* supporting the capsule *s*, and the point P, be now put in connexion with one pole of the pile, and the trough containing the acidulated water with the other, the apparatus (*fig.* 252.) will immediately begin to revolve round the point P with a motion of continued rotation, of which the direction will be reversed whenever the connexion of the movable conductor with the pile is inverted.

Fig. 253.

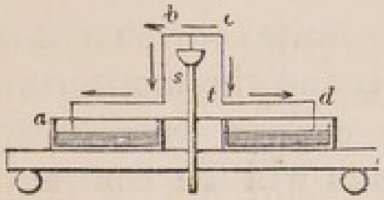
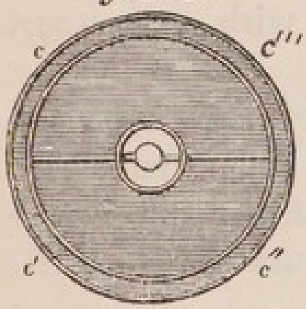


Fig. 254.



When the current proceeds from the point P by F E to the copper hoop, and from the hoop through the liquid to the copper trough, it runs along the hoop in the direction A′H B, shown by the tangent T′ T, and passes from the hoop at all points through the liquid to the sides of the trough, in directions, S, at right angles to the hoop. These may, therefore, be regarded as a system of finite currents, at right angles to an indefinite current running on the hoop ; and the former and the latter ought, according to the principles previously explained, to produce a mutual action, by which, while the liquid through which the finite current passes shall move in one direction, the hoop on which the indefinite current passes shall move in the other direction. The mass of the liquid is so considerable, that the effect on it will not be sensible, but the effect on the hoop is rendered apparent by its rotation.

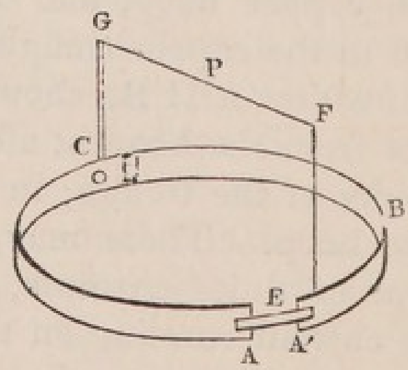
Although the hoop is not strictly an example of an indefinite rectilinear current, yet its extent, compared with the short rectilinear currents passing through the liquid between it and the side of the vessel, is such, that the same principles will be applicable, and the same effect will ensue.

If the current enters at P, the finite currents are directed *from* the indefinite current, and the movement of the conductor of the indefinite current proceeding from the action of the finite currents will be contrary to the direction of the indefinite current. The hoop will therefore, in this case, turn with a *retrograde* rotation.

If the current enter by the side of the trough, and leave the movable conductor by the pivot P, the directions of *both* the finite and indefinite currents will be changed, and therefore their mutual action will be unaltered.

The rotation of the hoop will be *direct*, if the wire F E be connected with the hoop on the side A′ of the ivory joint, as in the *fig.* 255., for by that means the direction of the indefinite current will be changed, while that of the finite current remains the same. — If the motion of the hoop be compared when the connexions of the apparatus with the poles of the battery are inverted, it will be found that, although the *direction* of the rotation is the same in both cases, the velocity of rotation will be different. This is explained by considering the effect of the earth's magnetism on the horizontal part, P F, of the movable current, which is, as already proved (460.), to give a motion of continued rotation to P F in the one direction or the other, ac-

Fig. 255.



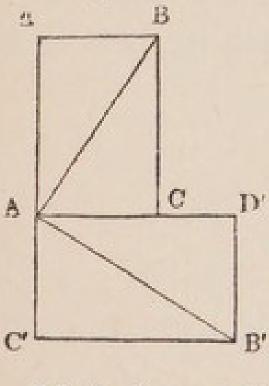
cording to the direction in which the current passes along P F. When the motion which the earth would thus give to P F agrees in direction with that which the movable current would impart, both forces conspire in giving rotation to the system; but when the motion which the earth would impart to P F is opposed in direction to that which the current would give to the system, then the motion of the system will be the result of the *difference* of these forces, instead of their *sum* as in the former case; and, consequently, the velocity will be greater in one case than in the other.

Proposition III.

(492.) *To determine, in general, the action of an indefinite rectilinear current on a finite rectilinear current.*

First. Let it be supposed that the finite current A B, (*fig.* 256.) has a length so limited that all its points may be considered as equally distant from the indefinite current, and, therefore, equally acted on by it. In this case the current A B may be replaced by two currents, A D perpendicular and A C parallel to the indefinite current, and the action of the indefinite current on A B will be equivalent to its combined actions on A D and A C.

Fig. 256.



If A be supposed to be the positive end of the finite current, it will also be the positive end of the component currents A D and A C. Supposing the indefinite current parallel to A C to run in the same direction as A C, then A D will be urged in the direction A C (490.), and A C in the direction A C′, by forces proportional to A D and A C. Hence if A D′=A D, and A C′=A C, A D′ and A C′ will express, in magnitude and direction, the two forces which act on the com-

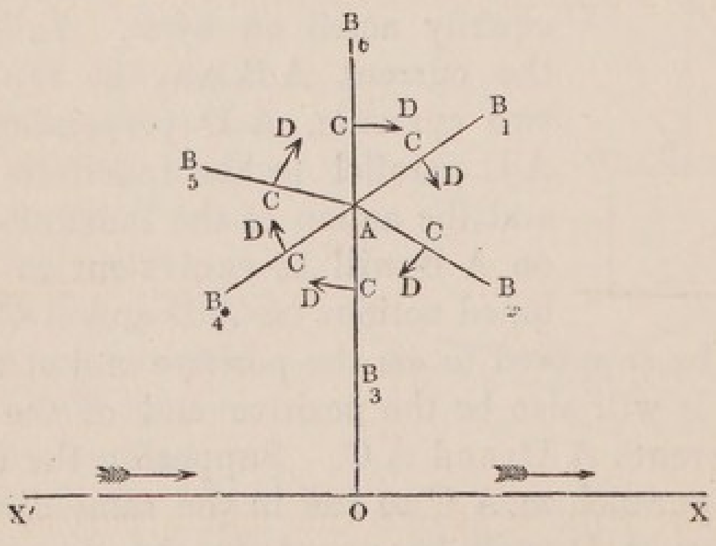
ponent currents. The resultant of these two forces A D′ and A C′ will be the diagonal A B′, which is evidently perpendicular to A B, and equal to it.

Secondly. Let the finite current have any proposed length, and from its positive end, A, let a line, A O, be drawn perpendicular to the indefinite current, X′ X, this current being supposed to run from X′ to X.

If the distance O A be greater than A B, the current A B, whatever be its position, will lie on the same side of X′ X, and the action of X′ X on every small element of A B will be perpendicular to A B, as has been just demonstrated. The current A B will therefore be acted on by a system of parallel forces perpendicular to its direction. The resultant of these forces will be a single force equal to their sum, and parallel to their common direction. Hence the indefinite current X′ X will act on the finite current A B by a single force, R, in the direction C D.

If the current A B (*fig.* 257.) be supposed to assume

Fig. 257.



successively different positions, B_1, B_2, B_3, &c., around its positive end A, the line C D will represent in each position the direction of the action of the current X′ X upon it.

It is evident that when the indefinite current runs from X′ to X, the action on the finite current is such as would cause it to turn round its positive end A with a retrograde rotation, or round its negative end B with a direct rotation.

If the indefinite current runs from X to X′, the direction of its action on A B, and the consequent motions of A B, would be reversed.

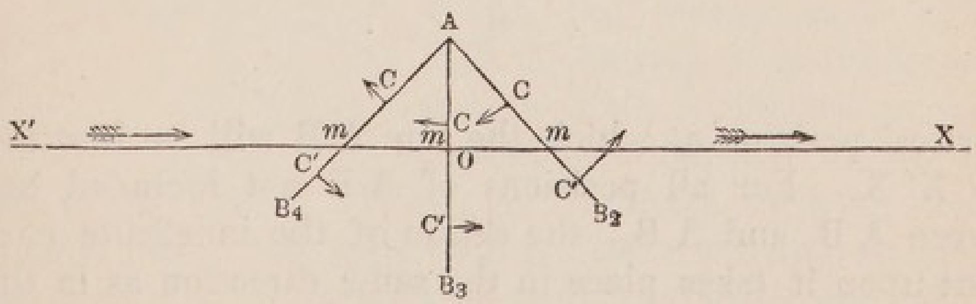
The point C of the current A B, at which the resultant R acts, will vary with the position of the current A B, approaching more towards X′ X as A B approaches the position A B_3, but in every position this resultant must be between A and B. The force producing the rotation, therefore, having a varying movement, the rotation will not be uniform.

If the distance O A be very great compared with A B, the resultant R will be sensibly constant, and will act at the middle point of A B.

In this case, if the middle point of A B be fixed, no rotation can take place.

If the distance O A be less than A B, the current A B will, in certain positions, intersect X′ X (*fig.* 258.);

Fig. 258.

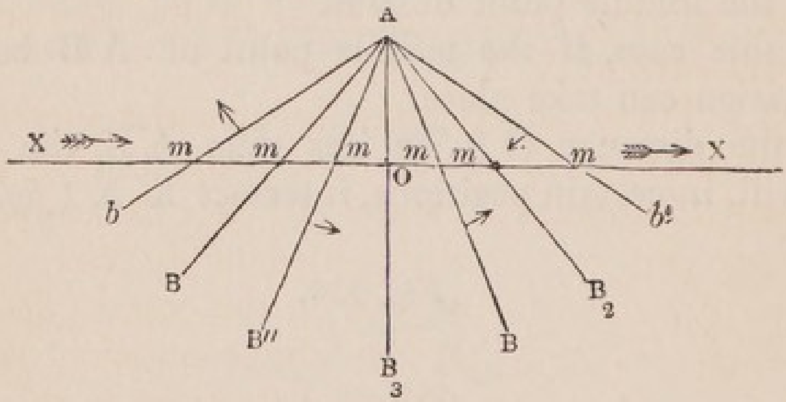


and a part will be at one side and a part at the other. In this case the action on A B, in all positions in which it lies altogether above X′ X, is the same as in the former case. When it crosses X′ X, as in the positions A B_2, A B_3, A B_4, the action is different. In this case, the forces which act on A m and those which act on

m B are in contrary directions, and their resultant is in the one direction or the other, according as the sum of the forces acting on each other is greater or less than the sum of the forces acting on the other part. If A *m* be in every position of A B greater than *m* B, then the resultant will, in every position, be in the same direction as if the current A B did not cross X′ X; and if the point A were fixed, a motion of continued rotation would take place in the same manner as in the former case, except that the impelling force would be diminished as the line A B would approach the position A B_3.

But if A O be less than $\frac{1}{2}$ A B, the circumstances will be different. In that case there will be two positions, A B_2 and A B_4 (*fig.* 259.), at equal distances from the

Fig. 259.



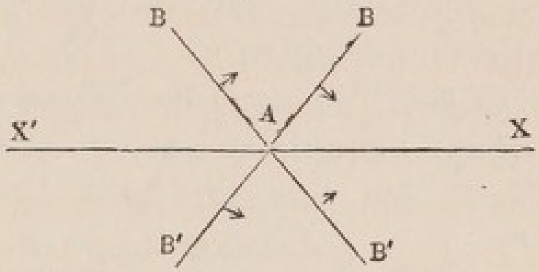
vertical position at which the line A B will be bisected by X′ X. For all positions of A B not included between A B_2 and A B_4, the action of the indefinite current upon it takes place in the same direction as in the former cases. But in the position A B′, where *m* B′ is greater than *m* A, the forces acting on *m* B′ exceed those acting in the contrary direction on *m* A, and, consequently, the resultant of the forces on A B, in all positions between A B_2 and A B_4, is contrary to its direction in every other position of the line A B.

In the positions A B_2 and A B_4 the resultant of the

forces in one direction on A m is equal and contrary to the resultant of the forces on B m. There will, in these positions, be no tendency of the current A B to move, except round its middle point.

If the indefinite current X′ X pass through A (*fig.* 260.), the resultants of its action on A B will be

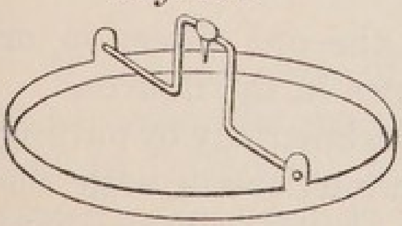
Fig. 260.



in contrary directions above and below X′ X, and will in each case tend to turn the current A B round the point A, so as to make it coincide in direction with the indefinite current X′ X.

(493.) These effects may be experimentally illustrated by means of the apparatus described in (491.), and represented in *figs.* 253. and 254. Let the copper hoop represented in *fig.* 261. be suspended on the cup, *s* (*fig.* 253.). When the connexion is made with the battery, as in the former case, two finite rectilinear currents pass in the direction of the arrows (*fig.* 253.). When an indefinite current is conducted under the apparatus at different distances from the vertical line passing through the pivot, the effects stated in the preceding articles will be exhibited.

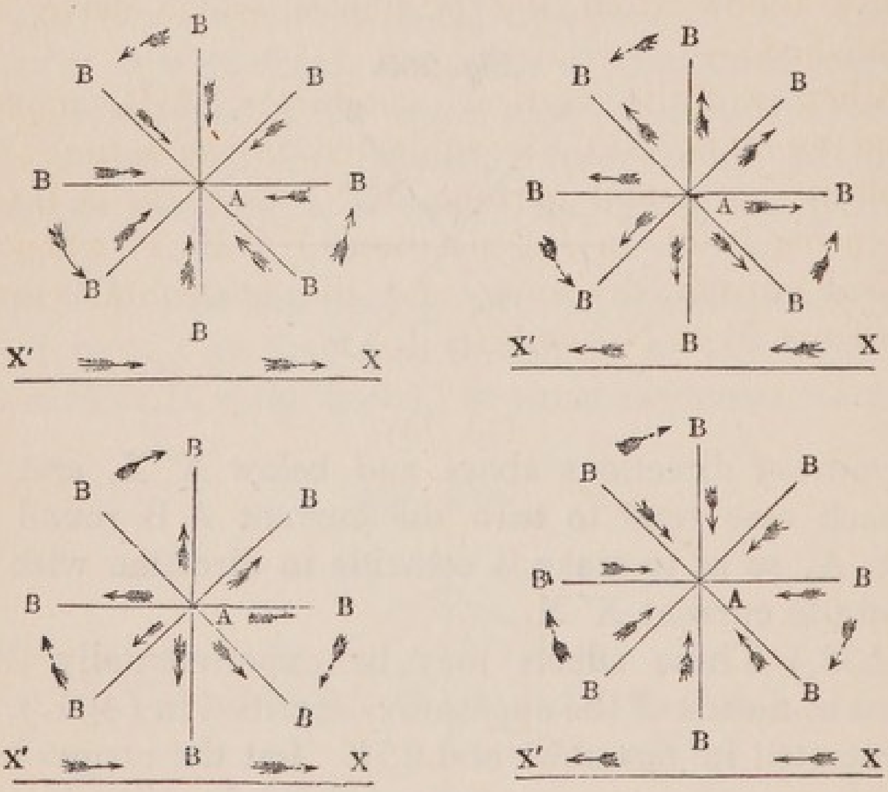
Fig. 261.



(494.) If any number of finite rectilinear currents diverge from, or converge to, a common centre, the system will be affected by another current near it in the same manner as a single radiating current would be affected. Thus, if a number of straight and equal wires have a common extremity, and are traversed by

currents from that extremity to the circumference of the circle in which their other extremities lie, an indefinite current, X′ X, placed in the plane of the circle as represented in *fig.* 262., will cause the radiating

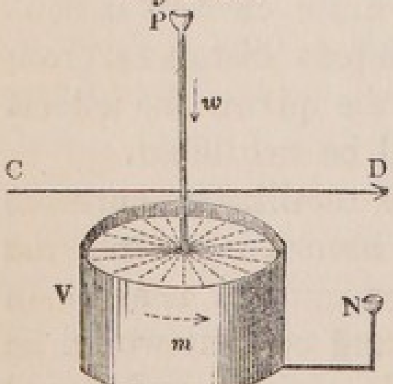
Fig. 262.



system of currents to revolve in the one direction or the other, as indicated by the arrows in the figures.

These actions may be shown experimentally by putting a vertical wire (*fig.* 263.) in communication with the centre of a shallow circular metallic vessel of mercury, V, and another wire, N, communicating with the outside of the vessel, into communication with the poles of a battery; diverging currents will be transmitted through the mercury in the one direction or the other, according to the connexion; and if a straight conducting wire, C D, conveying a powerful electric current, is brought near

Fig. 263.

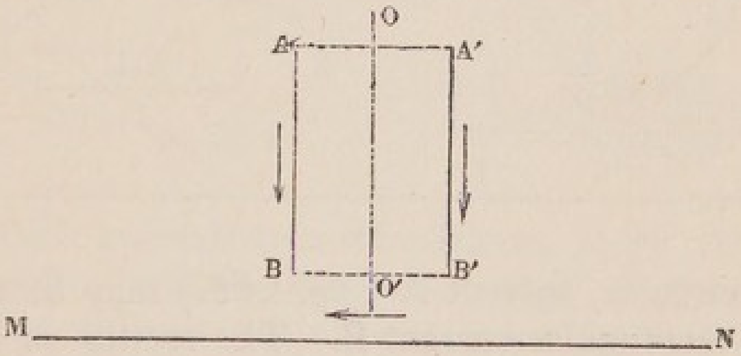


the vessel, a rotation will be imparted to the mercury, the direction of which will be in conformity with the principles just explained. Davy used a powerful magnet instead of the straight wire.

(495.) The following consequences respecting the action of finite and indefinite rectilinear currents will readily follow from the principles which have been established: —

When a finite vertical conductor, A B, movable round an axis, O O′, is subjected to the action of an indefinite horizontal current, M N, the plane A B O′ O will place itself in the position O′ O B′ A′ when the vertical current descends, and the horizontal current runs from M to N (*fig.* 264.).

Fig. 264.



If the direction of the vertical or horizontal current be reversed, the position of equilibrium of the former will be O O′ A B; but if the directions of *both* be reversed, the position of equilibrium will remain unaltered.

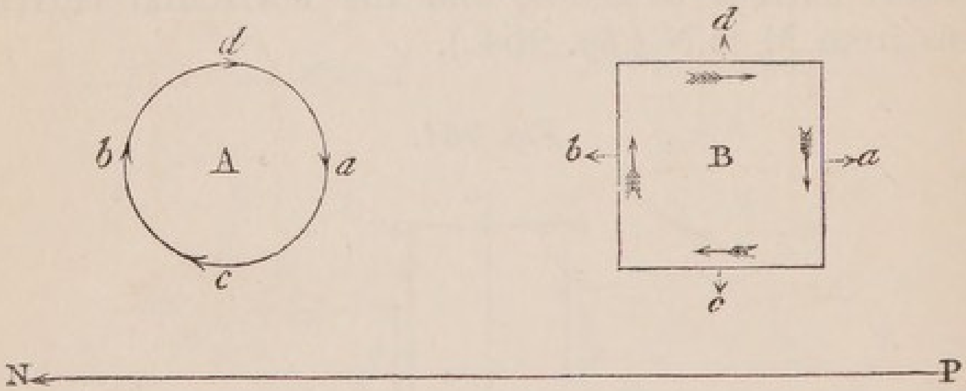
When two vertical conductors, A B and A′ B′, are movable round a vertical axis, O O′, and connected together, they will remain in equilibrium, whatever be their position, if they are both traversed by currents of the same intensity in the same direction, provided that the indefinite rectilinear current which acts upon them be at such a distance and in such a position that its distances from the points B and B′ may be considered always equal. When the wires A B and A′ B′ are

traversed by currents in opposite directions, one ascending and the other descending, the system will then turn on its axis O O′, until the vertical plane through A B and A′ B′ becomes parallel to M N.

Proposition IV.

(496.) *To determine the mutual actions of rectilinear and curvilinear currents.*

Fig. 265.



The circular current A (*fig.* 265.) may be resolved into the rectangular current B. The rectilinear current, P N, tends to move the *descending* side *a* in the direction *a*, *contrary* to that of the indefinite current (490.), and the ascending side *b* in the direction *b*, *similar* to that of the indefinite current; these forces being equal, and in opposite directions, neutralise each other. Again, the parallel and similar current *c* has a tendency to *approach*, and the parallel and dissimilar current *d* has a tendency to *recede* from P N. But, as the current *c* is nearer than *d*, its action is greater; and the result is that the rectangle B, or which is the same thing, the circle A, would approach P N. The same will hold good whether the circle be turned on an axis at *a b*, or on one at *c d*; in either case, it would move so as to bring *a* parallel with, and as near as possible to, P N. Of course, if the circle is fixed, and the indefinite cur-

rent movable, the latter will evince the approximating tendency.

(497.) If a terminated rectilineal current A B (*fig.* 266.) descend within a circular current, moving in the direction of the arrows Q N N, the current A B will tend to move in the converse direction to the other current, as shown by the arrows A B; and, if it is a rectangle free to move, it will pass round the axis O′.

Fig. 266.

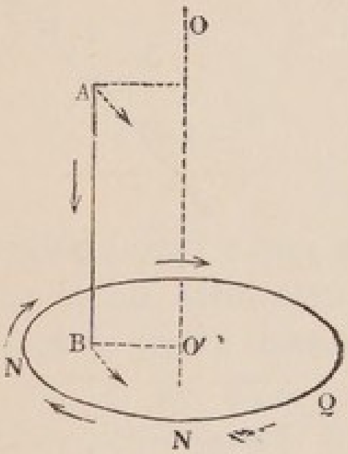


Fig. 267.

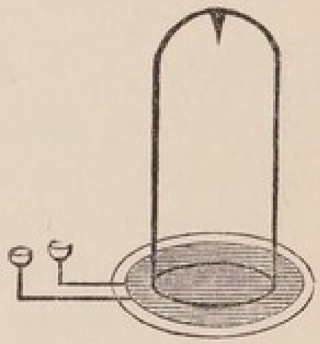


Fig. 267. represents a wire frame, to be suspended by the point, and to dip in a trough of mercury: a descending current will pass down both sides and add to its effect. The circular current Q N N (*fig.* 266.) is given by means of a coil of copper wire, placed round the base of the instrument, and terminating in the two cups; or else by means of a spiral

Fig. 268.

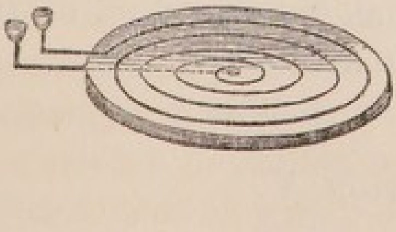
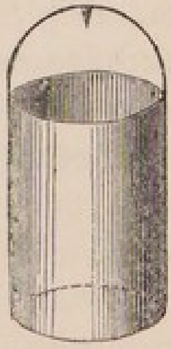


Fig. 269



wire (*fig.* 268.) placed beneath the instrument. A cy-

linder (*fig.* 269.) may be used instead of the wire rectangle; but its weight detracts from its mobility. If the spiral is made mobile, as in *fig.* 270., and the vertical current, not shown in the figure, is fixed, the converse takes place. The same general results attend currents moving at any angle.

Fig. 270.

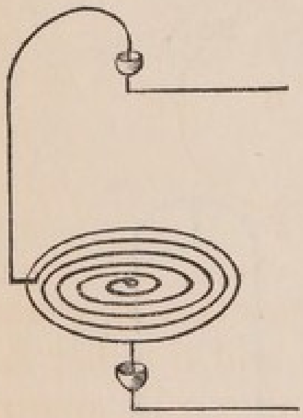
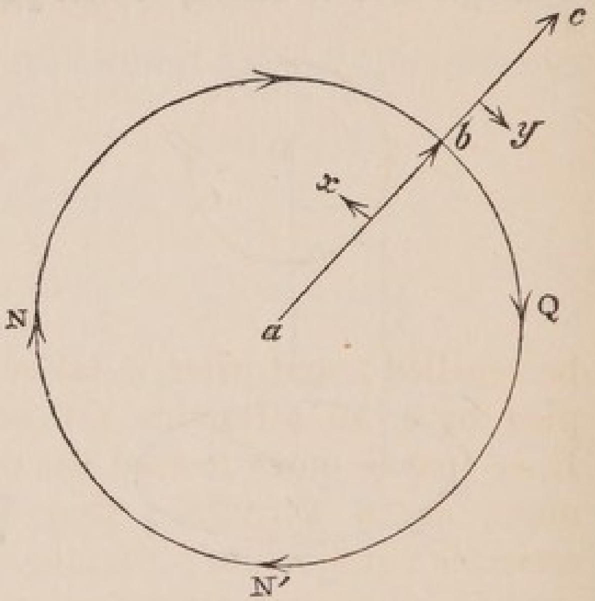


Fig. 271.



(498.) If the terminated current, instead of being perpendicular, were *parallel* to the plane of the circle, *i. e.* at the extreme angle, similar effects would ensue.

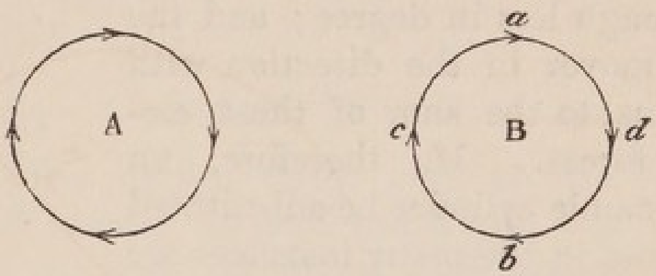
Let Q, N′, N (*fig.* 271.) be the circular current as before: — when the terminated current proceeds from *a* to *b*, it approaches the other current, and, therefore (490.), has a tendency to move in the *converse* direction, or *x*; when it proceeds from *b* to *c*, by receding from the other, it has a tendency to move in the same direction, or *y*; — when proceeding from *a* to *c* the two portions have contrary tendencies, and neutralize each other, if equal; or, if unequal, the direction of motion would be determined by their difference.

Proposition V.

(499.) *To determine the mutual action of curvilinear currents.*

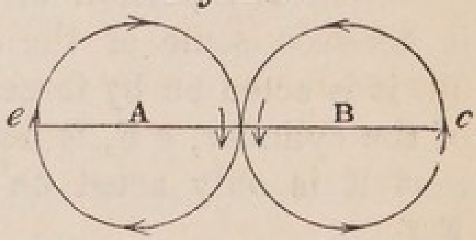
The transition to the consideration of cases in which both currents move in a circle, is very obvious. The currents A B (*fig.* 272.), as they lie before us, have a repulsive tendency; for the currents of the contiguous sides are moving in contrary directions; but if one of the circles B can rotate on an axis *a b*, the side *c* will

Fig. 272.



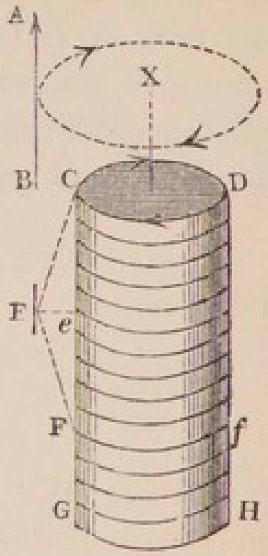
be repelled; and when *d* takes the position now occupied by *c*, an attraction will occur; and if either A or B is free to move toward the other, they will approximate, as in *fig.* 273.; they thus acquire a state of unstable equilibrium; for the remote similar currents *c e* have a mutual attraction, exerted in the right line *e c*, which now passes through the point of contact; but, if the least disturbance be given to either, so that this point is not included in the line, the two currents will turn, as on a hinge, at the said point, and mutually coalesce, — the one placing itself on the other.

Fig. 273.



(500.) This superposition of circular currents exactly represents the character of the electro-dynamic helix (*fig.* 235.), or Ampère's Solenoid (*fig.* 238.). It may be remembered, that we put out of the case (477.) the obliquity of the spirals, by returning the wire in the converse direction, so as to counteract this. We may, therefore, consider a helix under the form of the cylinder C D H G (*fig.* 274.), around which a series of parallel currents circulate in the same direction. Regarding the top C D of the cylinder as one of the

Fig. 274.

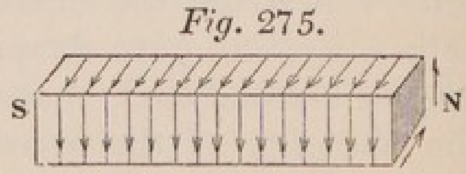


circular currents already examined (499.), its action on the terminated current B A may readily be determined. If the arrows on the cylinder represent the direction of its currents, those on the dotted circle are the direction to which A B will move. Now, all the circles exercise a similar action, though less in degree; and the line A B moves in the direction with a force equal to the sum of these elementary forces. If, therefore, an electro-dynamic cylinder be substituted for a magnet in the many instances we have given of wires, &c. rotating round magnetic poles, or the converse, we obtain experimental illustrations of the whole phenomena; the helix, in fact, possesses all the properties of a bar-magnet, the end at which the currents circulate *direct*, corresponding with the south end.

When any portion of the rectilinear current, as E, is between some of the circles, instead of above them all, it is acted on by forces in two directions; a portion of the cylinder, *e* F, is neutralized by *e* C, and the current E is only acted on by the portion F G, below F *f*.

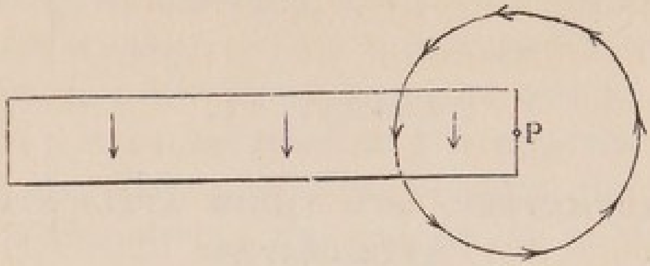
(501.) The cylinder, like its elementary circles (496.), may be resolved into a rectilinear form (*fig.* 275.), and this will assist in the examination of the action on a current at right angles to the cylinder. If it were opposite the centre, and in a similar direction to the current contiguous to it, it would be attracted in a *direct* line, as in *fig.* 265.; for the forces of the several circles would be equal in each direction. If it were not opposite to the centre, it would be attracted *towards* the centre while on ne side the cylinder; and *from* the cetnre, while on the other. And if it were free to

Fig. 275.



move on an axis, as P (*fig.* 276.), it would rotate in the direction of the arrows.

Fig. 276.



(502.) We cannot dwell long on the theories of electro-magnetism. Œrsted's idea was, that the circumference of the wire, conveying a current, might be regarded as surrounded by a series of minute magnets at right angles to the axis of the wire; and that thus it is that a needle approaches; and, if free to do so, takes a position parallel to these minute magnets, at right angles, that is, to the wire; but such an arrangement of stationary magnets would not produce *motion*; it was therefore necessary to add, that these magnetic forces have a vertiginous motion. But there are many objections to this theory.

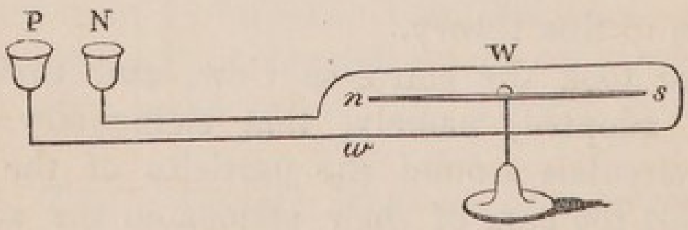
Ampère took the converse view, and this is now generally adopted, namely, that elementary electrical currents circulate around the particles of the magnet, and exhibit the sum of their actions on the surface, as in *fig.* 275.; indeed, on this principle it was that he constructed his *solenoid*, consisting of a series of such currents, and endowed with all the properties of a magnet.

CHAP. VI.

GALVANOMETERS, AND THEIR APPLICATION TO TELEGRAPHS.

(503.) In analyzing the mutual actions of currents and magnets, we have always increased the effects by using two currents in opposite directions, one on each side the magnet; the increase is still greater if we operate on two poles, one on each side the current. This is best shown by suspending a magnetic needle between two wires W *w*, terminating in cups P N, as in *fig.* 277. A strong current passing along the rectangle will deflect the needle at right angles to the wire. Such an instrument is a rough means of measuring the

Fig. 277.



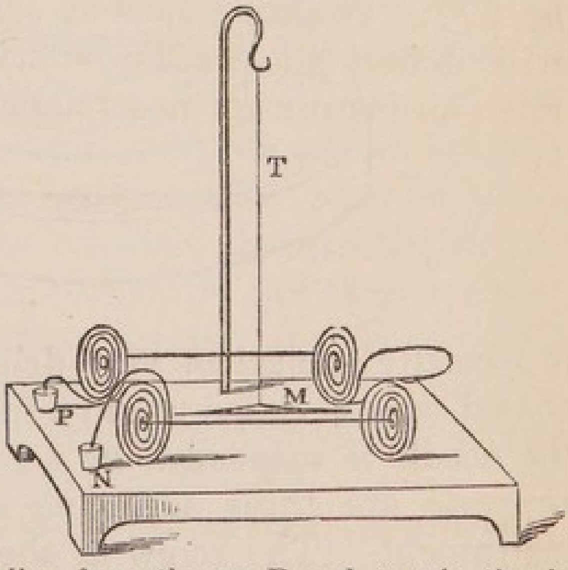
intensity of electric forces. But, if the current is not strong, an arrangement of this kind will either not act, or else act in a very small degree.

In this case we cover the wire W *w* with silk, and use several coils of it, so that the sum of the forces evinced by each wire shall act on the needle. A graduated circle is added, its centre coinciding with that of the needle; and thus we have the first form of a *galvanometer*. In some cases the needle is rendered more mobile by being suspended from a tall firm stem by a silk fibre. The needle is sometimes suspended above

the coil, instead of between the convolutions; and is then acted on by the *difference*, instead of the *sum*, of the forces. Occasionally the *needle* is made *astatic*, that is, having no tendency to one point of the compass more than to another. This is managed by suspending a second needle, of about the same power, from the same thread; with its poles in the opposite direction, and while the first needle is between the coils, the second is above them; the actions all unite in giving the same direction to the deflected system. Sometimes, instead of using coils encompassing the whole length of the needle, small, but very active coils are placed near its poles so as to concentrate their action there; and thus produce a delicate instrument.

This appears an extension of the principles involved in *Roget's galvanometer, fig.* 278.

Fig. 278.



"The needle is suspended from its centre by a fine thread, between four vertical spiral coils, the centres of which are brought very near to the poles of the needle. The same current is made to circulate through all the four spirals, the turns of which are directed so as to produce repulsion of the contiguous pole on the one side, and attraction of the same pole on the other side. This arrangement is shown in *fig.* 278., where M is the magnet, suspended by the thread T, between the four spiral discs, composed of the convolutions of the wire proceeding from the cup P, and terminating in the cup N." *

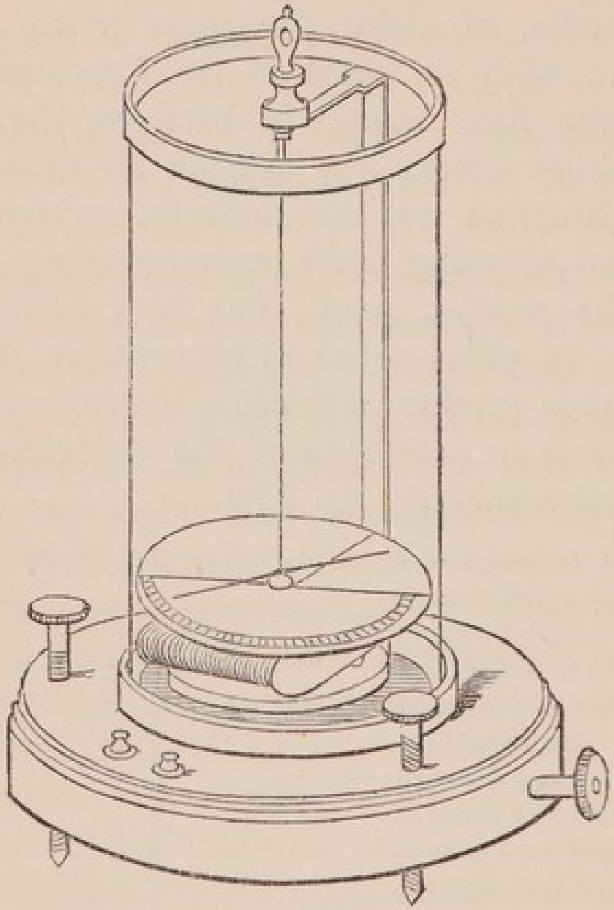
A *differential galvanometer* is one in which the wire consists of two insulated wires twisted round each other, along one of which one current can be sent, and along the other another. The *gold leaf galvanoscope* consists of a leaf of gold, held by forceps within a glass cylinder. It is used by sending a feeble current of electricity

* Library of Useful Knowledge, Electro-Magnetism, p. 44.

along the leaf, and observing the direction of its curvature when the poles of a magnet are applied near it.

Nobili's galvanometer is represented in *fig.* 279. It

Fig. 279.



is specially applied to very delicate observations. The coated wire is coiled round a frame beneath the needle; the needle is suspended by a single fibre of silk. The supports are three adjusting screws for levelling the instrument. The screw at the right is for turning the stage on which the system rests, so as to place the needle in the meridian. Connection with the electromotive apparatus is made by means of the two screws seen at the left in front.

Galvanometric deflections are very far from furnishing comparative indications of the relative electro-motive forces acting on the needle; for the degrees of deflection, as we elsewhere mentioned (328.), are not proportionate to the force. To obviate this objection, it has been found

necessary to determine, by a troublesome series of experiments, the actual value of each deflection in individual galvanometers. Fechner used to measure the value of the current by the number of oscillations made, in a given time, by the needle, when placed at right angles to the coil; and, according to the laws of the pendulum, comparing the squares of the numbers. Mr. Wheatstone has lately gone through a series of experimental investigations of certain formulæ of *electro-motive force* and *resistance*, which were a few years ago laid down by Ohm: and, in the practical application of these formulæ, he has devised a very ready method of valuing the several galvanometric deflections. We have not space to enter on the inviting subject of Ohm's law, nor to go into the details of this application of it. The principle is this: — The galvanometer is included in the circuit, and its deflection noted; a certain length of wire, exactly equal in resistance to the galvanometer wire, is then so placed that the current shall be divided betweeen it and the galvanometer; then, since the addition of this wire reduces the whole resistance of the circuit by one-half the resistance of the galvanometer wire, an additional resistance, equal to one-half that of the galvanometer, is added to the main circuit, and the deviation of the galvanometer will then indicate exactly one-half the force previously acting on it. For the mode of measuring these several resistances, the reader is referred to Mr. Wheatstone's Memoir in the Phil. Trans. for 1843, Part II.; where he will also find a description of the Rheo-stat and other instruments connected with this investigation.

Magnetic Needle Telegraphs.

(504.) After Œrsted had discovered the mutual action of electric currents and magnetic needles, Ampère "proposed, in consequence of an idea suggested to him by the illustrious Laplace, to employ as many circuits as there were letters of the alphabet, and to make each

of them act on a separate needle."* Schweiger's invention of the galvanometer (Int. 227.), followed more recently by Wheatstone's discovery of the velocity of electricity †, gave renewed impulse to these inquiries. Professor Ritchie illustrated Ampère's idea on a small scale, but rather with a view of pointing out the difficulties which enveloped it, than to propose it for practical purposes. Alexander's telegraph had thirty galvanometric needles and thirty-one wires ; each needle supported a screen, which it carried with it, when deflected, and thus exposed a letter. Davy's first telegraph was of the same character, only the letters were illuminated. "Baron Schelling and Fechner proposed to limit this number by employing fewer needles, and observing their combined motions,—a different character being indicated, according to the number of needles in motion." ‡ Mr. Bain has proposed to fix the magnet and deflect the coil. The arrangements peculiar to Mr. Wheatstone's needle telegraph are, that he has *one* wire only for each needle ; that *two* needles are thus always included in the circuit ; that the combination of the two needles, out of five, which he generally used, will produce twenty signals ; and that by a key-board, peculiarly his contrivance, these several circuits can be readily formed. By combining three or four needles, 200 signals could be given. As the motion of these deflected needles was not of itself sufficiently violent to ring a bell, in order to call attention, arrangement was made that one of the needles, by its deflection, should complete the circuit of a distant battery ; and this would then make an electro-magnet (506.), and liberate the detent of an alarm. Other modes of sounding an alarm were adopted, on account of the difficulties which attended the early experiments on that form of telegraph, which we shall presently describe (511.). As it is not the intention to give here a history of telegraphs, the above illustrations

* Bull. Acad. R. Bruxelles, 1838, No. 2.
† Electricity would travel round the globe in one-tenth of a second.
‡ Comp. to Almanack, 1843.

of the chief applications of the galvanometer to this purpose will suffice us.

(505.) Professor Wheatstone has availed himself of galvanometric effects, as one means of indicating the metereological conditions of the higher regions of the atmosphere, the instruments being in a captive balloon and the observer on the earth.

Connected with the mercury, in the bulb of the thermometer, is a fine platinum wire, which descends to one pole of a small voltaic pair; a short wire connects the other pole with one end of a galvanometer; and, from the other end of the galvanometer, a wire ascends to a movable rack-work, which carries a fine platinum wire, that can ascend or descend within the tube of the thermometer. When it is low enough to touch the surface of the thread of mercury, the circuit is complete, and the galvanometer deflects. Now, the rack is moved by clockwork, which coincides with a chronometer kept by the observer, and takes three minutes to ascend and three to descend; the position, therefore, of the point of the moving wire, that is, the height of the mercury, can be known at any time by consulting the chronometer; and so if the times of the deflections are noted, the temperature at those times is readily obtained.

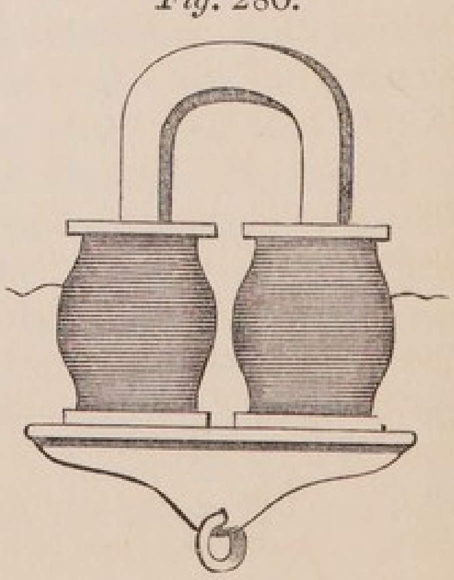
CHAP. VII.

ON ELECTRO-MAGNETIC INDUCTION, AND ITS APPLICATIONS.

(506.) THE great similarity between the electro-dynamic helix and bar-magnets, in connection with the theory, which assigns to magnets themselves a character exactly such as would be produced by electric currents circulating round the metal of which they were composed, would naturally lead to the actual experiment of passing such currents round a bar of iron or steel. M. Arago was the first to do this, and he found that the bar was converted into a powerful magnet: when soft iron is used, the effect is instantaneous, but ceases directly contact is broken; when steel is used the maximum effect is obtained gradually, but is lasting, the bar being converted into a permanent magnet.

A bar of soft iron, whatever be its form, with an electric current thus circulating round it, is termed an "electro-magnet" (*fig.* 280.). The lifting power of such magnets is enormous, especially when large quantities of electricity are made to circulate through stout wires. The powers of larger instruments now constructed for exhibition in public institutions, is immense. There is one which is adjusted to support a room full of people. The most powerful bar electro-magnet of which I am aware, is one constructed under the direction of Mr. Faraday for the magnetic obser-

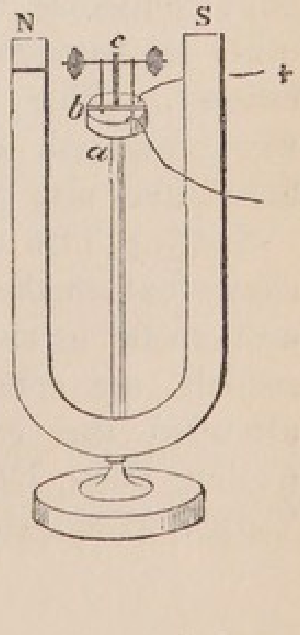
Fig. 280.



vations of Colonel Sabine at Woolwich. It was exhibited at a lecture of his before the Royal Institution, on June 10. 1843. The helix is 27 inches long by $2\frac{3}{8}$ inches internal diameter: it has four coils of No. 7, copper wire covered with tape; their lengths are 108 feet 10 inches; 120 feet; 129 feet, 7 inches; 143 feet; in all 501 feet, 5 inches; bars and clamps are arranged so as to admit of using one or more of the helices variously combined. It is firmly supported on a grooved square stand. The soft iron core is 28 inches long by $2\frac{3}{8}$ inches diameter: there are two other cores each $12\frac{1}{2}$ inches by $2\frac{3}{8}$ inches, for magnetizing a steel bar placed in the coil between them. When the electric current was sent through one, the pole of the core supported all the fire irons, which were collected from the several rooms of the Royal Institution: and when a shorter core was applied end-on, one man's force was not sufficient to draw out the core. The hand, applied between the core and a piece of iron, was painfully pressed. Porcelain plates, filled with a mass of iron nails, were firmly suspended between the nails and the electro-magnet.

A bar electro-magnet may be looked upon as an Ampère's helix with an *iron* core; but, while the current acts on the iron to make it a magnet, the magnetized iron re-acts on the current, and the magnetic character of the system, as a whole, is very highly exalted.

Fig. 281.



(507.) We have as yet seen Ampère's helix motive, only so far as to place itself on the magnetic meridian. Professor Ritchie produced permanent motion; and his instrument, under its various forms, is known as "Ritchie's Rotating Magnet." The general form is in *fig.* 281. N S are the two poles of a horse-shoe magnet; *a b* is a wooden cup for mercury, divided into two

parts a and b; a is connnected with one end of a single cell, and b with the other; c is the electro-magnet, consisting of a small bar of soft iron, surrounded at its ends with a continuous coil of stout copper wire, the two terminations of the wire dipping into the mercury. The polarity of either end, say x, will vary according to the termination of the wire, which may be in b or a. Now, when the electro-magnet is placed at right angles to the line joining N and S, and the current gives x a *north* polarity, the end x will be repelled by N and attracted by S; but the momentum which it acquires, will carry it a little beyond the line of neutrality, and, by this means the wire dipping in the mercury b, will pass over the partition into the mercury a: x will now be a south pole, and is, therefore, repelled by S and attracted by N, so that it is still urged onward toward N, and then, passing over the partition into b, the same series of effects are renewed, and a continued rotation is the consequence. When favourably constructed, Ritchie's magnet will rotate by the magnetism of the earth.

(508.) Professor Henry produced a reciprocating motion, by placing an electro-magnet, like a balance-beam, above the poles of different names of two magnets: it had two sets of wires, the ends of one set were such, that when the electro-magnet was attracted by a pole of the fixed magnet, the wires dipped in mercury cups connected with one battery, and the wires of the other set were raised from the mercury cups of another battery. The poles being thus changed, attractions were reversed, and an oscillation was kept up. Dr. Schulthess also produced reciprocating motion.

(509.) The applications of electro-magnetism are somewhat on the principles of Ritchie's rotary motion; and, so far as small models, and in some cases, working models, are concerned, a certain degree of success has attended the experiments of Sturgeon, Mc Gauley, Callan, Page, Davenport, Watkins, Joule, B. Hill, Fox, Talbot, Wheatstone, and others; it is said, indeed, that

the Frankfort diet have just awarded a sum of 100,000 florins to a Mr. Wagner, for having discovered a method of moving machinery on a large scale by electro-magnetism: but we did not hear* of any practical results having been deduced from his plan, and have reason to think that it may not possess the merit which he has assigned to it.

(510.) Professor Jacobi, of St. Petersburg, has done a great deal in these matters, and has so far succeeded as to navigate on the river Neva, a vessel manned by twelve persons. He obtained $\frac{3}{4}$ horse-power and ascended the river, for several hours, against a very violent wind: the electro-magnetic machine was only 4 feet high, $1\frac{1}{2}$ feet long, and not quite a foot wide.

Fig. 282.

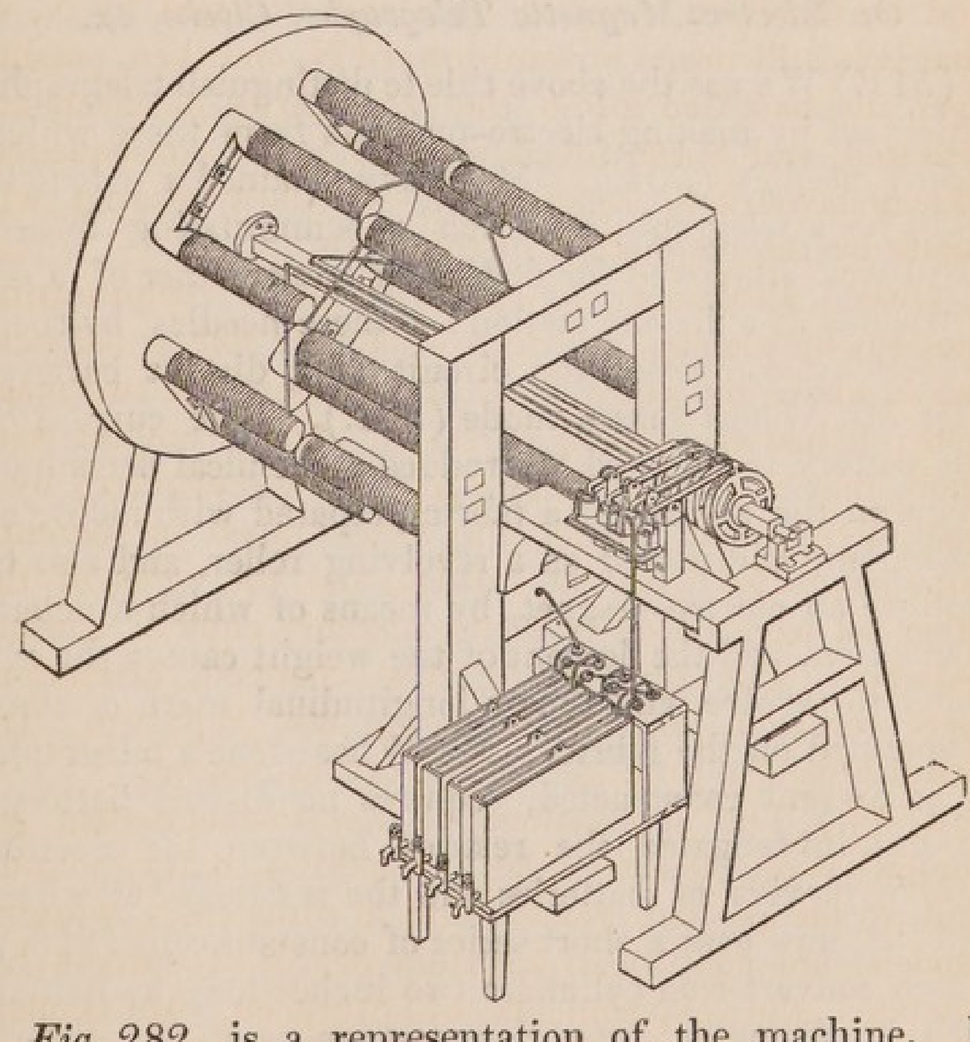


Fig. 282. is a representation of the machine. It will be seen to consist of four fixed electro-magnets

* January, 1844.

attached to the wooden frame-work; and four movable electro-magnets, which carry with them the circular disc and the axis. The battery is shown in front. Grove's arrangement (322.) is employed. A very important part of the engine is the commutator; by aid of which, the polarity of the moving magnets is changed directly momentum carries the poles beyond the poles of the stationary magnets. Mercury is not admissible for many reasons. The wheels and lever on the end of the axis are the commutators: they are so arranged, that the metal levers press on the periphery of discs, whose surfaces are partly copper and partly ebony; in the one case the circuit is completed, and in the other, it is broken, and then changed.

On Electro-Magnetic Telegraphs, Clocks, &c.

(511.) We use the above title to distinguish telegraphs which act by making electro-magnets from those which deflect needles (504.). Mr. Davy obtained a patent in 1839 for a telegraph, in which a commutating finger-board was employed for deflecting one or other of a set of needles at a distant station:—these needles, by their deflections, completed the circuit of a distant battery, after Mr. Wheatstone's mode (504.). The current of this battery is adjusted to produce a chemical decomposition on the surface of a fabric prepared with iodide of potassium, and placed on a revolving roller, and also to produce an electro-magnet, by means of which a detent is acted on, and the descent of the weight causes the cylinder to revolve, and thus a longitudinal mark or stain is obtained on the fabric. Mr. Wheatstone's telegraph, as at present constructed, requires no distant battery: he has investigated the relation between the electromotive powers of batteries and the resistance of wires, and he now uses a short series of constant cells (318.), which convert iron cylinders two inches long by half an inch in diameter, into electro-magnets at the distant station. Every time contact is made, the keeper of the

magnet is attracted; when contact is broken, a spring removes the keeper. In one form of the instrument (where the resistance is not great), two drivers, properly attached to the keeper, are made to act upon a toothed wheel, and thus convert the *alternate* into a *circular* motion, which motion is transmitted to an axis carrying a signal-disc; in another part of the instrument (where the resistance is great), the keeper merely moves a detent, and thus liberates the toothed wheel, and allows of a motion being given to the signal-disc or *indicator* by means of a clock-work movement. A *communicator* at the one station, is furnished with a disc corresponding to that of the *indicator;* so that, when any sign of one is brought to the place of observation by the application of the hand, the corresponding sign is exposed by the other. There is a commutator and indicator at each station, all four being included in the one circuit of a wire each way. — For transmitting *time*, instead of signals, the indicating disc is fixed and furnished with a clock face, the axis carrying an index or hand; and the communicating disc is moved round by the step by step action of a pendulum. By this means one good clock will communicate true time to a series of indifferent clocks, or even to *skeletons* of clocks, as they have been called. For *registering*, instead of merely exposing the signals, each letter of the indicating disc is on a spring radiating from the centre: and when the letter is brought, as before, to the proper place, a hammer, acted on by clock-work, liberated by a second electro-magnet, strikes the letter upon a pad of manifold writing-paper and fair paper, and so registers the signal. A cylinder, rotating on a spiral axis, exposes fresh surfaces of paper. The same current which works these telegraphs also rings a bell to call attention. Mr. Bain has proposed transmitting time and registering signals by the action of a deflected coil.

The electro-magnet is made use of by Professor Wheatstone, for some of the signals of the meteoro-

logical apparatus, and it acts by moving a detent, attached to its armature, and thus setting free the mechanism, which causes a hammer to strike on black copying paper, and impress a signal. This instrument is connected by wires, as was the thermometer (505.), and works for a week, printing the observations, without attendance: it is used also with the thermometer and the psychrometer, and, indeed, for many other purposes.

CHAP. VIII

ON VOLTA-ELECTRIC INDUCTION.

(512.) This term was applied to a class of inductive effects obtained from dynamic electricity, by Professor Faraday. He was the first to discover that if two helices of insulated copper wire be superposed round a cylinder of wood, and a current be passed through one of them, while the ends of the other are connected with a galvanometer, the needle is transiently deflected in one direction, when contact is *made*, and in the reverse when contact is *broken*: during the existence of the contact, the needle remains in its normal position, showing that the *primary* current induced a momentary *secondary* current in the other wire, in *one* direction when contact is made, and in the *converse*, when broken; the latter was found to be the more powerful. The secondary current on making contact was in the *reverse* direction to the primary, and on breaking contact was in the *same* direction as the primary. If the battery contact was first made; and the secondary wire then connected with the galvanometer, no first effects occurred; though, if battery contact was afterwards broken, the secondary effects would take place as before.—Mr. Faraday then showed that the secondary current is due, not merely to a commencing and terminating primary current, but rather to the production of a current in the vicinity of another wire, by any means. He stretched the primary wire on a board, into the form of a W., and the secondary on another board, into the same form; he connected the latter with the galvanometer, and the former with the battery; now, on moving the primary wire *toward* the other, a *contrary* current was induced on the other; and, on moving it *from* the other, a similar current was induced.

(513.) Subsequently, in consequence of a communication from Mr. Jenkin, that a shock could be obtained by means of a *single voltaic pair*, when contact was broken, and the hands were connected with a coil of wire, through which the current had passed, Professor Faraday was led onward in his inquiries:—he found no spark or shock on *making* contact with a primary helix only, but a bright spark and powerful shock, on *breaking;* the effects are exalted when the helix contains an iron rod; when, in fact, it is made an electro-magnet. When a wire 132 feet long, with one end connected with one plate of a single pair, was spread about the laboratory, a spark appeared, and a slight shock, sufficient to convulse a flounder or eel, occurred every time contact was broken. None of these effects occur without the intervention of a long wire. These effects were soon traced to a *momentary* current induced in the wire at breaking contact, in the *same* direction as the primitive current, and on the same principles as availed in producing the *secondary* current.

In fact, it is a *secondary* current induced in the *same* wire, which carries the *primary;* it was found to be effectual in producing chemical decomposition. By analogy with the preceding experiments, it was reasonable to infer that a *converse* current occurred when contact was *made;* and this inference was borne out by experiment.

(514.) These facts have added several pieces of apparatus to electricity, in the form of *coils* and *contact breakers*. Experience has shown that it is best to use a stout covered wire, of moderate length, for the *primary* current, and a very long fine superposed wire for the *secondary*; for instance, 150 feet of No. 18., and 2100 of No. 26. make a good coil. Mr. Bachhoffner found that a bundle of iron wires, as a core, gave much more powerful effects than a mere bar of iron. Dr. Bird and others adopted this plan; and we since find that many electro-magnets are made of bundles of soft iron wire. Mr. Joule preferred square to round metallic fibres. The shocks from small well-made coils

are beyond endurance intense; and as one occurs each time contact is broken, the reiteration of this act greatly magnifies the effect.

(515.) One form of "contact breaker," is Bachhoffner's toothed wheel, attached to one end of the primary wire, and a spring, working on the teeth, attached to the battery; the other end of the wire is connected with the other end of the battery; handles proceeding from the secondary wire are held in the moist hand. When the wheel is turned, a shock occurs every time contact is broken, by the spring leaving one tooth to pass to the next. Ritchie's rotating magnet is often used, and is more convenient as it acts of itself: in order to multiply the breaks, the mercury cells *a* and *b* (*fig.* 281.) are partially subdivided.— Sometimes the coil is made by twisting the wires round a horse-shoe form of soft iron or iron wire, and a rotating keeper makes and breaks contact of itself. The largest coil of which we are aware, is Mr. Gassiot's, containing twelve miles of secondary wire.

A most convenient contact-breaker is a small upright coil with a wire core, which, on becoming a magnet, attracts a piece of soft iron, and so breaks contact: the iron is then set free, and contact is again made. Dr. Bird described the first form of this to the Electrical Society.* Sometimes the coil in use is itself arranged to make and break its own contact (518.).

(516.) Prof. Henry, in studying the character of these currents, obtained all the effects of electricity from other sources, including the power of making electro-magnets — a power which is now being turned to some account (509.). He found that long coils gave effects of *intensity*, and short ones those of *quantity*; and that an *intensity* current can induce one of *quantity*, and *vice versâ*. He examined induction at a distance; and has devised a good experiment in "Physique amusante:"—

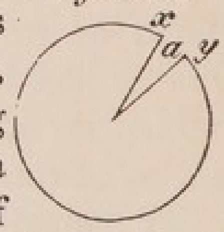
"This consists in causing the induction to take place through the par-

* Proceed. Oct. 14. 1837.

tition wall of two rooms. For this purpose, coil No. 1. [93 ft. copper ribbon, 1½ inch wide], is suspended against the wall in one room, while a person in the adjoining one receives the shock, by grasping the handles of the helix [1660 yards copper wire, one forty-ninth of an inch in diameter], and approaching it to the spot opposite to which the coil is suspended. The effect is as if by magic, without a visible cause."*

On interposing a sheet of iron between the coil and the helix, *no secondary effects occurred:* it was afterwards "found that all the perfect conductors, such as the metals, produced the screening influence; but non-conductors, as glass, wood, &c. appeared to have no effect whatever." A certain thickness of metal was necessary to constitute a screen, for foils exercised no influence. Thinking that currents in the metal screens might constitute their efficacy, he cut a section out of one, as *a* in *fig.* 283.: it then ceased to be a screen when two such were superposed with glass between them, so that the opening in one was covered by the continuous part in the other, they were still not screens;—on connecting a test instrument by wires to x and y, a current *was* found present. The current of the screen, when placed above the helix, instead of between the coil and helix, still had a neutralizing effect. When a flat coil was interposed, it was not a screen, unless the ends were in contact.

Fig. 283.



(517.) He now conveyed the secondary current through a third coil at a distance, and obtained by it another induced current, in a *fourth* coil; he took this to a *fifth*, and obtained an induced current in a *sixth*. He found the direction of the current to alternate from the second coil; the primary current being *plus*, the secondary was *plus* also; the third *minus;* the fourth *plus;* the fifth *minus;* and so on.—Though not included in the present branch of our subject, it will be as well to mention that the effects of induced currents were obtained also from ordinary electricity.

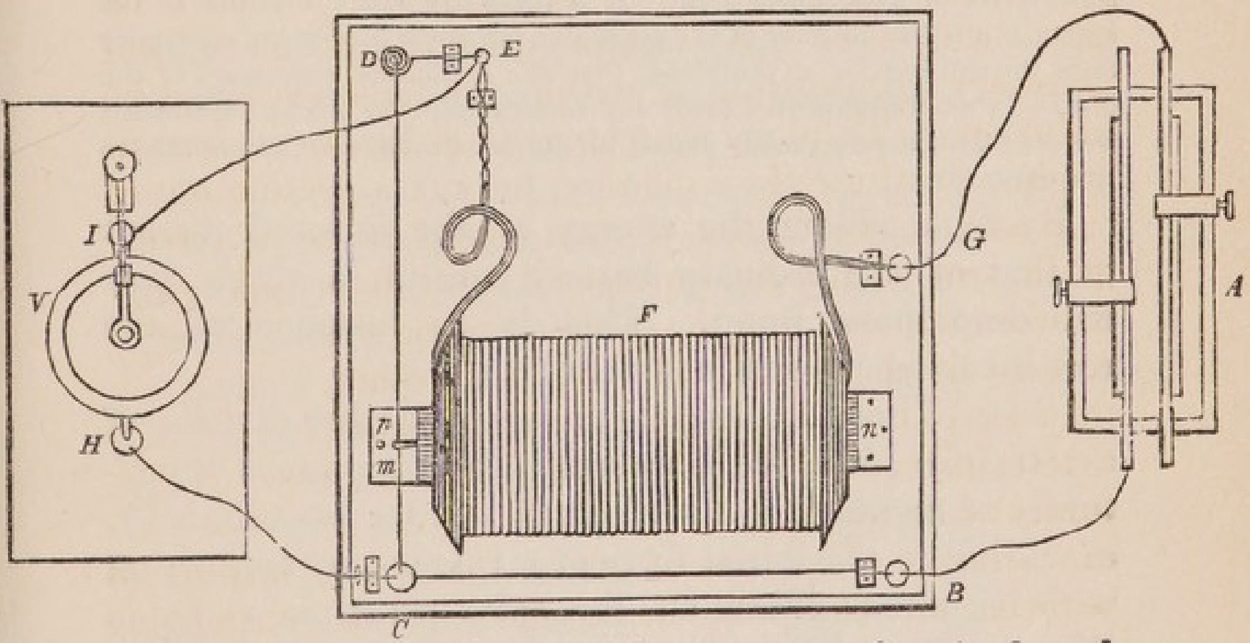
We dare not venture upon the papers of induced

* Ann. of Elect. vol. iv. p. 291.

currents by DOVE, ABRIA, MASSON, and BREGUET, jun., the most condensed analysis of which would carry us far beyond our limits, but refer our readers to No. V. of the ARCHIVES OF ELECTRICITY.

(518.) This account of voltaic-electric induction may not be concluded without giving a description of the "voltaic-condenser," an instrument in which M. de la Rive has availed himself of the induced current in

Fig. 284.



order to exalt the decomposing power of a single voltaic cell: —

"*A* (*fig.* 284.), the pair. *B* and *G* the extremities of each of the conducting wires of the pair, which are placed in cups of mercury, or are connected at *B* with the extremity of a wire *B C*, and at *G* with the extremity of a wire covered with silk. *C* small capsule of amalgamated copper. *C D* metallic rod furnished at *D* with a spring, that keeps the end at *C*, which is bent vertically downward, in contact with the bottom of the capsule *C*. *D E* conducting wire, which connects the rod *D C* with the end *E* of the wire covered with silk. *F* helix formed of wire covered with silk rolled round a bobbin; *E* and *G* are the two extremities of this wire. *m n*, cylinder of soft iron placed in the interior of the bobbin. *P*, small attached piece of soft iron, which is attracted by the extremity *m* of the cylinder of soft iron, when the latter is magnetized by the current. *H* and *I* the extremities of the conducting wires, *C H* and *E I*, which serve to include a voltameter *V* in the circuit. At the moment when the circuit is closed, the current circulates in *B C D E G*; the piece *p* is instantly attracted, because *m n* is magnetized; but the circuit is immediately interrupted at *C*, because the rod *D C*, the bended extremity of which touches the bottom of the capsule *C*, is raised. This interruption of the circuit

gives rise to an induced current in the wire of the helix *F*, which is determined in the same direction as that of the pair. On the other hand, a new circuit is formed whilst the rod *D C* is raised; this circuit, in which the pair *A* is included, is the circuit *B C H I D E G A*; the voltameter *V* is now seen to form part of this circuit, and it is traversed at once by the induced current, and by the current of the pair reinforced by the passage of the induced current through the pair. But as soon as the circuit is broken in *C*, the soft iron *m n* ceases to be magnetized, or at least is very feebly so, because the voltameter is in the circuit; the attached piece *p* being no longer attracted, the rod *D C*, subject to the action of the spring *D*, immediately falls, and the circuit is no longer interrupted at *C*. The current of the pair again commences to circulate by *B C D E G*, and the same series of phenomena occur. It is necessary that the power of the spring *D* and the distance of the piece *p* at the lower part of the extremity *m* of the soft iron be so combined, that the oscillatory movement of the rod *D C* should be executed easily and very rapidly; by a little adjustment the apparatus is very readily placed in the conditions most favourable to this effect."*

By thus adding the energy of the induced current to that of the ordinary battery current, a single pair will decompose water. This is an instance of the coil breaking its own contact (515.).

519.) Though belonging rather to another division of this treatise (348, &c.), we may take the present opportunity of mentioning a method Mr. Grove has adopted†, of adding to the initial force of a current, by associating with it another effect, on the same principle as De la Rive has associated the inductive effect. He takes a single pair of the nitric acid battery, and electrolyzes acid water by means of platinum electrodes; but, between the voltameter and the battery, he places a vessel of acid water, containing a large pair of platinum plates. Under these circumstances, the liberation of gas in the voltameter is in a decreasing ratio, because the large platinum plates become polarized, by the effects of electrolysis, and react on the battery current. If, when the liberation of gas has reached a minimum, the respective connections of the large plates be reversed, by means of an electropeter (478.), this reacting force is *added* to the initial; and the average quantity of gas liberated in a given time exceeds that which would be produced, were there no interposed resistance of large plates.

* Vide Elec. Mag. vol. i. p. 78.

† Phil. Mag. Dec. 1843.

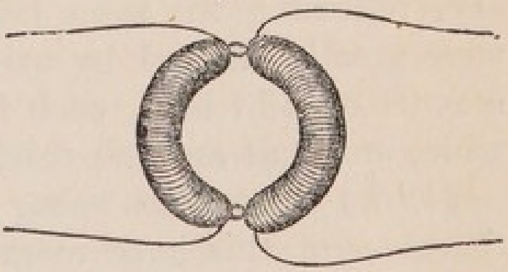
BOOK THE SIXTH.

MAGNETO-ELECTRIC INDUCTION.

(520.) When Faraday had found that a secondary current was produced on *approximating* a primary current to another wire (512.), he was led into a new series of researches, which terminated in the production of *electricity from magnetism*, which he termed "Magneto-electric induction," and which was the origin of magneto-electric machines.

Around a soft iron ring (*fig.* 285.) were wound two helices of insulated copper wire; when the ends of one helix were connected with a galvanometer, and a battery current was passed through the other, the needle was transiently deflected in one direction when contact was made, and in the other when contact was broken; the former gave an indication of a current in the *opposite* direction to that from the battery; the latter of a current in the *same* direction. The continued current caused no deflection. When the wires were superposed on a paper cylinder, the induced current was much more powerful when a soft iron bar was introduced into the cylinder than it was without the bar; the iron bar, in all forms of the experiment, being, as we are prepared to expect, converted into a powerful magnet. Thus far, however, the exciting cause has been voltaic electricity.

Fig. 285.



(521.) It now occurred to Mr. Faraday *to convert the soft iron into a magnet by other means than voltaic*

agency. Accordingly, he placed it in the helix, having first associated the wires into a continued series with a galvanometer included between the extremities; and he magnetized it, by applying to its ends the opposite poles of two bar magnets: when, agreeably to his anticipations,

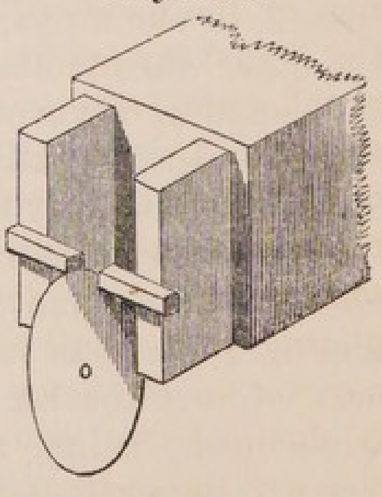
"Upon making magnetic contact, the needle was deflected; continuing the contact, the needle became indifferent, and resumed its first position; on breaking the contact, it was again deflected, but in the opposite direction to the first effect, and then it again became indifferent. When the magnetic contacts were reversed, the deflections were reversed.

"When the magnetic contact was made, the deflection was such as to indicate an induced current of electricity in the opposite direction to that fitted to form a magnet, having the same polarity as that really produced by the bar magnet." *

(522.) The iron bar was now removed, and a cylindrical magnet employed; when this was *introduced* within the helix, deflections occurred in one direction, and when it was *withdrawn* they were in the reverse direction; while it remained in, the needle was stationary, following the same laws as before. These effects were greatly exalted by using the Royal Society's large magnet of 450 bars, each fifteen inches long, one inch wide, and half an inch thick.

(523.) Two bars being placed, as in *fig*. 286., on the poles of this large magnet, in order to concentrate their effects, a disc of copper was arranged to rotate between the bars, as in the figure; and wires were arranged to collect any electricity which might be evolved during the revolution of the plate.

Fig. 286.

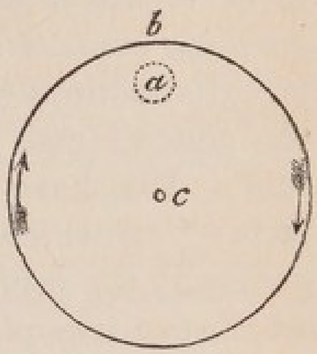


"The *relation of the current* of electricity produced, to the magnetic pole, to the direction of rotation of the plate, &c., may be expressed by saying, that when the unmarked pole is beneath the edge of the plate, and the latter revolves horizontally, screw fashion, the electricity, which can be collected at the edge of the

* Exp. Researches, Series i. §§ 37, 38.

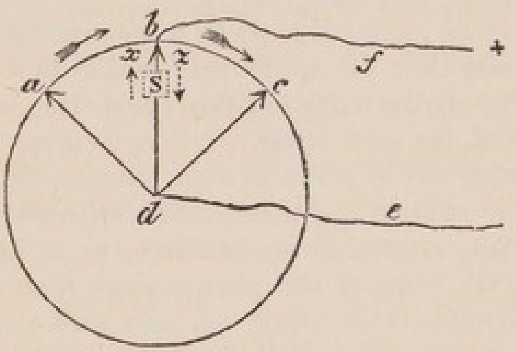
plate, nearest to the pole, is positive. As the pole of the earth may mentally be considered the unmarked pole, this relation of the rotation, the pole, and the electricity evolved, is not difficult to remember. Or if, in *fig.* 287., the circle represent the copper disc, revolving in the direction of the arrows, and *a* the outline of the unmarked pole, placed beneath the plate, then the electricity collected at *b* and the neighbouring parts is positive, whilst that collected at the centre *c*, and other parts is negative."*

Fig. 287.



(524.) Without carefully illustrating the theory of this action, it will be difficult to explain the operations of the magneto-electric machine (528.). Let the disc (*fig.* 287.) be analyzed into the three radii *a b c*

Fig. 288.



(*fig.* 288.) moving by direct rotation about the electro-magnetic† pole S, which, as we have already seen (448.), is traversed by electric currents in the direction of the hands of a watch, of which those shown by the dotted arrows are all that concern us now; and let a collecting wire *e* be attached to the centre *d*. As the wire *d a* approaches the magnet, the current *x* induces in *d a* a secondary current in the direction from *a* to *d*, which attains its maximum in the position *d b*; if ulterior inducing action be now terminated, by completing the circuit at *b* with the wire *f*, the *secondary current in the same direction as the inducing current x* is obtained; so, when the wire is receding to the position *c d*, the current *z* induces a current in the direction *c* to *d*, similar to its own; but if a wire completes the

* Faraday, § 99.

† All these effects can of course be produced by electro-magnetism.

circuit in *c*, a current obtains in the direction of the arrows *d c*, as before. The magneto-electric current is to be regarded as *the secondary current, consequent on breaking contact of volta-electric induction.* Some differential actions are included in the strict analysis ; but the general case may be gathered from what has been said. We have to regard the disc as made of these radii, "in which the directions of the currents will be generally the same, being modified only by the co-action which can take place between the particles now that they are in metallic contact."

(525.) These discoveries furnish a conclusive explanation of the causes in operation to produce the rotation of Arago's disc : —

" If a plate of copper be revolved close to a magneticane ne gedle or m,t suspended in such a way that the latter may rotate in a plane parallel to that of the former, the magnet tends to follow the motion of the plate ; or if the magnet be revolved, the plate tends to follow its motion ; and the effect is so powerful, that magnets or plates of many pounds weight may be thus carried round. If the magnet and plate be at rest, relative to each other, not the slightest effect, attractive or repulsive, or of any kind, can be observed between them. This is the phenomenon discovered by Arago ; and he states that the effect takes place, not only with all metals, but with solids, liquids, and even gases, *i. e.* with all substances." *

The explanation originally offered for these rotations was that the copper acquires a magnetic pole, of the opposite kind to that approximated to it ; but it is now evident that the effects are due first to the formation of currents by the magnet ; and then to the mutual action of the magnet and the currents.

These rotations had formed an object of investigation to BABBAGE, HERSCHEL, BARLOW, NOBILI, ANTINORI, BACCELLI, CHRISTIE, PREVOST, COLLADON and others. Mr. HARRIS investigated the nullifying influence of thick screens (516.), of copper, silver, zinc, and lead.

(526.) Mr. BARLOW has detailed a series of experiments, in which certain effects are produced on a needle by the rotation of an iron sphere. Now, in this case, the sphere *as a mass of iron* under the influence of the

* Faraday's Researches, Series i. § 81.

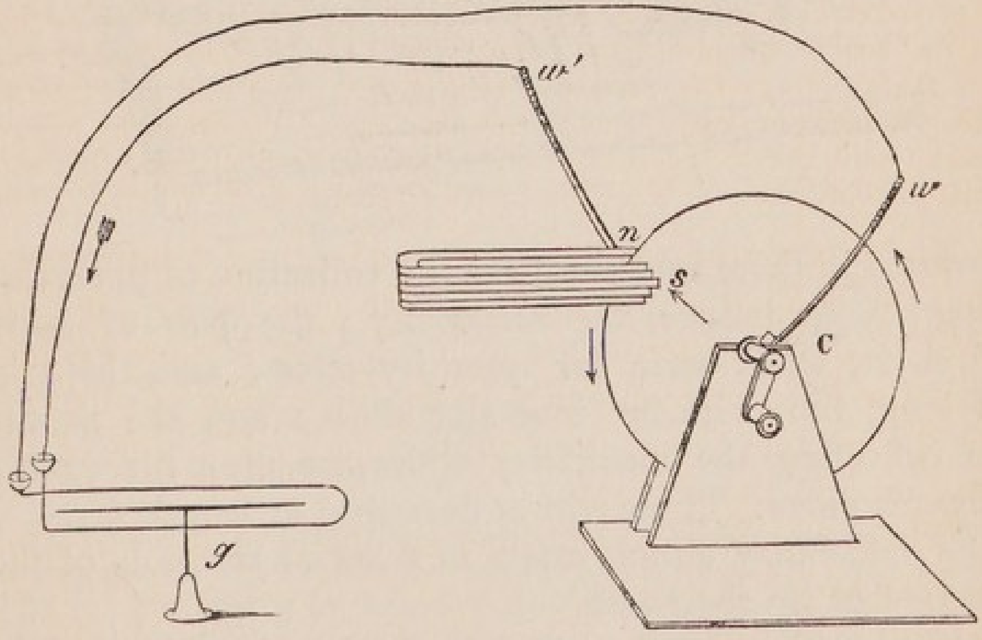
earth's magnetism, becomes a *magnet*, and, *as a mass of metal* rotating under similar influence, it acquires induced currents. With respect to the relative influence of these two causes, Faraday says : —

" When an iron plate similar to the copper one formerly described (523.), was passed between the magnetic poles, it gave a current of electricity like the copper plate, but decidedly of less power ; and in the experiments upon the induction of electric currents (512.), no difference in the kind of action between iron and other metals could be perceived. The power, therefore, of an iron plate to drag a magnet after it, or to intercept magnetic action, should be carefully distinguished from the similar power of such metals as silver, copper, &c. &c., inasmuch as in the iron, far the greater part of the effort is due to what may be called ordinary magnetic action." *

Magneto-electric Machines.

(527.) The first MAGNETO-ELECTRIC MACHINE was constructed by Mr. FARADAY, as shown in *fig.* 289 : —

Fig. 289.

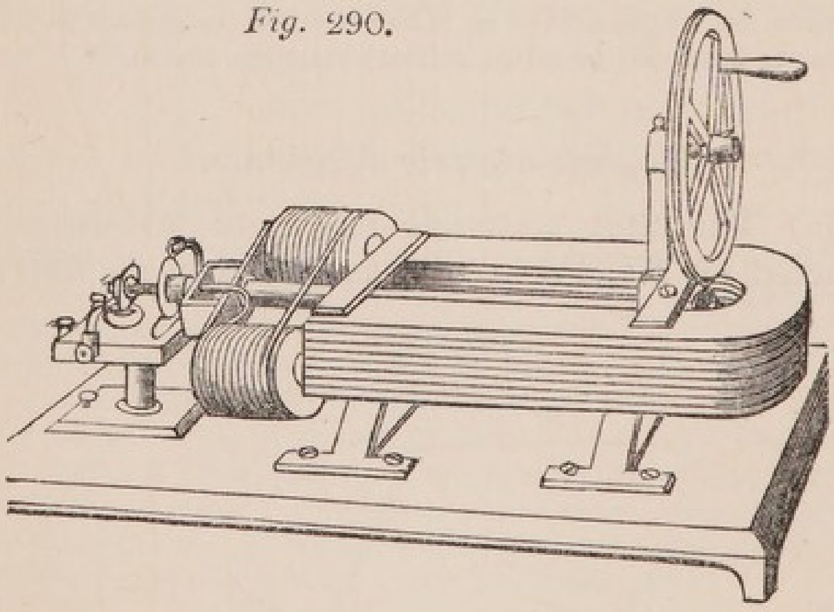


"*C* is a copper plate, so mounted as to admit of revolving upon its axis ; *n s* are the poles of a powerful horse-shoe magnet, so placed as to admit of the revolution of the plate between them ; *w w'* are conducting wires, one of which is retained in perfect metallic contact with the axis, and the other with the circumference of the plate, at the point between the poles *n s*. These wires terminate in the galvanometer *g*. When the copper plate is made to revolve from right to left, a current of electricity is produced in the direction of the arrows, and deflects the galvanometer accordingly." †

* Researches, § 138. † Brande's Manual of Chemistry, p. 343.

(528.) In 1832, M. Pixii of Paris produced a machine in which he used a coil of copper wire instead of a disc; and he rotated the magnet instead of the conductor. He obtained the spark, the shock, a Leyden charge, deflection of gold leaves, and chemical decomposition.—In the following year, Mr. Saxton submitted to the British Association his machine in which the magnets were fixed and the coil rotated. The appearance of this machine is shown in *fig.* 290. The chief

Fig. 290.



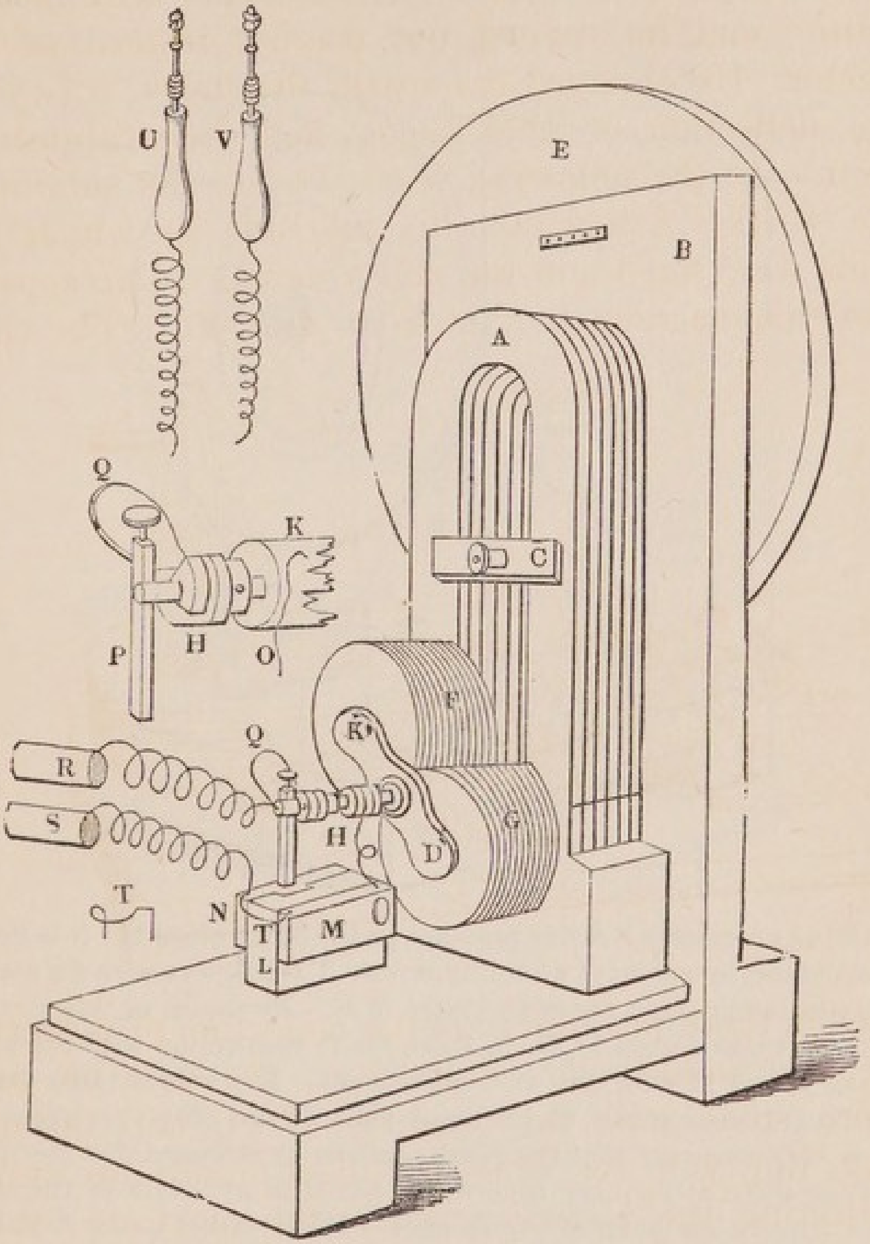
features in these machines are the collection of powerful magnets to induce the electricity; the pair of coils of short, stout wire for quantity effect, and the pair of long, thin wire for intensity effect; and the means for collecting the electricity under the most favourable circumstances. These will be described at length (529.). The coils may either rotate in *front* of the ends of the magnet or by their *side*.

(529.) The latter arrangement is adopted by Mr. Clarke, and is thus described by M. Becquérel *: —

A (*fig.* 291.) represents a series of six magnetized bars of steel, bent into a horse-shoe form, arranged vertically, and supported by four screws fixed to the board B, two of which are seen at M N (*fig.* 292.). A thick bar of brass C is pieced in its centre by an opening, into which passes a bolt with a nut, for the purpose of securing the magnet against the board B. By this arrangement, the magnet may easily be removed without disturbing the rest

* Traité sur l'Electricité, t. vi. p. 95.

Fig. 291.

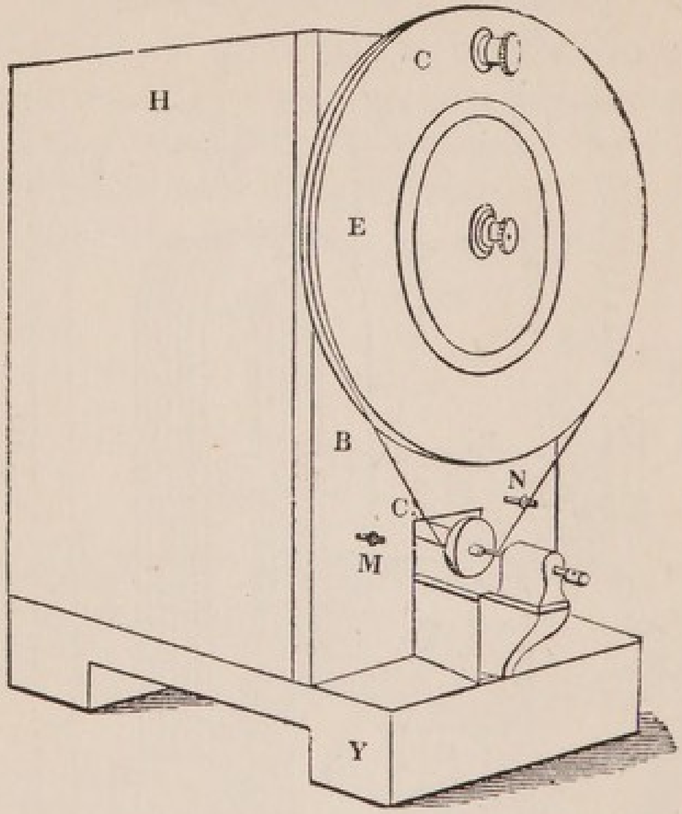


of the apparatus. D represents the armature of a double cylinder of soft iron G F, which is fixed to a brass screw placed between the poles of the battery A. This piece is set in motion in the manner indicated in *fig.* 292., by means of the wheel E, of an axis of rotation, and an endless cord. On each cylinder is rolled a helix of fine copper wire, coated with silk, and about 800 yards in length. One of the ends of each helix is soldered to the armature; perpendicular to the surface of which, at D, is a brass rod supporting two break-pieces, H. K represents a hollow brass cylinder, to which is soldered one of the free ends of the helices, and which is separated from the rod by means of a piece of hard wood resting on it; the other end of the helices is in communication with the rod. O is an iron-wire spring * to exercise a pressure against the hollow cylinder K, with which it is in

* In *fig.* 290. a revolving wheel is introduced, instead of a spring.

metallic contact, by means of a screw fixed in the brass plate M. P represents a square vertical brass rod fitted into the brass plate N. Q is a

Fig. 292.



metal spring exercising a feeble pressure on the break piece H: it is held in metallic contact by means of a binding-screw. T is a copper wire for making communication between the brass plates M N. By means of this arrangement, these various parts D, H, Q, P, N, are in connection with one of the ends, and K and M with the two other ends. It is very evident that, as the spring Q presses gently on the break piece H, the effects are regular... ... It is very necessary that the break piece be so arranged that the spring Q shall separate, at the very time when the iron cylinders of the armature are leaving the poles of the magnet. With respect to the iron wire, O, it always exercises a gentle pressure against the hollow brass cylinder K. By means of these arrangements a mercury bath *, which is always inconvenient, is superseded. When the shock is to be given by this machine, the two copper conductors R S (*fig.* 291.) are taken into the hands, which are moistened with salt-water, one of the conductors being in communication with the plate M, and the other with the plate N, in the manner shown in the figure; M and N are then united by the piece T. The shock received by this apparatus as soon as the wheel is turned is very violent. If we desire a current always in the same direction, one break-piece only is placed on. In this case, the circuit is interrupted when the current changes, that is, when each helix quits one branch of the magnet .... On

* Saxton broke the circuit by points immerging in, and emerging from, mercury: *fig.* 290. is copied from a machine of Mr. Knight's construction.

placing the two connecting wires R S, between M N, the shock is not so powerful.—U and V (*fig.* 291.) are handles connected with the conducting wires, and furnished with pieces of sponge, which are employed in the application of electricity for medical purposes. These sponges are moistened with acid or saline solutions. By means of them a succession of the most powerful shocks may be applied where they are needed. . . . To decompose water, Mr. Clarke uses the apparatus (*fig.* 293.) arranged in the following manner:—A is an earthen vessel with a brass lid, having

Fig. 293.

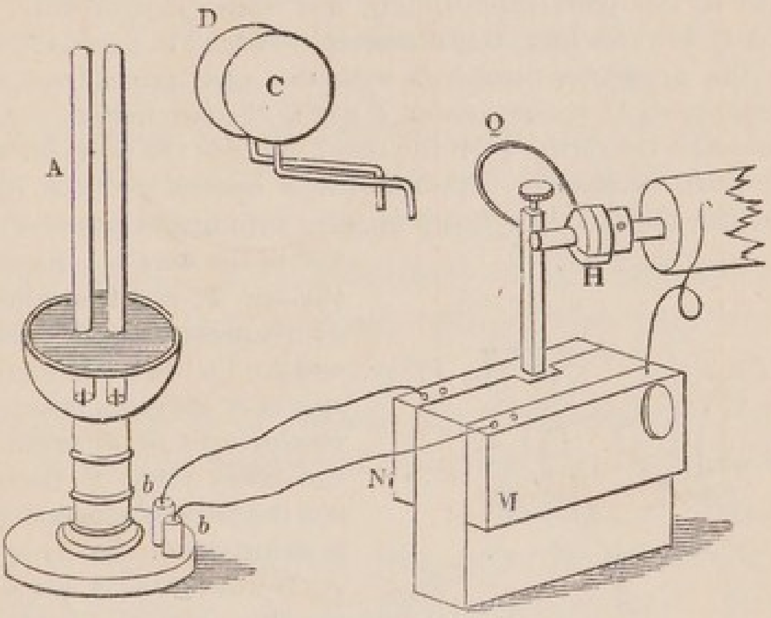
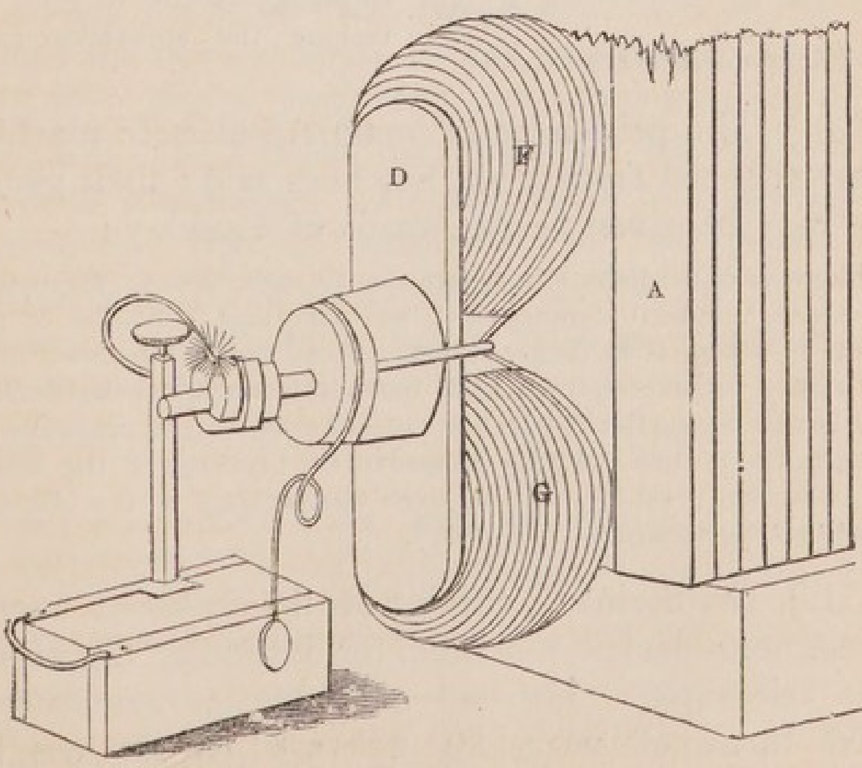
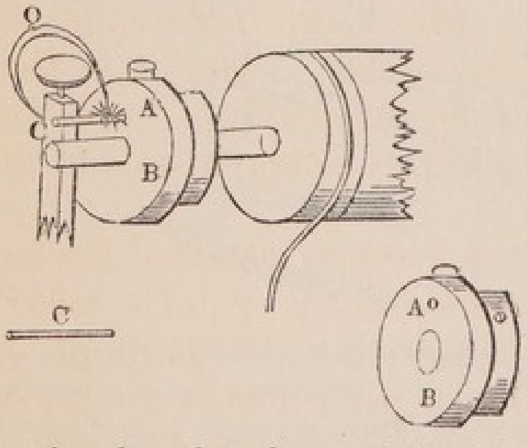


Fig. 294.



a base of hard wood, through which pass two copper wires soldered to platinum wires, and which are connected with M N. Two tubes, A, are filled with water, and then placed over the platinum wires, where they are supported by a cork. The two plates of platinum C and D, which are connected by copper wires with M and N, are for showing the effects of electro-chemical decompositions. For this purpose, a piece of litmus or turmeric paper previously moistened with a neutral salt, is placed between the discs. In place of the two preceding helices and their accessaries, which he calls the *intensity armature*, because the current obtained is from electricity of high tension, Mr. Clarke employs a quantity armature formed of less powerful cylinders, and with a copper wire, covered with silk, only 45 yards long, the diameter of which is greater. *Fig.* 294. represents the apparatus furnished with this new armature. A is the horse-shoe magnet, D the armature, F and G the two helices. Attention must be paid that the spring quits the break-piece at the moment when the piece is vertical, for then it is that it is in a neutral position relative to the poles of the magnet. To fuse iron wire with bright scintillations, one end of the wire is connected with the end P, and the other end is gently pressed on the rotating armature D. If we wish to obtain sparks of different colours by the employment of different metals, the break-piece is taken away, and the piece of copper B (*fig.* 295.) is substituted. In its open part, A, is introduced a piece of any metallic wire C, gold, for example; the extremity of the spring Q, is also of gold. On making the apparatus rotate, purple-coloured sparks are obtained."

Fig. 295.



(530.) The principles of magneto-electric machines will be gathered from what has been said: their general action may be given in the words of Faraday:—

"In the wire of the helix of magneto-electric machines, as, for instance, Mr. Saxton's beautiful arrangement, an important influence of these principles of action is evidently shown. From the construction of the apparatus, the current is permitted to move in a complete metallic circuit of great length during the first instants of its formation; it gradually rises in strength, and is then suddenly stopped by the breaking of the metallic circuit; and thus great intensity is given *by induction* to the electricity which at that moment passes" (§ 1118.).

(531.) Dr. Steinheil employed the induced current of a magneto-electric machine, for deflecting the needles of his telegraph. He had an intensity armature of 15,000 turns of wire, 39 inches of which weighed

$15\frac{1}{2}$ grs.* Professor Wheatstone now employs the magnetic machine as the source of electricity for his present telegraphs, in which signal discs are acted on by electro-magnets.† Half a rotation of the armature is equivalent to one signal.

Some experiments by Professor Morse have just been published, relative to the conducting power of wires. He employed 100 cells of Grove's, and from 1 to 160 miles of wire: he shows that very great increase may be made in the length of long circuits, without any proportionate increase in the resistance of the wire. Professor Draper converted the results of the experiments into a mathematical form; and he says, "When a certain limit is reached, the diminution of the intensity of the forces becomes *very small*, whilst the increase in the lengths of the wire is vastly great." This is, in fact, but another form of words for expressing Ohm's law. Mr. Wheatstone has made accurate measurements of the resistances of wires.

(532.) Mr. Woolrich has recently patented the art of electro-plating, by magneto-electricity. He uses a quantity armature, each coil having 50 yards of $\frac{1}{10}$ in. coated copper wire. He is particular in the break, so that the current shall always pass in one direction. ‡

(533.) For a further insight into magneto-electric induction, the reader may consult Faraday's Second Series of Researches. He will there find, among other illustrations, that the magnetism of the earth, equally with magnetism from any other source, avails to induce currents. A coil, for instance, with an iron core, when moved into the position of the dipping needle, developes electricity; so does a coil, in such a position, when a

* Ann. Elect. vol. iii. p. 513. Elec. Mag. vol. i. p. 64.

† *Supplementary note.* Telegraphic experimentalists, not included in the text, are found, who conveyed signals into a neighbouring room, by the action of frictional electricity or pith balls. Bétancourt is said by Gauss, to have telegraphed by the discharge of a Leyden jar, from Madrid to Aranjuez, 26 miles. Ronalds had signal discs moved by clock-work, and he illuminated the proper sign by a spark. Sömmering used a voltaic pile, and 35 gold pins in water. The bubbles of gas from either pin indicated the signal.

‡ Vide Mech. Mag. vol. xxxviii. p. 145. Feb. 25. 1843.

bar of soft iron is thrust into it. Rotating plates obeyed the law already given (523.).

(534.) MM. Palmieri and Linari have lately succeeded in constructing a machine, which, from the source of its magnetism, is termed a "Magnet-electro-telluric" battery. By rapid rotation given to a properly constructed armature, they obtain, by means of the earth's magnetism, the effects, on a smaller scale, of Saxton's machine.*

* Vide Compte Rendu, June 26, 1843. E.ec. Mag. No. 2.

BOOK THE SEVENTH.

THERMO-ELECTRICITY.

(535.) HEAT, as we mentioned in the INTRODUCTION (234.), is another means of disturbing the electric equilibrium of bodies; and it appears "that, during the movement of heat in a bar of metal, there occurs a succession of decompositions and recompositions of the electric fluid, which are analogous to the mode of propagating heat in bodies." If one end of a platinum wire is connected with the earth, and the other end with a delicate electroscope, heat, applied to convolutions in the course of the wire, will cause indications of positive electricity. Other metals act similarly, the oxidizable differing in that the current goes from the *cold* to the *warm* part. Mr. Seebeck first discovered this class of phenomena in a bar of antimony, heated differently in parts, having its extremities connected by a loop of brass wire twisted on. Mr. Sturgeon was of opinion that the effects were due to the crystalline state of the molecules of the metals—the obstacles, as M. Becquérel expresses it, "which can be more easily overcome by one electricity than the other." Professor Moll repeated and varied the original experiments: he found that other metals than antimony were efficacious. Professor Cumming found that the coils, where the conducting wire was twisted, were not concerned in the effects; he therefore rivetted, soldered, or cast the point of union, as convenient. His opinion of the phenomena was, "that, for the production of this species of electricity, there is required the juxtaposition of two particles of the same metal at different temperatures."

(536.) But the least part of thermo-electricity is that

referring to the use of one metal: when two metals, soldered together, are heated at the point of junction, greatly increased effects occur. The most powerful pair is antimony and bismuth. The intensity of many thermo-electric currents increases in *proportion* to the temperature up to 40° R.; but not after; and at a certain point it falls. It appears, too, from the experiments of M. Becquérel, that each metal has for itself a proper thermo-electric *power*, which is the same for any circuit. He thus expresses it:—

Metals.	Thermo-electric Power.
P. Iron -	- 5
P. Silver -	- 4·07
P. Gold -	- 4·052
P. Zinc -	- 4·035
P. Copper -	- 4
P. Tin -	- 3·89
P. Platinum -	- 3·68

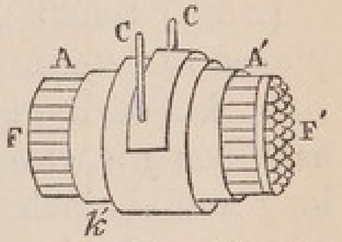
M. Nobili obtained thermo-currents by the contact of a hot and a cold cylinder of porcelain, on each of which was moist cotton. M. Becquérel considers that the water, at two temperatures, is here the exciting cause. The rank of the chief metals, in the thermometric series, beginning with the positive, is, according to Cumming,—Bismuth, Mercury, Platinum, Tin, Lead, Gold, Copper, Silver, Zinc, Iron, Antimony, When heat is applied to the junction of any pair of these, the current passes from that higher in the list to that lower. Thermo-electric batteries have been made by a combination of pairs in series. Baron Fourier made a hexagon of three pairs of bismuth and antimony,—by heating with a lamp or cooling with ice *three* junctions, he obtained increased effects; by heating and cooling the alternate junctions at the same time, he increased the effect. From experiments by Oersted, "it appears that the thermo-electric current produces a prodigious quantity of electricity, but in a state of very feeble intensity, while the voltaic current has a very great

intensity* ;" so that *short* elements are most advantageous. M. Pouillet found that, if the electro-motive power of a constant voltaic pair were 95, that of a thermo-pair of bismuth and antimony would be 1. Mr. Wheatstone, by his admirable application of Ohm's law, found the proportion 1 : 94·6.

(537.) The first proper thermo-electric battery is that devised by MM. Nobili and Melloni, thus described by Becquérel—

"The battery employed by M. Melloni is composed of fifty little bars of bismuth and antimony, placed parallel one beside the other, and forming one prismatic bundle (*fig.* 296. F F′) the length of which is thirty millimètres (1⅛ in.), and the section 96 sq. cent. The two terminal faces are blackened. The bars of bismuth, which alternate with those of antimony, are soldered to their extremities, and separated along their length by an isolating substance . . . . . The first and last bar have a copper wire which is attached to one of the pegs, C C′, of the same metal, passing through a piece of ivory, fixed on the ring A A′. . . .The free extremities of the two wires are in communication with the ends of a wire of a galvanometer, the movements of the needle of which indicate when the temperature of the anterior face of the pile is raised or lowered in respect to the posterior."†

Fig. 296.



This battery was employed for experiments on radient heat, and was so delicate that the warmth of a person thirty feet distant effected it.

(538.) The battery, by which Professor Botto succeeded in decomposing water, was a chain of 240 links, alternately platinum wire and soft wire, each link being 1 inch long and $\frac{1}{100}$ inch diameter ; the chain was wrapped as a spiral round a wooden rule. He also had a battery of 140 elements in the form of a parallelopiped, 2½ inches square by 1 inch high.—With a Nobili's pile of twenty-five elements, and a coil of 805 feet, Linari obtained the spark. Mr. Watkins employs a ribbon coil, on account of the quantity of electricity generated. A thermo-electric battery of fifty-six pairs of bismuth and antimony set in plaster, and contained in a box, would give evidence of electricity by the heat of the breath ; a difference of 19° would produce a spark with

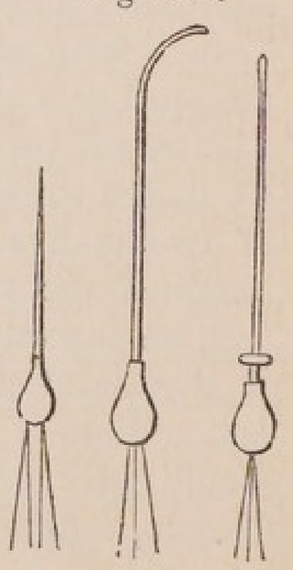
* Encyc. Brit. vol. xxi. p. 697. † Traité, vol. iii. p. 425.

the coil. It was used by being placed in ice, and hot water or oil poured in the top, M. Peltier, who has experimented very much, recommends that the soldering essential to insure perfect contact, should not be greater than is necessary to secure perfect conduction ; and says, that "a *long* soldered junction gives a more feeble current than a *short* one."*

Thermo-electricity has nothing to boast of in the way of brilliant effects ; but it promises, from its extreme delicacy, to become a most important means for estimating temperatures ; some arrangements will indicate a difference of $\frac{1}{100}°$ centigrade.

(539.) Small thermo-electric pairs have been employed to determine the temperature of the organic tissues, &c. of living subjects. Two pairs are prepared, each being a wire of steel and one of copper, 4 inches long and $\frac{1}{50}$ inch diameter, soldered end to end ; one of these pairs is thrust through the arm (for instance) so that the soldered part shall be within a muscle, whose temperature is desired ; the other pair is placed in a constant source of heat †, and is connected with the former : a galvanometer is included in the circuit ; and its deflexions, the thermometric value of which has been previously determined, are taken. It is not always convenient to thrust the pair through ; whence it is better formed, as in *fig.* 297., where the wires are side by side, and soldered at the end for about $\frac{1}{12}$ inch, which is then brought to a point ; between them, to prevent contact, is an isolating material, as, for instance, the membrane which covers the back of a pen ; they are mounted on ivory handles. — By somewhat similar means the temperature of vegetables and flowers has been determined. The constant source of heat in this case is a dead part of the plant operated on.—The temperature of lakes

Fig. 297.



* Ann. de Chim, t. 71.

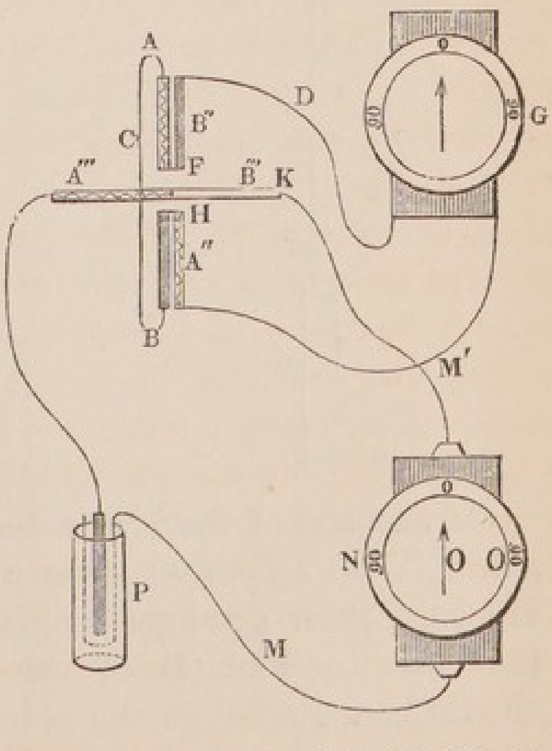
† M. Sorel employed a heated bath ; M. Becquérel employed the human mouth.

and seas, at different depths, is determined by a pair of copper and iron, with wires insulated from the action of the water, by silk and varnish. The heat of friction is measured by applying the bodies to a thermo-electric battery, or, which appears better, by having the junction of one of the above pairs within the body during friction.—The temperatures of the various parts of a flame have been estimated by thermo-pairs of platinum and paladium; and that of furnaces by platinum wires of different characters twisted together.

(540.) M. Peltier has constructed an *hygrometer* on thermo-electric principles. A tripod is made of six bars, three of bismuth and three of antimony, soldered into a series, whose extremities are connected with a galvanometer. It is under a glass shade, and on it is placed a platina vessel, containing the subject of experiment. It is used also to determine certain effects attendant on solution.

(541.) A sketch of thermo-electricity cannot be better terminated than by an account of the means by which Peltier detected the production of cold during the passage of feeble currents at the junction of certain metals. In *fig.* 298. the galvanometer, N O, is to indicate the strength of the current which produces the cold; and the galvanometer G is the indicator of the cold produced: the cold is produced at the junction of the two metals, A‴, B‴; and the thermometric pairs, A B″, and B A″, are pressed close upon the point of junction; so that any change of temperature shall produce on them thermo-electric effects. The voltaic circuit is P, M, O, M′, K,

Fig. 298.



B‴, A‴; the thermo-circuit is excited at the junctions F and H. The metals which crystallize readily are those which produce the most notable reductions of temperature.

In refutation of the suspicion that the effect might be produced in virtue of the action of the initial current upon the thermo-pairs, A B″ and B A″, M. Peltier produced the same evidence of cold by means of an air-thermometer. His arrangement is given in *fig.* 299., where C E is a glass tube, containing coloured liquid, immersed in a vessel D, filled with the same; A a globe of air containing the bar of bismuth P, and antimony G, soldered at S. When a feeble electric current is passed by the wires P and G, the cold at S is indicated by the rise of the liquid, consequent on the contraction of the air.

Fig. 299.

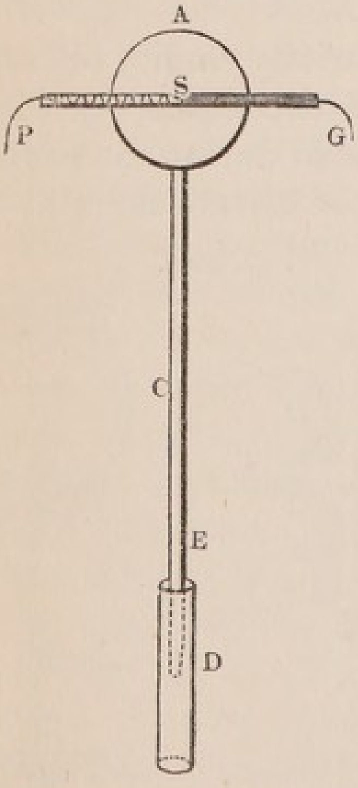
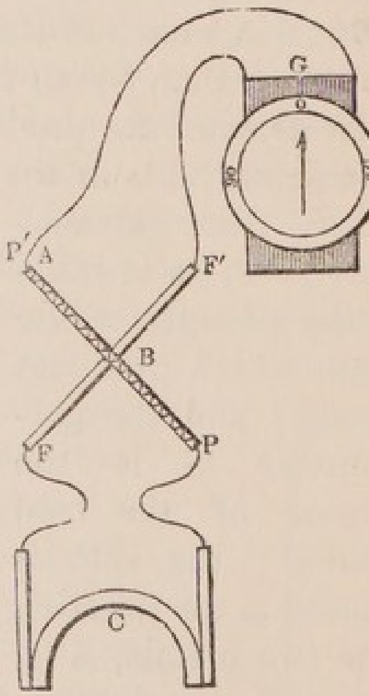


Fig. 300.



On account of the loss of heat where the experimental pair A‴ B‴ (*fig.* 298.) has to be in contact with F and H, M. Peltier arranges his apparatus as in *fig.* 300., so that the junction B of the thermometric pair P′ F′ should be included in the point of contact of the experi-

mental pair, P F. The circuit is first completed between P F and the voltaic pair C, which produces a change of temperature at B; by a mechanical arrangement, the circuit at F is broken, so that the voltaic pair ceases to act, and the circuit at P′ is made, by which the effect at B is indicated by the needle G.

Another mode of performing this experiment is to place the junction of a thermo-electric pair of bismuth and antimony on thawing ice; and in a small cavity at the juncture to place a little ice-cold water; on passing a feeble electric current, the water will be frozen.

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Printed by A. Spottiswoode,
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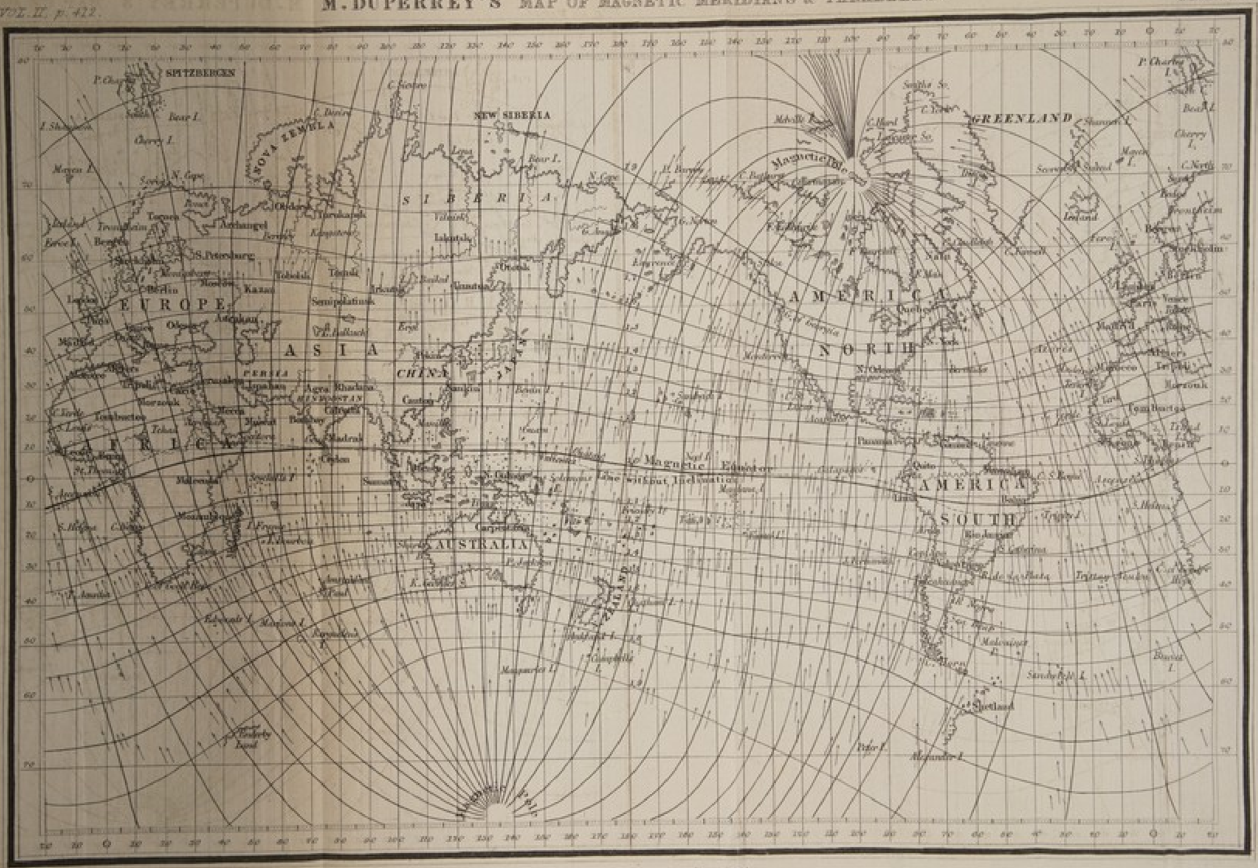
M. DUPERREY'S MAP OF MAGNETIC MERIDIANS & PARALLELS.



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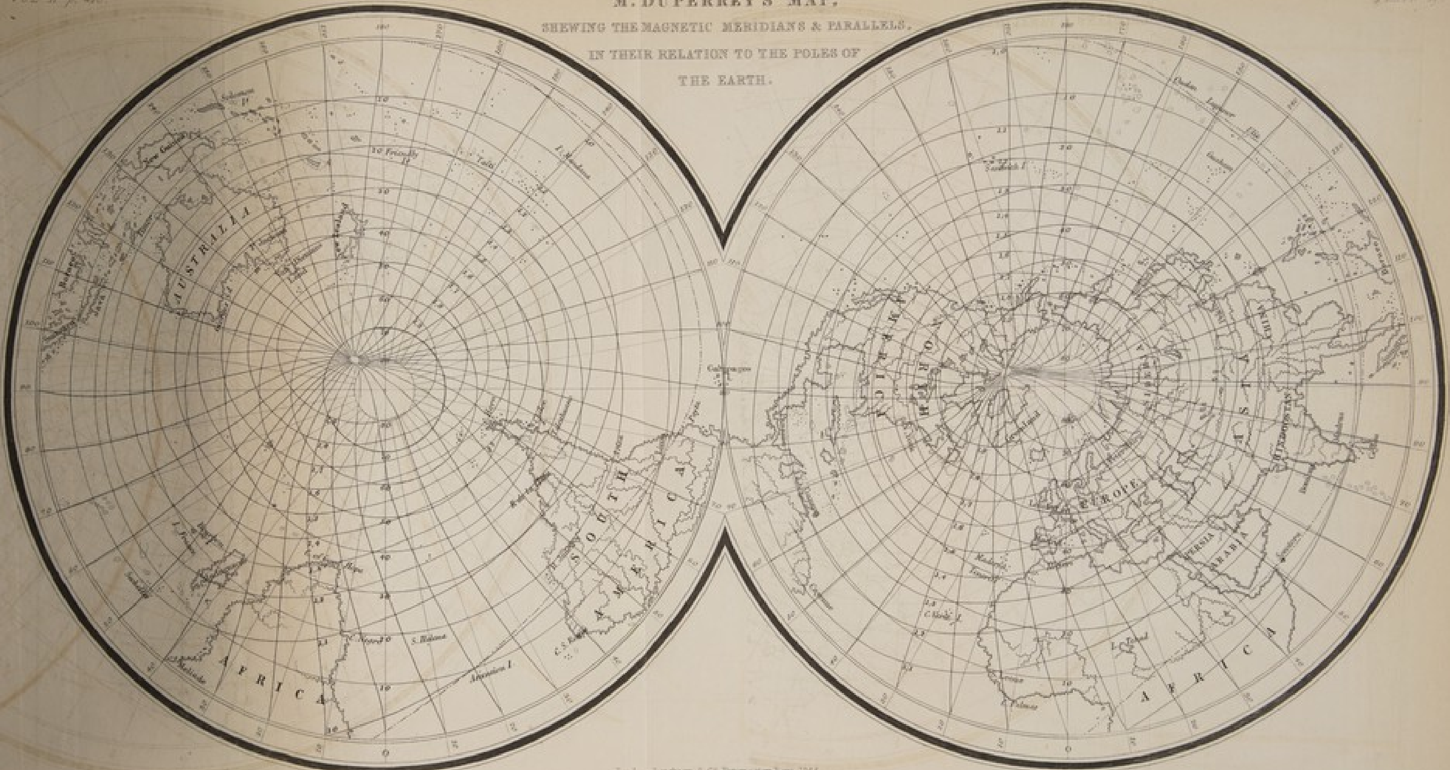
M. DUPERREY'S MAP,
SHEWING THE MAGNETIC MERIDIANS & PARALLELS, IN THEIR RELATION TO THE POLES OF THE EARTH.



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M. DUPERREY'S
MAP OF THE HEMISPHERE OF THE EARTH, WHICH CONTAINS BOTH MAGNETIC POLES.

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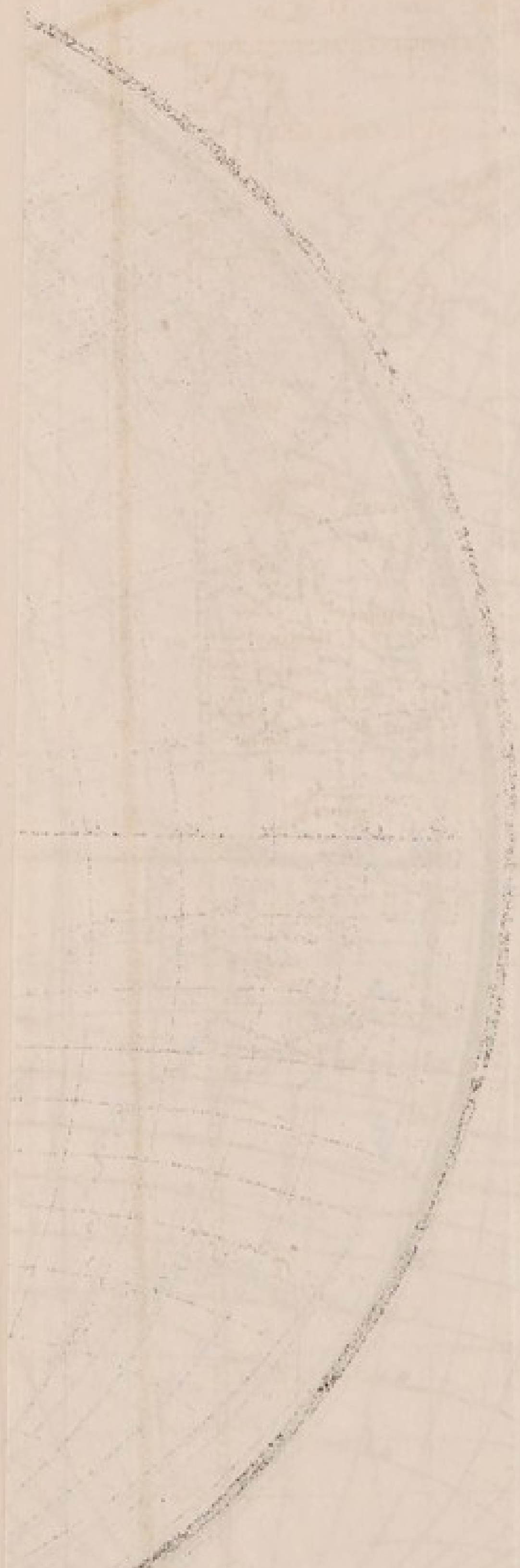
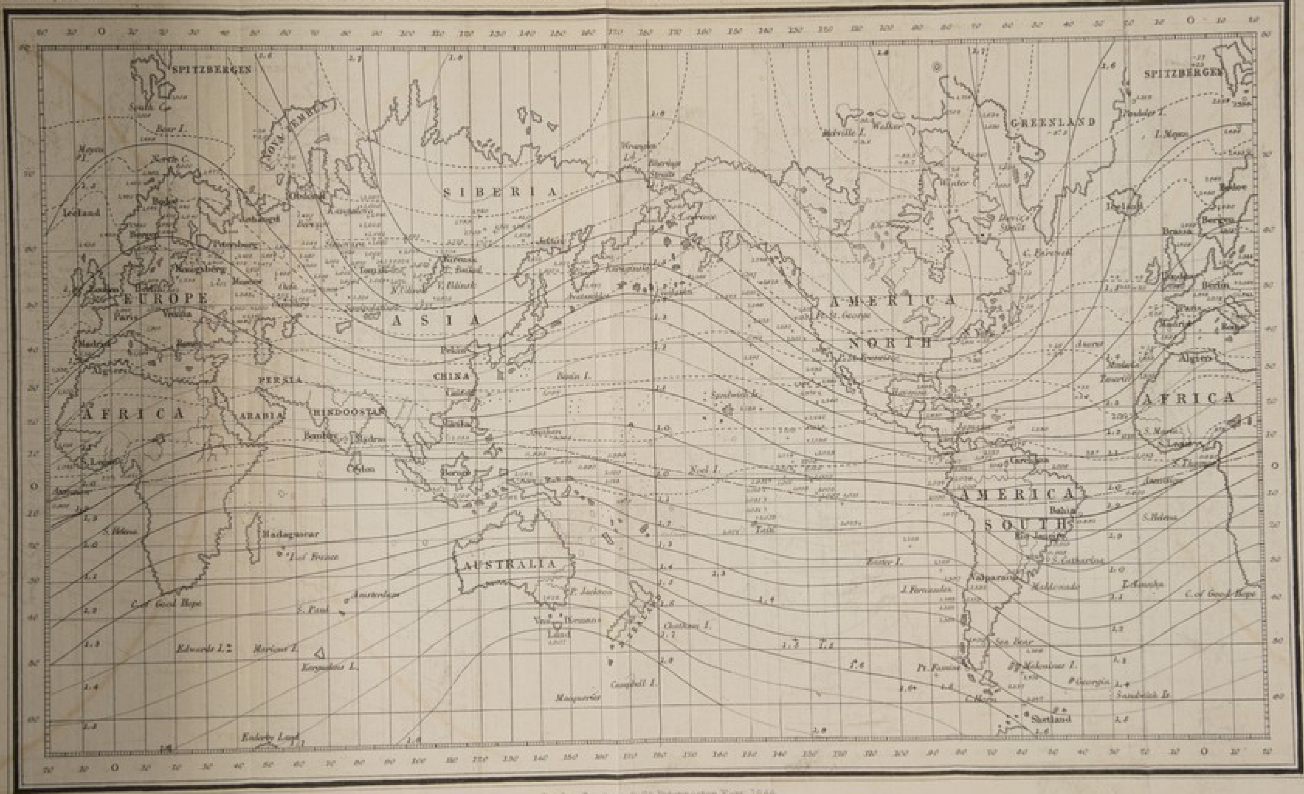


M. DUPERREY'S MAP OF ISODYNAMIC CURVES, WITH M. BERGHAUS' ISOTHERMAL CURVES.



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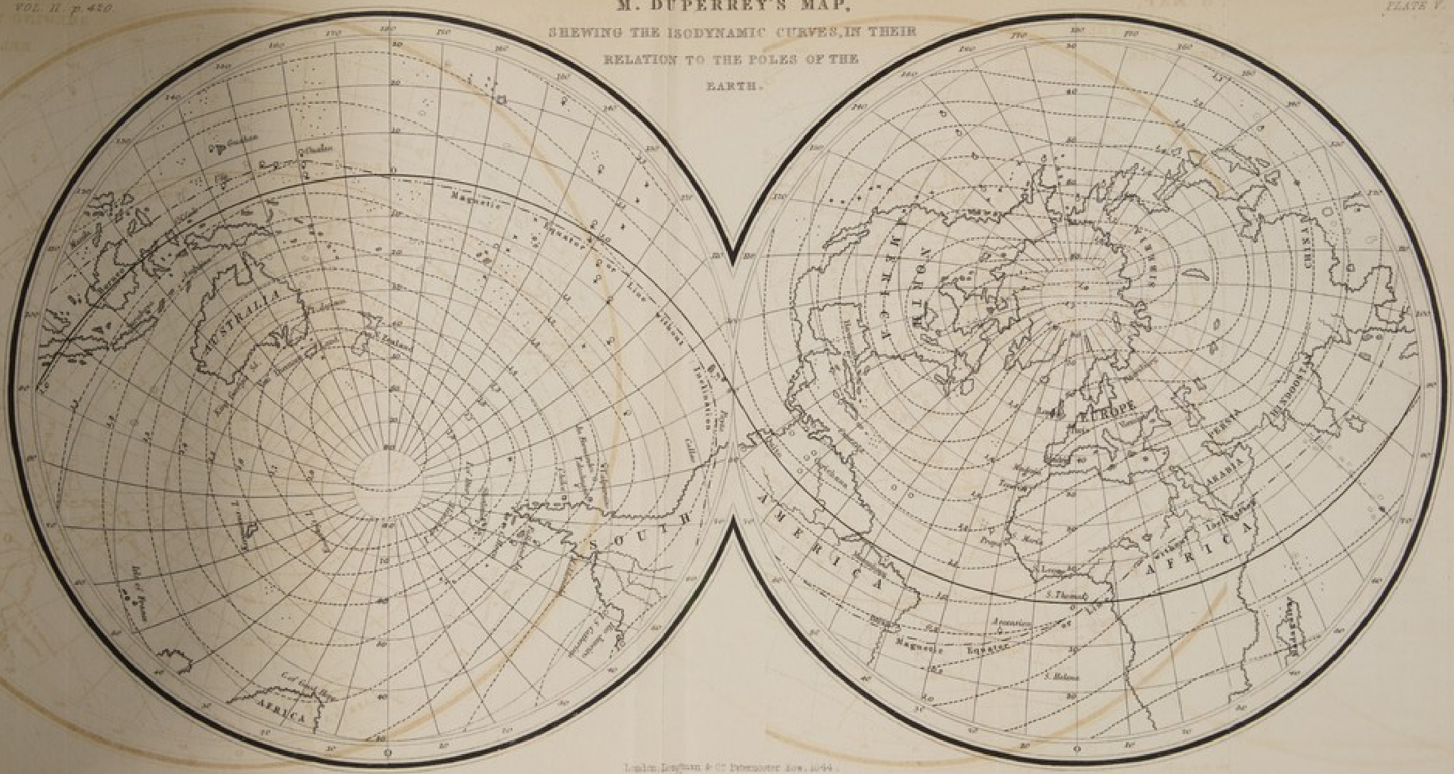
M. DUPERREY'S MAP, SHEWING THE ISODYNAMIC CURVES, IN THEIR RELATION TO THE POLES OF THE EARTH.



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