college consisted of the three ecclesiastical electors, Mentz, Treves, and Cologne, and the six secular, Bohemia, the palatinate of the Rhine, Saxony, Brandenburg, Bavaria, and Hanover. The dominions of the last elector palatine of the Rhine, having devolved in December 1777 to the elector of Bavaria, the electoral college was again reduced to eight members, until the peace of Luneville; when the three ecclesiastical electorates were secularised, the archbishop of Ratisbon introduced as a new elector arch-chancellor, and the duke of Wirtemberg, the landgrave of Hesse Cassel, the margrave of Baden, and the grand duke of Tuscany, as duke of Saltzburg, raised to the electoral dignity. This increased the number of electors to ten, viz. the elector arch-chancellor, Bohemia, Bavaria, Saxony, Brandenburg, Hanover, Wirtemberg, Hesse Cassel, Baden, and Saltzburg.

This arrangement was finally destroyed, as we have seen (article Diet), in the year 1806, when the German empire was dissolved. Bavaria and Wirtemberg, on joining the Confederation of the Rhine, under the protection of the French empire, assumed the royal dignity; Hanover was in possession of the French; Baden and Saltzburg took the titles of grand dukes; the elector arch-chancellor that of the prince primate of the Confederacy of the Rhine: and the year following Saxony assumed the royal dignity; Hesse Cassel was annexed to the new kingdom of Westphalia; Bohemia as part of the dominions of Austria, and Brandenburg as part of those of Prussia, reverted to these two houses as independent monarchical states. And thus the title of elector, which for so long a series of years conferred a rank equal to that of the old kings of Europe, became finally extinct.

The last electors of the German empire were, 1. Charles Theodore, baron Dahlberg, elector of Ratisbon, and arch chancellor, now prince primate. 2. Frederick William III., king of Prussia, elector of Brandenburg. 3. George III., king of Great Britain, elector of Hanover. 4. Ferdinand Joseph, elector of Saltzburg, now duke of Saltzburg. 5. Frederick II., elector, now king of Wirtemberg. 6. Charles Frederick, elector, now grand duke of Baden. 7. William IX., elector of Hesse Cassel, driven from his dominions by the French. 8. Maximilian Joseph, elector, at present king of Bavaria. 9. Frederick Augustus IV., elector, at present king of Saxony; and, 10. Francis II., elector of Bohemia, afterwards emperor of Austria.

The electors besides the power of electing an emperor, had a right to capitulate with the new head of the empire, to dictate the conditions on which he was to reign and to depose him if he broke those conditions. They actually deposed Adolphus of Nassau, in 1298, and Wenceslaus in 1401. They were sovereign and independent princes in their respective dominions, had the 'privilegium de non appellando illimitatum,' that of making war, coining, and exercising every act of sovereignty. They formed a separate college in the diet of the empire, and had among themselves a particular covenant, or league, called the 'Kur verein.' They had precedence of all the other princes of the empire, even of cardinals, and ranked with kings. There was, however, a difference between the secular and ecclesiastical electors; none of the latter could be chosen emperor, and they were to be thirty years of age before they could attain the electoral dignity, whilst the majority of the secular electors was fixed at eighteen years of age, and any of them might be placed at the head of the empire; indeed they might even vote in their own favor. The functions of the electors were exercised by deputies. The elector of Mentz was arch-chancellor in Germany; Treves, in Gaul and the kingdom of Arles; Cologne, in Italy; Bohemia was arch-cupbearer; Bavaria, arch-sewer, or officer who serves out the feasts; Saxony, arch-marshal; Brandenburg, arch-chamberlain; Hanover, arch-treasurer. During the vacancy of the imperial throne, the elector of Saxony used to be vicar of the empire in the north, and the elector of Bavaria of the southern circles. On the demise of an emperor of Germany, or a vacancy ensuing in the imperial throne, the electors were summoned by the archbishop of Mentz to meet (generally at Frankfort) within three months. One month was ordinarily allowed for their determination; if it was delayed longer they were, according to the imperial constitution, to be fed on bread and water until they had made a choice. Both their dress and functions are particularly described by Du Cange.

ELECTRICITY.

ELECTRE, *n. s.*
Ele'ctric, *adj.*
Ele'ctrical,
Electri'cian, *n. s.*
Electri'city,
Ele'ctrify, *v. a.*
Ele'ctrise, *v. a.*
Electro'meter, *n. s.*

Gr. ηλεκτρον; Latin, *electrum*, amber, which, having the quality when warmed by friction of attracting bodies, gave to one species of attraction the name of electricity, and to the bodies that so attract the epithet electric; which also means produced by an electric body; and metaphorically, rapid; powerful. Bacon uses electre for a metallic compound. An electrician is he who is skilled in electricity. To electrify, *electrum* and *fio*, to render electric, or apply electricity, and to electrise, are used synonymously. Electrometer, an instrument for ascertaining the presence and portion of electricity in any given body.

Change silver plate or vessel into the compound stuff, being a kind of silver *electre*, and turn the rest into coin. *Bacon.*

If that attraction were not rather *electrical* than magnetical, it was wondrous what Helmont delivereth concerning a glass, wherein the magistery of loadstone was prepared, which retained an attractive quality. *Browne.*

By *electrick* bodies do I conceive not such only as take up light bodies, in which number the ancients only placed jet and amber; but such as, conveniently placed, attract all bodies palpable. *Id.*

An *electrick* body can by friction emit an exhalation so subtile, and yet so potent, as by its emission to cause no sensible diminution of the weight of the elec-

trick body, and to be expanded through a sphere, whose diameter is above two feet, and yet to be able to carry up lead, copper, or leaf gold, at the distance of above a foot from the *electrick* body. *Newton.*

When I would observe the *electricity* of the atmosphere with this instrument, I thrust the pin I into the cork D, and holding the rod by its lower end A, project it out of a window on the upper part of a house, into the air; raising the end of the rod with the *electrometer*, so as to make an angle of about fifty or sixty degrees with the horizon. *Cavallo.*

Then mark how two *electric* streams conspire
To form the resinous and vitreous fire. *Darwin.*

If a metallic point be fixed on the prime conductor, and the flame of a candle be presented to it, on *electrising* the conductor either with vitreous or resinous ether, the flame of the candle is blown from the point, which must be owing to the *electric* fluid in its passage from the point carrying along with it a stream of atmospheric air. *Id.*

But now a bride and mother—and now there!
How many ties did that stern moment tear!
From thy Sire's to his humblest subject's breast
Is linked the *electrick* chain of that despair,
Whose shock was as an earthquake's, and opprest
Thy land which loved thee so that none could love
thee best. *Byron.*

And the wild sparkle of his eye seemed caught
From high, and lightened with *electric* thought.
Id.

1. The particular branch of science denominated electricity appears to have derived its name from that of the first substance in which any of its properties were discovered. This was amber, the Greek name of which is ηλεκτρον, evidently derived from Ἠλεκτωρ, a name by which Homer designates the Sun. It has been said by some that the ancients, observing amber to possess the property of attracting light substances when rubbed, termed it electrum, and that hence arose the word electricity. Those who entertain this opinion, would derive the name from the Greek verb ελκω to draw; but this appears to us to be a very forced derivation, since amber was doubtless called by the name of electron, long before it was known to possess the magnetic property of attraction. Perhaps it was so called from its bright and shining appearance. But, whatever may be the etymology of the term, it is now employed to designate that science which investigates the attractions and repulsions, the emissions of light, and explosions, which are produced, not only by the friction of vitreous, resinous, and metallic surfaces, but by the heating, cooling, evaporation, and mutual contact of a vast number of substances.

2. It is rather remarkable that, although the attractive energy of electricity has all the appearance of being a very recent discovery, it has been said to be 'the first physical fact recorded in the history of science.' The electrical properties of amber were known and pointed out upwards of 2000 years ago; but the subject did not engage the attention of the learned till the beginning of the seventeenth century. This was perhaps a fortunate circumstance, since it at all events prevented the science from being clouded or perverted by the ignorance of early times.

3. Dr. William Gilbert, of Colchester, appears to have been the first person who essentially contributed to the establishment of electricity as a science. In the year 1600 he published his work entitled De Magnete, which contains a number of experiments made with various substances, possessing the properties of amber, now termed electrics. Of Dr. Gilbert, Cavallo says that he ought to be considered as the father of electricity.

4. No further discoveries were made in this science of any importance till the year 1670, when the celebrated Mr. Boyle much enlarged the list of electrics, and by experiment discovered that their effects were much increased by warming and wiping them before the application of friction, and that during the friction they emitted faint flashes of light; this appearance he considered as an additional characteristic of the electrical power.

5. Otto Guericke of Magdeburg, the inventor of the air-pump, and a contemporary with Mr. Boyle, confirmed the experiments of the latter, and much enlarged the state of electrical knowledge. He constructed an apparatus in which the electric, a globe of sulphur, was made to revolve on an axis; the hand was applied to it as a rubber; and by this contrivance, which was in principle the same as the most modern construction of the electrical machine, he was enabled to obtain an accumulation of electricity far beyond any thing that had been effected by his predecessors. This philosopher discovered also the principle of electrical repulsion.

6. In the year 1709 appeared the first treatise on electricity; it was the production of Mr. Hawksbee, who far exceeded his predecessors in the discoveries which he made. He was the first who observed the electric power of rubbed glass; the flashing light of an excited electric had been observed by Boyle; but, as Mr. Hawksbee by his glass globe could collect the electric matter in much greater quantities than had been done before, he had the pleasure of beholding the intensity of its light, and of observing the snapping noise by which its discharges are attended. Some of the experiments made by Mr. Hawksbee were very curious, and deserve more notice than has hitherto been taken of them. Among others the following may be mentioned. He lined more than one-half of a glass globe with sealing-wax, and, having exhausted it of its air, he put it in motion in an appropriate frame. On applying his hand to it, for the purpose of excitation, he was surprised to observe an exact image of his hand on the concave surface of the wax, as distinctly defined as if there had been nothing but transparent glass between his eye and his hand, although the wax was in some places an eighth of an inch in thickness. When pitch was used instead of wax the effect was the same.

7. After this period the science of electricity appears to have been for some time stationary, from the discoveries of Sir Isaac Newton absorbing the attention of the public; but, soon after the death of that distinguished individual, it obtained renewed attention, and some very important discoveries were made in it by Mr.

Stephen Grey, a pensioner of the Charter-house. With the date of this gentleman's experiments commenced the modern triumph of electricity. Directing his attention to the nature of electrical phenomena, he endeavoured to excite them in all known bodies; and, though in many cases he was unsuccessful, he thus added considerably to the catalogue of electrics. Many substances, in which no attractive power was excited by rubbing while in their natural state, became strongly attractive if excited after being moderately warmed, but lost this property as they became cold. This fact, says the late ingenious Mr. Singer, clearly pointed out a relation between the state of bodies and their power of evincing electric appearances; and the nature of this relation was explained by Mr. Grey's subsequent experiments. Every attempt to render metals electric by friction or otherwise proved ineffectual in the hands of Mr. Grey, as well as in those of his predecessors, when it occurred to him that, as electric light appeared to pass between excited bodies and such as were incapable of excitation, the attractive power might be also capable of communication from one to the other.

8. For this purpose Mr. Grey inserted a wire and ball, by means of a piece of cork, in the extremity of a glass tube, and, on rubbing the tube, found its attractive power was communicated to the wire and ball. He proceeded with this experiment until the length of the wires which he used became inconvenient. He then suspended the ball by means of pack-thread, from the tube, and found the electricity was still communicated. The same result was obtained when the ball was suspended by the pack-thread, from a balcony twenty-six feet high: on exciting the tube small light substances were attracted by the ball from the pavement of the court below.

9. In connexion with Mr. Wheeler, Mr. Grey afterwards extended his experiments, and succeeded in transmitting the electric power from his excited tube through nearly 800 feet of pack-thread, without any apparent diminution of its force. In arranging the apparatus for these experiments these gentlemen found that a silken cord was incapable of transmitting the attractive power of the tube; an effect which they at first attributed to its comparative smallness, but they afterwards observed that a wire of much smaller diameter carried off the electrical effect completely, and thus discovered that there are in nature various bodies differently qualified for the transmission of the electric matter, some conveying it most readily, and to a great distance, and others incapable of transmitting it to any perceptible distance. The former class of bodies are now termed conductors of electricity, and the second class non-conductors, or electrics; these terms are said to have been first applied to them by Desaguliers.

10. Soon after Mr. Grey's discovery of the difference between conductors and non-conductors, M. Du Fay discovered the difference between positive and negative, or, as they were for some time, and are still by some called, the vitreous and resinous electricities. This discovery was accidentally made in consequence of his observing, that a piece of leaf-gold, repelled by an excited glass tube, and which he endeavoured to drive about the room with a piece of excited gum copal, instead of being repelled by it, as it was by the glass tube, was eagerly attracted. The same was the case with sealing wax, sulphur, resin, and many other substances. He discovered, also, that it was impossible to excite a tube in which the air was condensed. He also observed, that such substances as were least susceptible of electric excitement by friction were the best conductors of electricity; though all the bodies he tried became electric by communication when placed on a non-conducting support. In this way he electrified himself, being supported by silk lines, and touched by an excited glass tube; and on this occasion the abbé Nollet, who accompanied him in these experiments, drew the first electrical spark from the human body.

11. M. Du Fay, says Mr. Singer, has also the merit of having given the first clear account of that apparent repulsion which obtains in most electric experiments, and which was first observed by Otto Guericke, who had noticed that the fibres of an electrified feather receded from each other, and from the tube or globe by which they had been electrified. Du Fay viewed this as the indication of a general principle in electricity, which may be thus expressed. Electrified bodies attract all those that are not so, but repel them as soon as they are electrified by their contact.

12. The consideration of this general principle led the same assiduous philosopher to a discovery of the first importance, viz. the existence of two distinct attractive powers, produced by the friction of different substances, the one excited by rubbing glass, rock crystal, gems, wool, hair, and many other substances, he called vitreous electricity. The other, resulting from the friction of amber, copal, gum-lac, resins, sealing-wax, &c., he named resinous electricity. The characteristics of these attractive powers are, that they strongly attract each other, and produce a mutual counteraction of effect, whilst they separately act in an apparently similar manner on all unelectrified bodies: but the effect of either of them is destroyed or weakened by the approach of the other. If gold leaf be electrified by rubbed glass it immediately recedes from it, and will not again approach whilst it remains in its electric state. But in this state it is strongly attracted by any excited body of the resinous class, and will fly to sealing-wax or amber more rapidly than to an unelectrified body. Hence it was concluded, by Du Fay, that there are two distinct electricities, each repulsive of its own particles, but having a strong attraction for those of the other. So that all bodies electrified with the vitreous electricity repel those that are similarly electrified, and attract such as are unelectrified or endowed with the resinous electricity. And the converse of this is the case with such as are possessed of the resinous electricity.

12.* The terms resinous and vitreous electricity, continues the same author, were sufficiently appropriate at the time they were proposed; but it has been since found that either kind of elec-

tricity can be obtained at pleasure, both from glass and sealing-wax, by varying the nature of the substance with which they are rubbed. Hence the vitreous electricity of Du Fay is now called positive electricity; and the resinous, negative electricity; terms first proposed by Dr. Franklin.

13. To the labors of Messrs. Grey and Wheeler, and their coadjutors Du Fay and Nollet, all subsequent electricians are highly indebted; their means of research were extended by the improvement of electrical apparatus, necessarily resulting from the discovery of conducting and non-conducting power; whilst the generalisation of electric phenomena by Du Fay, and his discovery of the distinction between positive and negative electricity, was an enlargement of the existing sphere of knowledge in a degree before unparalleled. From this period, indeed, the science assumed a more important aspect, its cultivators increased in number, and the communication of their researches constituted a prominent feature in the transactions of the most celebrated societies and academies of Europe.

14. It was in the year 1745 that the remarkable properties of the Leyden phial were first observed. This discovery was merely accidental; yet it tended, more than any other discovery hitherto made, to promote the progress of electricity. The circumstances that led to this discovery were the following:—Professor Muschenbroeck observed, that when conducting bodies were placed on glass, &c., and electrified, their electricity was very soon carried off by the conducting particles floating in the atmosphere; he therefore imagined, if a conducting substance were put into a glass phial, that it could be charged much higher than in open air, as the glass would protect it from the dissipating action of the atmosphere.

15. This idea he attempted to put in practice by filling a small phial with water, which is a conducting substance. For this purpose he passed the end of a wire through the cork of the phial, so as to touch the water, and then charged the water by bringing the wire in contact with the prime conductor, but found no extraordinary result from the experiment. Mr. Cuneus, of Leyden, who was one of the party when the professor made the experiment, repeated it afterwards; and, happening to hold the phial in his hand, after he had connected the wire with the prime conductor, until the water, as he supposed, had received a full charge of electricity, and then applying his other hand to unloose the wire from the conductor, he received such a sudden shock in his arms and breast, as filled him with astonishment.

16. The report of such a strong effect of the electric power immediately raised the attention of all the philosophers in Europe. Many of them greatly exaggerated their accounts; either from a natural timidity, or a love of the marvellous. M. Muschenbroeck, who tried the experiment with a very thin glass bowl, told M. Reaumur in a letter written soon after the experiment, that he felt himself struck in his arms, shoulder, and breast, so that he lost his breath; and was two days before he recovered from the effects of the blow, and the terror. He added, that he would not take a second shock for the whole kingdom of France. Mr. Allamand, who made the experiment with a common beer glass, said, that he lost his breath for some moments; and then felt such an intense pain all along his right arm, that he was apprehensive of bad consequences, but it soon after went off without any inconvenience, &c. Other philosophers, on the contrary, showed their magnanimity, by receiving a number of electric shocks as strong as they could possibly make them. Mr. Boze wished that he might die by the electric shock, in order to furnish, by his death, an article for the memoirs of the Academy of Sciences at Paris. But, adds Dr. Priestley, in his history of electricity, it is not given to every electrician to die in so glorious a manner, as the justly envied Richman. Public curiosity was promptly and highly excited by this discovery, and all Europe was presently filled with itinerant exhibitors of the Leyden Jar, who obtained a livelihood by administering the electrical shock. The experiment was repeated and varied by the electricians of every country, and an explanation of the principle on which the effect depends, was offered by Dr. Franklin of America, and Dr. Watson in England, at the same time, without the one knowing that the other was engaged in the pursuit. The propositions of these two philosophers, observes Mr. Singer, were nearly similar; but that of Dr. Franklin being the more perfect, and having a real priority of publication, was adopted, and has been since celebrated as the Franklinean Theory of Electricity. He referred all electrical effects to the motion of a peculiar fluid, repulsive of its own particles, and having an attraction for all other matter. And he considered the opposite electricities of glass and sealing-wax as indications of different states of this fluid: the vitreous electricity being the plus or positive state, and the resinous the minus or negative state. All bodies can contain a certain quantity of electric fluid in a latent state. If this quantity be increased they become electrified positively; if it be diminished they are rendered negative. The production of electrical effects is therefore nothing but the result of the unequal distribution, by art, of a naturally diffused fluid. Such are the leading principles of the Franklinean theory; they have been considered mathematically by Mr. Cavendish, by Æpinus, and others, and, with some modifications, apply to most of the electrical phenomena at present known.

17. Frequent experiments, attended with close observation, were likely enough to lead to important results in this interesting science; and we have now arrived at a period in its history which is perhaps the most distinguished of any. We allude to the discovery of the identity of electricity and lightning. Mr. Grey and Dr. Wall seem to have been the first who thought of the resemblance between thunder and the snapping noise which is heard when an excited electric is approached by a conducting substance. The abbé Nollet, Mr. Winckler, and others, also enumerated many resemblances between the phenomena of electricity and those of thunder;

but they did not think of any method by which their suppositions could be brought to the test of experiment. The remarks of the abbé Nollet on this subject, considering the time at which they were made, are so striking, that we consider them well deserving of a place in the memory of every lover of the electrical science, and shall here record them.

18. 'If,' says he, 'any one should take upon him to prove from a well connected comparison of phenomena, that thunder is in the hands of nature what electricity is in ours; that the wonders which we now exhibit at our pleasure, are little imitations of those great effects that frighten us, and that the whole depends upon the same mechanism: if it can be demonstrated that a cloud prepared by the action of the winds, by heat, by a mixture of exhalations, &c., is opposite to a terrestrial object; that this is the electrified body, and at a certain proximity to that which is not; I avow that this idea, if it were well supported, would give me a great deal of pleasure; and, in support of it, how many specious reasons present themselves to a man who is well acquainted with electricity! The universality of the electric matter, the readiness of its action, its inflammability, and its activity in giving fire to other bodies, its property of striking externally and internally even to their smallest parts, the remarkable example we have of this effect in the Leyden experiment, the idea which we might truly adopt in supposing a greater degree of electric power, &c.; all these points of analogy, which I have been some time meditating, begin to make me believe, that, by taking electricity for the model, one might form to one's self, in respect to thunder and lightning, more perfect and more probable ideas than have hitherto been offered.'

19. It is generally admitted that the French philosophers were the first to verify these conjectures; they preceded the justly celebrated Dr. Franklin in drawing the electric matter from the clouds by means of an iron conducting rod; but, within a month after they had done so, the American philosopher effected the same thing in a manner that never seems to have entered into their minds. Speaking of the observations of the abbé Nollet, above quoted, Mr. Singer justly remarks, that thy bear no comparison with the acute conception, sound philosophical argument, and satisfactory experiments, by which Dr. Franklin has demonstrated the identity of the electric fluid, and the cause of thunder. Dr. Franklin, says he, had observed with equal attention the peculiarities of the natural phenomenon, and the power to which he ascribed its production; he enumerated the following as their leading features of resemblance:—

(1.) The zigzag form of lightning corresponds exactly in appearance with an electric spark that passes through a considerable interval of air.

(2.) Lightning most frequently strikes such objects as are high and prominent, in preference to others, as the summits of hills, the masts of ships, high trees, towers, spires, &c. The electric fluid, when striking from one body to another, always passes through the most prominent parts.

(3.) Lightning is observed to strike most frequently into those substances that are good conductors of electricity, such as metals, water, and moist substances; and to avoid those that are non-conductors.

(4.) Lightnings inflame combustible bodies. The same is effected by electricity.

(5.) Metals are melted by a powerful charge of electricity. This phenomenon is one of the most common effects of a stroke of lightning.

(6.) The same may be observed of the fracture of brittle bodies, and of other expansive effects common to both causes.

(7.) Lightning has often been known to strike people blind. Dr. Franklin found, that the same effect is produced on animals when they are subject to a strong electric charge.

(8.) Lightning destroys animal life. Dr. Franklin killed turkies of about ten pounds weight, by a powerful electric shock.

(9.) The magnetic needle is affected in the same manner by lightning and by electricity, and iron may be rendered magnetic by both causes. The phenomena are therefore strictly analogous, and differ only in degree; but if an electrified gun-barrel will give a spark, and produce a loud report at two inches distance, what effect may not be expected from perhaps 10,000 acres of electrified cloud? And is not the different extent of these conductors, equal to the different limit of their effects? But to ascertain the accuracy of these ideas, let us have recourse to experiment.

Pointed bodies receive and transmit electricity with facility; let, therefore, a pointed metal rod be elevated in the atmosphere, and insulated; if lightning is caused by the electricity of the clouds, such an insulated rod will be electrified whenever a cloud passes over it, and this electricity may then be compared with that obtained in our experiments. Such were the suggestions of this admirable philosopher: they soon excited the attention of the electricians of Europe, and having attracted the notice of the king of France, the approbation he expressed excited in several members of the French Academy a desire to perform the experiment proposed by Franklin, and several insulated and pointed metallic rods were erected for that purpose.

20. In this pursuit the most active persons were two French gentlemen, Messrs. D'Alibard and Delar. The former prepared his apparatus at Marly la Ville, five or six leagues from Paris; the latter at his own house, on some of the highest ground in that capital. M. D'Alibard's machine consisted of an iron rod forty feet long, the lower extremity of which was brought into a sentry-box, where the rain could not come; while on the outside it was fastened to three wooden posts by long silken strings defended from the rain. This machine was the first that was favored with a visit of the etherial fire. M. D'Alibard himself was not at home; but, in his absence, he had entrusted the care of his apparatus to one Coissier, a joiner, who had served fourteen years in the army, and on whose courage and understanding he could depend. This artisan had all the necessary instructions given him; and was desired to call some of his

neighbours, particularly the curate of the parish, whenever there should be any appearance of a thunder storm. At length the long expected event arrived. On Wednesday, 10th May, 1752, between two and three P. M. Coissier heard a pretty loud clap of thunder. Immediately he ran to the machine, taking with him a phial furnished with a brass wire; and presenting the wire to the end of the rod, a small spark issued from it with a snap like that which attends a spark from an electrified conductor. Stronger sparks were afterwards drawn in the presence of the curate and a number of other people. The curate's account of them was, that they were of a blue color, an inch and a half in length, and smelled strongly of sulphur. In making them, he received a stroke on his arm a little below the elbow; but he could not tell whether it came from the brass wire inserted into the phial, or from the bar. He did not attend to it at the time; but the pain continuing, he uncovered his arm when he went home in the presence of Coissier. A mark was perceived round it, such as might have been made by a blow with the wire on his naked skin.

21. Dr. Franklin himself had an opportunity, about a month after this, of verifying his own hypothesis. He was waiting for the erection of a spire in Philadelphia, not imagining that a pointed rod of a moderate height could answer the purpose. At last it occurred to him, that by means of a common kite he could have a readier access to the higher regions of the atmosphere than any other way whatever. Preparing, therefore, a large silk handkerchief and two cross sticks of a proper length on which to extend it, he took the opportunity of the first approaching thunder-storm to take a walk into a field where there was a shed convenient for his purpose. But, dreading the ridicule which too commonly attends unsuccessful attempts in science, he communicated his intention to nobody but his son, who assisted him in raising the kite. A considerable time elapsed before there was any appearance of success. One very promising cloud had passed over the kite without any effect; when, just as he was beginning to despair, he observed some loose threads of the hempen string to stand erect and avoid one another, just as if they had been suspended by the conductor of a common electrical machine. On this he presented his knuckle to a key which was fastened to the string, and thus obtained a very evident electric spark. Others succeeded even before the string was wet; but, when the rain had begun to descend, he collected electric fire pretty copiously. He had afterwards an insulated iron rod to draw the lightning into his house; and performed almost every experiment with real lightning, that had before been done with the artificial representations of it by electrical machines. With this apparatus he connected two small bells and a pendulum between them, which were so arranged as to ring when electrified, and thus to give notice of the approach of a thunder-cloud.

22. Experiments with the electrical kite were repeated in all directions, and with various success; in France a most brilliant display of its powers was made by M. de Romas. He constructed a kite of seven feet in height, and three feet wide; this kite he raised to the height of 550 feet by a string, in which was interwoven a fine metallic wire to render it a good conductor. On the 7th of June, 1753, when this kite was elevated, M. de Romas informs us that he drew from the conductor to which the string was attached sparks three inches long, and a quarter of an inch thick. On one or two occasions he met with increasing success, and was enabled to draw sparks, or rather streams, of the electric matter from his apparatus, of a foot in length, and an inch in thickness. But on the 16th of August, 1757, M. de Romas, with an additional length of string to his kite, was still more successful. The storm at the time was not great, neither was there much thunder, and but little rain had fallen; yet streams of lightning, nine or ten feet long, and an inch in thickness, darted from his conductor to the ground, accompanied with a noise equal to that attending the discharge of a pistol.

23. It was not to be expected that, in the infancy of the science, experiments on such a scale should be always conducted with safety: accidents will happen in the management of the best constructed apparatus, and the first operators on atmospherical electricity received many severe and unexpected shocks. Numerous, however, and dangerous as these accidents have been, there is only one instance known of their having proved fatal; to that we have already alluded, and shall here state some of the leading particulars attending the melancholy catastrophe. Professor Richman, of St. Petersburgh, had constructed an apparatus for making experiments on atmospherical electricity, for a work on that subject in which he was engaged. On the morning of the day that terminated his mortal career he was attending a meeting of the Academy of Sciences, and, hearing the sound of distant thunder, he hastened home to observe his apparatus, and took with him Mr. Solokow, his engraver, that he might make any sketch required during the action of the apparatus. On inspecting his electrometer, he found it indicated 4° on the quadrant; and, while pointing out to his friend the danger to be apprehended should it rise to 45°, a loud peal of thunder burst over the city. At this moment the professor inclined his head towards the apparatus to observe the height to which the electrometer had risen, and while in this posture, with his hand about a foot from the conducting rod, a ball of fire, of a bluish-white color, flashed from the rod to his head, with a report equal to that of a pistol. Richman fell backwards on a chest behind him, and expired in a moment. Solokow was much stunned by the discharge; and described the ball of electric fire as being about the size of his closed hand. The wires of the apparatus were melted and scattered about the room; the door was torn from its hinges and thrown upon the floor; the house was filled with sulphureous vapor, the ashes were thrown from the fire-place, and the door-posts rent asunder.

24. A vein was opened in the professor's body twice, but no blood followed; after which, they

endeavoured to recover life by violent friction, but in vain. There appeared a red spot on the forehead, from which spirted some drops of blood through the pores, without wounding the skin. The shoe belonging to the left foot was burst open, and uncovering the foot at that part, they found a blue mark; whence it was concluded, that the electric matter having entered at the head, made its way out again at that foot. Upon the body, particularly on the left side, were several red and blue spots resembling leather shrunk by being burnt. Many more also became visible over the whole body, and particularly over the back. That upon the forehead changed to a brownish red, but the hair of the head was not singed. In the place where the shoe was burst, the stocking was entire; as was the coat every where, the waistcoat only being singed on the fore flap: but there appeared on the back of Mr. Solokow's coat long narrow streaks, which probably arose from fragments of the red hot wires falling on it and burning off the nap. Next day, when the body was opened, the cranium was very entire, having neither fissure nor contra-fissure: the brain was sound; but the transparent pellicles of the windpipe were excessively tender, and easily rent. There was some extravasated blood in it, as also in the cavities below the lungs. Those of the breast were quite sound; but those towards the back of a brownish black color, and filled with more of the blood above-mentioned. The throat, the glands, and the small intestines, were all inflamed. The singed leather-colored spots penetrated the skin only. In forty-eight hours the body was so much corrupted that they could with difficulty place it in the coffin. It is said that, at the time of his death, professor Richman had in his pocket seventy rubles of silver, which were not in the least affected by the lightning.

25. There was no longer any doubt remaining as to the identity of lightning, and the electricity produced by the electrical machine; and the great practical use made of this discocovery was to secure buildings, ships, &c., from being damaged by lightning, by erecting on them pointed metallic rods, rising a little above the highest part of the building, and passing along it so as to communicate with the ground or the nearest water, a full account of which will be given in the course of this essay.

26. A short time previous to the event of professor Richman's death, a most remarkable attempt was made by a gentleman in Italy, to gain on the credulity of his countrymen and others, by pretending that if odoriferous substances were enclosed in glass tubes, and the tubes excited, the medicinal virtues of those substances would transpire through the glass, impregnate the atmosphere of the conductor, and thus be readily communicated to the patient without being taken into the stomach. The most astonishing cures were said to have been performed by these medicated tubes; and the inventor, J. Francisco Pivati, published an account of them to the world. Both the British and French philosophers united in investigating the merits of Pivati's experiments, and the result was a complete failure, in every instance in which the experiments were repeated, though this was done in the presence of those who pretended to have been so successful; and, in some cases, with the very apparatus they themselves had used. The theory was, consequently, no longer credited.

27. To enumerate, in chronological order, all the discoveries that have been made in the science of electricity, from the invention of the Leyden phial to the present period, would swell this introductory sketch far beyond its proper limits; and yet, as having so eminently contributed towards raising the science to its present elegant, improved, and highly prosperous state, there are several whose names it would be injustice to pass by in silence. As the chief of these we may notice the following: Mr. Canton, an eminent English electrician, who distinguished himself by a very successful repetition of Dr. Franklin's experiments on atmospherical electricity; a method of electrifying the air of a room, either positively or negatively; and particularly by disproving the correctness of the theory of vitreous and resinous electricity, and showing that every electric is capable of giving it both in a positive and negative form, according to the nature of the surface of the body, and the kind of rubber with which it is excited.

This ingenious electrician made several remarkably fine experiments on electrical atmospheres, which led to the establishment of the fact, that bodies immersed in them became possessed of the electricity the opposite of that of the body into the atmosphere of which they are placed.

28. In connexion with the name of Canton must be mentioned that of Beccaria, author of a work entitled Dell' Elettricismo Artificiale e Naturale, and which was translated into English in the year 1776. The discoveries of Signor Beccaria were nearly the same as those of his contemporary, Mr. Canton, although they had had no communication with each other on the subject. Beccaria also made some very important experiments on the conducting power of water; in these he ascertained, that water is a very imperfect conductor of electricity; that it conducts it according to its quantity, and that, when used in very small quantities, its resistance was greatest. See Beccaria.

29. Some interesting discoveries were made in the year 1759, on the electrical qualities of silk, by Mr. Symner. An account of these he published in the Philosophical Transactions. His attention seems to have been directed to the subject by accidentally observing, that, on pulling off his silk stockings in the evening, a crackling noise proceeded from them, and that in the dark they emitted sparks of fire. He found that these electrical appearances were always the strongest when a silk and worsted stocking were both on one leg, and that it was of no consequence which of them was next the skin, but that they must be of different colors, one white and the other black. Two stockings of this description, worn on the leg for the short space of ten minutes, on being pulled off, stood inflated as if the leg had been within them, and, on being drawn asunder, attracted each other at

the distance of eighteen inches. These effects are always most powerful when the stockings are new, or when newly washed. Those who choose to try this very simple experiment will find it succeed equally well if the stockings are placed one within the other, drawn a few times through the hand, and then quickly pulled asunder.

30. Mr. Kinnersly, an intimate friend of Dr. Franklin, made several experiments that contributed to the advancement of electricity. These related chiefly to the discovery of the two electricities, the conducting power of water at different temperatures, and the power of strong charges of electricity when passed through brass wires. In the first of these experiments he had been anticipated by M. Du Fay; but he soon perceived that Du Fay did not consider the two electricities in the same light as that in which they were viewed by Franklin, viz. positive and negative.

31. In 1757 a work appeared on electricity, entitled Disputatio Physica Experimentalis de Electricitatibus, by Mr. Wilke, of Rostock, in Lower Saxony, in which the author gives some very interesting details of his researches respecting the electricity developed during the melting and cooling of electrical substances, and also that produced by the friction of different bodies. This gentleman found that, when sulphur is melted in an earthen vessel placed upon conductors of electricity, it is strongly electrified when taken out after it is cold; but that it shows no signs of electricity if cooled upon electrics. Melted sealing-wax, he found, acquired negative electricity when poured into glass vessels, but positive electricity when poured into sulphur. Mr. Wilke also confirmed the experiments of Dr. Franklin and Mr. Canton on electrical atmospheres, and illustrated the phenomena of electrical light.

32. M. Alpinus, a member of the Imperial Academy at St. Petersburgh, seems to have been the first who gave to the world a mathematical demonstration of the theory of electricity. An exposition of his treatise was published by the abbé Hauy; and an excellent paper, on the same subject, was drawn up for the Royal Society by Mr. Cavendish, before he knew any thing of the theory of M. Alpinus. The merits of M. Alpinus are certainly great, but we consider Cavendish as having much higher claims as an electrician; his experiments on the conducting power of water and wire; his very ingenious construction of the artificial torpedo; and above all, his success in employing electricity as a chemical agent, justify this opinion.

33. The labors of Dr. Priestley, as an electrician, are deservedly held in the highest esteem; the doctor brought no common share of ingenuity and perseverance to bear upon the science; and to him we are indebted for a considerable number of important improvements and interesting experiments in electricity, as connected with chemistry; for a most excellent treatise on the History of Electricity; an Introduction to Electricity; several valuable papers on the same subject, inserted in the Philosophical Transactions; and for numerous improvements in the construction of electrical apparatus.

34. The theories of Alpinus and Cavendish were much improved on by the ingenuity of M. Coulomb. By those philosophers the action of the electric matter, in producing attraction or repulsion, was considered merely as diminishing with the distance; but by the experiments of Coulomb it was proved that the electrical force, like that of gravity, is in the inverse ratio of the squares of the distance. The instrument with which Coulomb made his experiments was of his own construction: he gave it the name of the 'torsion balance,' from the manner of its action; a description of it will be given in the course of this essay. Coulomb also made numerous experiments for the purpose of ascertaining the laws by which the dissipation of the electrical matter in the air is regulated; and also to ascertain the distribution of it in an overcharged body. In prosecuting these enquiries he was certainly as successful as could possibly be expected, considering the extreme delicacy of his apparatus, and the effects which the variableness of the atmosphere produces on the strongest electrical experiments.

35. To M. De Saussure we are also indebted for some remarkably fine experiments, which seem to have been made with great care, on the electricity developed during the conversion of fluids into vapor. The fluids on which he operated were distilled water, spirit of wine, and ether. The same philosopher likewise made some highly interesting experiments on atmospherical electricity, for the verification of which he made a journey to the Alps.

36. Most of those who have devoted their attention to the study of electricity, as a science, have distinguished themselves by the invention of some new instrument, the use of which has generally led to some important discovery.

This was peculiarly the case with Sig. Volta, professor of natural philosophy at Como in Italy. He invented the electrophorus, an ingeniously constructed instrument for collecting and retaining the electric matter; and another called a condenser, the use of which is to accumulate, and render visible, the smallest portions of electricity, natural or artificial. The celebrity of Volta, however, rests chiefly on the important improvements which he made in that branch of electricity designated GALVANISM, under which they will be fully considered.

37. We have already noticed the scientific experiments of Coulomb, and must here observe that Dr. Robison, late professor of natural philosophy in the university of Edinburgh, is justly entitled to a share of the honor bestowed on Coulomb, since he had, so early as the year 1769, made numerous and remarkably successful attempts, with an admirable electrometer of his own invention, to determine the laws of electric action. But the professor did not publish an account of his experiments at the time they were made, which certainly gives them the appearance of posteriority. The conclusion to which Dr. Robison's experiments led him was, that the force of electrical attraction and repulsion is nearly in the inverse ratio of the square of the distance. 'The specific result,' says Dr. Brewster, 'which he obtained was, that the mutual repulsion of

two spheres, electrified in the same manner, varied as $\frac{1}{d^2 \cdot 06}$, d representing the distance of their centres.'

38. As electricity now began to be more generally cultivated, it was to be expected that great improvements in the construction of apparatus would take place. This was the case; and the brilliant success of Van Marum of Haarlem, in experiments which had failed in the hands of others, was obviously owing to the prodigious power of the large apparatus constructed by Mr. Cuthbertson of London, and placed in Tyler's museum at Haarlem. Some notice of these experiments will be taken in the course of this article; at present it may be sufficient to state, that, whatever other philosophical instrument makers may have conceived, Mr. Cuthbertson has brought forth the most useful, because the most powerful, electrical apparatus with which we are yet acquainted.

39. Mr. Cavallo is justly entitled to respectful notice in every historical sketch of the rise and progress of the electrical science, to which he made many important additions. This philosopher made numerous experiments on atmospherical electricity; and also added to our stock of electrical apparatus, by his invention of the most ingeniously constructed instruments for measuring, doubling, condensing, and multiplying electricity.

40. There are other philosophers who have liberally contributed to the progressive improvement of this branch of natural philosophy, on whose merits we cannot here dwell; but this we the less regret as their improvements and discoveries must be still fresh in the memory of those who feel an interest in the science. Among these we would simply enumerate the ingenious and laborious Nicholson, the venerable M. Hauy, Mr. Brooks, Mr. Bennet, Mr. Henley, Mr. Morgan, La Place, and the truly ingenious annalist M. Poisson.

40.* Many other names of deserved celebrity might be here mentioned, as having successfully labored in raising electricity to its present eminent station among the sciences; but we must bring this part of our article to a conclusion by acknowledging our obligations to them, and intimating that we shall occasionally avail ourselves of their labors. This remark is meant to apply particularly to the excellent treatise on electricity by the late Mr. George John Singer, a popular lecturer on this science. Mr. Singer's name stands high in the scientific world; and competent judges have pronounced his Elements of Electricity and Electro-Chemistry one of the best and most original works on the subject in the English language

PART I.

ON THE PHENOMENA OF EXCITED ELECTRICITY.

41. The more simple methods of exciting electrics enable us to perform several pleasing and instructive experiments, without the aid of costly and complex apparatus; the principal of these we now proceed to describe.

If two silk ribands, the one black and the other white, about two or three feet in length, and perfectly dry, be applied to each other by their surfaces, and then drawn smartly a few times between the finger and thumb, or over dry silk velvet or woollen cloth, they will be found to adhere to each other with considerable force; and when separated at one end will rush together again with rapidity. Each riband, when separated, will attract any light substances to which it is presented; and, if the experiment be made in a dark room, a flash of light will occasionally attend the separation of the ribands.

42. Sticks of sealing-wax, resin, or sulphur, when rubbed with dry woollen cloth, or fur; and tubes or rods of glass, when rubbed with silk, exhibit similar powers; and, if of sufficient size, produce, when applied within a short distance of the face or hand, a distinct and singular sensation. These effects having been first produced by the friction of amber (electron) are called electrical phenomena; and the processes employed for their production, the excitation of electricity.

43. Attraction is the phenomenon most constantly attendant on excitation; it is therefore considered as an indication of the presence and action of electricity, and is the basis of all its tests. Electricians formerly, says Mr. Singer, employed for such trials a light wooden or metal needle, supported by its centre on a point, or a thread or feather delicately suspended. To these the excited body was presented, and, if they were attracted by it, the attraction was attributed to electricity, and the excited body was called an electric.

44. This suspended needle, and every other contrivance for the same purpose, they called an electroscope, when employed to indicate the existence of electricity; and an electrometer when considered as a measure of its force; but the latter term appears fully sufficient, since every contrivance hitherto employed to ascertain the presence of electrical phenomena is also calculated to measure their power. The most useful electrometers, for common purposes, are constructed by suspending two narrow slips of gold leaf from the cap of a glass cylinder. When these are unelectrified they will hang parallel and contiguous; the presence of the smallest quantity of electricity will cause them to diverge towards the sides of the cylinder.

Small balls turned from the pith of elder, and suspended by fine threads or silver wires, are sometimes substituted for the gold strips. They are less easily affected, but they are more durable. The pith balls, suspended by thread or wire, are also occasionally used without a glass cylinder. But these and other electrometers will be explained hereafter.

45. Electrical phenomena are thus characterised by the attraction and recession of light substances; the consequent production of motion in them, and of sensation in living bodies, and by the evolution or production of light. There are various methods by which these effects may be produced, but the following are the most obvious sources of their production. (1.) Friction. (2.) Change of form. (3.) Change of temperature. (4.) Contact of dissimilar bodies.

46. Of the first kind, viz. friction, the instances are most numerous, and, as Mr. Singer remarks, under certain limitations, universal; they may indeed be obtained by rubbing any of an extensive list of resinous and silicious substances; and of dry, vegetable, animal, and mineral productions. The electricity thus excited, is most readily rendered visible by its effects on the gold leaf electrometer.

47. Examples of the second kind are also very numerous. If a small quantity of sulphur be melted and poured into a conical wine glass, it will contract a little, and become electrical in cooling. A silk thread with a small hook at the end of it, or a rod of glass should be inserted in the sulphur while in a fluid state, to serve as a handle for separating it from the glass when cold. On being separated from the glass, the sulphur will exhibit other signs of electricity; if kept in the glass it will retain its electric virtue for years, and evince it very perceptibly on every attempt to separate the two substances.

48. Mr. Henly discovered that chocolate, fresh from the mill, becomes strongly electrical, as it cools in the tin pans. It soon loses this property, but recovers it once or twice, by being melted in an iron ladle and poured into the tin pans. When the mass becomes dry, the electricity cannot be restored by melting, unless olive oil be mixed with it in the ladle; in which case it completely recovers its electric power. M. Chaptal observed the same circumstance during the congelation of glacial phosphoric acid. Calomel also, when it fixes by sublimation to the upper part of a glass vessel, has been found strongly electrical. The condensation of vapor, and the evaporation of fluids, though apparently opposite processes, are alike sources of electrical excitation.

49. Various crystallised gems, and a stone called the Tourmalin, become electrical by the mere application of heat; but no other substances have yet unequivocally manifested the same property; though the effects of friction are generally increased, if it is preceded by a moderate elevation of temperature.

50. The contact of dissimilar bodies is probably in all cases the real primary cause of electrical excitement, but it is rarely employed alone, for electricity is known to us only by its effects, which are constantly the result of an artificial arrangement, and consequently may not immediately succeed the primary cause of electric powers, similar in their separate action on the electrometer, and other indifferent matter; but exerting a mutual influence on each other, destructive of their individual properties.

51. It was at first supposed that these phenomena were peculiar to the substances by which they were produced; hence the power excited by the friction of glass was termed vitreous electricity; and that by the friction of sealing-wax, resinous electricity. It has, however, long since been proved that both powers are produced in every case of electrical excitation; and, because their mutual counteraction of effect resembles that of an affirmative and negative power, they have been styled positive and negative electricity.

52. The determination of these two states of electricity in different excited bodies, continues Mr. Singer, is of importance to the practical electrician, and may be thus effected:—Sealing-wax when rubbed on woollen cloth is negatively electrified. Glass, when rubbed with silk is positively electrified. Let an electrometer be made to diverge by its being approached by an excited stick of sealing-wax: while in this state, approach it with any excited body, the electricity of which is to be determined. If the divergence of the electrometer increase, the presented body is negative; if it be diminished, the presented body is positive. In other words, all those substances that lessen the divergence occasioned by excited wax, are positive; and such as increase it, negative: whilst those which lessen the divergence produced by excited glass, are negative; and such as increase it positive. Examining, by this test, the effects produced in some of the instances of excitation already considered, we find the truth of the preceding statements, and the relation of the different electrical states to the processes by which they are produced, become more intelligible. Care ought to be taken to destroy the divergence of the electrometer after every experiment of this nature; this is best effected by touching its cap with one end of a piece of brass wire.

53. As an illustration of the doctrine here advanced let the following simple and easily performed experiments be made.

(1.) Roll up a warm and dry piece of flannel, so that it may be held by one extremity, while a stick of sealing-wax is rubbed with the other. After a slight friction present the flannel to an electrometer, which will instantly diverge; while this divergence continues, bring the stick of sealing-wax near the cap, and the leaves of the electrometer will quickly collapse. Both these substances, it is obvious, are electrified by mutual friction, but their electricities are opposite; that of the wax being negative, and that of the flannel positive.

(2.) The electricities thus produced are equal to each other: for if the friction be repeated, and the two substances be both presented to the electrometer at the same time, no signs of electricity appear: the opposite electricities, when applied together, producing a reciprocal counteraction of effect.

(3.) If a black and a white silk riband be excited in contact, in the manner already described, the black riband will be found to be negatively, and the white one positively electrified.

(4.) Take the sulphur cone described at 47, apply it and the glass separately to the electrometer; the cone will be found to be negatively and the glass positively electrified.

54. From the above experiments it appears, that in all cases of excitation positive and negative electricity are produced at the same time, and may be observed by the use of proper means. But it also appears that by friction with the same substance, different bodies are variously affected; for glass rubbed with silk evinces positive electricity: but wax rubbed with silk is rendered negative. Again, polished glass, when rubbed with silk, skin-wool, or metal, becomes positive; but if it be excited by friction against the back of a living cat, it appears negative. Wool, silk,

or fur, rubbed against sealing-wax, are rendered positive; but gold, silver, or tin, are by the same process rendered negative.

55. Electricians have drawn up tables for showing at one view what kind of electricity will be produced by rubbing various electrics with different substances; the following Mr. Singer gives us on the authority of Mr. Cavallo.

	Is rendered	By friction with
The back of a cat	Positive	Every substance with which it has been hitherto tried.
Smooth Glass	Positive	Every substance hitherto tried, except the back of a cat.
Rough Glass	Positive	Dry oiled silk, sulphur, metals.
	Negative	Woollen cloth, quills, wood, paper, sealing-wax, white-wax, the human hand.
Tourmalin	Positive	Amber, blast of air from bellows.
	Negative	Diamonds, the human hand.
Hare's skin	Positive	Metals, silk, loadstone, leather, hand, paper, baked wood.
	Negative	Other finer furs.
White silk	Positive	Black silk, metals, black cloth.
	Negative	Paper, hand, hair, weasel's skin.
Black silk	Positive	Sealing-wax.
	Negative	Hare's, weasel's, and ferret's skin, loadstone, brass, silver, iron, hand, white silk.
Sealing wax.	Positive	Some metals.
	Negative	Hare's, weasel's, and ferret's skin, hand, leather, woollen-cloth, paper, some metals.
Baked wood	Positive	Silk.
	Negative	Flannel.

In a note appended to the preceding table Mr. Singer says, Mr. Cavallo had inserted metals, which appeared to imply that the friction of all metals electrified sealing-wax positively; this I find is not the case: iron, steel, plumbago, lead, and bismuth, render sealing-wax negative, and all the other metals I have tried leave it positive. I have therefore made a slight alteration in the table. The least difference in the conditions of such experiments will occasion singular varieties of result: with the same rubber (an iron chain), positive electricity may be excited in one stick of sealing-wax, and negative in another, if the former have its surface scratched, and the latter be perfectly smooth. Many repetitions of each experiment are therefore essential to an accurate conclusion.

56. The result of experiments of the kind just described, Mr. Singer found to be much influenced by the state of the bodies employed, and the manner in which the friction was applied to them. In general, he remarks, strong electric signs can only be produced by the friction of dissimilar bodies; but similar substances, when rubbed together so that the motion they individually experience is unequal, are sometimes electrified; and, in such cases, the substance of which the friction is limited to the least extent of surface, is usually negative. This he farther remarks is the case with the strings of a violin, over a limited part of which the bow passes in its whole length, and the hairs of the bow become positive.

57. From these facts he draws the following conclusions, viz. that positive and negative electricity are concomitant phenomena, and that in all cases of electrical excitement, they are both produced, though one only may occasionally appear; and that these phenomena are not peculiar to any distinct class of bodies, but may be produced alternately in various substances, by changing the materials or method by which friction is communicated to them.

The Communication of Electricity.

58. Mr. Cavallo, speaking of communicated electricity, remarks, that under such a title falls almost all that we know of the subject: the passage of this virtue, says he, from one body to another is what causes its light; by being communicated to other bodies we see its attraction; by its quick transition it melts metals, destroys animal and vegetable life; and, in short, it is by this communication that the science is known and cultivated.

The following observations and experiments on this particular part of the subject we give from Mr. Singer, with a few necessary exceptions, preferring them to any thing we have yet seen for their appropriateness and conciseness.

59. From the few simple experiments which we have already described the reader must be aware that electricity can be communicated or conveyed from one body to another. But the faculty of electrical transmission is very different in different bodies; some convey it with great rapidity; others more slowly; and there are some that appear absolutely to arrest its progress. Examples of this fact are apparent in the most simple experiments. The divergence of an electrified electrometer may be destroyed, weakened, or maintained, by touching its cap with different bodies; now, as the divergence of the electrometer is caused by its electricity, such effects can only be produced by the relative power of the touching bodies to deprive it thereof; for so long as the electricity remains the divergence will continue unaltered.

60. This may be shown most satisfactorily by the two following experiments. (1.) Touch the cap of the electrified electrometer with a stick of dry glass, sulphur, or sealing-wax; the divergence of its leaves will continue; this shows therefore that these substances do not transmit electricity. (2.) Touch the cap of the electrified electrometer with a piece of wood, a rod of

any metal, a green leaf, or with the point of the finger; its divergence immediately ceases. Such bodies therefore permit the transmission of electricity.

61. By experiments of this kind it is found, that there is a gradation of effect from one class of bodies to the other. Those which transmit electricity with facility are called conductors; those whose transmitting powers are inferior, imperfect conductors; and such as have no power of transmission, non-conductors: but in general the various bodies in nature are divided into two classes only; the remote extremes of each forming the intermediate class.

62. In the following enumeration of the principal conductors, and non-conductors, the substances are placed nearly in the order of their perfection; but the determination of this circumstance has not hitherto been accomplished with much precision.

CONDUCTORS.

All the known metals.
Well-burnt charcoal.
Plumbago.
Concentrated acids.
Powdered charcoal.
Diluted acids, and saline fluids.
Metallic ores.
Animal fluids.
Sea water.
Spring water.
River water.
Ice above 13° of Fahrenheit.
Snow.
Living vegetables.
Living animals.
Flame.
Smoke.
Steam.
Most saline substances.
Rarefied air.
Vapor of alcohol.
Vapor of ether.
Most of the earths.
Most stones.

To the above Dr. Brewster adds powdered glass and powdered sulphur, which, he says, have been found to be conductors by the experiments of Van Swinden.

63. Many of the above mentioned substances fail to conduct electricity when they are made perfectly dry; hence it is concluded that their conducting power arises from the water they contain. Indeed this faculty does not permanently exist in any of the bodies enumerated, but varies and disappears with their modifications of temperature, &c. Thus hot water is a much better conductor than cold water is; the same is the case with charcoal and other substances.

NON-CONDUCTORS.

64. These are also denominated electrics, as before remarked, and occasionally insulators; but the latter term will only apply to the most perfect of them.

Shell-lac, amber, resins.
Sulphur, wax, jet.
Glass and all vitrifications, talc
The diamond and all transparent gems.
Raw silk, bleached silk, dyed silk.
Wool, hair, feathers.
Dry paper, parchment, and leather.
Air, and all dry gases.
Baked wood, dry vegetable substances.
Porcelain, dry marble.
Some silicious and argillaceous stones.
Camphor, elastic gum, lycopodium.
Native carbonate of barytes.
Dry chalk, lime, phosphorus.
Ice at 13° of Fahrenheit.
Many transparent crystals when perfectly dry.
Ashes of animal bodies.
Ashes of vegetable bodies.
Oils, the heaviest are the best.
Dry metallic oxides.

65. The most perfect non-conductors, continues Mr. Singer, become conductors by the accession of moisture; hence the necessity of preserving them clean and dry during electrical experiments. Resinous substances, raw silk, and Muscovy talc, are least liable to attract moisture, and are therefore most useful where perfect non-conductors are required.

66. Glass becomes moist on its surface only, and this moisture may be checked by covering it with sealing-wax or good varnish. Glass consequently enters most extensively into the structure of an electrical apparatus; its strength, and the facility with which it may be procured of any form, fitting it most admirably for that purpose.

67. Many substances in the preceding list lose their non-conducting power, and become conductors, when intensely heated. Such is the case with red hot glass, melted resin, wax, &c.; but the most intensely heated air, if unaccompanied by flame, is not a conductor. Many fibrous substances attract water so readily, that it is absolutely necessary to dry and warm them before their non-conducting property appears; this is particularly the case with paper, flannel, parchment, leather, &c. The influence of heat on this property is, indeed, very remarkable. It is well exemplified in the following instance: Wood, in its natural state, is a conductor; if baked, its moisture is expelled, but its organisation is not altered: it is then a non-conductor. By exposure to a greater heat its volatile elements are dissipated, and its indestructible base (charcoal replete with alkali) only remains; this is a conductor; but if exposed again to heat, with access of air, it suffers combustion, and is converted into ashes and gases, which are non-conductors.

68. There does not appear any definite relation between the chemical characters of bodies and their conducting powers; for the best conductors (metals), and the best non-conductors (resins, sulphur, &c.), are alike inflammable substances. The products of combustion, too, are dissimilar in this respect: acids and alkalis conduct electricity, but the metallic oxides do not. Neither does it appear that specific gravity, hardness, tenacity, or crystalline arrangement of particles, are connected with the power of electrical transmision; for similar characters of this kind are possessed by bodies of both classes. Thus platina, the densest of bodies, is

a conductor; but so also are charcoal, and rarefied air.

69. Whatever be the cause of non-conducting power, it is evident that without its existence as a property of air, and other substances, electrical phenomena would be unknown; for, if the faculty of electrical transmission existed universally, the cause of every effect of this kind would be dissipated and lost at the moment of its production. But, by the property of non-conductors, any excited electricity which they surround is preserved; and it is then said to be insulated. A support of glass, sealing-wax, silk, or any non-conductor, is, for the same reason, called an insulating support, or an insulator; and a piece of metal or other conductor, so supported, is named an insulated conductor.

70. The use of insulators and conductors in practical electricity may be exemplified by very simple experiments, which, says Mr. Singer, will form no improper introduction to the consideration of more important apparatus. He gives the following:—

(1.) Hold a sheet of writing paper before a fire till it be perfectly dry and warm; lay it flat upon a table and rub the upper surface briskly with Indian rubber. The paper will adhere to the table, and if lifted up by one corner and presented quickly to any flat conducting surface, as the wainscot, &c., will be attracted by and adhere to it. This adherence is occasioned by the attraction of electricity excited on the paper, which in its dry state is an insulator or non-conductor; the necessity of which circumstance to the success of the experiment is rendered evident by the paper falling down as soon as it has attracted moisture enough to destroy its insulating property, and is further apparent from the impossibility of producing the same results by the friction of paper in its ordinary state of dryness.

(2.) Repeat the excitation of the paper in a dark room; when the paper is lifted from the table by its corner, present the knuckle of the other hand successively to various parts of its surface, a series of faint divergent flashes of light will ensue. This light is occasioned by the transmission of the electricity excited on the paper to the hand; and it occurs at every contact, because the non-conducting power of the paper prevents its transmission from one part of the surface to another, the effect existing over the whole portion that has been subjected to friction.

(3.) Excite the dry sheet of paper as before, and place it upon an insulating stand, a piece of apparatus to be described hereafter, present the knuckle to the edge or under side of the metal plate, and a bright spark will appear; but a second approach will produce either a very slight effect, or none that is perceptible; for the metal is a conductor, and it transmits the whole effect of the excited electric at once. Hence insulated conductors are employed in the electrical apparatus to receive or collect the diffused electricity of excited bodies, and to apply it to the purposes of experiment.

71. It is rather remarkable that the ingenuity of Mr. Singer did not lead him to try the experiments here detailed with brown, as well as writing paper. This idea, however, does not seem to have occurred to writers on the subject till very recently. When very coarse brown paper is used, the effects produced are much stronger; nor is there in this case any necessity for the application of Indian rubber; for if a piece of coarse brown paper, of about twelve inches long and six inches broad, be made very dry and warm, and then drawn gently three or four times between the knee and the lower part of the arm, both being covered with woollen, it will be found to be highly electrical, and will with considerable force adhere to the wainscotting of a room. If any conducting substance be applied to it immediately after the friction, such as the knuckle of the folded hand, or a brass ball, a strong spark will instantly dart from the paper to it, attended by the usual snapping sound. So powerful indeed is excited brown paper, when carefully managed, that a small jar may be charged with it; and it has been recently proposed as a covering for a circular board to be used instead of a plate of glass in constructing a cheap kind of electrical machine.

PART II.

ON ELECTRICAL APPARATUS.

72. Numerous, extremely beautiful, and delicate experiments may be made in electricity with but a small quantity of apparatus, and that of a simple form, and at a trifling expense. Such an apparatus consists chiefly of a few glass tubes, of about an inch in diameter and two or three feet long; one or two very large sticks of sealing-wax; a few pieces of silk, old silk handkerchiefs answer extremely well; a few pieces of new flannel; some wires and balls of different sizes; and half a dozen small balls made of the pith of elder.

But, when it is required to exhibit the more striking and important of the electrical phenomena, we must have recourse to a much more powerful, complicated, and consequently expensive apparatus.

73. The principal article, the very fountain, so to speak, of all electrical apparatus, is what is commonly denominated the electrical machine; of the structure of this instrument we have various accounts in different works on electricity, but as it is not our intention to swell our pages with a repetition of what others have said before us on what is now become obsolete, we shall not put our readers to the trouble of travelling over an uninteresting description of apparatus which has nothing to recommend it but its antiquity.

74. Of the *Electrical Machine*, there are now various kinds in use; these, however, may be classed under two heads, the cylindrical and the plate machine. But before entering on a particular description of these we feel strongly inclined to lay before our readers the following remarks of Mr. Singer on electrical apparatus in general.

75. The structure of an electrical apparatus, says this distinguished electrician, consists in the judicious arrangement of insulators and conductors, so that the former shall prevent the dissipa-

tion of the effects the latter are employed to collect or transmit; thus the cap and leaves of the gold leaf electrometer form a conductor intended as a test of electrical action; but to fit this conductor for its purpose it is insulated, being supported on the glass cylinder by which the leaves are enclosed.

76. When electricity is excited by friction, the quantity of effect is, within certain limits, proportioned to the extent of the rubbed surface; hence it appears that every part of that surface is concerned in the production of the general effect. Now, that this may be the case, it is essential that every part of such surface be insulating; for friction is a progressive process, a succession of contacts; and the effect produced by it in the first instant would otherwise be destroyed by conducting power, before a second operation could contribute to its increase. For this reason electricity is most usually excited by the friction of a conductor of limited size, against the extensive surface of a non-conductor.

77. An apparatus, then, properly arranged for the excitation of electricity, is called an electrical machine. To excite positive electricity, a glass tube, of about an inch in diameter and two feet long, is generally used; the excitation is produced by rubbing it lengthwise by a piece of dry oiled silk, held in the hand which is made to grasp the tube. In this way both the silk and the tube are electrified; but the electricity of the silk is destroyed by the conducting power of the hand, and that of the tube only appears. In a similar way negative electricity is procured by rubbing a large stick of sealing-wax with dry flannel or fur; the electrical power of the sealing-wax being all that results.

78. Thus, with the most simple machinery, two processes are employed to procure the opposite electricities, although they are at the same time both excited in each; but, to obtain them both, it would be necessary to insulate the silk, or flannel, used as rubbers, either by employing them in a very dry state, rolled up, so as to produce the friction with one extremity, at a distance from the hand, or by affixing them to a glass or other non-conducting support; but neither of these methods would be convenient where many experiments are to be made. This difficulty does not occur when large surfaces of glass are employed instead of tubes as sources of excitation; for these may be made circular, and proper friction be communicated to them from a fixed cushion, placed on an elastic support, against which they are made to revolve.

79. We shall here give a brief description of the two forms of the electrical machine which are most generally approved of, and shall begin with the cylindrical machine. In point of power, the very best kind of cylindrical electrical machine with which we are acquainted is the improved one, as constructed by the late Mr. Geo. Adams, of London, an eminent lecturer, and author of several valuable philosophical works. This machine is represented in plate I, fig. 1, ELECTRICITY. The parts of the machine, which fall more immediately under our attention are, (1.) The electric, or the glass cylinder which is to be excited. (2.) The mechanical contrivances by which it is put in motion. (3.) The cushion and its appendages. (4.) The conductor or conductors. The glass cylinder of the machine is put in motion by a simple winch. This is less liable to be out of order than those that are turned with a multiplying wheel, and also enables us to excite the machine more powerfully. The cylinder, FGHI, is supported by two strong perpendicular pieces, DE. The axis of one cap of the cylinder moves in a small hole at the upper part of one of the supports. The opposite axis passes through the upper part of the other support. To this axis the winch or handle is fitted. The cushion is supported and insulated by a glass pillar; the lower part of this pillar is fitted into a wooden socket, to which a regulating screw is adapted, to increase or diminish the pressure of the cushion against the cylinder. A piece of silk comes from the under edge of the cushion, and lies on the cylinder, passing between it and the cushion, and proceeding till it nearly meets the collecting points of the conductor. The more strongly this silk is made to adhere to the cylinder, the stronger is the degree of excitation. Before the cylinder, or opposite to the cushion, is a metallic tube, YZ, supported by a glass pillar LM. This is called the conductor, and sometimes the prime conductor. For the more conveniently trying experiments with this machine, and exhibiting the different states of the cushion and conductor, there are two wires to be fixed occasionally, the one to the conductor, the other to the cushion; on the upper part of these are balls furnished with sliding wires, that they may be set apart from each other at different distances.

80. It is matter of surprise that this simple and very powerful electrical machine should have totally escaped the notice of some modern writers on the subject, who have taken much pains to describe others of far inferior importance. This remark is equally applicable to another form of the cylindrical machine which is but little known, but which has many good qualities to recommend it to the attention of those who prefer the cylinder to the plate machine. The principle on which this machine, as well as that just described, is constructed, is that adopted by Mr. Nairne; but whatever of improvement it possesses is due, we believe, to Mr. Bywater, author of an excellent little work on electricity. The following is Mr. Bywater's own description of this machine: AAAA, fig. 2, is the board on which the supporters and pillars are erected, and by which the machine is made fast with cramps to a table. BBBB are two wooden pillars or supporters, the lower ends of which are morticed into the board AAAA, and in the upper ends of which the axis of the cylinder CCCC turns. DD is the winch by which the cylinder is turned on its axis. EE is a piece of wood, a part of which is slided into a groove under the board AAAA, and made fast by the thumb-screw *f*. GG is a glass pillar, which is fixed to the wood EE, and supports what is called the negative conductor and rubber HH. II is another piece of wood, part of which is slided into a similar groove under the board AAAA, and is made fast by the thumb-screw *j*. KK is a glass pillar fixed into the wood II, and supports the prime conductor LL; to this con-

ductor a number of metallic points are attached, to collect the electric fluid which flows on the surface of the cylinder. M M is a rod of brass inserted in the prime conductor, having a joint by which it may be raised or lowered, to suit the height of the apparatus; this rod is a most useful appendage to the prime conductor. To the upper part of the rubber a piece of black silk is attached, which proceeds from thence over the top of the cylinder, to within about half an inch of the points of the wires inserted in the prime conductor; by which means the fluid that is brought into action by the attrition of the cylinder and rubber is prevented from being dissipated in the air, and carried round with the cylinder to the prime conductor. The action of the silk on the cylinder tends very much to increase the excitation of the machine, as may be seen by removing the cushion a little back from the cylinder, and leaving the silk to act upon it alone, in which case the excitation will often be found to be scarcely less than when the rubber is also in contact with the cylinder.

81. The plate machine, like the cylindrical, has had a few varieties introduced into its construction at different times. The largest specimen of this instrument is that which was constructed by Mr. Cuthbertson, for Tyler's museum, at Haarlem. The following will convey to the reader's mind some idea of the powers of this immense machine; and its construction will be readily understood by the description which we shall add of the most improved form of the instrument. It consists of two circular plates of glass, each sixty-five inches in diameter, and made to turn upon the same horizontal axis, at the distance of seven inches and a half from one another. These plates are excited by eight rubbers, each fifteen inches and a half long. Both sides of the plates are covered with a resinous substance to the distance of sixteen inches and a half from the centre, both to render the plates stronger, and likewise to prevent any of the electricity from being carried off by the axis. The prime conductor consists of several pieces and is supported by three glass pillars, fifty-seven inches in length. The plates are made of French glass, as this is found to produce the greatest quantity of the electricity next to English flint, which could not be produced of sufficient size. The conductor is divided into branches which enter between the plates, but collect the fluid by points only from one side of the plate. The force of two men was required to work this machine; but when it is required to be put in action for any length of time, four are necessary. At its first construction nine batteries were applied to it, each having fifteen jars, every one of which contained about a foot square of coated glass; so that the grand battery, formed by the combination of all these, contained 135 square feet. The effects of this machine are astonishing: but Dr. Van Marum, who principally made experiments with it, imagining that it was still capable of charging an additional quantity of coated glass, afterwards added to it ninety jars of the same size with the former; so that it now contains a coated surface of 225 feet, and the effects are found to be proportionable.

82. The principal objection to the plate machine has hitherto been the difficulty of insulating for the purpose of producing negative electricity. This objection is now removed; and, by using the machine as constructed by Mr. Cuthbertson, both kinds of electricity are produced with ease. The following description of this beautiful and powerful instrument is given by Dr. Brewster in the Appendix to his new edition of Ferguson's Essays. Fig. 3 is a representation of this machine: A B is a circular disc of plate glass, supported upon an horizontal axis, the ends of which rest upon two upright pillars E F. By turning the winch or handle, W, a rotatory motion is given to the plate, which is excited by two rubbers X, Y, fixed at the opposite ends of a diameter of the circle. Each rubber consists of two cushions, which embrace the outer margin of the glass plate, as shown in the figure. The conductor, which is made of brass, is shown at C D, and it is attached to the upright pillar E by the glass rod R. To the right hand of C, and above B, are seen the points for the receiving the electricity from the machine. From each rubber there proceeds to within a little of the points, a flap or double piece of oiled silk, which prevents the dissipation of the electricity.

As it is difficult to insulate the rubbers of the plate glass machine, without giving it an unseemly appearance, Mr. Cuthbertson introduced the practice of insulating the whole machine by the glass supports G, H, I, K, so that negative electricity can thus be obtained as easily as positive.

83. The cylindrical machine, however, being at present in more common use than the plate machine, it is hoped the following remarks may be of use to those who possess such an instrument, and particularly to such as may be disposed to provide themselves with it for the sake of economy. A cylindrical electrical machine ought never to be less than ten inches in diameter; there are cylinders of six, seven, eight, and nine inches diameter, often neatly mounted, and sold by the philosophical instrument makers, but they are of no manner of use for the purpose of experiment, and serve only as a kind of philosophical toy, for the amusement of children, and that too on a very narrow scale. To construct such machines, therefore, is an absolute waste of the materials. With a cylinder of ten inches, properly managed, a tolerable exhibition may be made, but the most convenient size is from twelve to sixteen, the length of the cylinder being in proportion.

84. The most powerful excitation of the machine is produced as follows:—Let the machine be placed within the influence of a good fire, but not so near as to injure any of its parts by the action of the heat. With a flat round pointed knife spread a little amalgam evenly along the cushion, and return it to its place: turn the cylinder a few times round; then take off the cushion, and observe carefully those parts on its surface that have not been touched by the cylinder while revolving; on these parts put a little more amalgam, and repeat the process of turning the cylinder, and supplying the defective parts with amalgam, till every point of that part of the surface of the cushion which presses on the cylinder appears to be properly supplied with

amalgam. Take now a piece of leather about five or six inches square, and spread over one side of it a quantity of amalgam; throw back the silk flap, and, turning the machine gently round, apply the amalgam side of the leather to the cylinder for the space of two minutes or more, as circumstances may require, during which time the excitation will be observed to increase rapidly. The cylinder must next be wiped perfectly clean with an old silk handkerchief, and afterwards with a soft dry linen cloth. Let the cushion be again removed; and the amalgam which appears above and below the line of contact with the cylinder carefully scraped off, the silk flap wiped with a linen cloth, and the whole returned to its place and made fast. If now the cylinder be turned slowly round, streams of the electric fluid will be seen rushing from the silk flap round the lower part of the cylinder, attended with a hissing and snapping noise, while large brushes of the same, of several inches in length, may be observed flying off from the lower edge of the silk into the surrounding air. The machine is now fit for use, and may be fastened to the table, after which the whole of its parts are to be well wiped with a warm and dry linen cloth to free them from dust.

85. The operator, however, must not expect this high and rich state of excitation to be of long duration. The cylinder will soon cool; dust will be attracted by the action of the machine; and the moisture produced in the air of the room by the breath of his audience, will, by their united effects, render all his efforts to produce a copious supply of electricity entirely fruitless.

86. To remedy this defect, which gentlemen who deliver public lectures on electricity have often found to be a grievous one, provide a box of thin plate iron, ten or twelve inches long, four inches wide, and one inch and a half in depth, with a lid to fit very easily over it. In this box a piece of bar iron of about six inches in length, three in breadth, and half an inch in thickness, after being heated in the fire to a dull red heat is to be placed, the lid of the box put on, and the whole, on a suitable iron stand, placed under the cylinder, on the board of the machine in a longitudinal direction. The radiation of heat from the iron will effectually preserve the equality of the temperature of the surrounding air for a considerable length of time, and indeed for any length of time required, since, by employing two bars of iron, the one may be kept in the fire while the other is in the box, and thus no other interruption in the course of the experiments will be necessary beyond what is occasioned by the changing of the irons. By this means the machine may be made to act in full vigor under the most disadvantageous circumstances.

87. Dr. Brewster mentions a method used by Mr. Ronalds of aiding the excitation of the machine, which he represents as being attended with the greatest advantages. He thus describes it: In the cylinder machine, the rubber is placed in front of a half cylinder of copper, which communicates with a copper pipe, that serves for the support of the rubber. A very small spirit-lamp, whose burner consists of only one thread of cotton, is placed immediately beneath the mouth or lower end of the copper pipe, so as to keep the rubber and the parts adjacent to it always hot and dry. Besides this contrivance, Mr. Ronalds places his prime conductor upon a glass support, so that a similar spirit-lamp may be placed below it in order to convey heat to its interior.

Mr. Ronalds remarks, that a cylinder machine thus constructed, of half the dimensions of one made upon the usual plan, is highly and permanently effective. The same principle may easily be applied to plate machines. The heat is supposed to assist the excitement by promoting the oxidation of the amalgam.

88. This method may certainly, in some degree, prove beneficial; but it will be found to be in many respects inferior to the simple method above mentioned. In the first place, the radiation of heat will be neither so general nor so great; in the second place, the flame of a lamp or a candle absorbs the fluid; and in the third place, the light, which must necessarily be emitted from two spirit-lamps, would prove highly detrimental to the effect of those experiments which require to be performed in darkness. To which may be added, the expense of the lamps, and the spirit to be consumed.

89. Where a plate machine of large dimensions is used, this additional article will not be required; for the great thickness of the glass renders it capable of retaining the heat much longer than can be done by a thin cylinder; for which reason it must be obvious that, if cylinders were made much stronger than they generally are, their action would be effectual for a greater length of time than it is. Opinion, however, runs in favor of thin cylinders, but the consistency of such opinion remains to be shown. It is well known that the old globular machines, which were made of thick glass, when once put in a state of powerful excitation, retain that state much longer than the modern thin cylinder will do under the same circumstances.

90. The following directions for preparing the amalgam for electrical machines are given by Mr. Singer, in his treatise, already mentioned. Melt in an iron ladle two ounces of zinc with one ounce of tin, and, while this mixture is in a fluid state, pour into it six ounces of mercury; let the whole be then put into an iron or wooden box, and agitated until it be quite cold. It must then be reduced to fine powder in a mortar, and mixed with sweet hogs' lard to the consistence of thick paste. This part of the process need not be performed till the amalgam is wanted for use. This amalgam, he remarks, answers exceedingly well, but, he afterwards adds, I have since made it with a still less proportion of mercury with equal effect. The proportions may be two ounces of tin, four ounces of zinc and seven ounces of mercury. The mercury must be heated to about 300° Fahrenheit, before the fused metals are added to it. When thy amalgam has been agitated until cool, and finely powdered, it is to be mixed with hogs'-lard be trituration in a mortar; and should it at any time become hard, more lard must be added and the trituration be repeated.

91. The application of the electrical apparatus to the purpose of experiment will afford the best

illustration of its subordinate parts; and, in adopting this plan, we shall be enabled to give such an arranged view of the chief properties of the electrical fluid as may be of service in aiding the inexperienced electrician in making an orderly display, instead of a series of experiments which have no regular connexion, and in which sometimes one property, and sometimes another, is illustrated. We shall commence with some observations on the action of the machine itself, and for these we must acknowledge our obligation to Mr. Singer.

92. The machine being prepared according to the directions already given, and the cushion pressed moderately against the cylinder by the action of its adjusting screw, it may be put in motion, and the following phenomena will be observed. 1. Distinct lines of light, accompanied by lateral scintillations, pass from one conductor to the other, across that part of the cylinder which is not covered by the silk flap; these are called electrical sparks. 2. Bright sparks pass between either of the conductors and the knuckle, or any smooth uninsulated substance presented to them at a moderate distance; and if received on the knuckle, or any part of the body, produce a painful sensation. 3. These effects are more distinct, and the sparks from each conductor stronger, when they are taken from both at the same time. 4. The power of the spark from either the positive or negative conductor, singly, will reach its maximum when the opposite conductor is uninsulated, by suspending a chain or wire from it to the ground. 5. If the two conductors are connected by a wire, or other conducting substance, the most vigorous friction of the cylinder will not electrify either. 6. If, instead of a wire, the conductors are connected by a silk string on which a number of shot or metal beads are strung, at the distance of a twentieth of an inch from each other, a series of bright sparks will pass between the beads as long as the turning of the machine is continued. It must be remembered, that the conductor to which the cushion is fixed shows the electrical phenomena of the cushion, and the opposite conductor, that of the electricity of the glass cylinder; hence the observation of their phenomena is properly an observation of the circumstances that occur in all cases when electricity is excited by friction.

93. On these very beautiful phenomena, Mr. Singer makes the following judicious observations. The first and second phenomena seem to show that the cause of electricity is corporeal; for sensation is affected by it, and a mechanical impulse experienced, which it is difficult to ascribe to any other than a material cause. The third phenomenon proves that there is a mutual action between the electricities excited in the opposite conductors; since their effects are more powerful when directed at the same time to one conducting body. The fourth phenomenon shows that the same relation which is observed between the opposite electrified conductors exists also between either of them and the ground, but in a different degree. By the fifth phenomenon it is seen that positive and negative electricity, if excited to the same extent, and united by conducting matter, exhibit no electrical phenomena. The sixth phenomenon is observed to show that when the conductors are connected, the machine continues to excite electricity, but is prevented from displaying it by their mutual contact.

94. From these appearances the following explanation of electrical phenomena may be deduced:—1st. The cause of electrical phenomena is material, and possesses most of the properties of an elastic fluid. 2. This electric fluid attracts and is attracted by all other matter, and, in consequence of such attraction, exists in all known substances. 3d. The attraction of different bodies for the electric fluid is various, so also is that of the same body under different circumstances, consequently the quantity of electricity naturally existing in different substances may be unequal; and the same body may attract more or less than if alone, when combined with other matter: but its original attraction will be restored by destroying the artificial combination. 4th. From some peculiarity in the nature of the electric fluid, its attraction for common matter is more influenced by figure than by substance; and consequently is stronger in extensive than in limited surfaces. 5th. From this peculiarity, it moves with great facility over the surface, or through the substance of some bodies, and is arrested in its progress by others. 6th. When the attraction of any substance for electricity is equal to the electric fluid it contains, that substance will evince no electrical signs; but these are produced when there is either more or less electricity than is adequate to the saturation of the existing attraction: if there be more, the signs will be positive; if less, they will be negative.

95. Electrical excitation then, may be thus effected:—The bodies employed have each a certain quantity of the electric fluid proportioned to their natural attraction for it; this they retain, and appear unelectrified so long as they remain in their natural state. And, if two such bodies are brought in contact, their natural attractions will be altered, one of them attracting more than in its separate state, and the other less; the electric fluid thus diffusses itself amongst them in quantities proportioned to their relative attractions, and hence they appear unelectrified. But if they are suddenly separated, the new distribution of the electric fluid remains, whilst the original attractions are restored, and as these are not equal to each other the bodies will appear electrical; that of which the natural attraction was increased by contact, having received an addition to its quantity of electric fluid, will be positively electrified; and the other will be negative.

Attraction and Repulsion.

96. The motion of light bodies produced by electricity, is usually called attraction and repulsion, and is occasioned by the mutual attraction existing between the electric fluid and common matter. In practical electricity there are numerous methods of illustrating this motion; the following are some of the principal.

(1). Fix at the end of the prime conductor a knobbed rod, and hang on it two small pith-balls, suspended by threads of equal length. The

balls will now touch one another, the threads hanging perpendicularly, and parallel to each other. But if the cylinder of the machine be turned, by turning the winch, then the pith balls will repel one another, more or less according as the electricity is more or less powerful. If the electrometer be hung to a prime conductor negatively electrified, i. e. connected with the insulated rubber of the machine, the balls will also repel each other. If, in this state of repulsion, the prime conductor is touched with some conducting substance not insulated, the pith balls will immediately come together. But if, instead of the conducting substance, the prime conductor is touched with an electric, as a stick of sealing wax, a piece of glass, &c., then the pith balls will continue to repel each other; because the electric fluid cannot be conducted through that electric.

(2.) Take a small downy feather or a pith ball suspended by a thread, and, holding the thread, bring the ball near an electrified conductor, either positive or negative: the ball will be attracted by the electrified conductor, and adhere to it, until its electricity is destroyed.

Such bodies as are positively electrified, tend to diffuse their superabundant fluid amongst surrounding substances; and those that are negative, endeavour to acquire electric fluid: hence, either state of electricity will produce attraction; for if light bodies are to be moved, it is indifferent whether the electrified surface attracts their natural electric fluid, or the matter to which it is attached; for the attraction arises only from the different proportions of these in any two bodies, and will of course continue whilst that difference exists.

(3.) Repeat the preceding experiment with a ball or feather supported by a silk thread: the light body will first be attracted to the electrified conductor, and will then recede from it; nor can it again be brought in contact until it has touched some conducting substance. Mr. Singer thus explains the cause of this:—The light body is here attracted for the same reason as before, but it is insulated, and consequently receives, by contact with the electrified surface, a similar electric state; it therefore recedes from that surface, being attracted by the ambient air, or other surrounding bodies; for they have their natural portion of electricity, and therefore differ from the light body, which has either more or less; but the electrified surface does not differ from the light body, and consequently cannot attract it, till, by touching some conductor, its natural electric state is restored.

(4.) The following is a very pleasing variety of the last-mentioned experiment.—Take a glass tube, whether smooth or rough is not material, and, after having rubbed it, let a small light feather be let out of your fingers at the distance of about eight or nine inches from it. This feather will be immediately attracted by the tube, and will stick very close to its surface for about two or three seconds, and sometimes longer; after which it will be repelled; and, if the tube be kept under it, the feather will continue floating in the air at a considerable distance from the tube, without coming near it again, except it first touch some conducting substance; and, if the tube be managed dexterously, you may drive the feather through the room at pleasure. This experiment may be varied as follows: A person may hold in his hand an excited tube of smooth glass, and another may hold an excited rough glass tube, a stick of sealing-wax, or any other electric negatively electrified, at about one foot and a half distance from the smooth glass tube; a feather now may be let go between these two differently excited electrics, and it will leap alternately from one electric to the other.

(5.) Place a leaf of gold, silver, or other metal, on the palm of the hand, and bring it within a few inches of an electrified conductor; it will be attracted and continue to move, alternately from the hand to the conductor, as long as the latter is electrified.

(6.) Suspend from the conductor, by a brass chain, a circular plate of copper, reaching to within an inch and a half or two inches of the table. Directly under this plate place another of the same form, and a little larger, on the table. Turn the machine, and the fluid will pass from the upper to the lower plate. If now small figures cut out of pasteboard, or pith of elder, be introduced between the plates, they will dance about with apparent vivacity, and sometimes appear to course round the edge of the lower plate. This experiment is represented by fig. 4.

(7.) The electrical bells furnish a pleasing illustration of the attraction and repulsion of the electric matter. They are variously constructed, but the form exhibited fig. 5 is the simplest. The two outer bells are suspended by brass chains; the middle bell and the two clappers by fine silk threads. When the bells are attached to the conductor, and the machine is turned very gently, the fluid will pass along the chains to the two outer bells, but will not pass along the silk to the clappers and middle bell. Thus the outer bells being charged with an extra quantity of fluid will attract the clappers, but the moment they touch the bells they become charged, and are repelled with such force as to cause them to strike against the middle bell, on which they deposit their electricity, and are again attracted. By this means a constant ringing is kept up while the machine is turned. From the inside of the middle bell a brass chain passes to the table, for the purpose of conveying away the fluid deposited on it by the clappers. A more elegant form of the electrical bells is thus made:—Fix eight bells near the edge of a circular board supported on four feet, fig. 6, having a glass pillar *e*, in the centre, terminated by a point *g*. On this point place the pointed wires used in the last experiment, hanging from one of them, as *d*, a small glass clapper by a silken thread; and connecting the apparatus by a chain *h*, proceeding from the prime conductor. On setting the machine in motion, the wire will move round, and the clapper ring the bells.

(8.) Place a pointed wire on the machine, electrify the inside of a dry glass tumbler by holding it over the wire whilst the machine is in motion; place some pith balls on the table and cover them with the electrified glass; they will be

alternately attracted by it and the table, and continue their motion for some time. See fig. 7. An instrument is constructed on purpose for this experiment, by which the dancing of the balls may be kept up for any length of time, as it may be connected with the conductor.

(9.) Insulate a circular ring of brass so as to stand about an inch and a half from the flat surface of a table; connect the brass ring with the conductor of the electrical machine, and place within it on the table, a very light and round glass ball of two inches diameter; the ball will be attracted by the ring, touch it, and become electrified at the point of contact; this point will then recede and be attracted by the table, whilst another part of the ball is attracted by the ring; and, by the repetition of this process, the ball is made to revolve and travel round the circumference of the ring.

(10.) Fasten a small piece of sealing-wax on the end of a wire, and set fire to it. Then put the electrical machine in motion, and present the wax, just blown out, at the distance of a few inches from the prime conductor. A number of very fine filaments will immediately dart from the sealing-wax to the conductor, on which they will be condensed into a kind of net-work, resembling wool.

If the wire with the sealing-wax be fixed into one of the holes of the conductor, and a piece of paper be presented at a moderate distance to the wax, just after it has been ignited, on putting the machine in motion, a net-work of wax will be formed on the paper.

If the paper on which the wax is thus received be gently warmed, by holding the back of it near the fire, the wax will adhere to it, and thus the result of the experiment will be rendered permanent. A remarkably fine experiment of the same kind may be made with camphor. Let a silver spoon containing a piece of lighted camphor be made to communicate with an electrified body, as the prime conductor of a machine; while the conductor continues electrified, by keeping the machine in motion, the camphor will throw out numerous ramifications, and appear to shoot like a vegetable.

(11.) Take about a dozen of flaxen threads and tie them together at top and bottom; annex them to the conductor of the electrical machine; when electrified the threads will separate from each other, and the knot at the bottom rising they will assume a spheroidal figure, which will continue as long as they are electrified.

(12.) The following experiment we give as being one of the earliest made by Dr. Franklin in illustration of the principle of attraction and repulsion. Fig. 8 represents an electric jar, having a wire C D E fastened on its outside, which is bent so as to have its knob E as high as the knob A. A is a spider made of cork, with a few short threads run through it to represent its legs. It is fastened at the end of a silk thread, proceeding from the ceiling of the room, or from any other support, so that it may hang mid-way between the two knobs A and E, when the jar is not charged. Let the place of the jar upon the table be marked; then charge the jar, by bringing its knob A in contact with the prime conductor, and replace it in its marked place. The spider will now begin to move from knob to knob, and continue this motion for a considerable time, sometimes for several hours. The inside of the jar being charged positively, the spider is attracted by the knob A, which communicates to it a small quantity of electricity; the spider then becoming possessed of the same electricity with the knob A, is repelled by it, and runs to the knob E, where it discharges its electricity, and is then attracted by the knob A, and so on. Thus the jar is gradually discharged; and, when the discharge is nearly completed, the spider finishes its motion.

Effect of Points on the Electric Fluid.

97. The facility with which pointed bodies transmit electricity has given rise to several very delicate and beautiful experiments on the electrical apparatus, of which the following are the most deserving of attention.

(1.) *The Electrical Flies.*—These flies are composed of small brass wires, fig. 9, fixed into a cap of brass, easily moveable upon an axis of the same metal, and exactly balanced, so that they may turn with the smallest force. The ends, which ought to be very sharp, are all bent one way, with regard to one another, as those belonging to *a*, *b*, in the figure; though the two sets of points, constituting the two flies there represented, are contrary to each other; so that the whole flies must have a contrary motion. Fixing the axle with the two flies upon the prime conductor, and working the machine, both will begin to turn very swiftly, each in a direction contrary to that of the points. In this manner, with a powerful machine, several flies may be made to turn either in the same or in contrary directions; and by their gradual increase or decrease in size may represent a cone or other figure; for the course of each will be marked by a line of fire, and thus the whole will exhibit a beautiful appearance in the dark. The light is more brilliant when the ends are slightly covered with sealing-wax, grease, or other electric matter. The flies, in this experiment, turn the same way whether the electricity be positive or negative; the reason of which is that in positive electricity the fluid issues from the body electrified, and that in negative electricity it enters into it. In the former case, the recoil of the fluid, which acts equally on the air and on the point from whence it issues, must continually urge the point the contrary way; and in negative electricity, when the point solicits a continual draught of electric matter from the air, the direct impulse of the former must also produce a motion in the point in the course in which the fluid itself moves. In vacuo no motion is produced; because there is no air on which the fluid may act when it issues from the point.

(2.) *The Electrical Orrery*, fig. 10, is another instrument frequently used for showing the effect of points in the transmission of the electric fluid. The principle of its action is this: the ball S represents the sun, E the earth, and M the moon, connected by wires *a c* and *b d*; *b* is the centre of gravity between the earth and moon. These three balls and their connecting

wires are hung and supported on the sharp point of a wire A, which is stuck upright in the prime conductor B of the electrical machine; the earth and moon hanging upon the sharp point of the wire *c a c*, in which wire is a pointed short pin, sticking out horizontally at *c*; and there is just such another pin at *d*, sticking out in the same manner, in the wire that connects the earth and the moon.

When the cylinder of the electrical machine is turned, these balls and wires are electrified; and the electrical fire, flying off horizontally from the points *c* and *d*, causes S and E to move round their common centre of gravity *a*, and E and M to move round their common centre of gravity *b*. And as E and M are light, when compared with S and E, there is much less friction on the point *b*, than S and E make about the point *a*. The weights of the balls may be adjusted so, that E and M may go twelve times round *b*, in the time that S and E go once round *a*.

(3.) *The Electrical Inclined Plane* affords another and a still more beautiful illustration of the same thing, showing also that a stream of the electric matter issuing from points possesses force sufficient to counteract the power of gravitation in light bodies. Fig. 11 represents the inclined plane, where A is a board of mahogany, fourteen inches long and four inches broad; BBBB are four glass pillars, three-tenths of an inch in thickness; the length of the two longer is seven inches, and that of the two shorter is five inches.

From the longer to the shorter pillars are stretched two fine brass wires, parallel to each other, and tightened by screws which pass through the brass balls which surmount the pillars. On these wires the axis of the fly C rests, the ends of which are formed like a small pulley, having a groove in them to prevent their slipping off the wires, and to guide the fly when in action. It is obvious that, if the fly be placed on the upper part of the wires, it will roll down them by its own gravity; but when it has reached the bottom of the plane, if the upper end of the wires be connected with the machine while in action, the escape of the fluid from the points will cause it to roll very rapidly up the plane till it reach the top of it. These experiments may be varied to a great extent, and models of corn-mills, water-pumps, astronomical clocks, &c., constructed of cork and pasteboard, are readily put in action by directing against their main wheels a stream of electricity from a strong pointed wire inserted into the prime conductor.

(4.) By a fine flaxen thread attach a large downy feather to the prime conductor of the machine; turn the cylinder gently round, and the fibres of the feather will repel each other; approach it with a brass ball, or with the closed hand, and it will endeavour to turn itself towards the ball or hand; but present a pointed wire to it, and it will instantly shrink from it back on the conductor, as if animated, which arises from its being suddenly deprived of its electricity by the point. This experiment may be varied by inserting the brass stem of fig. 12, into one of the holes in the prime conductor. The action of the machine will cause the hairs on the head to diverge from each other, and to stand on end.

98. Such, says Mr. Singer, are the principal phenomena of motion produced by the action of electricity; they are susceptible of almost unlimited variety, but uniformly result from the simples already stated, namely, the attraction of the electric fluid for common matter, its tendency to equal diffusion; and the occasional interruption of these properties by non-conducting power and altered force of attraction.

Luminous Exhibition of Electricity.

99. It may be necessary to observe here that all experiments made for the purpose of displaying the brilliancy of the electric matter, in passing from one conducting substance to another, should be made in a darkened room, as the presence of either natural or artificial light robs them of more than half of their beauty. The articles of apparatus, too, must be all free from dust, and perfectly dry, besides being a little warm, otherwise the effect expected will not result; we think it particularly necessary to observe that in any experiment requiring the exhaustion of glass vessels the above precautions are peculiarly needful, as we have seen some of the following experiments utterly fail in the hands of public lecturers merely from inattention to them.

100. To render the electrical fluid luminous it must be collected in considerable quantities, and the brilliancy of the display will depend on the particular configuration of the conducting surface over which it is made to pass. The light evolved in ordinary cases, says Mr. Singer, extends only to faint flashes and scintillations, sparks being only produced when these effects are concentrated, as they are in the electrical machine by the action of its conductors.

101. There are three circumstances that influence the electric spark in its passage from one conductor to another, namely, the form of the conductors, their extent, and the nature and density of the medium through which the spark passes. The following remarks on these three circumstances we give nearly in Mr. Singer's own words.

102. The distribution of electricity on conductors has but little relation to their solid contents, and depends almost entirely on extent of surface, for the same effects are produced by the thinnest cylinder or sphere of metal as by the most compact solid body of the same form and dimensions; it is probable that the action of insulated conductors consists in the ready communication of their electric state to the contiguous surface of the extensive stratum of air by which they are surrounded, and to the facility they present to the discharge of that electrified stratum when an uninsulated or differently electrified body is brought near them; for every positively electrified conductor is surrounded by a positive atmosphere, and every negative conductor with a negative atmosphere whose densities decrease as the square of their increased distance. Hence any insulated electrified body will retain its electrical state until its intensity is sufficient to

overcome the resistance of the air, and the greater or less interval through which the spark passes is called the striking distance.

103. When the surface of the conductor is uniform, the re-action of the air around it is also uniform; but if the surface of the conductor be irregular, the tendency of the electric fluid to escape or enter it will be greatest at the most prominent parts, and most of all when these are angular or pointed. To understand this it is only necessary to recollect that every electrified conductor is surrounded by an atmosphere of its own figure, the contiguous surface of which is similarly electrified: and that electricity is not transmitted through air, but by the motion of its particles.

104. For this motion of particles is resisted by a uniform surface from the similar action of the air around it, which is all equally capable of receiving electricity, and cannot tend to distribute it in one direction more than another; the immediate electrical atmosphere of the conductor will be therefore resisted in any attempt to recede from it by a column of air which is equally opposed in every part; but if there be any prominent point on the conductor projecting into the atmosphere, it will facilitate the recession of the electrified particles opposite to it by removing them farther from the electrified surface, and opposing them to a greater number of such as are unelectrified.

105. The action then, of bodies that are pointed or angular, appears to consist in promoting the recession of the particles of electrified air, by protruding a part of the electrical atmosphere of the conductor into a situation more exposed to the action of the ambient unelectrified medium, and thereby producing a current of air from the electrified point to the nearest uninsulating body. Hence the most prominent and the most pointed bodies are such as transmit electricity with the greatest facility, for with them this condition is most perfectly obtained.

106. A spherical surface is that which, considered with regard to its surrounding atmosphere, is most uniform; hence balls, or cylinders, with rounded ends, are naturally employed for insulated conductors, and their magnitude is proportioned to the intensity of the electrical state they are intended to retain; for a point is but a ball of indefinite diameter, and will act as such on very small quantities of electricity; and a ball of moderate size may also be made to act as a point by electrifying it strongly.

107. If two spheres of equal size are connected together by a long wire and electrified, their atmospheres will extend to the same distance, and they will of course have respectively the same intensity; but if the spheres be of unequal size, the atmosphere of the smallest will extend furthest, and it will necessarily have the greatest intensity; so that a longer spark can be drawn from a small ball annexed to the side of a conductor than from the conductor itself, and longer in proportion as the ball projects farther from the side. Hence the finer the point, and the more freely it projects beyond any part of the conductor to which it is annexed, the more rapidly will it receive or transmit electricity.

108. Let, for example, a fine point be fixed in the axis of a large brass ball, from beneath the surface of which it may be protruded more or less by the action of a fine screw, the effect of a ball of any size may be obtained; when beneath the surface of the ball the point does not act, but in proportion as it is protruded it increases the transmitting power, and, if projected far enough, at length entirely overcomes the influence of the ball.

109. The same writer gives the following experiments, among others, for illustrating the influence of the form and extent of the conductor on the appearance of the electric spark.

(1.) Present a brass ball of about three inches in diameter to the positive conductor of a powerful electrical machine; sparks of brilliant white light will pass between them, accompanied by a loud snapping noise: to produce these sparks in rapid succession the ball must be brought near the conductor, and they then appear perfectly straight.

(2.) Annex a ball of an inch and a half or two inches diameter to the conductor, so as to project three or four inches from it; present the large ball to this, and much longer sparks will be obtained than from the conductor itself, but they will be less brilliant and of a zigzag form.

(3.) Substitute a small ball for that used in the former experiment; the fluid will now pass to a greater distance, but in the form of a divided brush of rays, faintly luminous, and producing little noise; this brush will even occur with larger balls, if the machine be very powerful; it is most perfect when procured by presenting a flat imperfect conductor, as a piece of wood or paper.

(4.) Whilst a current of sparks is passing between a large ball and the conductor, present, at the distance of about an inch and a half, a sharp point at double that distance, and the sparks will immediately cease, the electric matter being silently drawn off by the point.

110. The brilliancy of the electric spark is always in proportion to the conducting power of the bodies between which it passes; hence metals are almost exclusively employed for this purpose, as wood and other imperfect conductors produce only faint red streams; yet these substances act as points with some efficacy, and the particles of dust which collect around the apparatus are often troublesome to electricians from the same cause.

111. The nature and density of the medium through which the electric spark passes has also a powerful influence on its character. Dr. Watson seems to have been the first who made experiments on this subject; these he conducted on a very large scale, and he describes the results as having been very beautiful; they will be noticed in another part of this article.

112. The following is a description of the simple apparatus used by Mr. Singer for showing the effect of different gaseous mediums on the passage of electricity. It consists of a glass globe, fig. 1, plate II., of about four inches diameter, having two necks capped with brass; to one of the necks a stop-cock is screwed, with a wire and ball projecting into the globe; another

ball is attached to a wire that slides through a collar of leathers screwed to the opposite cap, so that the balls may be set at any required distance from each other within the globe. This apparatus may be exhausted by connecting the stop-cock with an air-pump, and various gases may be introduced into it, or the air it contains may be rarefied or condensed, and the effect of these processes on the form of the spark examined. In condensed air the light is white and brilliant; in rarefied air, divided and faint; and in highly rarefied air, of a dilute red or purple color. The effect of gases seems to be proportioned to their density; in carbonic acid gas the spark is white and vivid, in hydrogen gas it is red and faint.

113. The brilliancy of the electric spark seems to be in proportion to the density of the medium through which it is made to pass. This is proved by the following experiments:—1. Fix with cement a short iron or platina wire within one end of a glass tube thirty inches long, so that the wire may project a little way within the tube, and fix a small brass ball on the outer extremity of the wire. Fill the tube with mercury, and at the open end place a drop of ether, which secure by the point of the finger while the tube is inverted in a vessel of mercury, so as to form a Torricellian vacuum in the upper part. The ether will rise to the top; and upon the removal of the finger, and the fall of the mercury, will expand into vapor. If now electricity be transmitted through this vapor, it will be rendered luminous, and assume various hues according to its strength. When the spark is strong, and has to pass through some inches of the expanded vapor, the light is usually of a beautiful green color. 2. Take an air-pump receiver twelve or fourteen inches high, and six or seven inches in diameter; adapt a wire, pointed at its lower extremity, to the top of the receiver, letting the point project about two inches into its inside; place the receiver on the plate of the air-pump, and electrify the wire at its top positively; whilst the air remains in the receiver, a brush of light of very limited size only will be seen, but in proportion as the air is withdrawn by the action of the pump it will enlarge, varying its appearance and becoming more diffused as the air becomes more rarefied; until at length the whole of the receiver is filled by a beautiful blush of light, changing its color with the intensity of the transmitted electricity. 3. Into a piece of soft deal about three inches long and an inch and a half square, insert two pointed wires obliquely into its surface at nearly an inch and a half distance from each other, and to the depth of an eighth of an inch; the wires should incline in opposite directions, and the track between the points be in that of the fibres; a spark in passing from one point to another through the wood will assume different colors in proportion as it passes more or less below the surface; and by inserting one point lower than the other, so that the spark may pass obliquely through different depths, all the prismatic colors may be made to appear at once. Sparks taken through balls of wood or ivory appear of a crimson color; those from the surface of silvered leather are of a bright green; a long spark taken over powdered charcoal is yellow; and the sparks from imperfect conductors have a purple hue. The quantity of air through which these sparks are seen also influences their appearance; for the green spark in the vapor of ether appears white when the eye is placed close to the tube, and reddish when it is viewed from a considerable distance.

114. When metallic conductors are of sufficient size and perfectly continuous, they transmit electricity without any luminous appearance; but if the continuity be interrupted in the slightest degree a luminous effect is produced, a bright spark occurring at every separation. Various articles of apparatus are used for the exhibition of this effect, according to the fancy of the operator; the following are those used in general by public lecturers:—1. The spiral tube: this instrument is represented by fig. 2, and is composed of two glass tubes C D, one within another, and closed with two knobbed brass caps A and B. The innermost of these has a spiral row of small round pieces of tin-foil stuck upon its outside surface, and lying at about one-thirtieth of an inch from each other. If this instrument be held by one of the extremities, and its other extremity be presented to the prime conductor, every spark that it receives from the prime conductor will cause small sparks to appear between all the round pieces of tin-foil stuck upon the innermost tube; which in the dark affords a beautiful spectacle, the tube appearing encompassed by a spiral line of fire. Fig. 3 represents several spiral tubes placed round a board, in the middle of which is screwed a glass pillar, and on the top of this pillar is cemented a brass cap with a fine steel point. In this a brass wire turns, having a brass ball at each end, nicely balanced on the wire. To make use of this apparatus, place the middle of the turning wire under a ball proceeding from the conductor, so that it may receive a succession of sparks from the ball; then push the wire gently round; and the balls in their relative motions will give a spark to each tube, and thereby illuminate them down to the board, which from its brilliancy and rapid motion, affords a most beautiful and pleasing sight. Fig. 4 is another instrument for showing the same effect in a diversified form: the action being in this case the same as in the preceding, no further explanation is necessary. The beauty of this kind of exhibition is sometimes much increased by laying down the devices on glass stained of different colors. There are other methods of rendering the electric fluid visible in a very pleasing manner, some of which we shall here enumerate.

115. The luminous conductor, as represented at fig. 5, consists of a glass tube about eighteen inches long, and four in diameter, to the ends of which are cemented the hollow brass pieces D F, E B, the former having a point, C, for receiving electricity from the electrical machine, while the other has a wire terminating in a ball, G, from which a strong spark may be drawn. From each piece a knobbed wire proceeds within the cavity of the glass tube. One of these brass pieces is composed of two parts, in one of which is a valve covering a hole by

which the tube may be exhausted of its air. The whole is supported on two glass pillars fixed in a wooden frame. When this tube is exhausted of its air, and the point C set near the machine, this point will appear illuminated with a star, while the glass tube will exhibit a weak light on its inside; and, from the knobs within the glass, the appearance of positive and negative light will be evident, as the knob at D will show a bright pencil of rays, and the opposite knob a round star. If the point C, instead of being presented to the cylinder, or the positive conductor, be placed near the rubber or negative conductor, the appearance of the light from the internal knobs will be reversed.

116. The visible electrical atmosphere is exhibited by the apparatus represented at fig. 6, where G I represents the receiver with the plate of an air-pump. In the middle of the plate I F a short rod is fixed, having at its top a ball B, whose diameter is nearly two inches. From the top of the receiver another rod A D with a like ball A proceeds, and is cemented air-tight into the neck C; the distance of the balls from one another being about four inches. If, when the receiver is exhausted of air, the ball A be electrified positively, by touching the top D of the rod A D with the prime conductor, or an excited glass tube, a lucid atmosphere appears about it, which, although it consists of a feeble light, is yet very conspicuous, and very well defined; at the same time the ball B has not the least light. The atmosphere does not exist all round the ball A, but reaches from about the lower half of it. If the rod, with the ball A, be electrified negatively, then a lucid atmosphere, like the above described, will appear upon the ball B, reaching from its middle to a small distance beyond that side of it that is towards the ball A; at the same time the negatively electrified ball A remains without any light.

117. Fig. 7 represents a mahogany stand, so constructed as to hold three eggs at a greater or smaller distance, according to the position of the sliding pieces. A chain C is placed at the bottom, in such a manner as to touch the bottom of the egg at B with one end, and with its other the outside coating of a charged jar. The sliding wire A at the top is made to touch the upper egg; and the distance of the eggs asunder should not exceed a quarter or the eighth part of an inch. The electric spark, being made to pass down by means of the discharging rod through the wire and ball at A, will, in a darkened room, render the eggs very luminous.

Accumulation of Electricity.

118. Although the electricity we have already described be sufficient for the performance of many very fine experiments, and for enabling us to investigate the nature and properties of the electric fluid; yet the full energy of this wonderful agent can only be displayed when it is collected in great quantities, and made to operate on substances in a strongly concentrated state. This, it might be supposed, would be best effected by diffusing the electrical matter over very extensive conductors, and at once discharging the quantity thus accumulated, on the subject of experiment: but such is not the case, since the extension of the surface of any conducting body diminishes its intensity. This fact is admirably illustrated by Mr. Singer in the following experiment.

119. Insulate a flat metal plate with smooth rounded edges, and connect with it a pith-ball electrometer; electrify the plate, and the balls will diverge: bring a similar plate uninsulated near that which is electrified, keeping their flat surfaces parallel and opposite to each other; the balls of the electrometer gradually collapse as the plates approach, and, when they are within about half an inch of each other, the insulated plate appears unelectrified; but, on the removal of the uninsulated plate, the original divergence is restored. See fig. 8.

120. When the insulated conductor, he adds, is electrified, its pith-balls separate, because they are in a different electrical state to the air by which they are surrounded, the fluid of which they attract; but all unelectrified bodies have the same relation to the electrified balls like the ambient air, and such as are conductors and connected with the ground present a more ample source of matter and electricity; consequently, if such bodies are brought near the electrified conductor, its attraction is exerted on them, and the influence of the surrounding air is proportionably diminished; and if the proximity be sufficient, the attraction of the electrified surface will be so exclusively exerted in that direction as to be imperceptible in any other.

121. In the above experiment the bodies are not brought in contact, but only near each other, and consequently there is no communication or loss of electricity, but merely a compensation of its attractive power; hence, when the uninsulated plate is removed, the divergence of the electrometer is restored.

122. The grand instrument used by electricians for the accumulation of electricity is denominated the Leyden jar, or phial: its construction has already been in some measure described, but it may be necessary still further to explain it, and to make some remarks on the principle of its action.

123. *The Leyden Jar* in whatever form it may be constructed is nothing more than an electric placed between two non-electrics. The following description of this remarkable instrument is from Mr. Cavallo's treatise on electricity. If, says he, to one side of an electric, sufficiently thin, as for instance a pane of glass, a piece of sealing-wax, &c., be communicated one electricity, and to the opposite side the contrary, that plate in that case is said to be charged; and the two electricities can never come together except a communication of conducting substances be made between both sides, or the electric be broken by the power of electric attraction. When the two electricities of a charged electric are by any means united, and therefore their power destroyed, that electric is then said to be discharged and the act of union of these two opposite powers is called the electric discharge.

124. To avoid the difficulty of communicating electricity to an electric plate, it is customary to coat the sides of it with some conducting sub-

stance, as tin-foil, gilt paper, &c., by which means the charging and discharging becomes very easy; for when the electricity is communicated to one part of the coating, it is immediately spread through all the parts of the electric that are in contact with that coating; and, when the electric is to be discharged, it is sufficient to make a conducting communication between the coatings of both sides, to discharge entirely the electricities of that electric.

125. When plates of glass are thus coated, it is of essential importance that the glass should extend two or three inches beyond the metal coatings; for, although they do not absolutely touch one another, yet, when they are electrified, the electricity will easily force a passage through the air, and by passing over the surface of the electric, from one coating to the other, render it incapable of receiving any charge.

126. If a glass plate be properly coated on both sides with a conducting substance, and if to one of these coatings be communicated some electricity, the other coating, while communicating with the earth, or with other conducting bodies, acquires by itself an equal quantity of the contrary electricity; but if, while one side is acquiring electricity, the opposite side does not communicate with the earth, or the conducting substances, the glass cannot be charged. The reason of this is founded on the property of bodies to acquire an electricity, contrary to that possessed by a contiguous electrified body; and the cause that hinders these two electricities from mixing, is the interposition of the glass plate which is impermeable to electricity. Although if the glass be too thin, or the charge too high, the strong attraction, between the positive and negative electricities, forces a passage through the glass and discharges it.

127. The most usual, and by far the most convenient form of the Leyden jar is that represented at fig. 9. It is coated on the inside and also on the outside with tin-foil to within two inches and a half of the top. With the inside coating a wire is connected which rises through a lid of baked wood neatly fitted into the mouth of the jar, and terminating in a smooth brass ball. The uncoated part of the jar must be kept perfectly clean and dry, otherwise the action will be very incomplete. The coating is best fastened on with very strong gum water, but some electricians use common paste; and in some instances the tin-foil is first pasted upon paper, and afterwards on the glass: this is considered an improvement both as it respects the facility of drying the gum or paste, and also the strengthening of the jar.

128. If a jar thus constructed be held in one hand by the lower part, and the knob applied to the prime conductor when the machine is in action, it will become charged in a few seconds; and if then a communication be formed between its outside and inside coatings, by touching the ball with the other hand, a smart explosion takes place, and a peculiar and painful sensation is felt chiefly at the wrists and elbows, and across the breast: this sensation is called the electric shock, and it may be communicated to any number of individuals, holding each other by the hand and forming the line of communication between the coatings of the jar. In this way the abbé Nollet succeeded in giving the shock to 180 of the French Guards in the king's presence.

129. When it is wished to discharge the jar without allowing the charge to pass through the body, an instrument is used called the discharging rod, which is composed of a bent wire or two branches, connected by a joint, and furnished with a glass handle. The extremities of the rod or branches are pointed, but have screws, by means of which they are fitted with balls. In discharging a jar with this instrument, it is held by the glass handle, and, while one end is applied to the outer coating of the jar, the other is made to approach the ball of its wire, and thus the electricity passes through the metallic part of the discharger from the one coating to the other of the jar. If the extremities be without their balls the discharge is effected without noise, but otherwise there takes place an explosion, more or less loud according as the jar is more or less charged. The neatest form of the discharging rod is that represented at fig. 10; where AA is the glass handle by which it is held, and BC are the two branches with their balls.

130. When the accumulation of great quantities of electricity is required, the instrument then made use of is termed the electrical battery, and is composed of a number of Leyden jars connected together and placed in an appropriate box. The most modern construction of the battery, is represented at fig. 11. It consists of twelve jars placed in a mahogany box, the bottom of which is covered with tin-foil, for the purpose of connecting together all the outside coatings; the inside coatings being connected together by the wires and balls that rise from their centres, and are united together at the top. On one side of the box there is a small brass hook A for the purpose of connecting the battery by means of a chain with any substance through which the discharge is to be made; this hook passes through the box and is fixed in contact with the tin-foil which connects the exterior coating of the jars.

131. A battery may also be constructed by a combination of panes of glass properly coated. Dr. Franklin formed a battery of this kind with eleven panes of common window-glass, and with it he made the greater part of his experiments.

132. In whatever form batteries are constructed they are charged and discharged in the same manner as a single jar. If one of the knobs of the battery communicate with the prime conductor of the machine in a state of action, it will soon be charged; and the discharge may be effected by making a communication between the coatings, by means of a discharging rod, or any other conductor.

133. Batteries of great size have been constructed by different electricians, so as to accumulate an enormous quantity of electricity, capable of melting the hardest metals, and of putting an instantaneous termination to animal life. Dr. Priestley constructed a battery consisting of sixty-four jars, and containing thirty-two square feet of coated surface. Mr. Cuthbertson completed, in 1784, for the Teylerian Museum at Haarlem, a battery of 135 jars and 132 feet

of coated surface; and in 1789 he completed another battery for the same institution, consisting of 100 jars, and containing 550 feet of coated surface.

134. It is of the utmost importance that a practical electrician should be expert in constructing batteries, and in coating jars himself, not only because of the expense attending the employment of others, but because they may often be at too great a distance from workmen who are accustomed to operations of this kind. A difference of opinion exists with respect to the size of the jars and the kind of glass they are to be made of. Fine flint or crystal glass may be used with greater advantage than any other; but the expense becomes a very considerable object, especially as the jars of a battery are very apt to break by the inequality of their strength; for the force of the fluid in a battery is equally distributed among all the bottles, however their capacities may differ. Thus, if we express the quantity of charge which one jar can easily receive by the number 10, we ought not to combine such a jar in a battery with another whose capacity is only 8; because the whole force of electricity expressed by 10 will be directed also against that the quantity of which is only 8; so that the latter will be in danger of being broken. It will be proper, therefore, to compare the jars with one another before putting them together in a battery.

135. Besides the consideration of the absolute capacity which each jar has of receiving a charge, the time which is taken up in charging it must also be attended to; and the jars of a battery ought to be as equal as possible in this respect as well as in the former. The thinner a glass is, the more readily it receives a charge, and vice versa; but it does not follow that, on account of its thickness, it is capable of containing a greater charge than a thicker one. The reverse is actually the case: and though a thick glass cannot be charged so quickly as a thin one, it is nevertheless capable of containing a greater power of electricity. If the thickness of the glass be very great, no charge can, indeed, be given it; but experiments have not yet determined how great the thickness must be which will prevent any charge. Indeed it is a fact, that, though a thick glass cannot be charged by a weak electric machine, it may be so by a more powerful one; whence it seems reasonable to suppose, that there is no real limit of this kind; but that if machines could be made sufficiently powerful, glasses of any thickness might be charged.

136. The expense of constructing large batteries is an object of great importance, and has led some electricians to devise a cheaper method of making them than is commonly used. Among those who have thus labored must be mentioned Mr. Brooke of Norwich, who introduced batteries of green glass bottles, instead of flint glass jars. Some of them consisted of nine bottles; but when a greater power was required more were added. Jars would have been preferred to bottles, on account of their being more easily coated; but, being less easily procured, he was content to put up with this inconvenience. The mean size of these bottles was about eight inches in diameter; they were coated ten inches high, and made of the thickest and strongest glass that could be procured, weighing from five pounds and a half to seven pounds each. In the construction of a battery of twenty-seven bottles, he disposed of them in three rows; nine of the stoutest and best composing the first row, nine of the next best being disposed in the second, and the third containing the nine weakest. These were all of green glass, but not of the same kind. Some of those in the front row were composed of a glass like that of which Frontigniac wine bottles are made; and this kind of glass seemed to be by much the best, as being both harder and stronger, and less liable to break by a high charge. The second and third rows of the battery consisted of bottles the diameter of which was from six and a half to ten inches, and which were coated from eight and a half to eleven inches high; none of their mouths being larger than an inch and a half, nor less than three quarters of an inch. The bottles of which Mr. Morgan made use were not coated all over the surface usually coated, but slips of tin-foil were laid on of about three quarters of an inch in breadth, at the distance of about a slip between each: a circumstance which clearly shows that a perfectly continuous coating is not of essential importance.

137. We have already noticed that the uncoated interval of the Leyden jar should be clean and dry; but this must be understood with some limitation, as if it be perfectly clean and so dry as to approach to warmness, an explosion will take place between the coatings over the glass, and thus occasion a loss of the charge with a great waste of time. These effects may be prevented by breathing on the glass through a piece of barometer tube, but much more effectually by pasting a slip of writing paper, an inch broad, on the inner surface of the jar, close to the upper edge of the coating. By this means the intensity of the charge is diminished at the very spot where its tendency to explode is the greatest. The breadth, however, of this rim of paper must be proportioned to the size of the jar. Some prefer varnishing the uncoated part of the jar, in which case the varnish must be of the very finest quality.

138. The precarious process of charging very large batteries to a high degree of intensity is well known to those who have had to make very powerful experiments with them; and, as frequent fractures of jars take place, it may be of importance to the practical electrician to know how to repair them when they are but slightly injured; although, at the same time, we would rather persuade him to substitute a new jar than to undergo the very troublesome and expensive process of repairing, by cement, one that has been burst.

139. The following is the method adopted by Mr. Brooke for repairing the bottles of his battery when they become injured. Take, he says, of Spanish white eight ounces; heat it very hot in an iron ladle, to evaporate all the moisture; and when cool sift it through a lawn sieve; take three ounces of pitch, three quarters of an ounce of resin, and half an ounce of bees'-wax; heat them all together over a gentle fire, stirring the whole

frequently for nearly an hour; then take it off the fire, and continue the stirring till it is cold and fit for use.

140. To the above account of the electrical battery we shall here add Mr. Morgan's rules for its construction. They are the following.

141. Its connecting wires should be perfectly free from all points and edges.

142. They should be easily moveable, so that when accident has lessened the number of jars, the number of wires may be reduced so as to correspond with the remaining quantity of glass.

143. The jars should not be crowded; for in such a case, if necessity should oblige us to employ jars of different heights or sizes, the tin-foil of the higher ones, being in contact with the uncoated glass of the lower ones, the insulation will thus be rendered less complete.

144. The size of the jars should not be large; for though an increase of magnitude lessens the trouble of cleaning the battery, it at the same time increases the expense of repairing damages which frequently occur.

145. The several wires should be fixed very steadily, or in such a manner as not to admit of any shaking.

146. The battery should take up the least possible room; for as it increases in size, so is the probability increased of its being exposed to the influence of surrounding conductors.

147. The strength of the charge that can be produced by either a single jar or a battery is estimated according to the number of square feet of coated surface in each. Hence arises the necessity of forming a combination of jars, as single ones of convenient size cannot be obtained. One of the largest, perhaps, ever constructed was used by Mr. Singer in his lectures on electricity. This jar, he informs us, was eighteen inches in diameter, and two feet in height; its external coating exposing a surface of about six square feet. The principal experiments performed by the aid of the electrical battery will be explained in another part of this article.

Instruments for Measuring Electricity.

148. The instruments used for the purpose of ascertaining the presence of electricity, and measuring its intensity, are denominated electrometers, and hold a very important place among the necessary articles of electrical apparatus. Some of these are so constructed as to be of use only in indicating the presence of electricity; others perform the two-fold office of showing its presence, and indicating the precise degree of its intensity at the same instant; while others are constructed for the purpose of exactly measuring the strength of, and giving the required direction to any accumulation of the electric matter, from the charge of a small phial to that of the most powerful battery. We shall here give a very brief description of the principal of these useful instruments.

149. The first electrometer is generally allowed to have been that of the abbé Nollet; it was composed of two silk threads, which were made to recede from each other on being approached by an electrified body. The angle of the divergency of the threads was observed by the shadow which they cast on a flat surface placed behind them. This was certainly a very simple apparatus, though, at the same time, very imperfect: it was improved by Mr. Waitz, who appended small weights to the threads.

150. The electrometer of Mr. Canton consisted of a pair of small pith-balls suspended by very fine flaxen threads from a peg enclosed in a small box having a sliding cover fitted to it; when he used this instrument the lid was drawn off, the box held horizontally, so that the balls might hang freely. A more complicated instrument, but founded on the same simple principles, and containing four electrometers, is represented in fig. 12. A is the basis of the stand which supports these, and is made of mahogany. B is a pillar of wax, glass, or baked wood. To the top of the pillar, if it be of wax or glass, a circular piece of wood, C, is fixed; but if the pillar be of baked wood, that may constitute the whole. From this circular piece of wood proceed four arms of glass, or baked wood, suspending at their ends four electrometers, two of which, D, E, are silk threads about eight inches long, suspending each a small downy feather at its end. The other two electrometers, F, G, are made of very small balls of cork, or of the pith of elder; and they are constructed in the following manner:—*a b* is a rod of glass about six inches long, covered with sealing-wax, and formed at top into a ring: from the lower extremity of this stick proceed two fine linen threads, *c c*, about five inches long, each suspending a cork or pith-ball *d*, about one-eighth of an inch in diameter. These threads should be moistened with a weak solution of salt. When this electrometer is not electrified, the threads *c c* hang parallel to each other, and the cork balls are in contact; but when electrified they repel one another, as represented in the figure. When it is inconvenient to use the insulating stand, A B, the electrometers may be easily supported by a glass rod or tube.

151. Electrometers constructed of pith of elder were employed by Mr. Cavallo in many of his experiments in electricity, particularly in those on the electricity of the atmosphere. One of these instruments is represented in figs. 13 and 14. The case or handle of this instrument is formed of a glass tube, about three inches in length, and three-tenths of an inch in diameter, one-half of which is coated with wax on the outside. From one extremity of this tube, viz. that without sealing-wax, a small loop of silk proceeds, which occasionally serves to hang the electrometer on a pin, &c. To the other extremity of the tube a cork is adapted, which, being cut tapering on both ends, can fit the mouth of the tube with either end. From one extremity of this cork two linen threads proceed, a little shorter than the length of the tube, suspending each a little cone of pith of elder. When this electrometer is to be used, that end of the cork which is opposite to the threads is pushed into the mouth of the tube; the tube then forms the insulated handle of the pith electrometer, as represented in fig. 13. But when the electrometer is to be carried in the pocket, the threads are put into the tube, and the cork stops it, as repre-

sented in fig. 14. The advantages of this electrometer are, its convenient small size, its great sensibility, and its continuing longer in good order than any other. Fig. 15 represents a case to carry the above described electrometer in. This case is like a common toothpick-case, except that it has a piece of amber fixed on the extremity A, which may occasionally serve to electrify the electrometer negatively; and on the other extremity a piece of ivory fastened upon a piece of amber B C. This amber serves only to insulate the ivory; which, when insulated, and rubbed against woollen cloths, acquires a positive electricity, and is therefore useful to electrify the electrometer positively.

152. Another form of the pith-ball electrometer is that invented by Mr. Henley; it is simple in its construction, and extremely useful in numerous experiments, as will afterwards appear. It consists (fig. 16) of a perpendicular stem formed at top like a ball, and furnished at its lower end with a brass ferrule and pin, by which it may be fixed in one of the holes of the conductor, or at the top of a Leyden jar. To the upper part of the stem, a graduated ivory semicircle is fixed, about the middle of which is a brass arm or cock, to support the axis of the index. The index consists of a very slender rod, which reaches from the centre of the graduated arch to the brass ferrule; and to its lower extremity is fastened a small pith-ball nicely turned in a lathe. When this electrometer is in a perpendicular position, and not electrified, the index hangs parallel to the pillar; but when it is electrified the index recedes more or less according to the quantity of electricity, from the stem. Fig. 17, represents this electrometer separated from its stand, and fixed upon the prime conductor. The scale in Mr. Henley's quadrant is divided into equal parts; but M. Achard has shown that, when this is the case, the angle at which the index is held suspended by the electric repulsion is not a true measure of the repulsive force; to estimate this force truly, he demonstrates that the arc of the electrometer should be divided according to a scale of arcs, the tangents of which are in arithmetical progression.

153. One of the most useful electrometers for indicating the presence of very small portions of electricity, is that invented by the Rev. Mr. Bennet. The common construction of this instrument is very good; but a highly improved form of it is described by Dr. Brewster in the appendix to his new edition of Ferguson's Essays. The chief difference between this and the original construction consists in the cap and stand being of brass instead of wood. He thus describes it:—

It consists of two stripes of gold leaf, *m*, *n*, suspended within a glass cylinder A B E D. This cylinder has a brass cap A B, a little broader than itself, in the centre of which is a hole, *a*, in the inside of the cap, which receives a small wedge of wood. On each side of this wedge, two equal stripes of gold leaf, free of all roughness at their edges, are fixed by a little varnish; these stripes are generally about two inches long, and about a quarter of an inch broad. The inside of the cap A B, and the upper part of the glass cylinder, are coated with sealing-wax. On the inside of the glass cylinder are pasted two slips of tin-foil, *b*, *c*, diametrically opposite to each other, and rising higher than the stripes of gold leaf. The lower ends of the tin-foil are in contact with the brass stand D E F, which supports the whole. For observing the electricity of the atmosphere, a pointed wire, C, is inserted in the brass cap A B. To use the electrometer, turn round the cap A B, till the surfaces of the gold leaf are parallel to the surfaces of the pieces of tin-foil *b*, *c*, so that the two stripes of gold leaf may hang in contact in the middle of the cylinder. Then, if a body containing a small quantity of electricity, be brought in contact with the cap A B, the gold leaves, *m*, *n*, will diverge, and their extremities will strike the slips of tin-foil *b*, *c*, and thus convey the electricity to the ground. See figs. 1 and 2, plate III.

154. There have been other improvements proposed on this electrometer, one of which was by Mr. Singer, and chiefly respects the mode of insulation. This instrument is represented in fig. 3: the following brief description of it will suffice to convey a correct idea of it. Like the preceding it is constructed with a glass cylinder, surmounted by a broad cap of either wood or metal. The insulation depends on a glass tube of four inches long, and one-fourth of an inch diameter, covered on both sides with sealing-wax, and having a brass wire of a sixteenth or twelfth of an inch thick, and five inches long, passing through its axis, so as to be perfectly free from contact with any part of the tube, in the middle of which it is fixed by a plug of silk, which keeps it in a concentric position with the internal diameter of the tube. A brass cap is screwed upon the upper part of this wire; it serves to limit the atmosphere from free contact with the outside of the tube, and at the same time to defend its inside from dust. To the lower part of the wire the gold leaves are fastened. The glass tube passes through the centre of the cap of the electrometer, and is cemented there about the middle of its length. When this construction is considered, it will be evident that the insulation of the wire, and also of the gold leaves, will be preserved until the inside as well as the outside o. the glass tube become coated with moisture; but so effectually does the arrangement preclude this, that some of these electrometers have remained for seven years without being either warmed or wiped, and have still appeared to retain the same insulating power as at first. No. 2 shows this electrometer complete.

155. An electrometer of common use in the administration of medical electricity, sometimes attached to the Leyden jar, and sometimes made to fit into one of the ends of the prime conductor, is termed Lane's electrometer. Fig. 4 is a representation of this electrometer: it consists of two brass balls of equal size, one of which is connected with the inside coating of the jar, and the other insulated opposite to the first, yet so as to admit of its being placed in contact with it, or at any required distance from it. That which is insulated is connected by a wire with the outer coating of the jar, so as to serve as a course for the discharge which, it is very obvious from an inspection of the figure, will take place sooner or

later, according as the balls are placed either nearer to, or farther from, each other. But before we proceed to notice the *discharging* electrometer, we must describe one or two others which are both ingenious and useful.

156. We have described Mr. Cavallo's pocket electrometer at No. 154, but this gentleman constructed another portable electrometer for atmospherical purposes, which deserves particular notice. Its principal part consists of a glass tube CDMN, fig. 5, cemented at the bottom into the brass piece AB, by which part the instrument is to be held when used for the atmosphere; it also serves to screw the instrument into its brass case, AC, fig. 6. The upper part of the tube, CDMN, is tapered to a small extremity, which is entirely covered with sealing-wax; to this tapering part a small tube is cemented; the lower extremity being also covered with sealing-wax, projects a short way within the tube CDMN; into this smaller tube a wire is cemented, which with its under extremity touches the flat piece of ivory H, fastened to the tube by means of a cork; the upper extremity of the wire projects about a quarter of an inch above the tube, and screws into the brass cap EF, which cap is open at the bottom, and serves to defend the waxed part of the instrument from the rain, &c.

157. A section of the brass cap is represented in fig. 7, to show its internal structure, with the manner in which it is screwed to the wire projecting above the small tube L. This small tube and the upper extremity of the large tube, CDMN, appear like one continued piece when joined, from the sealing-wax covering them both. The conical corks, P, fig. 5, which show the electricity by their repulsion, are made very small, and suspended by very fine silver wires, shaped like rings at the top, by which they hang very loosely on the flat piece of ivory H, which has two holes in it. By this method of suspension, which Mr. Cavallo says is applicable to every sort of electrometer, the friction is reduced to almost nothing, and the instrument is thus rendered sensible to a very small degree of electricity. IM and KN are two narrow slips of tin-foil, fixed on the inside of the glass CDMN, and communicating with the brass bottom AB. They serve to convey that electricity which, when the balls touch the glass, is communicated to it, and, being accumulated, might disturb the free motion of the balls.

158. To use this instrument for artificial electricity, affect the brass cap EF, by an electrified substance, and the divergence or convergence of the balls of the electrometer, at the approach of an excited electric, will show the quality of the electricity. The best manner to electrify this instrument is, to bring excited wax so near the cap, that one or both of the corks may touch the side of the bottle CDMN, after which they will soon collapse and appear unelectrified. On removing the wax, they will again diverge, and remain electrified positively.

159. To try the electricity of the fogs, air, clouds, &c., by this electrometer, the electrician must unscrew it from its case, and hold it by the bottom AB, to present it to the air a little above his head, so that he may conveniently see the balls P, which will immediately diverge if there is any electricity; i. e. whether positive or negative may be ascertained, by bringing an excited piece of sealing-wax, or other electric, towards the cap EF.

160. M. Saussure has made an improvement in this electrometer. The principal circumstances in which his electrometer differs from Mr. Cavallo's, are: The fine wires, by which the balls are suspended, should not be so long as to reach the tin-foil which is pasted on the inside of the glass; because the electricity, when strong, will cause them to touch this tin-foil twice consecutively, and thus deprive them in a moment of this electricity. To prevent this defect, and yet give them a sufficient degree of motion, it is necessary to use larger glasses than those that are generally applied to Mr. Cavallo's electrometer; two or three inches diameter will answer the purpose very well. But, as it is necessary to carry off the electricity, which may be communicated to the inside of the glass, and may thus be confounded with that which belongs to those substances that are under examination, four pieces of tin-foil should be pasted on the inside of the glass; the balls should not be more than $\frac{1}{20}$ of an inch diameter, suspended by silver wires, moving freely in holes nicely rounded. The bottom of the electrometer should be of brass; for this renders it more easy to deprive them of any acquired electricity, by touching the bottom and top at the same time.

161. This electrometer may be used instead of the condenser of M. Volta, by only placing it on a piece of oiled silk, a little larger than the base of the instrument: but in this case the base, and not the top, of the instrument must be brought in contact with the substance, the electricity of which is to be explored. By this instrument it is easy to ascertain the degree of conducting power in any substance. If it is placed on an imperfect conductor, as dry wood or marble, and if the instrument is electrified strongly, and afterwards the top is touched, the electricity will appear to be destroyed; but, on lifting up the instrument by the top, the balls will again diverge, because the imperfect conductor formed with the base a kind of electrophorus, by which the electric fluid was condensed, and lost its tension, till the perfect conductor was separated from the imperfect one; whereas, if the conductor had been more perfect, it would have been deprived of its electricity immediately on the application of the hand. It is useful to discover also the electricity of any substance, as of clothes, hair of different animals, &c. For this purpose it must be held by the base, and the substance rubbed briskly (only once) by the ball of the electrometer; the kind of electricity may be ascertained in the usual manner. But as the top of the electrometer acts, in this case, as an insulated rubber, the electricity it acquires is always contrary to that of the rubbed body.

162. To collect a great quantity of electricity from the air, this electrometer is furnished with a pointed wire from fifteen inches to two feet long, which unscrews in three or four pieces, to render the instrument more portable, see fig. 8.

When it rains or snows, the small cover, fig. 9, is to be screwed on the top of the instrument, as by this its insulation is preserved. This indicates not only the electricity of fogs, but also that of serene weather, and enables the observer to discover the kind of electricity which reigns in the atmosphere; and, in some degree, to form an estimate of its quantity, and that under two different points of view, the degree of intensity, and the distance from the earth at which it first begins to be sensible. A conductor exhibits signs of electricity only when the electric fluid is more or less condensed in the air than in the earth. Though the air resists the passage of the electric fluid, it is not absolutely impermeable to it; it suffers it to pass gradually, and generally with more ease in proportion as its mass is less. It is, therefore, interesting to discover at what height it is necessary to be elevated, in order to find a sensible difference between the electricity of the earth and that of the air.

163. Mr. Brooke of Norwich constructed an electrometer of a very ingenious description, and certainly valuable in its application, of which he has given a full account in his Miscellaneous Experiments; the limits, however, within which our article must be confined, will not allow of our giving his lengthened description of the instrument. We shall, therefore, present our readers with a short account of another electrometer, the invention of professor Robison of Edinburgh, which in our opinion is, in its chief essentials, much superior to that of Mr. Brooke. This beautiful and delicate instrument is represented by fig. 10, where A, a finely polished brass ball of a quarter of an inch diameter, is fixed on the point of a common sewing needle about three inches long, and as slender as can be procured of that length. On the other end of the needle is fixed a ball of amber, glass, or other non-conducting substance, of about ½ or ¾ths of an inch in diameter. This ball is so fixed as that the needle does not quite reach to its surface, though the ball F must be completely perforated. From the electric ball there passes a slender glass rod, F, E, L, bent at right angles at E, so that the part F E may be about three inches long, and the other extremity L, immediately opposite to the centre of the ball A. A piece of amber C, so cut as to have two parallel cheeks, is fixed on the extremity L of the glass rod. For the principal part of the instrument, a strong dry silk thread is to be prepared by dipping it perpendicularly in melted sealing-wax, till it be fully penetrated by the wax, so as to retain a thin coating of it.

164. The thread, thus coated, must be kept extended, so that it may be quite straight; it must be made perfectly smooth by holding it before a fire, and rolling it on a smooth table. It is then to be passed through a small cube of amber, that has two holes drilled in two of its opposite faces, perpendicularly to the stalk. By these holes the cube is suspended, so as to move readily, on two fine brass pins, between the cheeks of the piece of amber at L. The waxed thread is about six inches long, and is equally divided by the amber cube. To the end B is fixed a ball of some conducting substance, as of polished metal, or gilt cork, a quarter of an inch in diameter. The other extremity D passes through a cork ball, so as to move with a slight friction.

165. The construction of this part of the electrometer is such that when F E lies perpendicularly to the horizon, and the stalk B D, with its balls, is allowed to hang freely, the ball B just touches the ball A, as represented in fig. 11. The ball F is fixed to one end of a glass rod F I passing perpendicularly through the centre of a graduated circle G H O, and furnished at the opposite extremity I with a knobbed handle of boxwood. H K is the stand of the electrometer, in the head of which is a hole in which the rod F I slides smoothly but not easily. There is also adapted to the glass rod F I an index N H that turns round it. This index is placed so as to be parallel to a line L A drawn through the centre of the ball A. And, as the circle is divided into 360 degrees, 0 being marked above, and 90 on the right hand; the index will point out the angle which the line L A makes with the vertical line. It is convenient to have another index on the rod F I turning with some friction round it, and extending considerably beyond the circle G H O.

166. When this electrometer is used for computing the quantum of electricity belonging to any body, it must be connected by means of a wire with the substance to be examined: the wire must be fixed into the hole of the ball F, which is in part filled by the needle; and indeed it must come in contact with the needle. The index must now be turned round by the handle I until it stand at 90°. In this position C B is horizontal, and the ball B contiguous to A. If in this position the balls B and A are electrified, they do not separate till the index be turned back towards 0. In some part of this space they will separate, and the point must be carefully noted, as this is the measure of their electric power while in contact. By turning still more towards 0, the separation is increased. An assistant must now turn the long index till it be parallel to the other, and consequently to C D. On loading the cork ball D with grain weights till B D be nicely balanced in a horizontal position, and computing for the proportional length of C B and C D, we obtain an exact measure in grains of the electric force with which the balls B and A separate in this position.

167. The electrometers already described have all been found highly useful to the practical electrician, according to the peculiar nature of the course of his experiments; but for ascertaining the actual repulsive and attractive powers of very faintly electrified bodies, they are perhaps all excelled by the ingenious invention of M. Coulomb, a French philosopher. The construction of this delicate instrument, which is called the *torsion balance*, will be best understood by a reference to the plate, where we have given a representation of it in its complete state, and of some of its parts on an enlarged scale.

Fig. 1, Plate IV., is a cylinder of flint glass twelve inches in diameter, and twelve in height, covered with a plate of glass, which is made to fit to it by a projecting fillet on the lower surface and having in it four round perforations, of

an inch and three-fourths in diameter, one of which is in the centre *f*, and receives the glass tube *fh*, which is two feet in height, and is fixed in the glass plate with cement. Into the top of this tube is inserted the brass piece H, fig. 2, No. 3, which is perfectly cylindrical, and having a small shoulder which rests on the top of the tube into which it is cemented. This brass piece is made to fit by means of a screw on the hollow cylinder, No. 2, fig. 2, to which is joined the circular plate *ab*, divided into 360 degrees, and having a hole G in its centre for admitting the cylindrical pin *i*, No. 1, fig. 2. This pin is surmounted with a milled head *b*, from which an index *io* projects, having a point turned downwards at *o*, to mark the divisions on *ab*. This pin moves with some friction in the hole G, while the cylinder moves steadily in the brass piece H. To the lower end of the pin there is attached the pincer *q*, resembling the end of a solid port crayon, and capable of being tightened by a sliding ring: so as to seize a fine silver wire, while its lower end is held by a similar pincer, shown by P*o*, fig. 3, and tightened by the sliding ring *r*.

168. The stalk *ro* is cylindrical, and is made so heavy as to keep the wire quite straight without breaking it. Fig. 3 exhibits this pincer with the arm *z*C*q* passing through it. The length of this arm is eight inches, and it is formed of a stout silk thread, or a fine round straw coated with wax, or with lac; it is about one-tenth of an inch diameter, and six inches long, and is terminated by two inches of wax drawn out into a fine thread. The end *q* carries a pith-ball *a* turned very smooth, and gilded, and the other end is a small circular plane of paper covered with varnish, and of sufficient weight to counterpoise the pith-ball *a*, which is from one-fourth to one-half of an inch in diameter.

169. Fig. 1 represents the whole of the parts of the instrument in their combined form. The arm is represented as hanging horizontally in the middle of the glass cylinder, so as to admit of its turning freely round its centre, in a circle described on the glass by a graduated slip of paper divided into 360°. When *a* is opposite to *o* on this graduated circle it is contiguous to the ball *b*, which hangs within the cylinder by a silk thread covered with lac, and kept steady by the piece of wood, which is seen lying on the cover, from which it is suspended. This position of the instrument is produced by turning the milled head *b*, which carries the index *io*, called the *twist index*, round until it points to *o* on the graduated circle *ab*, and the whole is then turned in the brass socket H, till the ball *a* stands at O on the graduated paper circle Q. Fig. 4 represents a cylindrical stick of sealing-wax in the one end of which is inserted a fine brass wire terminated by a smooth ball. Fig. 5 is another part of this apparatus shown on an enlarged scale; it consists of a plug of sealing-wax A, which is made to fit tightly into the upper part of the instrument; through this plug of wax a wire *c*, hooked at the top, passes perpendicularly, and terminates in the finely polished metallic ball *d*; its use is to connect the electrometer with other bodies.

170. We shall here add, as an illustration of the method of using this ingenious instrument, an account of Coulomb's method of determining by it the electrical repulsion of the two balls *a* and *b* when electricity was communicated to them. Having electrified the brass pin, fig. 5, it was introduced through the hole *m*, in the top of the cylinder, and made to touch the ball *b*, in contact with the ball *a*, thus communicating its electricity to the two balls, which consequently became electrified with the same electricity; and, on this pin being withdrawn, a mutual repulsion took place between the two balls, *a* being driven from *b* to a distance easily measured on the graduated scale, and obviously regulated by the resistance of the wire to farther torsion. After a few slight oscillations the arm will rest and the degree of repulsion may be accurately noted. The index *i o* is now to be turned backwards till the ball *a* come to its former position, by which movement the silver wire will be twisted, and a force produced proportional to the angle of torsion which is required to bring the ball *a* in contact with the ball *b*. By this means M. Coulomb ascertained the distance at which different angles of torsion bring the balls in contact after mutual repulsion; by comparing the forces of torsion with the corresponding distances of the balls, he obtained a measure of their repulsive force.

171. The following are given by Dr. D. Brewster, as the results of some experiments with this curious instrument, by its inventor.

(1.) The two balls being electrified with the head of the pin, and the index of the micrometer being set to zero, the ball *a* was repelled by the ball *b* to the distance of 36°.

(2.) The silver wire being twisted by turning the index of the micrometer 126°, the ball *a* approached to the ball *b*, and stopped at the distance of 18° from it, having moved backwards through an arc of 18°.

(3.) Having again twisted the silver wire through an arc of 567°, the two balls approached, and stopped at the distance of 8° 30′.

172. Now, as the force of torsion, or the force which is capable of keeping a thread twisted to a certain degree, so as to hinder it from turning round its axis, and recovering its natural state, has been shown by Coulomb to be proportional to the angle of torsion, or the arc through which it has been twisted, we have in the first experiment such a force, equal to 36°; and in the second experiment, when the distance of the balls was 18°, the angle, and consequently the force of torsion, was $126° + 18 = 144°$; hence the repulsive force, at the distance of 36°, was 36°: and the repulsive force, at the distance of 18°, was 144°, or quadruple at half the distance. In the third experiment, when the distance of the balls was 8° 30′, the force of torsion was 567°; so that, at a quarter of the distance, the repulsive force was nearly eight times as great. From this it follows, that the repulsive force of two small globes electrified either positively or negatively, is in the inverse ratio of the squares of the distance of the centres of the two globes.

173. In these experiments, the wire P*l* was twenty-eight inches long, and $\frac{1}{16}$ of a grain in weight,

and the force necessary to twist it through an angle of 300°, when at the distance *a* P, was $\frac{1}{340}$ of a grain, as calculated from the formulæ given by M. Coulomb in his Memoir on the force of Torsion. Hence the real forces in the preceding experiments were,

Distances of the Balls.	Angles and Forces of Torsion.	Absolute Forces in grains.
36°	36	$\frac{1}{3400}$th of a grain.
18	144	$\frac{1}{850}$
8½	576	$\frac{1}{212}$

174. An electrometer has been constructed by Mr. Cuthbertson, which, we think, in point of real utility, to the practical electrician, is equalled by none with which we are acquainted. Those only who have to go through the operation of melting wires before a public audience, can duly appreciate the value of this incomparable instrument. We have given in fig. 6 a representation of this discharging compound electrometer, as connected with a single jar, which, if it be about six inches in diameter and twelve inches high, will be sufficient to fuse four inches of fine pendulum wire. A description of it may be of use to the inexperienced electrician. The base G H is an oblong square piece of mahogany of about eighteen inches long, and six in breadth: in this are three glass supports, D, E, F, mounted with brass balls, *a*, *b*, *c*. Under the brass ball *a* there is placed a brass hook; the ball *c* is made of two hemispheres, the under one being fixed to the brass mounting, and the upper turned with a groove to shut upon it, so that it may be taken off at pleasure. The ball *b* has a brass tube fixed to it, about three inches long, cemented to the top of F; and a hole at the top, of about half an inch in diameter, corresponding with the inside of the tube. A B is a straight brass wire, with a knife-edged centre in the middle, placed a little below the centre of gravity, and equally balanced with a hollow brass ball at each end, the centre, or axis, resting upon a properly formed piece of brass fixed in the inside of the ball *c*; that side of the hemisphere towards *c* is slit open, to permit the end *c* A of the balance to descend till it touches the ball *a*, and the upper hemisphere C is also so opened to permit the end *c* B to ascend; *i* is a weight of a certain number of grains, and made in the form of a pin with a broad head; the ball B has two holes, one at the top, and the other at the bottom; the upper hole is so wide as to let the head of the pin pass through it, but to stop at the under one, having its shank hanging freely in *b*; several such pins are made to each electrometer of different weights; *k* is a Henley's quadrant electrometer, and when in use it is screwed upon the top of *c*.

175. It is obvious, from the construction, that if the foot stand horizontally, and the ball B be made to touch *b*, it will remain in that position without the help of the weight *i*; and if it should receive a low charge, the two balls *b*, B, will repel each other; B will begin to ascend, and, on account of the centre of gravity being above the centre of motion, the ascension will continue till A rest upon *a*. If the balance be again set horizontally, and a pin *i*, of any small weight, be put into its place in B, it will cause B to rest upon *b*, with a pressure equal to that weight, so that more electricity must be communicated than formerly, before the balls will separate; and, as the weight in B is increased or diminished, a greater or less quantity of electricity will be required to effect a separation.

176. When this instrument is to be used with a jar, or battery, one end of a wire, L, must be inserted into the ball *b*, and the other end into a hole of any ball proceeding from the inside of a battery, or jar, as M; *k* must be screwed upon *c*, with its index towards A; the reason of this instrument being added, is to show, by the index continuing to rise, that the charge of the battery is increasing, because the other part of the electrometer does not act till the battery has received its required charge.

177. It was formerly observed that the uncoated part of a jar might be too dry to admit of its being highly charged: the following experiment will illustrate the truth of this, as well as show the use of the electrometer just described in fusing wires. Every thing being prepared, as represented in the figure, with the jar M annexed to the electrometer, which jar may contain 168 square inches of coating put into B, the pin marked 15, take two inches of watch pendulum wire, fix to each end a pair of small pincers, as is represented at G *m*, hook one end to *m*, and the other to the wire N, communicating with the outside of the jar; let the uncoated part of the jar be made very clean and dry; and let the prime conductor of the machine, or a wire proceeding from it, touch the wire L; if then the machine be put in motion, the jar and electrometer will be charged, as will be seen by the rising of the index *k*, and, when charged high enough, B will be repelled by *b*; A will descend and discharge the jar through the wire, which was confined in the pincers, and the wire will be fused and run into globules.

178. Repeat this experiment with the following variations, viz. instead of two inches of wire take eight; and instead of loading the ball with fifteen, insert the pin weighing thirty grains; charge, as before, and a spontaneous explosion will take place between the coatings of the jar without moving the electrometer, and consequently the wire will remain as it was. But let the uncoated part of the jar be now a little moistened by breathing on it through a glass tube; charge the jar again, the electrometer will operate, the charge pass through the circuit, and the whole length of the wire will appear red-hot, and be instantly fused into globules.

179. A very useful instrument, called the universal discharger, was invented by Mr. Henley. It is shown in fig. 7, and consists of a mahogany base, A A, fourteen inches long, and about four broad. B, B, are two glass pillars, cemented in two holes upon the board A, and furnished at top with brass caps, each of which has a turning joint, and supports a spring tube, through which the wires D, D, slide. Each of the caps is composed of three pieces of brass, connected so that the wires D, D, besides their sliding through the sockets, have a horizontal and vertical motion. Each of the wires, D, D, is furnished with an

open ring at one end, and at the other it has a brass ball, which, by a short spring socket, is slipped upon the pointed extremity, and may be removed. E is a circular piece of wood, having on its surface a slip of ivory, inlaid, and furnished with a foot, which slides into the socket F, in which it is made fast at any required height by the screw S. To this discharger belongs the small press, fig. 8, the stem of which fits into the socket, instead of the circular table E. On the top of the stem are two oblong boards, which are pressed together by means of two screws. Between these boards may be placed any substance which requires to be pressed while the electric fluid is sent through it. The construction of this instrument is such as to enable the operator to use it with advantage in numerous experiments; particularly the oxidation of metallic leaves between slips of card paper, or of glass; splitting small pieces of oak, firing gunpowder, &c.

Condensers and Doublers of Electricity.

180. Condensers of electricity are instruments used for the detection of very small portions of that matter, portions too minute to be rendered sensible by any of the electrometers which we have yet described. Several very ingenious electricians have employed themselves in the construction of instruments for this purpose: the principal of these contrivances we shall now briefly describe.

181. Volta appears to have been the first who attempted any thing of this description. His condenser of electricity consists of a flat and smooth metal plate, furnished with an insulating handle, and a semi-conducting, or imperfectly insulating, plane. When it is required to examine a weak electricity with this apparatus, as that of the air in calm and hot weather, which is not generally sensible to an electrometer, the operator must place the above-mentioned plate upon the semi-conducting plane, and a wire of some other conducting substance must be connected with the metal plate, and extended in the open air, so as to absorb its electricity; then, after a certain time, the metal plate must be separated from the plane; and, on being presented to an electrometer, it will electrify it much more than if it had not been placed upon the above-mentioned plane.

182. The principle on which the action of this apparatus depends, says Mr. Cavallo, is, that the metal plate, whilst standing contiguous to the semi-conducting plane, will both absorb and retain a much greater quantity of electricity than it can either absorb or retain when separate, its capacity being increased in the former and diminished in the latter case.

182.* This condenser was afterwards improved on by Mr. Cavallo, by employing a small metallic plate, about the size of a shilling, having affixed to it a glass handle covered with sealing-wax. When the larger plate appeared so slightly electrified by the communicated electricity as not to affect the electrometer, he then placed the small plate on the plane and touched it with the edge of the large one, holding the latter in an almost vertical position; the small plate was thus found to indicate a very sensible degree of electricity.

183. One of the most convenient and elegant condensers yet contrived is that of Mr. Cuthbertson. This instrument is shown in fig. 9, and is composed of two metallic plates, *a* and *b*, about six inches in diameter, tightly screwed to two brass balls, but so as that one of them be fixed immoveably to a glass pillar, as *e*, while the other is fastened to a brass pillar *f*, having a hinge at its lower extremity by which it can be moved backwards into the position *g*. When the instrument is used, the electricity to be examined is communicated to the insulated plate *b*, while it is parallel to the uninsulated plate *a*, and after remaining for some time in this position the uninsulated plate is drawn back, and the intensity of the insulated plate, *a*, is shown by being presented to an electrometer in the usual way.

184. A modification of this instrument, called the condensing electrometer, is represented by fig. 10. In this construction the plates are smaller, and the insulated plate is attached to the cap of a gold-leaf electrometer; by this means very small degrees of electricity are discovered, and their intensity shown by the divergence of the gold leaves within the cylinder.

185. A condenser, of a remarkably simple description was proposed by Mr. Singer, and is constructed by placing three small spots of sealing-wax, at equal distances, on the lower face of the cover of an electrophorus, to serve as insulating feet, by which the cover may be supported at the distance of about the twelfth of an inch from the surface of a smooth and even table. If a Leyden jar, he adds, be now charged, and afterwards discharged, so as not to affect an electrometer, and its knob be then placed in contact with the condenser resting on the table for a few seconds, the small residuum of electricity in the jar will be absorbed by the condensing plate; and when this is raised from the table it will affect the electrometer with the same electricity as that with which the jar was charged.

185*. Doublers of electricity are instruments so constructed as that very small quantities of electricity may be continually doubled by them, until, being condensed, they are rendered perceptible by the common electrometer.

186. An instrument of this kind was invented by the Rev. Mr. Bennet, and is represented by fig. 1, plate V. It is formed by the addition of two polished brass plates, with insulating handles, to the common gold-leaf electrometer. The plates are varnished on the lower side, and the insulating handle of one of them, B, is fixed to the side, while that of the other, A, is placed perpendicularly in the centre. Though this apparatus appears to be very simple, it requires a very complex process, and has, therefore, generally given place to what are called moveable or revolving doublers.

187. Revolving doublers appear to have been first introduced by Dr. Darwin, who claims the merit of the invention. Darwin's doubler was moved by a train of wheels, and required to be touched by the hand to place the plates in the requisite positions. This instrument was much improved by Mr. Nicholson; a representation of

it, in its improved form, is given in fig. 2. The whole is supported on a glass pillar six inches and a half high, and consisting of the following parts:—Two fixed plates of brass, A and C, are separately insulated and disposed in the same plane, so that a revolving plate B may pass very near them without touching. Each of these plates is two inches in diameter; they have adjusting pieces behind, which serve to place them correctly in the required position. D is a brass ball on which they turn, of two inches diameter, fixed on the extremity of an axis that carries the plate B. Besides the essential purpose which this ball is intended to answer, it is so loaded within on one side, that it serves as a counterpoise to the revolving plate, and enables the axis to remain at rest in any position.

188. The use of this ingenious instrument will be best understood from the following account of it given by Mr. Nicholson in the Philosophical Transactions:—'When the plates A and B,' says Mr. Nicholson, 'are opposite to each other, the two fixed plates A and C may be considered as one mass; and the revolving plate B, together with the ball D, will then constitute another mass. All the experiments yet made concur to prove that these two masses will not possess the same electric state; but that, with respect to each other, their electricities will be plus and minus. These plates would be simple, and without any compensation, if the masses were remote from each other; but, as that is not the case, a part of the redundant electricity will assume the form of a charge in the opposed plates A and B. From other experiments I find,' says Mr. Nicholson, 'that the effect of the compensation on plates opposed to each other at the distance of one-fortieth part of an inch, is such, that they require to produce a given intensity at least 100 times the quantity of electricity that would have produced it in either, if placed singly and apart.

189. The redundant electricities in the masses under consideration, will therefore be unequally distributed: the plate A will have about ninety-nine parts, and the plate C one; and, for the same reason, the revolving plate B will have ninety-nine parts of the opposite electricity, and the ball D one. The rotation, by destroying the contacts, preserves this unequal distribution, and carries B from A to C, at the same time that the tail K connects the ball with the plate C. In this situation, the electricity in B acts upon that in C, and produces the contrary state, by the communication between C and the ball; which must therefore acquire an electricity of the same kind with that of the revolving plate. But the rotation again destroys the contact, and restores B to its first situation opposite to A.'

190. Here, if we attend to the effect of the whole revolution, we shall find that the electric states of the respective masses have been greatly increased; for the ninety-nine parts in A and in B remain, and the one part of electricity in C has been increased so as nearly to compensate ninety-nine parts of the opposite electricity in the revolving plate B, while the communication produced an equal mutation in the electricity of the ball. A second rotation will of course produce a proportional augmentation of these increased quantities, and a continuance of turning will soon bring the intensities to their maximum, which is limited by an explosion between the plates.'

191. 'If one of the parts be connected with an electrometer, more especially that of Bennet, these effects will be very clearly seen. The spark is usually produced by a number of turns between eleven and twenty; and the electrometer is sensibly acted upon by still fewer. When one of the parts is occasionally connected with the earth, or when the adjustment of the plates is altered, there are some variations in the effects not difficult to be reduced to the general principles, but sufficiently curious to excite the attention of persons the most experienced in this branch of natural philosophy.

192. 'If the ball be connected with the lower part of Bennet's electrometer, and the plate A with the upper part, and any weak electricity be communicated to the electrometer, while the position of the apparatus is such that the cross piece G H touches the two pins, a very few turns will render it perceptible. But here, as in the common doubler, the effect is rendered uncertain by the condition that the communicated electricity must be strong enough to destroy and predominate over any other electricity which the plates may possess. I need scarcely observe, that, if this difficulty should be hereafter removed, the instrument will have great advantages as a multiplier of electricity in the facility of its use, the very speedy manner of its operation, and the unequivocal nature of its results.'

The Electrophorus.

193. Several of the instruments we have now described appear capable of collecting and imparting small quantities of electricity; but it may be questioned if any of them can be said to do so on a scale comparable with that of the common electrophorus of Volta, which may be said to be a kind of electrical machine. Fig. 3 is a representation of this simple but highly useful article of apparatus, which any person at all skilled in the use of electrical apparatus may construct for himself by attending to the following directions. Procure two circular plates of metal, or of wood covered with tin-foil, and well rounded at the edges; these are the conductors: between them is placed a resinous plate, formed by melting together equal parts of shell-lac, resin, and Venice turpentine, and pouring this mixture, whilst fluid, within a tin hoop of the required size, placed on a marble table, from which the plate may be readily separated when cold. This plate should be half an inch in thickness; it is sometimes made by pouring the mixture on one of the conductors, which is then formed with a rim for that purpose. In the centre of the upper conductor is fixed a glass handle of about ten inches long, for the purpose of lifting it without drawing off its electricity; and, when the electric state of the lower conductor is to be examined, the whole apparatus must be placed on an insulating stand. To use the electrophorus, rub the upper surface of the resinous plate with a piece of dry fur; cat's skin is

reckoned the best, and it will be excited negatively. Place the upper conductor upon it, and then raise the same by its insulating handle; it will be found to exhibit very faint, if any, electrical signs. Replace the conductor, and, whilst it lies on the surface of the excited plate, touch it with a finger or any other uninsulated conductor, and then raise it again by its handle. It will now be positively electrified, and afford a spark: if it be then replaced on the resinous plate, touched, and again raised, another spark will be procured, and this process may be repeated for a considerable time without any perceptible diminution of effect. Jars may be charged by bringing them in contact with the conductor each time it is lifted, with an instrument of this kind only six inches in diameter. Cavallo charged a jar several times successively, and such was the strength of the charge that it was capable of piercing a card.

194. Such is the tenacity, so to speak, with which this instrument holds the electricity once excited, that some have been led to consider it as affording a perpetual source of that matter. On this opinion Mr. Cavallo makes the following just remarks:—'As to the continuance of this electric plate, when once excited without repeating the excitation, I think there is not the least foundation for believing it perpetual, as some gentlemen have supposed it to be; it being nothing more than an excited electric, it must gradually lose its power, by continually imparting some of its electricity to the air, or other substances contiguous to it. Indeed its electricity, although it could never be proved to be perpetual by experiments, lasts a very long time, it having been observed to be pretty strong several days, and even weeks, after excitation. The great duration of the electricity of this plate, I think, depends upon two causes: first, because it does not lose any electricity by the operation of putting the metal plate upon it, &c.; and, secondly, because of its flat figure, which exposes it to a less quantity of air, in comparison with a stick of sealing-wax, or the like, which, being cylindrical exposes its surface to a greater quantity of air, which is continually robbing the excited electrics of their virtue.' Numerous experiments are given in the writings of electricians as having been performed by the aid of this instrument; these we shall not here detail, but simply remark, that, if properly managed, it will be found capable of communicating a very high charge to tolerably sized Leyden jars.

PART III.

MECHANICAL EFFECTS OF ELECTRICITY.

195. Under this part of the subject it is intended to give a popular view of a variety of electrical phenomena rather of a general and promiscuous nature, and which, from the variety necessarily involved, could not have been conveniently introduced under any other head. Among others we shall notice chiefly the following, viz. the direction of the electric fluid; its influence in expanding bodies through which it is made to pass; its power in rending solid bodies; its agency in the combustion and oxidation of metallic substances, and in inflaming numerous combustible substances.

Direction of the Electrical Fluid.

196. From among the numerous experiments given to demonstrate, as far as it can be done, the course of the electric fluid in its passages from one body to another, we select the following from Mr. Singer and others.

197. The direction of the electric fluid may be rendered visible by taking a Leyden jar that has been rendered slightly damp by being breathed on, and placing it with its knob in contact with the positive conductor of an electrical machine in a darkened room; when the jar is fully charged, if the action of the machine be continued, the fluid will be observed to pass from the internal to the external coating over the uncoated interval in luminous streams, like water overflowing from the top of a vessel kept constantly supplied. If the jar be removed, and its knob placed against the negative conductor, the stream will evidently pass in the contrary direction. A degree of dampness on the uncoated part of the glass is necessary, in this experiment, to prevent the discharge of the jar by a spontaneous explosion, in which case the fluid passes too rapidly from one surface to the other to allow the observer to ascertain its direction. If the moisture be not sufficient, diverging brushes of light will occasionally pass from the positive surface, instead of the continuous streams above mentioned.

198. Let a light wheel, the vanes of which are made of fine card-paper, be made to turn freely on its axis, a stream of electricity from a pointed wire fixed in the conductor will give it motion; and it will move from the electrified point whether its electricity be positive or negative. In this experiment the current seems to be produced by the recession of the similarly electrified air in contact with the point; and, therefore, the circumstance of the wheel turning in the same direction when the electricity is negative, cannot, as Mr. Singer has justly observed, be considered as a proof of the existence of a double current of the electric fluid.

199. Make a groove, either by bending a piece of clean card-paper, or by hollowing out a piece of baked wood, or by placing, parallel to each other, two straight sticks of sealing-wax; lay the groove upon the plate of Henley's universal discharger, and place a large pith-ball, about half an inch in diameter, so as to be at an equal distance from the two brass knobs of the discharger. The distance of these should be about four inches, and the groove placed in the line joining the knobs. If one of the wires be now connected with the outside of a charged jar, while the knob of it is brought in contact with the other wire of the discharger, so that a small spark may pass from the one knob to the other, the pith-ball will be impelled from the positive to the negative knob. In performing the above experiment Mr. Singer used pointed wires instead of knobbed ones, and assigned, as his reason for this, that the knobs may attract the pith-ball, whereas the stream from the pointed wire must impel it.

200. Mr. Singer in the following experiment has availed himself of the discovery of Cavallo, who observed that some mineral colors are affected by passing over them the electrical discharge. Color, says he, both sides of a card with vermilion, and place it upon the table of Henley's discharger; one of the wires should be beneath the card, and the other in contact with its upper surface; the distance of the points of the wires being one inch. If a charge be now sent through the wires, the fluid will pass from the positive wire across the surface of the card to the part over the negative wire, and will there perforate the card in its passage to that wire. The course of the fluid is indicated by a black line on the card, reaching from the point of the positive wire to the perforation; and by a diffused black mark on the opposite side of the card around it, and next the negative wire. These effects are pretty constant, the black line always appearing on the side of the card which is in contact with the positive wire, and the perforation being near the negative wire.

201. But the most satisfactory exhibition of the course of the fluid from the positive to the negative conductor is afforded in the next experiment, which was the contrivance of Mr. Singer, and which he himself considered as removing all difficulties on the subject. It has, observes he, been long known that a light float-wheel, made by inserting several vanes of card in the periphery of a cork that is made to turn freely on a pin or centre, will be put in motion by presenting it to an electrified point; and the motion of the wheel being always from the point, whether that point was positive or negative, has been occasionally urged as an argument for a double current of the fluid; although it is evident, from what has been already stated, that a point either positive or negative must produce a current, by the recession of the air opposed to it when similarly electrified, by its contact, which is fully adequate to the production of these effects. Conjecturing that the currents of electrified air would not take place in this manner if the points were opposed to each other, the following arrangement was made.

202. A light float-wheel of the above description, being mounted so as to turn freely between two upright wires, was placed on an insulated stem, and introduced between the pointed wires of Henley's discharger, which were placed accurately opposite to each other, and at the distance of rather better than an inch from the upper vanes of their respective sides. On connecting one of the wires with the positive conductor of the machine, and the other with the negative conductor, and turning the machine, the wheel will move in a direction from the positive to the negative wire. On reversing the connexions, so that the wire which was negative may become positive, and that which was positive be made negative the motion of the wheel will be reversed; for it will still move from the positive to the negative wire, thus proving that the electricity moves in that direction. A representation of this wheel, with the method of using it, is given in fig. 3, where A is the float-wheel placed on the universal discharger B, the wires of which, C, C, are directed against the floats of the wheel.

Expansive Power of the Fluid.

203. The influence of the electric matter in expanding bodies through which it is sent, may be clearly illustrated by these experiments. Place a small card, or the cover of a book, against the outer coating of a charged jar, exposing about a square foot of coated surface; put one end of the discharging rod against the card, and bring the other to the knob of the jar; the charge will pass through the card and perforate it, producing a small bur on the side next the discharging rod, and a larger one on the side which was in contact with the coating of the jar. In the same manner, by using the more powerful charge of a battery, a perforation may be made through a quire of paper or a thin unbound book; and, if either of these be freely suspended between the balls of the universal discharger, no motion of the paper will be produced, but the charge will pass through it without in the least disturbing it, for the same reason that a musket ball will pass through a door without causing it to turn on its hinges, although, under the same circumstances, a very slight force would be sufficient to move it.

204. The effects produced on the card in the preceding experiment, as well as some others that have resulted when the experiment has been varied, have led some electricians to suppose that they might be viewed as indications of the course of the electric matter, and as affording no obscure proof of the existence of two fluids; but Mr. Singer has, in our opinion, satisfactorily shown that they are produced solely by an expansion of the paper.

205. The following illustration of this influence is attributed to Mr. Lane, the inventor of the discharging electrometer. Roll up a piece of soft pipe-clay, in the form of a small cylinder, and insert in it two wires, so that their ends, without the clay, may be about one-fifth of an inch from one another. If a charge be sent through this clay, by connecting one of the wires with the outside of a jar, and the other with the inside, it will be inflated by the shock passing between the two wires, and, after the explosion, will appear swelled in the middle. If the charge sent through it is too strong, and the clay not very moist, it will be broken by the explosion, and the fragments scattered in every direction. To make this experiment with a little variation, take a piece of the tube of a tobacco-pipe, about one inch long, and fill its bore with moist clay; then insert in it two wires, as in the above rolled clay, and send a charge through it. This tube will be burst by the force of the explosion, and its fragments will be scattered about to a great distance. If, instead of clay, the above-mentioned tube of the tobacco-pipe, or a glass tube, which will answer as well, be filled with any other substance, either electric or non-electric, inferior to metal, on making the discharge it will be broken to pieces with nearly the same force.

206. The expansion of fluids by electricity is truly remarkable, and often productive of some singular results. When the charge is strong, no

glass vessel can resist its force. Beccaria placed a drop of water between two wires in the centre of a solid glass ball of two inches in diameter; on passing a shock through the water the ball was dispersed with great violence. Mr. Morgan succeeded, by the same means, in breaking green glass bottles, filled with water, when the distance between the wires that conveyed the spark and the sides of the glass was upwards of two inches.

207. A single spark may be made to perforate a strong glass tube by the following simple process: fill a small phial with olive oil, and insert into it a pointed wire bent at right angles, so that by sliding through a cork fixed in the neck of the phial, the point of the wire may rest against any part of the inside beneath the oil: attach the phial by its wire to the conductor of the machine, and bring the knuckle or a brass ball near the outside of the phial, opposite to the point of the wire within it; a spark will pass from the point to the knuckle, and make a small hole in the glass. By varying the situation of the point, many such perforations may be made in the glass.

208. Of this very singular experiment Mr. Singer offers the following rational account. The point, he says, serves as an internal coating to a very small portion of the glass; and the charge being prevented from extending, by the surrounding oil, the whole power of the machine is concentrated in that point, and consequently soon overcomes its resistance. Similar effects will always result when a large quantity of electricity is suddenly transferred to a comparatively limited surface.

209. Make a small mortar of ivory, with a cavity of half an inch diameter and an inch deep; insert two wires through the sides of the mortar, so that their points within the cavity may be separated by an interval of $\frac{1}{4}$ of an inch; fit a cork cap so as to close the aperture as accurately as possible without friction: when a strong charge is passed through the wires, the air within the mortar will be suddenly expanded, and the cork projected to a distance with some violence.

210. Satisfactory and striking as the preceding experiments are, they appear inferior to the following: in making experiments on the effects of explosions of electricity sent through metallic bodies, Dr. Priestley found that a chain which he had used as the medium of conveying the charge was shorter after being used than it was before. This led him to try the effect of a strong charge on a definite length of chain: the charge was sent from sixty-four square feet of coated surface, through twenty-eight inches of chain, which, on being measured again, was found to be contracted a quarter of an inch in its whole length.

211. This experiment was repeated by Mr. Nairne with a piece of hard-drawn iron wire ten inches in length, and $\frac{1}{150}$ of an inch in diameter. Through this wire he discharged twenty-six feet of coated surface nine times; after the sixth and the ninth time the wire was measured, and it was found to be shortened $\frac{1}{40}$ of an inch after each discharge. By farther discharges sent through it, the wire was shortened $1\frac{1}{10}$th inch. That this contraction arose from expansion appeared from the wire having increased in thickness whilst it was diminished in length.

Solid Bodies ruptured by Electricity.

212. The simplest form, perhaps, in which this can be done, is to place on the table of Henley's discharger a piece of dry writing-paper, and pass over it, by means of the pointed wires, a powerful charge from a large jar; if the wires be placed at about two inches asunder, and so as to touch the ends of the paper, it will be torn in pieces. If, instead of the paper, a number of wafers be placed in the circuit, they will be curiously dispersed, and many of them broken to pieces.

213. Make two small holes in the opposite ends of a piece of oak, of about half an inch long and a quarter of an inch thick; introduce two wires into the holes, so that their extremities within the wood may be rather less than a quarter of an inch distant; on passing a strong charge from one wire to another, the wood will be split. Several other substances that are imperfect conductors, such as loaf-sugar, marble, &c., undergo similar injuries, when introduced into an electrical circuit; and even the hardest bodies, and the most perfect non-conductors, such as glass, are perforated or broken by a strong charge.

214. Lay a piece of plate-glass of about an inch square, and half an inch thick, on the table of the universal discharger, or screw it very tightly within the press of the same; set the prints of the sliding wires opposite to each other, and against the under surface of the glass, so that the charge may pass along that surface. If now a strong charge be passed in this way, the glass will be broken into small fragments, and some of it reduced to an impalpable powder.

215. The following experiment affords a beautiful, though rather an expensive, illustration of the same principle. Charge a very large jar, and connect its external coating with that of one ten or twelve times smaller; form a communication between their internal coatings by the discharging rod, and the small jar will be broken in pieces, by the strength of the quantity of electricity thus suddenly transferred to it.

Inflammable Substances Kindled by Electricity.

216. Almost all inflammable substances may be kindled by means of electricity, but those generally selected for the purpose of experiment are resin, gunpowder, rectified spirit of wine, ether, and hydrogen gas.

217. The common method of kindling resin by the electric spark is to pulverise it, and dust the powder on some dry cotton wool. Thus, if a small quantity of flax, or of cotton wool, be loosely tied on one of the knobs of the discharging rod, and a little finely-powdered resin dusted on it, and a jar be discharged by bringing the end of the rod thus prepared in contact with the knob of the jar, the charge will pass through the flax, or wool, and in so doing will melt and ignite the resin, and set the whole on fire. A very neat contrivance for giving this experiment

a better effect is represented by fig. 4. A is a mahogany board, six inches in length, three in breadth, and half an inch in thickness. B is a glass pillar fixed in the middle of A, and supporting a piece of wood C, which is three inches long, an inch and a half broad, and about three quarters of an inch thick. In each end of this piece there is a small screw-ring: the extremities of these screws just touch a wire proceeding to each of them from two small brass knobs inserted at the ends of a shallow groove on the upper side of C; these rings serve to hook the chains on when the instrument is used. On the back part of C stands the perpendicular piece D, in the top of which is fixed the brass pin E. To use this for the purpose of igniting resin, it is only necessary to dust the cotton with powdered resin, and hang it on the pin E, letting the lower part of it reach down to the piece C. Connect one end of C with the inside of a jar and the other end with the outside; discharge the jar, and the fluid in passing between the two small brass knobs will inflame the resin and kindle the cotton.

218. But the inflammation of resin is rendered still more striking by the following experiment: let a flat porcelain dish be filled with water, and on the surface of the water strew a quantity of finely powdered resin; place two wires at the opposite sides of the dish, having their ends near the surface of the water, and at about the distance of four inches from each other. Pass the charge of a large jar through this circuit, and the resin which forms a part of it will be beautifully inflamed.

219. The firing of gunpowder by the electrical explosion requires considerably more care and address than the firing of resin. It may, however, be effected by the following method: take either a large goose-quill or a small cartridge of paper, and fill it with gunpowder ground very fine; into this insert two wires, one at each extremity, so that their ends within the quill or cartridge may be about one-fifth of an inch from each other: this done, send the charge of a phial through the wires; and the spark between their extremities, that are within the cartridge, or quill, will inflame the gunpowder. If the gunpowder be mixed with steel-filings, it will take fire more readily, and with a very small charge.

220. Rectified spirit of wine, or ether, may be thus inflamed by a single spark from the conductor of the machine when in action: hang to the prime conductor a short rod having a small knob at its end; then pour some spirit of wine, a little warmed, into a metallic spoon; hold the spoon by the handle, and place it so that the small knob on the rod may be about one inch above the surface of the spirit. In this situation, if a spark be taken from the knob, it will set the spirit on fire. This experiment may be varied and rendered very agreeable to a company of spectators. A person standing upon the insulating stool, and communicating with the prime conductor, may hold the spoon with the spirit in his hand, and another person standing upon the floor may set the spirit on fire by bringing his finger within a small distance of it. Instead of his finger, he may fire the spirit with a piece of ice, when the experiment will seem much more surprising. If the spoon is held by the person standing upon the floor, and the insulated person brings some conducting substance over the surface of the spirit, the experiment succeeds equally well. This experiment is sometimes rendered still more striking in the following manner: near the prime conductor of the machine, place on the table three wine glasses; connect the first glass with the conductor by a brass chain, which will reach to the bottom of it; and with it let the second and third be connected by a piece of fine brass wire, bent in the form of the letter A. Fill the first and second glasses with water, and into the third pour a little ether; turn the machine, and with a wire, having a small ball affixed to it, draw a spark from the ether, and it will be immediately inflamed. In this experiment the electric fluid had to pass through two distinct portions of water before it could come to the ether.

221. Hydrogen gas is generally inflamed by the electric spark in the following manner: take a brass cannon, such as is represented in fig. 5, and charge it with hydrogen gas by holding the mouth of it for about half a minute over a stone or glass bottle in which the gas is generated, and then fix the cork tightly into the mouth of the cannon. The person who is to discharge it must now stand on the insulating stool, and, holding in his hand a chain attached to the prime conductor, must, with a wire and ball held in the other hand, communicate a spark to the knob of the cannon: this spark will pass into the interior of the cannon through the glass tube B, and the gas will instantly explode with a loud report, and the cork will be driven out to a considerable distance. This experiment may be rendered more effectual by mixing about one-third of oxygen with the hydrogen gas; or, if oxygen cannot be conveniently procured at the time, the operator may easily contrive to have some atmospheric air in the cannon, which will render the hydrogen gas more explosive.

222. The very great ease with which inflammable air is kindled by even a small spark of electricity seems to have suggested to M. Volta the idea of what he calls his inflammable air-lamp, an instrument which appears to have laid the foundation for the patent apparatus for obtaining instantaneous light. This curious instrument is represented in fig. 6, where A is a glass globe for containing hydrogen gas; B a glass reservoir for holding water; and D a stop-cock, by which a communication is formed between the water and the gas. The water passes into the globe through the pipe *g g*, which is fixed into the top of the reservoir A; at *s* there is a cock to cut off or open a communication between the air and the jar K. N is a contrivance for holding a wax-taper; L a brass pillar, on the top of which is fixed a ball of the same metal; *a* is a pillar of glass, with a socket at the top, in which the wire *b* slides, having a ball screwed on the end of it. F is a cock by which the globe is filled with hydrogen gas, and which afterwards serves to confine it, and what water falls into B and A. To use this instrument,

having filled the globe with gas, and the reservoir A with water, turn the cocks D and *s*, and the water will fall into the globe, forcing up a quantity of gas, which will rise through the pipe K. If, now, an electric spark be made to pass from the ball *m* to that marked *n*, it will set fire to the gas which passes through the pipe K. To extinguish the lamp, first shut the cock *s*, and then D. The gas is obtained in the usual way, from diluted sulphuric acid and iron filings; and the globe is to be filled in the following manner:—Having previously filled it with water, place the foot R in a vessel of water, so that it may be covered, and the bent glass tube, through which the gas is to be introduced, may pass commodiously below the foot. When the gas has displaced nearly all the water, turn the cock F, and the lamp is ready for use.

223. This instrument is sometimes constructed so as to be connected with an electrophorus for the purpose of producing a light at pleasure. In this case the electrophorus is placed in a box beneath the vessel containing the hydrogen gas; from this box a wire passes through a glass tube to the opening of the stop-cock. The cover of the electrophorus must be connected by a silk string with the handle of the stop-cock, so that the same motion that opens the cock, may raise the cover of the electrophorus, and the spark that strikes from it be conveyed by the insulated wire to the stream of gas, which it inflames. This effect will take place every time the stop-cock is opened, for the electrophorus will produce sparks for a considerable time, without any fresh excitation; and the quantity of gas consumed at each repetition of the process is very small, so that a light may be obtained above a hundred times before the contents of the reservoir are expended; and it may then be easily replenished.

224. But by far the most remarkable effects of electricity in producing combustion, result from its action on metallic substances. This property of the electric matter seems to have been first observed by the celebrated Dr. Franklin, who made several experiments on the subject. These experiments were repeated and extended by Mr. Kinnersly, and also by Beccaria; and have since then been prosecuted with great accuracy by Mr. Brook, Dr. Van Marum, Mr. Cuthbertson, Mr. Singer, and others. In treating on this part of the subject, we shall, as in the preceding instances, give a course of progressive experiments, which may be made with an appropriate apparatus, from a single jar of a tolerably large size, up to a powerful battery, previously remarking that the whole of the apparatus must be in the very best state in which it can be put, otherwise disappointment, in many cases, and inaccuracy in all, will be the result.

225. The slightest indication of the fusing of metallic substances is observed in the discharge of the Leyden phial: on this occasion, if the discharge be made by means of the common discharging rod, the knob that touches the outside coating will be found to adhere slightly to the jar after the discharge; and this arises from the fusing of a small portion of the tin-foil coating.

226. This may be rendered very obvious by the following experiment:—Charge a large jar, and place a smooth piece of coin between the knob of the discharger and the coating of the jar; when the discharge has been made, the piece of coin will be found slightly adhering to the tin-foil, by its fusion at the point of contact, and will remain so as to require some force to separate them.

227. Dr. Franklin's experiments on the fusing of metals may be thus imitated:—Take three pieces of window-glass, each one inch wide, and three inches long, and place them contiguous to each other, with two narrow strips of gold-leaf between them, so that the middle glass may have, on each side of it, a strip of gold, with its ends projecting a little beyond the glass. Let the whole be properly secured within the press of the universal discharger; pass the charge of a large jar through the strips of gold, they will be melted and driven into the glass. The outer pieces of glass are generally broken, but the middle piece is often left entire, and is marked with an indelible metallic stain on each of its surfaces.

228. The colors produced when metals are thus fused, either on glass or paper, are sometimes exceedingly beautiful, and have been in some cases employed in impressing letters, and ornaments of various kinds, on silk and paper. The process observed in such cases, Mr. Singer thus describes in his Elements:—'The outline of the required figure is first traced on thick drawing paper, and afterwards cut out in the manner of stencil plates. The drawing paper is then placed on the silk or paper intended to be marked; a leaf of gold is laid upon it, and a card over that; the whole is then placed in a press, or under a weight, and a charge from a battery sent through the gold leaf. The stain is confined, by the interposition of the drawing paper, to the limit of the design; and in this way a profile, a flower, or any other outline figure may be very neatly impressed.'

229. In describing Cuthbertson's electrometer, No. 177, we made some remarks on the fusing of wire, by passing through it the discharge of accumulated electricity; it may be necessary to offer here some general observations on the same subject; and to give some account of the results of the experiments made by those whose names we have already enumerated.

230 For the fusing of wires of different lengths very large batteries were formerly considered as indispensable; but Mr. Singer observes, that, if the wire be sufficiently fine, a single jar, exposing a coated surface of about 190 square inches, will be sufficient to afford an example of the effect. The finest flattened steel wire, sold at the watchmakers' tool shops under the name of pendulum wire, is the best for the purpose; harpsichord wire not being fine enough, excepting where great power is used. Cuthbertson's Balance Electrometer should be invariably used to regulate the charge; the circuit made as short as possible; and the wire to be fused placed in a straight line, and held at the ends between a small forceps made of wire.

231. The following is the substance of Mr. Singer's remarks on the numerous experiments of Messrs. Brook and Cuthbertson on the fusion of metallic wires. Their conclusion was, that the action of electricity on wires increases in the ratio of the square of the increased power: since two jars, charged to any degree, will meet four times the length of wire that one jar will melt; and this will be again quadrupled by doubling the height of the charge.

232. This law, adds Mr. Singer, I have found, obtains in all accurate experiments with moderate lengths of wire; and it is apparent in Mr. Cuthbertson's experiments, to some extent. His batteries usually contain fifteen jars, and one of these is just sufficient to fuse half an inch of wire of $\frac{1}{150}$th of an inch diameter: but the whole fifteen jars combined, will fuse sixty inches of the same wire. Mr. Singer made some experiments with an iron wire of $\frac{1}{250}$th of an inch diameter, on an extensive scale; but he found that some of the charge was lost in pervading such a considerable length of wire, so much so, that the explosion of the battery, at other times remarkably loud, was then scarcely audible. With a battery, however, of forty feet of coated surface, Mr. Singer says he frequently melted eighteen feet of the above-mentioned wire by a single explosion, and the phenomena were remarkably brilliant; a shower of intensely ignited globules being dispersed in every direction. This law, however, Mr. Singer found to vary with the thickness of the glass employed; thick jars displaying the same intensity with a comparatively small quantity of electricity; and consequently having, as he expresses it, less wire-melting power. Of this he produces a proof, furnished by his large Leyden jar, to which we have already alluded; this jar, from the extent of its coated surface, ought to have melted three feet of wire, with a charge of thirty grains; but from its extreme thickness, which limited its electrical virtue, it would only melt eighteen inches. Mr. Singer remarks, that this is correspondent with the conclusion of M. Cavendish, that the quantities of electricity required to charge different coated jars of the same extent, will be in the inverse proportion of their thickness.

233. The fusion of wire may therefore be employed as a measure of the quantity of electricity accumulated on any charged surface; for the preceding experiments show that any given quantity of electricity will fuse the same length of wire, whether that surface be disposed on two jars or one; hence it may be inferred that the actual intensity of a charge does not materially affect its power in melting wire. This test is therefore practically useful; for the various electrometers measure only the intensity, and are as much affected by one jar as by a battery of 100. When the fusion of wire is employed as a test of electrical power, care should be taken that the length of the circuit be always the same, and that the degrees of ignition be uniform; for a wire may be melted with but slight variations of appearance when very different portions of electricity are passed through it. The lowest degree of perfect ignition ought therefore to be obtained in all comparative experiments; and, as soon as the discharge is made, the wire should become red-hot in its whole length, and then fall into fine globules.

234. The gradually increasing effects produced are very remarkable, when, on wires of the same length and diameter, progressively strong charges are transmitted. If the charge be very low, it is found that the color is changed to yellow; it then becomes blue by a higher charge; then red-hot; then red-hot and melted into balls; and, if we increase the charge still further, it becomes red-hot, and drops into balls, then disperses in a shower of balls, and finally disappears with a bright flash, producing an apparent smoke, which turns out when collected to be a fine powder, consisting of the metal combined with oxygen, and weighing more than the metal which was originally fused.

235. The experiments and results already enumerated do by no means form the boundary of the power of the electric fluid; bodies which resist the most intense heat, produced in the common way, are by it converted into oxides in a moment. Of this more will be said in a future part of this article; in the meantime a few examples may be given, which properly belong to the present. The most laborious experimenters on this part of electricity have been Cuthbertson and Singer, of whose operations we shall here avail ourselves, as being both numerous and valuable. The apparatus used by Mr. Cuthbertson, and, in some of his experiments, by Mr. Singer also, may be thus described:—

236. It consists of a glass cylinder *a b*, fig. 7, about eight inches high, and two inches and a half diameter, mounted air-tight with two brass caps. On the lower cap *a* is screwed a stop-cock, and above the cap is fixed a small roller, on which a quantity of wire, attached to a packthread at intervals of four inches, is coiled. A brass tube *c*, about three inches long, is screwed into the centre of the upper cap *b*, and, by means of a long needle, the end of the packthread and wire is thrust through it, and hog's lard is placed in the tube, so that the wire and packthread shall always move through it air-tight. In this way the wire is extended in the centre of the cylinder, and, when one length is exploded, another may be drawn forward by means of the packthread, without opening the cylinder. For ascertaining the quantity of air absorbed during the process, a gauge, represented by A, about ten inches long, made of a glass tube, is screwed into the lower end of the stop-cock, and immersed in a vessel of quicksilver, the rise of which, when the stop-cock is opened, will be a measure of the air absorbed. The air left in the receiver, after a number of explosions, is always found to have been deprived of a portion of its oxygen; and, if hydrogen or nitrogen gas be substituted in place of atmospheric air, the metal will not suffer any oxidation, but will be fused, and minutely divided.

237. To accomplish the complete oxidation of metallic substances, a higher power is required than that which is merely adequate to fuse them. The following is a statement of the comparative strength of the charges which Mr. Cuthbertson

employed in exploding the wires mentioned, the length of each wire being ten inches: the coated surface was the same in all the experiments, viz. one of his batteries of fifteen jars, exposing seventeen feet of coated surface. The column marked A, shows the diameter of the wires in parts of an inch; B the number of grains with which the electrometer was loaded; and C the color of the oxide deposited on the receiver:—

	A.	B.	C.
Lead wire . .	$\frac{1}{90}$	20	Light gray.
Tin wire . .	$\frac{1}{90}$	30	Nearly white.
Zinc wire . .	$\frac{1}{90}$	45	Nearly white.
Iron wire . .	$\frac{1}{150}$	35	Reddish brown.
Copper wire .	$\frac{1}{150}$	35	Purple brown.
Platina wire .	$\frac{1}{150}$	35	Black.
Silver wire . .	$\frac{1}{150}$	40	Black.
Gold wire - .	$\frac{1}{150}$	40	Brownish purple

238. Mr. Singer was of opinion that the charges here given by Mr. Cuthbertson were rather high, and attended with considerable risk of fracture to the jars: he repeated the experiments with shorter lengths of wire, and of less diameter; and with more moderate charges obtained the following results:—

	A.	B.	C.
Gold wire	$\frac{1}{150}$	18	Purple and brown.
Silver wire	$\frac{1}{150}$	18	Gray, brown, and green.
Platina wire	$\frac{1}{150}$	13	Gray and light brown.
Copper wire	$\frac{1}{150}$	12	Green, yellow, and brown.
Iron wire .	$\frac{1}{150}$	12	Light brown.
Tin wire .	$\frac{1}{150}$	11	Yellow and gray.
Zinc wire .	$\frac{1}{150}$	17	Dark brown.
Lead wire .	$\frac{1}{150}$	10	Brown and blue gray.
Brass wire .	$\frac{1}{150}$	12	Purple and brown.

239. In the above experiments Mr. Singer did not use the receiver; the wires, which were five inches in length, were stretched parallel to the surface of a sheet of paper, and distant from it about one-eighth of an inch. Brass wire is sometimes decomposed by the electrical charge, in which case its component parts, copper and zinc, are separated from each other, and appear in their distinct metallic colors when the explosion is made over a piece of glass. Indeed the figures of all the oxides are most beautiful when impressed on glass, although their colors are certainly less permanent.

240. This most amazing power of the electric matter is not only adequate to the oxidation of metallic substances, but is yet more remarkable in restoring oxides, already formed, to their metallic, or original state, for which purpose a very simple process will be found sufficient.

241. Into a small glass tube introduce a little of the oxide of tin; let it cover about half an inch of the lower internal surface. Place the tube thus prepared on the table of Henley's discharger, and introduce the pointed wires at each end, that the oxide may form part of the circuit. Pass now several strong charges in succession through the tube, taking care to replace the oxide in its proper situation, should it be dispersed. If the charges are strong, the tube will soon become stained with the tin revived from the oxide.

242. In the same way other metallic oxides may be revived; but if vermilion be employed, which consists of sulphur and mercury, the mercury will be separated with such ease as that the charge of a moderately sized jar will be found quite sufficient.

Decomposition of Water by Electricity.

243. The decomposition of water by electricity was first effected by Van Troostwyk and Deiman, assisted by Mr. Cuthbertson; this they effected by means of a complicated apparatus, and a very tedious process. Their method of procedure was improved on by Dr. Pearson, and after him by Mr. Cuthbertson: but the most simple form of an apparatus for this purpose is that of Dr. Wollaston. This apparatus is thus constructed:—Two finely pointed wires of gold or platina are inserted into capillary tubes; each wire is thrust into the tube till it nearly reaches the end of it, and the glass is softened by heat until it adheres to the wire and covers its point. The glass is then carefully ground away, till the point of the wire can be seen by the help of a magnifying glass. One of these wires is made to communicate with the ground, or with the negative conductor of the machine, and the other with an insulated ball placed near the positive conductor, the two points are placed near each other in a vessel of water; when a current of sparks is discharged through the wires, a series of minute bubbles of gas will rise from the points of the gold wires, and, when collected in an inverted receiver, will explode on the application of a lighted taper. Dr. Wollaston found by experiment, that a point $\frac{1}{700}$ of an inch in diameter, decomposed the water when the spark which passed from the conductor to the insulated ball was $\frac{1}{8}$ of an inch in length; and that a point $\frac{1}{1500}$ of an inch in diameter, produced the same effect when the sparks were only $\frac{1}{20}$ of an inch in length. Hence the rapidity of the decomposition was in proportion to the limited size of the point of the wire.

244. Of the results obtained in some experiments made with this apparatus, Dr. Wollaston gives the following account. By transmitting a current of sparks by means of two gold points over the surface of a card a little moistened, and tinged with litmus, and placed between the points, a redness was perceived about the positive wire after a few turns of the machine. When the negative wire was placed upon the red spot it was quickly restored to its former color. Hence he infers that the effect of an acid is produced at the positive wire; and that this effect is counteracted by reversing its electricity.

245. Dr. Wollaston next coated two wires with sealing-wax, so that their ends only were exposed: these he inserted into a solution of copper, and found that, on transmitting a current of sparks between them, the negative wire was coated with copper: the electricity of the wire being reversed, the copper quickly disappeared

246. When it is wished to decompose oils, alcohol, ether, &c., a much more simple, and less expensive apparatus will be found to answer every purpose. This apparatus, which is represented by fig. 8, consists of a glass tube having a platina wire projecting from the top inwards and reaching nearly to the lower end. The lower

extremity is open, and is placed in a metallic dish nearly filled with the fluid which is to be decomposed. The cylinder must be filled with the fluid as receivers are filled with water in the pneumatic trough. When charges are successively sent through the wire, the fluid will be gradually decomposed, and the gaseous product rising to the upper part of the cylinder will displace the liquid. In all experiments of this kind the glass used ought to be very strong to resist the expansion caused by the explosion.

247. Having spoken of the decomposition of water by means of the electric fluid, it may be proper just to notice the process of forming water from the gases that compose it, by the action of the same agency. For this curious experiment Mr. Singer employed the apparatus represented in fig. 9, which consists of a stout globe of glass, with a stop-cock, having a wire passing through its centre to within a short distance of the cap to which the stop-cock is screwed. The globe must be exhausted by means of an air-pump, and then screwed on a receiver containing a mixture of oxygen and hydrogen gases, furnished with a stop-cock. When the cocks are opened, the globe will be filled with the gases; they must then be shut, and a spark passed from the wire in the inside of the globe to the cap. A bright flash follows, and the inside of the globe becomes covered with moisture; the cocks are then to be opened, and more gas will rush into the globe. The cocks being again closed, a second explosion may be made, which will increase the dew on the inside of the globe; and the experiment may be repeated in this way until drops of water may be observed.

248. Such experiments as the preceding naturally led to numerous others on various liquids and also on different gaseous bodies: to detail these would be foreign to our purpose; yet to pass them over in silence would be to do them injustice. We shall, therefore, merely give the results of some remarkably fine experiments by Cavendish, and others, as drawn up in a tabular form by Mr. Singer. The numbers prefixed to some of the gases indicate the proportionate measures employed of each.

MIXED GASES.	RESULT.
Atmospheric air and hydrogen	Water and nitrogen.
Oxygen and hydrogen	Water.
Chlorine and hydrogen	Muriatic acid.
Muriatic acid and oxygen	Chlorine.
Carbonic oxide and oxygen	Carbonic acid.
Nitrogen and oxygen	Nitric acid.
Sulphurous acid and oxygen	Sulphuric acid.
Phosphureted hydrogen and oxygen	Water and phosphoric acid.
Sulphureted hydrogen and oxygen	Water and sulphurous acid.
Oxygen and ammonia	Water and nitrogen.*
100 olefiant gas and 284 oxygen	Carbonic acid and water.
100 olefiant gas and 100 oxygen	Carbonic oxide and hydrogen.
100 carbureted hydrogen and 100 oxygen	Carbonic oxide and hydrogen.
100 carbureted hydrogen and 200 oxygen	Carbonic acid.

COMPOUND GASES.	RESULT.
Muriatic acid	Hydrogen.*
Fluoric acid	Hydrogen.*
Nitrous gas	Nitric acid and nitrogen.
Carbonic acid	Carbonic oxide and oxygen.
Sulphureted hydrogen	Sulphur and hydrogen.
Phosphureted hydrogen	Phosphorus and hydrogen.
Ammonia	Hydrogen and nitrogen.
Olefiant gas	Charcoal and hydrogen.
Carbureted hydrogen	Charcoal and hydrogen.

The results marked with a star are given on the authority of Dr. Henry and Mr. Dalton. In making the above experiments when the mixture consisted of inflammable gases with oxygen, the change was usually effected by a single spark; but in other cases it was found necessary to continue the current of sparks for many hours.

Electrical Configurations.

249. This is a most interesting and curious branch of mechanical electricity, and one which certainly challenges a more vigorous enquiry than has hitherto been made respecting it. It is thought by some that the experiments which we shall here briefly notice afford satisfactory proof that electricity is the real cause of crystallisation. The subject seems to have been first noticed by professor Lichtenberg, of Gottingen, and afterwards by Mr. Bennet, Cavallo, and others.

250. Excite a plate of any resinous substance, as gum-lac, by friction, and let any metallic body of any shape whatever, a brass ring for instance, be placed upon the plate. Let the ring be then electrified with an electricity opposite to that of the plate, and afterwards removed from the plate by a stick of sealing-wax, or any other non-conductor. Let some powdered resin be now shaken upon the plate, then if the plate has been excited negatively, and the brass ring positively, the powder will fall only on those points of the plate that were touched by the ring, and will form radiating appearances resembling stars, while almost no powder will be found on any other part of the plate. If, on the other hand, the

plate has been electrified positively, while the ring was electrified negatively, the powdered resin will fall only on the parts of the plate which were formerly uncovered, the figures being now indicated by the absence of the powder.

251. Mr. Bennet who repeated with much care the experiments of Lichtenberg, has given the following account of the method which he adopted for rendering figures produced in this way permanent. When it is wished to make the figures red, 'Take a pound of rasped Brasil wood; put it into a kettle with as much water as will cover it, or rather more: also put in about an ounce of gum arabic, and a piece of alum about the size of a large nut; let it boil about two hours, or till the water be strongly colored; strain off the extract into a broad dish, and set it in an iron oven, where it is to remain till all the water be evaporated, which with me was effected in about twelve hours; but this depends on the heat of the oven, which should not be so hot as to endanger its burning. Sometimes I have boiled the strained extract till it was considerably inspissated before it was placed in the oven, that it might be sooner dry.

252. 'When it is quite dry, but not burnt, scrape it out of the dish, and grind it in a mortar till it be finely pulverised. In doing this, it is proper to cover the mortar with a cloth, having a hole through it for the pestle, to prevent the powder from flying away and offending the nose, and also to do it out of doors if the weather be dry and calm, that the air may carry away the powder necessarily escaping, and which otherwise is very disagreeable. When ground, let it be sifted through a fine hair sieve, returning the coarser part into the mortar to be ground again.

253. 'The plate I have mostly used, was composed of five pounds of resin, half a pound of bees'-wax, and two ounces of lamp-black, melted together, and poured upon a board sixteen inches square, edged round with slips of wood, at least half an inch high, to confine the composition whilst fluid: the plate was thus half an inch thick, which is better than a thinner plate, the figures being more distinct. After the composition is cold, it will be found covered with small blisters, which may be taken out by holding the plate before the fire till the surface be a little melted, then let it cool again; and upon holding it a second time to the fire, more blisters will appear; but by thus repeatedly heating and cooling the surface, it will at last become perfectly smooth. Some plates were made smaller, and the resinous composition confined to the form of an ellipsis, a circle, or escutcheon, by a rim of tin half an inch broad, and fixed upon a board.

254. 'The next thing to be done is to prepare the paper, which is to be softened in water, either by laying the pieces upon each other in a vessel of cold water, or first pouring a little hot water upon the bottom of a large dish; then laying upon it a piece of paper, so that one edge of the paper may lie over the edge of the dish, to remain dry, that it may afterwards be more conveniently taken up. Then pour more hot water upon its upper surface. Upon this place another piece in the same manner, again pouring on more water, and thus proceed till all the pieces are laid in. By using hot water, the paper will be softened in a few minutes.

255. 'When the figures are to be made, the resinous plate must lie horizontally, whilst the electricity is communicated, if the experiment requires any thing to be placed upon the plate: but it is convenient afterwards to place it in a vertical position whilst the powder is projected, lest too much powder should fall where it is not required.

256. 'A little of the powder may be taken between a finger and thumb, and projected by drawing it over a brush; or, what is better, a quantity of it may be put into the bellows and blown towards the plate. When the figure is sufficiently covered with powder, let the plate be again laid horizontally upon a table; then take one of the softened papers out of the water by its dry edge, and lay it carefully between the leaves of a book, pressing the book together, and permitting it to lie in this situation about half a minute. Then remove the paper to a dry place in the book, and press it again about the same time, which will generally be sufficient to take off the superfluous moisture. Then take up the paper by the two corners of its dry edge, and place the wet edge a little beyond the figure on the resinous plate, lowering the rest of the piece gradually till it covers the figure without sliding; then lay over it a piece of clean dry paper, and press it gently; let it remain a short time, and then rub it closer to the plate with a cloth; or, which is better, press it down by means of a wooden roller covered with cloth, taking care that the paper be not moved from its first position.

257. 'When the paper is sufficiently pressed, let it be taken up by its dry edge, and laid upon the surface of a vessel of water, with the printed side downwards; by this means the superfluous powder will sink in the water, and the figure will not be so liable afterwards to spread on the paper. After the paper has remained on the water a few minutes, take it up and place it between the leaves of a book, removing it frequently to a dry place. If it be desired that the paper should be speedily dry, let the book-leaves in which it is to be placed be previously warmed, and by removing it to several places it will be dry much sooner than by holding it near a fire. By the above process, it is obvious that leather, calico, or linen, as well as paper, may be printed with these figures, and the effects of the diffusion of electricity upon a resinous plate be exhibited to those who have not leisure or inclination to perform the experiments.'

258. To the above it may be proper to add, that with a resinous plate of the kind now described, a very beautiful exhibition may be made of the different powers of positive and negative electricity. For this purpose prepare equal quantities of red lead and resin, by weight, finely powdered and intimately mixed, by being sifted together through a fine hair sieve. Put this powder into a bottle of India rubber for use. Let now a small jar be charged at the positive conductor of the machine, and, with its knob,

quickly write the letter P on the resinous plate: take the bottle containing the mixed powders, and by gently striking the sides of it between the palms of the hands, the mouth of it being directed towards the plate, which must be placed in a vertical position, project on the electrified part a little of the powder, and the letter will instantly appear, well defined, and covered with the red lead, while the resin will be dispersed. If now the whole be wiped clean off, and, with a jar charged at the negative conductor, the letter N be written on the plate, and the powder projected as before, it will be found that the negative electricity has selected the resinous particles for the formation of the letter, while those of the red lead have been rejected.

Magnetic Effects of Electricity.

259. The connexion between magnetism and electricity will be fully treated of in a subsequent part of this article; at present we shall merely offer the following general remarks in the way of showing the amount of what was known on the subject previously to the interesting discoveries recently made.

260. Dr. Franklin appears to have been the first who paid any serious attention to this subject. He sent the charge of some large electrical jars through fine sewing-needles; the ends of the needles were rendered blue, and on being carefully laid on water they traversed, evincing evident proofs of polarity. The most remarkable circumstance attending these experiments was, that if the needle lay east and west when the charge was passed through it, the end which was entered by the fluid pointed to the north: but if it lay south and north, the end which lay pointing to the north would continue to do so, whether the charge entered by that end or the other; although the Dr. imagined that a still stronger charge would have reversed the poles, even in that situation, since this effect had been actually produced by lightning. The polarity he also found to be strongest when the needle received the charge while lying north and south, and weakest when it lay so as to point east and west.

261. But the experiments most to be relied on were made by Van Marum with the large machine and battery in the Tylerian museum at Haarlem. He and his assistants tried to give polarity to needles made of watch-springs, of from three to six inches in length; and also to steel bars nine inches long, from a quarter of an inch to half an inch broad, and about a line in thickness. The result was, that when the bar was placed horizontally in the magnetic meridian, whichever way the shock entered, the end of it that stood toward the north acquired the north polarity, and the opposite end acquired the south. If the bar, before it received the shock, had some polarity and was placed with its poles contrary to the usual direction, its natural polarity was uniformly diminished, and often reversed; so that the extremity of it, which in receiving the shock pointed to the north, became the north pole, &c.

262. When the bar was struck standing perpendicularly, its lowest end became the north pole in any case, even when the bar had previously some magnetism, and was placed with the south pole downwards. Things remaining the same, the bars seemed to acquire an equal degree of magnetic power, whether they were struck whilst standing horizontally in the magnetic meridian, or perpendicular to the horizon. When the needle was placed in the magnetic equator, whichever way the charge entered, it never produced any magnetism; but if it was passed through its width, then the needle acquired a considerable degree of magnetism, and the end which lay towards the west became the north pole, and the other end the south pole. If a needle or bar, already magnetic, or a real magnet, was struck in any direction, its power was always diminished. For this experiment they used considerably large bars, one of which was 7·08 inches long, 0·26 broad, and 0·05 thick. When the shock was so strong in proportion to the size of the needle, as to render it hot, then the needle generally acquired no magnetism at all, or very little. These experiments were made with the power of a battery composed of 135 phials, containing among them about 130 square feet of coated surface.

Medical Electricity.

263. The very remarkable properties of the electric fluid seem to have occasioned the application of its powers to organised bodies at an early period of its history; and the results, whether real or imaginary, gave rise to various opinions, which are now only viewed as monuments of credulity and imposture. It is not our intention to enter here minutely into an investigation of this department of the science of electricity; yet, although this would be improper on several grounds, we must not pass it over in silence. The application of electricity as a medical agent has recently been much revived; but that application is, we believe, most successfully made in the form of Voltaic electricity; and will therefore fall, with more propriety, under consideration in another place. From the numerous respectable testimonies extant, as to the real utility of electricity in the healing art, we shall make a choice selection, which it is hoped will satisfy the reader, that in the hands of a skilful operator, it may be applied in numerous instances with certainty of success. Let it however be observed that no one ought to attempt its application who is not thoroughly conversant with the use of the apparatus, and capable of forming a correct judgment, as to the strength and duration of the application.

264. Speaking of the power of the apparatus which ought to be used in the application of electricity for medical purposes, Mr. Singer justly remarks, that the machine employed ought to be such as will furnish a constant stream of sparks; if a plate machine, it ought to be two feet in diameter; if a cylinder machine, not less than ten inches, and fourteen if possible. Machines called medical electrical machines, are sometimes made on a very small scale, and hence the application of them only produces trouble, waste of time, and final disappointment.

265. In connexion with a *powerful* electrical

machine, the auxiliary apparatus requisite for medical purposes are the following:—A jar fitted up with Lane's electrometer, by which shocks may be given of any required force. A pair of directors, each consisting of a glass handle, surmounted by a brass cap with a wire of a few inches in length, having a ball screwed on its extremity, which may be occasionally unscrewed and a wooden point substituted for it. When shocks are given by means of these directors, they must be applied at the opposite extremities of the part through which the charge is required to pass; and being respectively connected by conducting wires, the one with the outside of the jar and the other with the receiving ball of the electrometer previously placed at the requisite distance, the jar may be set to the machine, which is then put in motion until any required number of shocks has been given.

266. The insulated director is also employed to give sparks, being held by its glass handle, and its ball previously connected with the conductor by a fine chain being brought near the patient, or rubbed lightly over a piece of flannel or woollen cloth laid on the affected part. When the eye or any delicate organ is electrified, the ball of the insulated director is unscrewed and the wooden point applied, at the distance of about half an inch from the part. The stream of electricity which passes from the point, in such cases, produces rather a pleasant sensation than otherwise.

267. An insulated stool is sometimes employed; it should be of sufficient size to receive a chair upon it, with a resting place in front of the chair for the feet. The patient being placed on the insulated chair, and connected with the conductor of the machine by means of a chain, sparks may be drawn from any part of the body by a person who stands on the ground and presents a brass ball to it.

268. The following enumeration of instances of disease in which electricity has been successfully applied, is given by Mr. Singer as established on good authority:—1. Contractions. Those only that depend on the affection of a nerve; and in many of these it has been employed without effect, whilst in others of long duration immediate relief has been obtained. 2. Rigidity. Very frequently relieved, but usually requiring some perseverance in the application, to complete the cure. 3. Sprains, relaxation, &c. Electricity may be applied in all these cases with good effect, but its application should be deferred until the inflammation has subsided. 4. Indolent tumors. Strong sparks, and slight shocks, are often effectual. The most numerous cases are those of scirrhous testicle; and there are some instances of the successful dispersion of scirrhous induration of the breast. 5. Mr. Carpue states, that electricity is a good preventive against chilblains; and mentions two instances in which they were removed by the action of electrical sparks. 6. Epilepsy. In several instances of persevering application, not one successful case occurred. 7. Deafness. Sparks thrown on the mastoid process, and round the meatus auditorius externus, and drawn from the same parts on the opposite side, usually afford relief; and about one in five are permanently cured. 8. Opacity of the cornea. This is sometimes cured by the long continued action of electricity thrown for ten minutes a day on the eye by a wooden point. When caused by the small-pox, it is said to yield most readily. 9. Gutta serena. The method of electrifying for opacity of the cornea has been successful in some instances of gutta serena; but there are numerous unsuccessful cases. 10. Amenorrhæa. Cases of suppressed menstruation are generally relieved by sparks and slight shocks; but in retention of the menses electricity has been tried without success. 11. Knee cases. In instances of pain and swelling of the knee, the application of sparks has been effectual in about one case in ten. 12. Chronic rheumatism. Very numerous are the instances of success; the usual application is by sparks, for ten or fifteen minutes every day. In recent cases, a few days is sometimes sufficient; but in those of long standing, very considerable perseverance is often required. 13. Acute rheumatism. In one case out of six a cure was effected in about a month by the application of electricity. 14. Palsy. Moderate shocks, with sparks, have been occasionally successful in about one case of paralysis in every fourteen that have been tried. 15. St. Vitus's dance has been frequently relieved by electricity. There are indeed scarcely but few diseases in which some successful instances of its application are not recorded; but we are still in want of a scientific examination of the statements that have been made on this subject.

269. It appears that the nerves are most powerfully affected by electricity, since the effect of a discharge sent through the body is always most conspicuous in their direction. When the charge of a battery is sent through the head of a bird, the optic nerve is generally found to be injured, and often completely destroyed; a like discharge sent through a larger animal is found to produce a universal protraction of strength, with trembling and depression. Mr. Singer says he once accidentally received a considerable charge from a battery, through the head, which produced the sensation of a violent but universal blow, followed by a transient loss of memory and indistinctness of vision, but was unattended by any permanent injury.

270. Mr. Morgan, who paid considerable attention to medical electricity, has remarked, that if the diaphragm be made to form part of the circuit of a coated surface equal to two feet, fully charged, the lungs make a sudden effort, which is followed by a loud shout; but that if the charge be small, it never fails to produce a violent fit of laughter; and that even those whose calmness and solemnity are not easily disturbed by ludicrous occurrences, are seldom able to withstand the powers of electricity. The first effect of a strong charge on the diaphragm is frequently followed by involuntary sighs and tears, and sometimes by a fainting fit. If the charge be passed through the spine, it produces a degree of weakness in the lower extremities; so that if a person be standing at the time, he sometimes drops on his knees, or falls prostrate on the floor.

271. Numerous cases of the successful application of electricity as a medical agent have been published by different authors; Mr. Cavallo has related some of a very striking nature, as have also Mr. Carpue, and Mr. Ferguson, whose testimony stands high in consequence of the candor and unaffected simplicity of their narrations. To the above-mentioned names we must add the name of Mr. La Beaume, who has recently published an excellent little work on the Application of Galvanic Electricity in the cure of chronic diseases; to these works the reader is referred for more ample information on the subject than our limits will allow us to give.

PART IV.

ATMOSPHERICAL ELECTRICITY.

272. In the preceding parts of this article we have had occasion to make several references to the identity of lightning and the electricity excited by artificial means; we now proceed to show, by a selection of strictly appropriate experiments, that that agent which is ever active in the atmosphere which surrounds our earth, and is occasionally producing some of the most astonishing, and awfully grand phenomena of nature, is nothing more than a vast explosion of accumulated electricity.

273. The discovery of this important fact was by no means an instantaneous thing; even some modern writers on philosophy appear to have formed opinions on the nature of lightning essentially incorrect; and this is the more remarkable when it is considered that, so long ago as the days of the abbé Nollet, such remarks as the following should have been published, and read, and verified by actual experiment soon after. 'If,' said the abbé, 'any should take upon him to prove, from a well-connected comparison of phenomena, that thunder is in the hands of nature what electricity is in ours; that the wonders we now exhibit at pleasure are little imitations of those great effects which frighten us; and that the whole depends on the same mechanism:—if it could be shown, that a cloud prepared by the action of the winds, by heat, by a mixture of exhalations, &c. is, when opposite to a terrestrial object, that which an electrified body is, when at a certain distance from one that is not electrified; I confess this idea, if it were well supported, would afford me much pleasure; and to support it, how many specious reasons present themselves to a man well versed in electricity. The universality of the electric matter, the rapidity of its action, its inflammability, and its activity in inflaming other bodies; its property of striking bodies externally and internally, even to their smallest parts, the remarkable example we have of this effect in the Leyden experiment, the idea we may legitimately form in supposing a greater degree of electric power, &c. All these points of analogy, which I have for some time meditated, begin to make me believe that one might, by taking electricity for a model, form to one's-self, in relation to thunder and lightning, more perfect and probable ideas than any that have been hitherto offered.'

274. This was certainly a bold hypothesis; highly creditable to the judgment of the author, and affording no obscure intimation that electricity was about to make some unprecedented degree of progress; but to Dr. Franklin undoubtedly belongs the honor of accomplishing, by actual experiment, all that the abbé Nollet's penetrating sagacity led him to speak of in the words just quoted. In a series of letters to one of the members of the Royal Society, the Dr. first gave in detail an hypothesis to explain the phenomena of thunder and lightning by the known properties of electricity, which was soon followed by a demonstration of its truth in the most remarkable experiment ever made.

275. The following are the leading points of resemblance which Dr. Franklin observed to obtain between the electricity of the atmosphere and that which is produced by artificial means. (1.) The zig-zag appearance of the lightning is exactly the same as that of a strong electric spark when it passes through a considerable interval of air. (2.) Lightning generally strikes such bodies as are high and prominent, as the summits of high hills, the tops of lofty trees, high towers, spires, masts of ships, points of spears, &c., and the electric fluid always passes through the most prominent parts, when striking from one body to another. (3.) Lightning is observed to strike most frequently into those substances that are good conductors of electricity, such as metals, water, and moist substances; and to avoid those that are non-conductors. (4.) Lightning inflames combustible bodies. The same is effected by electricity. (5.) Metals are melted by a powerful charge of electricity. This phenomenon is one of the most common effects of a stroke of lightning. (6.) The same may be observed of the fracture of brittle bodies, and of other expansive effects common to both causes. (7.) Lightning has been known to strike people blind. Dr. Franklin found, that the same effect is produced on animals when they are subjected to a strong electric charge. (8.) Lightning destroys animal life. Dr. Franklin killed turkeys of about ten pounds weight, by a powerful electric charge. (9.) The magnetic needle is affected in the same manner by lightning and by electricity, and iron may be rendered magnetic by both causes. The phenomena are, therefore, strictly analogous, and differ only in degree; and, if an electrified gun-barrel will give a spark, and produce a loud report at two inches distance, what effect may not be expected from perhaps 10,000 acres of electrified cloud? And is not the different extent of these conductors, equal to the different limit of their effects?

276. Reasoning on these strong resemblances, Franklin formed the design of erecting a conducting rod by which the lightning might be drawn from the clouds, and thus afford an opportunity of ascertaining its identity with the electric fluid. 'The electric fluid,' said he, 'is attracted by points; we do not know whether this property be in lightning; but since they agree in all the particulars in which we can already compare them, it is not improbable that in this they likewise agree. Let the experiment be made.' And doubtless he would himself have made it before

any other person could have anticipated him in it, but waiting for the erection of a spire in Philadelphia, and his opinions becoming known, he was anticipated by the French philosophers D'Alibard and De Loe, who erected a rod such as Franklin had suggested, and succeeded in the experiment. But the honor and merit of the idea were not to be thus rent from Franklin; for in the mean time, and without any knowledge of the attempts of the French electricians, it occurred to him that, by sending up a kite, he could obtain a readier access to the clouds than by the longest rod which he could raise on the highest spire. He made the attempt, and, as we have before shown, was successful; and thus was the identity of lightning with electricity satisfactorily established.

277. In treating of the electricity of the atmosphere it may be proper to begin with the more gentle and silent manifestations of it: thence to proceed to the consideration of its accumulated discharges in meteors and thunder-storms; and then make some remarks on its general influence on the surface of our earth.

278. From long, correct, and patient investigation, it has been proved that the various luminous phenomena that appear in our atmosphere, are to be resolved into the agency of electricity, although it must be allowed that, with all our knowledge of those effects, they are still surrounded with such difficulties, that scientific men are not quite of one mind respecting them. Of this description the aurora borealis, or northern light, must be allowed to be an instance.

279. The aurora borealis, or, as the same appearance is commonly termed, streamers, and in the Shetland Isles, the merry dancers, can seldom be seen in the southern parts of the kingdom; and, even when seen there, the appearance is far less brilliant than in northern latitudes, where this wonderful phenomenon is the constant attendant of clear evenings, affording a great relief to the inhabitants, amid the gloom that would otherwise attend their dreary winter nights.

280. Of this kind of meteor, the late Mr. George Adams has given the following concise account in his valuable lectures:—The appearances of the aurora come under four different descriptions. (1.) A horizontal light, like the morning aurora, or break of day. (2.) Fine, slender, luminous beams, well defined, and of dense light. These often continue a quarter, a half, or a whole minute, apparently at rest, but oftener with a quick lateral motion. (3.) Flashes pointing upward, or in the same direction with the beams, which they always succeed. These are only momentary, and have no lateral motion; but they are generally repeated many times in a minute. They appear much broader, more diffuse, and of a weaker light than the beams: they grow gradually fainter till they disappear; and sometimes continue for hours, flashing at intervals. (4.) Arches, nearly in the form of a rainbow: these, when complete, go quite across the heavens, from one point of the horizon to the opposite point.

281. When an aurora happens, these appearances seem to succeed each other in the following order:—(1.) The faint rainbow-like arches; (2.) The beams; and (3.) The flashes. As for the northern horizontal light, it appears to consist of an abundance of flashes of beams, blended together by the situation of the observer.

The beams of the aurora borealis appear at all places to be arches of great circles of the sphere, with the eye in the centre; and these arches, if prolonged upwards, would all meet at one point.

The rainbow-like arches all cross the magnetic meridian at right angles. When two or more appear at once they are concentric, and tend to the east and west; also the broad arch of the horizontal light tends to the magnetic east and west, and is bisected by the magnetic meridian; and when the aurora extends over any part of the hemisphere, whether great or small, the line separating the illuminated part of the hemisphere from the clear part is half the circumference of a great circle crossing the magnetic meridian at right angles, and terminating in the east and west: moreover, the beams perpendicular to the horizon are only those on the magnetic meridian.

That point in the heavens to which the beams of the aurora appear to converge, at any place, is the same as that to which the south pole of the dipping-needle points at that place.

The beams appear to rise above each other in succession; so that, of any two beams, that which has the higher base has also the higher summit.

Every beam appears broadest at or near the base, and to grow narrower as it ascends; so that the continuation of the bounding lines would meet in the common centre to which the beam tends.

281*. Now between these appearances and those of electricity, under certain circumstances, there are several points of close resemblance. For it is found by a simple experiment that, when the electric fluid is made to pass through rarefied air, it exhibits a diffused luminous stream, which has all the characteristic appearances of the northern lights. There are to be seen the same varieties of color and intensity, the same undulating motion and occasional corruscations; the streams exhibit the same diversity of character, at one moment minutely divided into ramifications, and at another beaming forth in one body of light, or passing in well defined flashes; and, when the rarefaction is high, various parts of the stream assume that peculiar glowing color which occasionally appears, and which, on the whole, leaves but little room to doubt that the phenomena are produced by the passage of electricity through the upper regions of the atmosphere, although at the same time it ought to be mentioned that this opinion has been doubted by some since the accomplishment of the recent voyages of discovery to the polar regions.

282. It has been stated above, that this most beautiful phenomenon is seldom witnessed by the inhabitants of the southern parts of the kingdom; to them, therefore, at all events, as well as to those who have witnessed the aurora borealis in a fainter degree, the following extract from

Mr. Dalton's description of one which he witnessed must be acceptable. It is taken from his Meteorological Essays.

283. 'Attention,' says Mr. Dalton, 'was first excited by a remarkably red appearance of the clouds to the south, which afforded sufficient light to read by, at eight o'clock in the evening, though there was no moon, nor light in the north. Some remarkable appearance being expected, a theodolite was placed to observe its altitude, bearing, &c.

'From half past nine to ten o'clock, P. M., there was a large, luminous, horizontal arch to the southward, almost exactly like those which we see in the north; and there were some faint concentric arches northward. It was particularly noticed that all the arches seemed exactly bisected by the plane of the magnetic meridian. At half past ten o'clock streamers appeared very low in the south-east, running to and fro from west to east; they increased in number, and began to approach the zenith apparently with an accelerated velocity; when all on a sudden the whole hemisphere was covered with them, and exhibited such an appearance as surpasses all description. The intensity of the light, the prodigious number and volatility of the beams, the grand intermixture of all the prismatic colors in their utmost splendor, variegating the glowing canopy with the most luxuriant and enchanting scenery, afforded an awful, but at the same time the most pleasing and sublime spectacle. Every one gazed with astonishment; but the uncommon grandeur of the scene only lasted about one minute; the variety of colors disappeared, and the beams lost their lateral motion, and were converted into the usual flashing radiations; but even then it surpassed all other appearances of the aurora, in that the whole hemisphere was covered with it.

284. 'Notwithstanding the suddenness of the effulgence at the breaking out of the aurora, there was a remarkable regularity in the manner. Apparently a ball of fire ran along from east to west, and the contrary, with a velocity so great as to be barely distinguishable from one continued train, which kindled up the several rows of beams one after another: these rows were situated before each other with the most exact order, so that the bases of each row formed a circle crossing the magnetic meridian at right angles; and the several circles rose one above another in such sort, that those near the zenith appeared more distant from each other than those near the horizon, a certain indication that the real distances of the rows were either nearly or exactly the same. And it was further observable that, during the rapid lateral motion of the beams, their direction in every two nearest rows was alternate; so that whilst the motion in one row was from east to west, that in the next was from west to east.

285. 'The point to which all the beams and flashes of light uniformly tended was, in the magnetic meridian, and, as near as could be determined, between 15° and 20° south of the zenith. The aurora continued, though diminishing in splendor, for several hours. There were several meteors seen at the same time; they appeared below the aurora, and unconnected with it.' This brilliant display of the aurora borealis Mr. Dalton witnessed on the 13th of October, 1792.

286. Similar appearances are often seen towards the south pole, but they are said to be unattended with the same variety of color; they are called aurora australis. A very feeble, though certainly a pleasing imitation of this remarkable phenomenon may be thus exhibited:—Take the glass vessel represented in fig. 9, resembling a Florence flask, and fitted with a valve at top by which it may be exhausted of its air: when exhausted, and rubbed in the common manner used to excite electrics, it will appear luminous within, being full of a flashing light which plainly resembles the aurora borealis, or northern light. This phial may also be made luminous, by holding it by either end, and bringing the other end to the prime conductor; in this case all the cavity of the glass will instantly appear full of flashing light, which remains in it for a considerable time after it has been removed from the conductor: instead of the glass phial a glass tube exhausted of air and hermetically sealed may be used, and perhaps with more advantage. The most remarkable circumstance of this experiment is, that if the phial or tube, after it has been removed from the conductor (and even several hours after its flashing light has ceased to appear), be grasped with the hand, strong flashes of light will immediately appear within the glass, which often reach from one end to the other.

287. The next form of atmospherical electricity that claims our attention is that which it assumes in those meteors, to which the vulgar name of falling, or shooting stars, has been given. The aurora borealis, we have said, is caused by streams of the electric fluid passing rapidly through the higher regions of the air; and these phenomena of which we are now speaking, are, in all probability, portions of the same matter moving through a more resisting medium, since they are always observed to be in comparatively small altitudes.

288. These meteors vary considerably in their size and color, and also in the rapidity of their motion; they move in various directions, but chiefly incline towards the earth. They occur in different states of the atmosphere, but prevail most in clear frosty nights, and at other times when the winds are easterly, and the sky clear; in the intervals also of showery weather they are frequent, and on summer evenings, when well defined clouds are seen floating in a clear atmosphere.

289. In favorable states of the atmosphere, Mr. Singer remarks, these appearances are seen to succeed each other so rapidly, that he has often counted thirty of them in the space of an hour, and, on some occasions, twice that number. The frequency of their occurrence, he thinks, indicates that they are produced by some of the usual atmospherical changes, and that the circumstance of their explosion being unattended by the fall of stones, renders it almost certain that their nature is essentially different from that of the large meteors.

290. The same gentleman offers the following as arguments in favor of the electrical origin of

these meteors:—(1.) The light of falling stars is similar to the light of the electric spark. (2.) They occur as frequently and as irregularly as other electrical changes in the atmosphere. (3.) Their motion, like that of electricity, is exceedingly rapid; and the longest interval through which they strike, is traversed in an interval of time too minute to admit of measurement. (4.) They occur most frequently during, or near to those changes of weather, that are known to influence the electrical state of the atmosphere. (5.) Their direction is never constant; they occur in every part of the atmosphere, and move in almost every direction; such is also the case with lightning. (6.) The appearance of falling stars may be accurately imitated by electricity; and the circumstances on which the success of such experiments depend, are such as are likely to occur in the production of the natural phenomena.

291. Hence if electricity be passed gradually through an exhausted receiver, it assumes, as we have already seen, the appearance of the aurora borealis; but if an accumulation of it be suddenly transmitted, it will pass through the receiver with the straightness and brilliance of a shooting star. This appearance also occurs most readily when the receiver is but partially exhausted. The imitation therefore of these two phenomena seems evidently to require the same conditions for its production, as those which obtain in nature; that is to say, the aurora occurs in those regions where the air is highly rarefied; and the most complete imitation of it is effected in a thoroughly exhausted receiver; falling stars take place where the air is much more dense, and the imitation of them requires a medium which offers from its density considerable resistance.

292. Different writers on electricity have proposed different methods of producing an imitation of these meteors, but that of Mr. Singer is undoubtedly the most effectual as well as the most elegant. He used for this purpose a glass tube, five feet in length, and about five-eighths of an inch in diameter, mounted with a brass cap at each end, and fitted at one extremity with a valve to allow of its being exhausted. When this tube was exhausted, no spark would pass through it except in a very diffused state; but when the charge of a very large jar was employed, a brilliant spark was obtained through the whole length of the tube, resembling in appearance a shooting star.

293. There are various other luminous appearances of the electricity of the atmosphere, which might with propriety be described here, such as those frequently observed on the tops of spires, and the masts of ships, and occasionally on the points of spears, &c.; but we must not enlarge, and shall only observe respecting them, that they seem analogous to the light that is observed on the point of any slender and prominent conductor, when placed within an electrical atmosphere, or brought near to an excited electric. These, and similar phenomena observable in the atmosphere, will be fully treated of in the article METEOROLOGY.

294. But the most magnificent display of atmospherica electricity is to be seen during a thunder-storm, the particular phenomena of which we must now proceed to notice. We have already seen the most satisfactory ground for the conclusion that lightning and electricity are identical, and have adverted to most of the known means by which the latter are produced: and if the analogy be correct in the one case we may conclude it to be so in the other, although with some differences perhaps, which have hitherto been, and which may for ever remain, inaccessible to human observation.

295. If then, it be asked, whence comes the electricity of the atmosphere? it may in reply be said, that from the sum of our knowledge respecting meteorological phenomena, there appears good reason to conclude that the causes which produce artificial electricity, are all in full operation in the masses of vapor, among which natural electricity appears active.

296. This opinion is maintained by several eminent practical electricians of the present day; it was warmly espoused by the late Mr. Singer, who advanced in support of it the following positions:—(1.) That the electrical phenomena of the atmosphere take place, in all climates, to the greatest extent, about the period of the greatest degree of heat, when the rays of the sun have caused a considerable accumulation of vapor. (2.) Where this cause operates to the greatest extent, as, for instance, within the tropics, natural electricity is produced on the largest scale. (3.) When the natural source of evaporation is assisted by collateral causes, electrical changes occur with astonishing activity, as in the eruption of a volcano, or the heat imparted to the air in its passage over large extents of hot sands, as those of Africa. (4.) By the action of winds, currents of air of different temperatures are often mixed,—so that such as have been heated and charged with moisture, become suddenly cooled, thus occasioning a precipitation of water, and the occurrence of electrical changes. This is often witnessed on the coast of Guinea during the existence of the harmattan. (5.) These electrical changes are every where most frequent when the causes of evaporation and condensation suddenly succeed each other.

297. After advancing several cogent arguments in favor of the above facts, and noticing in a very candid manner some objections urged against the theory they are intended to support, Mr. Singer concludes with the following truly appropriate and judicious observations:—'Although the immediate causes by which the various phenomena of the atmosphere are produced, be still far beyond our comprehension; yet the connexion of their several effects is a sufficient demonstration that they are not purely mechanical, but subservient to the direction of supreme power and intelligence. By this means the most simple arrangement becomes the source of sublime effects. The process of evaporation which modifies the action of the sun's rays, and conveys to every part of the earth's surface a source of fertility, does at the same time diversify the appearance of the atmosphere by an endless variety of imagery, enlivening the horizon with the most brilliant and glowing tints

and in all probability effecting those electrical changes, which are the precursors of the most magnificent phenomena in nature.'

298. The phenomenon of the thunder-storm itself is always one of intense interest to the electrician. Some writers on the subject of electricity have furnished us with very beautiful descriptions of a thunder-storm, but of all these we feel disposed to give the preference to that of Sig. Beccaria, as containing a neat and unvarnished statement of facts, instead of being decorated with the effusions of a poetical imagination.

299. 'Thunder-storms,' says Beccaria, 'generally happen when there is little or no wind; and their first appearance is marked by one dense cloud, or more, increasing very fast in size, and rising into the higher regions of the air; the lower surface black, and nearly level, but the upper finely arched, and well defined. Many of these clouds seem frequently piled one upon another, all arched in the same manner; but they keep continually uniting, swelling, and extending their arches.

300. 'At the time of the rising of this cloud, the atmosphere is generally full of a great number of separate clouds, motionless, and of odd and whimsical shapes. All these, upon the appearance of the thunder-cloud, begin to move towards it, and become more uniform in their shapes as they approach, till, coming very near the thunder cloud, they mutually stretch towards one another, immediately coalesce, and together make one uniform mass. But sometimes the thunder-cloud will swell, and increase very fast, without the conjunction of these adscititious clouds, the vapors of the atmosphere forming themselves into clouds wherever it passes. Some of the adscititious clouds appear like white fringes at the skirts of the thunder-cloud, but these are continually growing darker and darker as they approach or unite with it.

301. 'When the thunder-cloud is grown to a great size, its lower surface is often ragged, particular parts being detached towards the earth, but still connected with the rest. Sometimes the lower surface swells into various large protuberances, bending uniformly towards the earth. When the eye is under the thunder-cloud, after it is grown larger, and well formed, it is seen to sink lower, and to darken prodigiously; at the same time that a number of adscititious clouds (the origin of which can never be perceived) are seen in a rapid motion, driving about in every direction under it. While these clouds are agitated with the most rapid motions, the rain generally falls in the greatest plenty; and, if the agitation is exceedingly great, it commonly hails.

302. 'While the thunder-cloud is swelling, and extending its branches over a large tract of country, the lightning is seen to dart from one part of it to another, and often to illuminate its whole mass. When the cloud has acquired a sufficient extent, the lightning strikes, between the cloud and the earth, in two opposite places, the path of the lightning lying through the whole body of the cloud and its branches. The longer this lightning continues the rarer the cloud grows, and the less dark is its appearance, till at length it breaks in different places, and displays a clear sky.'

303. From the circumstance of almost constant injury attending thunder-storms it is impossible to witness one without some feelings of personal danger; in this case attention to the following observations may often be of service in relieving the mind from unnecessary fear, or in suggesting the necessary steps to be taken for the prevention of accident.

304. *The Place of the Explosion.*—The electrical explosion generally takes place in the air, and at a considerable height; but in many instances it happens between the clouds and the earth. In most instances, perhaps, the lightning descends from the clouds to the earth, and the explosion is then called the descending stroke: but in some cases it is known to pass from the earth to the clouds, and is then termed the ascending stroke: of the latter kind appears to have been the explosion which took place on the Malvern hills, in the summer of 1826, and which was attended with such melancholy consequences. A very curious instance of the ascending stroke is related by G. F. Richter, in his work on thunder. He informs us that in the cellar belonging to the Benedictine monks of Fontigno, while the servants were employed in pouring into a cask some wine which had been just boiled: a fine light flame appeared round the funnel, and they had scarcely finished their operation when a noise like thunder was heard; the cellar was instantly filled with fire; the cask was burst open, although hooped with iron, the staves were thrown with prodigious violence against the wall; and, on examination, a hole of three inches diameter was found in the bottom of the cask.

305. *The Distance of the Thunder Cloud.*—This is a point of some importance to be determined; and the interval between the flash and the commencement of the report furnishes the data necessary for the calculation. Sound travels at the rate of 1142 feet in a second: consequently, by a watch which beats and points the seconds, the distance of the cloud is easily ascertained, for the flash and the sound are really contemporaneous; and the former requires hardly any perceptible lapse of time to travel through any ordinary distance. Thus, for example, suppose the flash to occur five seconds before the sound is heard, then $1142 \times 5 = 5710 = 1$ mile 430 feet, the distance of the explosion from the place of the observer. So far this calculation is very gratifying, but it is no criterion of safety, for it only indicates the distance of a discharge that has taken place: the next may render the observer incapable of observation.

306. *Indications of real danger.*—During a thunder-storm there are certain circumstances which afford strong indications of actual danger. Such, for instance, are a rapid approach of the charged cloud, and the almost perpendicular direction of the lightning. When the cloud seems to be vertical as soon as it is formed, we are exposed to its utmost fury; and, when it increases in darkness as it approaches, it also indicates great danger. When the flashes strike perpen-

dicularly, it is a certain indication that the clouds are at that height from which they may readily strike into the ground. It is also supposed that the appearance of two flashes at once indicates danger; but this is uncertain, as it may arise from an optical illusion, or the interposition of a cloud.

307. The precautions generally offered by writers on electricity, as necessary for the safety of those who are exposed to the action of a thunder-storm, may be thus enumerated. Shelter should not be taken under trees, hedges, &c.; for, should they be struck, such situations are particularly dangerous; at the same time a person is much safer at about thirty or forty feet from such objects than at a greater distance, as they are likely to operate as conductors. Large portions of water also ought to be carefully avoided if possible, and even streamlets that may have resulted from recent rain; these are good conductors, and the height of a human being connected with them, may sometimes determine the course of the lightning. In a house the safest situation is considered to be the middle of the room; and this situation may be rendered still more secure bystanding on a glass-legged stool: but, as such an article is not in the possession of many people, a hair mattress, or a thick woollen hearth rug makes a very good substitute. It is very injudicious to take refuge, as some persons do, in the cellar during a thunder storm, since the discharge is often found to be from the earth to the clouds, and many instances are recorded of buildings that were struck having sustained the greatest injury about the basement story. But, whatever situation is chosen, the greatest care should be taken to avoid going near the fire-place, since the chimneys are most likely to attract the fluid, and even if there be no fire in the grate, at the time, it should be remembered that soot is a powerful conductor. The same caution is necessary with respect to all large metallic surfaces; gilt furniture, bell wires, &c.

308. But the most important and useful application that has ever yet been made of the discoveries of the electrician is in the method of securing buildings, ships, &c., from the effects of lightning. To the ingenuity of Dr. Franklin the world is indebted for this invention, as well as for his discovery of the identity of lightning and common electricity. He first proposed to erect a perfectly continuous metallic rod by the side of any building intended to be secured from injury by lightning: this rod was to be pointed at each extremity; to rise some feet above the highest part of the building, and to extend some feet below the foundation, in moist ground, or water if practicable. By such a precaution, he conceived that the house could never receive any damage; for, whenever the lightning should happen to fall upon it, it is evident that the conductor, being of metal, and higher than any part of the building, would naturally attract it, and, by conducting it to the ground, prevent that building from receiving any damage; it being well known that electricity always strikes the nearest and best conductors.

309. As this subject is of the utmost importance, we shall here quote the very concise and judicious observations of Mr. Cava o respecting it. Speaking of the proposal of Dr. Franklin, which we have just noticed, he proceeds to remark, that the reasonableness and truth of such an assertion has been confirmed by numberless facts, and the practice of raising such conductors has been found exceedingly useful, particularly in hot climates, where thunder storms are very frequent, and the damage occasioned by the same too often experienced.

310. In regard to the construction of such conductors, there have been some controversies among electricians; and the most advantageous manner of using them has not, without a great many experiments, and but very lately, been ascertained. Some philosophers have asserted, that such conductors should terminate in an obtuse end, that they might the less invite the lightning from the clouds; for such an end will not attract electricity from so great a distance as a sharp point. But other philosophers have thought a pointed termination to be much preferable to an obtuse one; and their assertion seems, on the following accounts, to be better founded.

311. 'A sharp-pointed conductor, it is true, will attract electricity from a greater distance than one with an obtuse point, but at the same time will attract and conduct it very gradually, or rather by a continued stream, in which manner a remarkably small conductor is capable of conducting a very great quantity of electricity; whereas an obtusely terminated conductor attracts the electricity in a full separate body, or explosion, by which it is often made red-hot, melted, and even exploded in smoke, and by such a quantity of electricity as perhaps would not have at all affected it, if it had been sharply pointed.

312. 'A sharp-pointed conductor certainly invites the matter of lightning easier than an obtuse one; but to invite, receive, and conduct it in small quantities, never endangers the conductor; and the object of fixing a conductor to a house, is to protect the house from the effects of, and not the conductor from transmitting the lightning.

313. 'It is an observation much in favor of sharp-pointed conductors, that such steeples of churches, and edifices in general, as are terminated by pointed metallic ornaments, have very seldom been known to be struck by lightning; whereas others that have flat terminations and have a great quantity of metal in a manner insulated on the tops, are often struck; and it is but seldom that they escape without great damage.

314. 'Besides these considerations a sharp-pointed conductor, by the same property of attracting electricity more readily than an obtusely terminated one, may prevent a stroke of lightning, which the latter is incapable of doing.

315. 'A conductor, therefore, to guard a building, as it is now commonly used, should, from several considerations and experiments, consist of one iron rod about three quarters of an inch thick, fastened to the wall of the building, not by iron cramps, but by pieces of wood. If this conductor were quite detached from the building, and supported by wooden posts at

the distance of one or two feet from the wall, it would be much better for common edifices, but it is more particularly advisable for powder-magazines, powder-mills, and all such buildings as contain combustibles ready to take fire. The upper end of the conductor should be terminated in a pyramidal form, with the edges, as well as the point, very sharp: and if the conductor be of iron, it should be gilt, or painted, for two or three feet. This sharp end should be elevated above the highest part of the building (as above a stack of chimneys, to which it may be fastened) at least five or six feet. The lower end should go five or six feet into the ground, and in a direction leading from the foundation; or it would be better to connect it with the nearest piece of water, if any be at hand. If this conductor, on account of the difficulty of adapting it to the form of the building, cannot conveniently be made of one rod, then care should be taken, that where the pieces meet, they be made to come in as perfect a contact with one another as possible; for, as we observed before, electricity finds considerable obstruction where the conductor is interrupted.

316. 'For an edifice of a moderate size, one conductor of the kind already described, is perhaps sufficient; but, in order to secure a large building from sustaining any damage by lightning, there should be two, three, or more conductors, in proportion to the extent of the building.

317. 'In ships a chain has often been used for this purpose, which, on account of its pliableness, has been found very convenient, and easy to be managed among the rigging of the vessel; but, as the electricity finds a great obstruction in going through the several links, so that chains have been actually broken by the lightning, their use is now almost entirely laid aside; and, in their stead, copper wires a little thicker than a goose-quill have been substituted, and found to answer extremely well. One of these wires should be elevated two or three feet above the highest mast in the vessel; this should be continued down the mast, as far as the deck, where, by bending, it should be adapted to the surface of such parts, over which it may most conveniently be placed, and by continuing it down the side of the vessel, it should be always made to communicate with the water.'

318. M. Cavallo gives, with cordial approbation, the following extract from the earl of Stanhope's learned work on electricity:—As requisites for the proper construction of conducting rods for the preservation of buildings from the effects of lightning he directs, (1.) 'That the rods be made of such substances as are the best conductors of electricity. (2.) That the rods be uninterrupted and perfectly continuous. (3.) That they be of a sufficient thickness. (4.) That they be perfectly connected with the common stock. (5.) That the upper extremity of the rods be as acutely pointed as possible. (6.) That it be very finely tapered. (7.) That it be prominent. (8.) That each rod be carried in the shortest convenient direction, from the point at its upper end to the common stock. (9.) That there be neither large nor prominent bodies of metal upon the top of the building proposed to be secured, but such as are connected with the conductor by some proper metallic communication. (10.) That there be a sufficient number of high and pointed rods: and, (11.) That every part of the building be very substantially erected.'

319. For the purpose of illustrating the principle on which the thunder-rod acts, there are some very satisfactory experiments generally employed by lecturers on electricity, which it may be proper here to explain, and before doing which we would just observe, that the charge used on these occasions should be moderate, having found from experience that, in that part of the experiments which is intended to show the effect of interruptions in the conductor, a strong charge has injured the apparatus.

320. The simplest form in which these experiments are made is that known by the name of the *thunder-house*. This is represented by fig 10, where A is a board about three-quarters of an inch thick, and shaped like the gable end of a house. It is fixed perpendicularly upon the bottom board B, upon which the perpendicular glass pillar C D is also fixed, in a hole about eight inches distant from the base of the board A. A square hole, I L M K, about a quarter of an inch deep, and nearly one inch wide, is made in the board A, and is filled with a square piece of wood, nearly of the same dimensions. This board must fit in rather easily, so that the slightest shaking may throw it out. A wire, L K, is fastened diagonally to this square piece of wood. Another wire, I H, of the same thickness, having a brass ball, H, screwed on its pointed extremity, is fastened upon the board A; so also is the wire M N, which is formed into a hook at O. From the upper extremity of the glass pillar, C D, a crooked wire proceeds, having a spring socket F, through which a double-knobbed wire slides perpendicularly, the lower knob G of which falls just above the knob H. The glass pillar D C must not be fixed very tightly into the bottom board; but it must be fixed so as to be pretty easily moved round its own axis, by which means the brass ball G may be brought nearer or farther from the ball H, without touching the part of E F G. When the square piece of wood L M I K, is fixed into the hole so that the wire L K stands in the dotted representation I M, then the metallic communication from H to O is continuous, and the instrument represents a house furnished with a proper metallic conductor; but if the square piece of wood L M I K is fixed so that the wire L K stands in the direction L K, as represented in the figure, then the metallic conductor H O, from the top of the house to its bottom, is interrupted at I M, in which case the house is not properly secured.

320.* Fix the piece of wood, L M I K, so that its wire may be as represented in the figure, in which case the metallic conductor H O is discontinued. Let the ball G be fixed at about half an inch perpendicular distance from the ball H, then, by turning the glass pillar D C, remove the former ball from the latter; by means of a chain connect the wire E F with the wire Q of the jar P, and let another chain, fastened to the hook O, touch the outside coating of the jar. Connect the wire Q with the prime conductor,

and charge the jar; then, by turning the glass pillar D C, let the ball G come gradually near the ball H, and when they are arrived sufficiently near one another, the jar will explode, and the piece of wood, L M I K, will be driven out of the hole to a considerable distance from the thunder-house. In this experiment the ball G represents an electrified cloud; which, when it is arrived sufficiently near the top of the house A, the electricity strikes it; and, as this house is not secured with a proper conductor, the explosion breaks part of it, as is seen by the violent removal of the piece of wood I M.

321. Repeat the experiment with only this variation, viz. that the piece of wood I M is situated so that the wire L K may stand in the direction I M, in which case the conductor H O is not discontinued; and then the explosion will have no effect upon the piece of wood L M, this remaining in the hole unmoved; which shows the usefulness of the metallic conductor.

322. Again, unscrew the brass ball H from the wire H I, so that this may remain pointed. With this difference only in the apparatus, repeat both the above experiments, and it will be found that the piece of wood I M is in neither case moved from its place, nor will any explosion be heard; which not only demonstrates the preference of the conductors with pointed terminations to those with obtuse ends; but also shows that a house furnished with sharp terminations, although not furnished with a regular conductor, is almost sufficiently guarded against the effects of lightning.

323. This apparatus is sometimes made in the shape of a house, as represented by fig. 11; for the sake of distinctness, the side and part of the gable end A C represents that of the thunder-house, and may be used in the same manner with that above described, or more readily by the following method:—Let one ball of the discharging rod touch the ball of the charged jar, and the other knob A of the conductor A C of the thunder-house; the jar will then explode, and the charge will act upon the conductor just mentioned. The conducting wire at the windows *h*, *h*, must be placed in a line. The sides and gable, A C, of the house, are connected with the lower part of the house by hinges, and the building is kept together by a ridge on the roof.

324. To use this model, fill the small tube *a* with gunpowder, and ram the wire *c* a little way into the tube; then connect the tube *e* with a large jar or battery. When the jar is charged, form a communication from the hook at C, on the outside, to the top of the jar, by the discharging rod; the discharge will fire the powder, and the explosion will throw off the roof, with the sides, back, and front, so that they will all fall down together. Fig. 12 represents a small ramrod for the tube *a*, and fig. 13 a pricker for the touch-hole at C. Philosophical and mathematical instrument makers now construct the front of the common thunder-houses as well as the powder-houses above described, with two pieces of wood or windows, which, by being placed in proper situations, the one to conduct and the other to resist the fluid, will illustrate by one discharge the usefulness of good conductors for securing buildings or magazines from the explosion of thunder, as well as the danger of using imperfect ones.

325. The most elegant method of performing this experiment, however, is represented in fig. 14, which exhibits a hollow pyramid of wood, composed of several pieces, having a wire through each, so that their ends may come in contact with each other, as seen at *s*, *s*, *s*. One corner of the pyramid must be made loose as shown at *d*, having the conducting wire passing nearly through it, but not quite so. The wire, passing through the rest of the pyramid, must join (by a chain) the outside coating of a Leyden jar. If the cloud *x* be supported by a wire from the prime conductor, and hang half an inch from the knob *g* of the pyramid; when the jar is charged, a flash will take place between *x* and *g*; the fluid will pass along the wires *s*, *s*, *s*, till it comes to the break at *d*; there an explosion will take place, that will force out the corner piece *d*, and throw down the fabric in separate pieces.

326. The preceding experiments sufficiently illustrate the use of conductors raised on buildings that are much exposed to the effects of thunder-storms; but, that we may not omit any information on the subject that may be deemed useful, we shall just add Mr. Morgan's method of preventing all possible danger in these cases. The plan which Mr. Morgan proposes is that, whilst a house is being built, the foundation of each partition wall should be laid on a strip of lead, or that the strip be fastened to the sides of these partition walls. The strips should be two inches wide, and at least a quarter of an inch thick, and closely connected with each other. A perpendicular strip, on each side of the house, should rise from the conductors to the surface of the ground; whence a strip should be continued round the house, and carefully connected with water-pipes, &c. The strips on the sides of the house should then be continued to the roof, which ought to be guarded in the same manner as the foundation. The top should be surrounded by a strip, which should be connected with every edge and prominence, and be continued to the summit of each separate chimney. It is particularly necessary to guard the chimneys; for Mr. Morgan mentions a case, in which a house that had been guarded in most respects, according to the preceding directions, except that the chimneys were unprotected, was struck with lightning, which entered by one of the chimneys: here it spent its fury; but the chimney falling on the roof, did considerable damage. The principal objection to this method is the expense attending it; but this may be in a great measure avoided, by making proper use of the leaden pipes, gutters, and copings, which belong to most houses.

327. Before leaving the subject of conducting rods, we think it due to the ingenious professor Leslie of the University of Edinburgh, to notice an article on electrical theories, published by him in the Edinburgh Philosophical Journal for July, 1824. In this paper Mr. Leslie endeavours to show that thunder-rods are of no use whatever in the way of protecting buildings against the

effects of lightning. But lest we should in any degree misrepresent the professor's sentiments, by giving an abridged statement of them, we shall quote his own words :—

328. 'But, whatever speculations we may form in regard to electrical light, and the mode in which the point and the knob produce their different effects, we must admit that the electricity is never communicated, in any perceptible degree, to a remote and unconnected body, but by means of a current of air; and this established principle will enable us to estimate the real effects of conductors or thunder-rods.

329. 'When two portions of air, near the point of saturation, and of different temperatures, are mixed, a quantity of the dissolved vapor is precipitated, and resumes its aqueous state. By this conversion the mass acquires electricity; and the consequent repulsion exerted, tends to disperse the minute globules of water, which will float in the atmosphere, or rather, will descend with that slow motion which is sufficient to occasion a resistance on their large surface equal to their gravitation. If the cloud thus generated reach the ground, it will soon communicate its electricity. If it be suspended at some height, the electrified air will stream from it in all directions; and if its formation be gradual, this discharge may suffice to waste its force. But when a vast cloud is suddenly formed, the aërial emission hardly impairs its electricity; and, as it is carried along, it continually approaches, by its attraction, to the surface, which assumes an opposite electricity; the air now rushes with violence, and the cloud bends faster downwards, till at last its lowest verge reaches the ground, and a total discharge is made. The magnitude of the stroke will evidently depend on the extent of the aqueous mass, the suddenness of its precipitation, and the rapidity of its descent.

330. 'The air, which streams in all directions from the cloud, is dissipated among the more remote portions, and thus gradually communicates its electricity. Hence, from the wide dispersion, owing to the distance, the electricity of the air at the surface of the earth must be weak; and, even in the midst of the storm, the electrometer is less affected than if placed only a yard behind the prime conductor. Yet the action of the thunder-rod is confined entirely to the air which immediately surrounds it, and the quantity of aërial current which it can produce, must evidently be inferior to what is directed to the point, when held several feet from the conductor of an electrical machine. But, to avert the stroke, it would be necessary that the whole air between the surface and the cloud should be brought successively in contact with the top of the rod. Nor is this all; for the air will be constantly replaced by other electrified portions emitted from the cloud. The effect of the thunder-rod is therefore, comparatively, but a drop in the ocean. It may be easily shown that, however pointed and tapered, it would require 1000 years to guard at the distance of 100 yards; if terminated with a knob, it may take 10,000 years. Such are the vaunted performances of thunder-rods, and such the advantages of their different forms! Nor can we appeal to experience; it never can be proved that thunder-rods have produced beneficial effects, but several instances may be cited where they have afforded no sort of protection. Nay, we shall be convinced, that fully an equal proportion of the buildings armed with such supposed safeguards have been struck with lightning. But if thunder-rods are useless, they are also innocent; and, that they provoke the shaft of heaven, is the suggestion of superstition rather than of science. The cloud exerts an attraction, indeed, upon the surface of the ground, but the force depends solely on the distance, and is not, in the least degree, affected by the shape or quality of the substances below. It rolls towards the nearest and most elevated objects, and strikes indiscriminately a rock, a tree, or a spire.

331. 'If a thunder-rod be then a harmless, though idle, appendage to a house, why awaken uneasy apprehensions? It might at least inspire confidence in the moment of danger; and if happiness consists merely in idea, why not indulge delicious error?—Yet, though the inevitable stroke cannot be turned aside, its destructive effects may be lessened; and an investigation of the real action of thunder will conduct us to the proper principles.'—*Ed. Phil. Jour.* No. XXI. pp. 25.28.

332. The above theory is certainly ingenious and worthy of attention, but it wants confirmation in another way than that attempted by its author. We would, with all deference to Mr. Leslie's well-known abilities, ask if he would advise large fires to be kept up round powder magazines for the purpose of preventing them from being struck by lightning? We do not know, either, why *he* advises that they should have copper conductors raised near them? nor why, to save ships, ribands of copper should be extended from the masts to the keel, since he affirms that the idea of *diverting* or dissipating the storm is *wholly chimerical.*

Spontaneous Electricity of the Atmosphere.

333. Very numerous are the observations which have at different times been made by able observers on this branch of atmospherical electricity. We cannot here enter minutely into these, and shall therefore only offer an outline of their general results.

334. The earliest observations of this nature appear to have been those of Monnier; his experiments were made with an apparatus, which consisted of a pole thirty-two feet in height, insulated in a piece of turf, having at its top a strong glass tube, to which a tube of tinned iron was attached, and which terminated in a point. About the middle of this tube there was fastened a fine iron wire about fifty lines long, which, without touching any other body, was connected with a silk cord stretched horizontally. He found although the atmosphere was constantly electrified more or less, yet that in dry weather the electricity increased from sun-rise, when it was weakest, till about four o'clock in the afternoon, at which time it was strongest, gradually diminishing from that time till the dew began to fall, after which it diminished till midnight. The

same results were afterwards obtained by Saussure and Beccaria.

335. The abbé Mazeas made several observations with an atmospherical apparatus, consisting of an iron wire 370 feet long, raised about ninety feet from the ground, and properly insulated. The results of his experiments with this instrument were the following:—In very dry weather the wire readily attracted light bodies, if brought within three or four lines of it; and, if the weather was not stormy, the electricity of the air was about half as great as that of a stick of sealing-wax two inches long. When he grasped the wire in his hand, the signs of electricity disappeared entirely, and did not return till after an interval of three or four minutes. He also found that the electricity of the atmosphere was not increased with storms and hurricanes unattended with rain; for during a violent storm of wind, which continued uninterruptedly for three days, in the month of July, he found it necessary to place the dust within four or five lines of the conductor, before it exhibited a sensible attraction. No change was produced by the different directions of the winds. In the driest nights of summer he never could observe any electricity in the air, but it began to appear in the morning at sunrise, and vanished in the evening at about half an hour after sun-set. In the month of July, in a very dry day, when the sky was serene, and the heat intense, he found the electricity stronger than he had ever observed it. The dust was then attracted at the distance of ten or twelve lines from the conductor.

336. Mr. Kinnersley made several observations on the electricity of the atmosphere in its ordinary state, and informs us that when the air was very dry, he found it always contained some electricity, and that he rendered this electricity visible by electrifying himself negatively, and holding in his hand a long sharp needle, which, in the dark, appeared luminous at the point.

337. Beccaria, who was particularly attentive to this subject, and made numerous experiments both with rods and kites, found that, during the three following states of the atmosphere, it afforded no sensible indications of electricity. (1.) When the weather was clear, but at the same time windy. (2.) When the sky was covered with well defined black clouds, moving slowly. (3.) During moist weather, when not actually raining. The electricity was always perceptible when the sky was clear and the weather calm; in rainy weather, and when it did not lighten, the electricity appeared always a little before the rain fell, continued during the falling of the rain, and disappeared shortly after the rain ceased. The higher he raised his rods, the stronger he found these electrical signs.

338. M. de Saussure, however, has furnished us with the most extensive course of experiments on atmospherical electricity. He informs us that it is constantly varying, according to situation. It is generally strongest in elevated and insulated situations, not to be observed under trees, in streets, in houses, or any enclosed places, though it is sometimes to be found pretty strong on quays and bridges. It is also not so much affected by the absolute height of the places as their situation; thus a projecting angle of a high hill will often exhibit a stronger electricity than the plain at the top of the hill, as there are fewer points than in the former to deprive the air of its electricity. This variation in the intensity of the electricity of the atmosphere, seems influenced by numerous circumstances, some of which it is difficult satisfactorily to account for.

339. When the weather is not serene, it is impossible to assign any rule for their variation, as no regular correspondence can then be perceived with the different hours of the day, nor with the various modifications of the air. The reason is evident; when contrary and variable winds reign at different heights, when clouds are rolling over clouds, these winds and clouds, which we cannot perceive by any exterior sign, do, nevertheless, influence the strata of air in which we make our experiments, and produce these changes of which we only see the result, without being able to assign either the cause or its relation. Thus, in stormy weather, we find the electricity strong, then completely gone, and in a moment after rise to its former force; one instant positive, the next negative, without being able to assign any reason for these changes.

340. M. Saussure says, that he had known these changes succeed with such rapidity, that he had not time to note them down. When rain falls without a storm these changes are not so sudden; they are, however, very irregular, particularly with respect to intensity of force; the quality of them, too, is more constant. Rain or snow almost uniformly gives positive electricity. In cloudy weather, without rain or storms, the electricity follows generally the same laws as in serene weather. Strong winds generally diminish its intensity; they seem to mingle together the different strata of the atmosphere, and make them pass successively towards the ground, and thus distribute the electricity uniformly between the earth and the air. M. Saussure has observed a strong electricity with a strong north wind. The state of the air in which the electricity is strongest is foggy weather; this is also accompanied with electricity, except when the fog is going to resolve into rain.

341. The most interesting observations, and those which throw the greatest light upon the various modifications of electricity in our atmosphere, are those made in serene weather. In winter, and in serene weather, the electricity is generally weakest in the evening, when the dew has fallen, until sun-rising; its intensity afterwards augments by degrees, sometimes sooner and sometimes later; but generally before noon, it attains a certain maximum, whence it again declines, till the fall of the dew, when it will be sometimes stronger than it had been during the whole day; after which, it will again gradually diminish during the whole night; but, it is never quite destroyed, if the weather is perfectly serene. Atmospherical electricity seems, therefore, like the sea, to be subject to a flux and reflux, which causes it to increase and diminish twice in twenty-four hours. The times of its greatest force are some hours after the rising and setting of the sun: those when it is weakest precede these periods.

342. M. Saussure has given an instance of this periodic flux in electricity. On the 22nd of Feb. 1785, one of the coldest days ever remembered at Geneva, the hygrometer and thermometer were suspended in the open air on a terrace exposed to the south-west; the electrometer, from its situation, indicated an electricity equal to what it would have shown if it had been placed on an open plain. The height of the barometer was reduced to what it would have been if the mercury had been constantly at the temperature of 10° of Reaumur's thermometer. The place of observation was elevated sixty feet above the level of the lake. The observations of the day preceding and following this great cold were registered by him. There was a weak south-west wind during the whole three days; and it is rather remarkable, that most of the great colds, which have been observed at Geneva, were preceded by, or at least accompanied with, a little south-west breeze. From the first eighteen observations made during these three days, when the sky was quite serene, we learn that the electricity was pretty strong at nine o'clock A. M.; that from thence it gradually diminished till towards six o'clock P. M., which was its first minimum; after which it increased till eight o'clock, its second maximum; from whence it gradually declined till six the next morning, which was the time of its second minimum; after which, it again increased till ten in the morning, which was the first maximum of the following day; as this was cloudy, the periods were not so regular.

343. As we have hitherto but slightly noticed the method of exploring the atmosphere by the electrical kite, we shall here introduce an account of an experiment of this kind made by Mr. Cavallo, which is, in every respect, most gratifying and satisfactory; at least, it will be viewed in this light by every real lover of the science of electricity; and will, at the same time, read him a most useful lesson on the caution to be observed in making this boldest of all electrical experiments. It must be observed, that this experiment was made when there was no thunder; and that there had been none for three days before, nor did there happen to be any for three days after at the place where the scene occurred.

344. 'After,' says Mr. Cavallo, 'having rained a great deal in the morning and night before, the weather became a little clear in the afternoon, the clouds appearing separated, and pretty well defined. The wind was west, and rather strong, and the atmosphere in a temperate degree of heat. In these circumstances, at 3 P. M., I raised my electrical kite with 360 feet of string. After that the end of the string had been insulated, and a leather ball, covered with tin-foil, had been hung to it, I tried the power and quality of the electricity, which appeared to be positive and pretty strong.

345. 'In a short time, a small cloud passing over, the electricity increased a little; but the cloud being gone, it decreased again to its former degree. The string of the kite was now fastened by the silk lace to a post in the yard of the house in which I lived, which was situated near Islington, and I was repeatedly charging two coated phials, and giving shocks with them. While I was so doing, the electricity, which was still positive, began to decrease, and in two or three minutes' time it became so weak, that it could be hardly perceived with a very sensible cork-ball electrometer. Observing at the same time that a large and black cloud was approaching the zenith (which, no doubt, caused the decrease of the electricity), indicating imminent rain, I introduced the end of the string through a window, in a first-floor room, in which I fastened it by the silk lace to an old chair. The quadrant electrometer was set upon the same window, and was, by means of a wire, connected with the string of the kite.

346. 'It being now three-quarters of an hour after three o'clock, the electricity was absolutely unperceivable; however, in about three minutes time, it became again perceivable, but now upon trial was found to be negative; it is therefore plain, that its stopping was nothing more than a change from positive to negative, which was evidently occasioned by the approach of the cloud, part of which by this time had reached the zenith of the kite, and the rain also had begun to fall in large drops. The cloud came farther on, the rain increased, and, the electricity keeping pace with it, the electrometer soon arrived to 15°. Seeing now that the electricity was pretty strong, I began again to charge the two coated phials, and to give shocks with them; but the phials had not been charged above three or four times, before I perceived that the index of the electrometer was arrived at 35°, and was keeping still increasing. The shocks now being very smart, I desisted from charging the phials any longer; and, considering the rapid advance of the electricity, thought to take off the insulation of the string, in case that if it should increase farther it might be silently conducted to the earth, without causing any accident, by being accumulated in the insulated string.

347. To effect this, as I had no proper apparatus near me, I thought to remove the silk lace, and fasten the string itself to the chair; accordingly I disengaged the wire that connected the electrometer with the string, laid hold of the string, untied it from the silk lace, and fastened it to the chair; but while I effected this, which took up less than half a minute of time, I received about a dozen or fifteen very strong shocks, which I felt all along my arms, in my breast and legs, shaking me in such a manner, that I had hardly power enough to effect my purpose, and to warn the people in the room to keep their distance. As soon as I took my hands off the string, the electricity (in consequence of the chair being a bad conductor) began to snap between the string and the shutter of the window, which was the nearest body to it. The snappings, which were audible at a good distance out of the room, seemed first isochronous with the shocks which I had received, but in about a minute's time oftener; so that the people of the house compared their sound to the rattling noise of a jack going when the fly is off.

348. The cloud now was just over the kite; it was black, and well defined, of almost a cir-

cular form, its diameter appearing to be about 40° ; the rain was copious, but not remarkably heavy. As the cloud was going off, the electrical snapping began to weaken, and in a short time became inaudible. I went then near the string, and finding the electricity weak, but still negative, I insulated it again, thinking to keep the kite up some time longer; but observing that another larger and denser cloud was approaching apace towards the zenith, as I had then no proper apparatus at hand, to prevent every possible accident, I resolved to pull the kite in; accordingly a gentleman who was by me began pulling it in, while I was winding up the string. The cloud was now very nearly over the kite, and the gentleman, who was pulling in the string, told me that he had received one or two slight shocks in his arms, and that if he were to feel one more, he would certainly let the string go; upon which I laid hold of the string, and pulled the kite in as fast as I could, without any farther observation, being then ten minutes after four o'clock.'

349. Mr. Cavallo, from the numerous experiments which he made with electrical kites, lays down the following results, which will be found correct in the generality of cases. (1.) 'The air appears to be electrified at all times; its electricity is constantly positive, and much stronger in frosty than in warm weather; but it is by no means less in the night than in the day-time. (2.) The presence of the clouds generally lessens the elasticity of the kite; sometimes it has no effect upon it; and it is very seldom that it increases it a little. To this the above-mentioned instance is a most remarkable exception. (3.) When it rains, the electricity of the kite is generally negative, and very seldom positive. (4.) The aurora borealis seems not to affect the electricity of the kite. (5.) The electric spark taken from the string of the kite, or from any insulated conductor connected with it, especially when it does not rain, is very seldom longer than a quarter of an inch; but it is exceedingly pungent. When the index of the electrometer is not higher than 20° the person who takes the spark will feel the effect of it in his legs; it appearing more like the discharge of an electric jar, than the spark taken from the prime conductor of an electrical machine. (6.) The electricity of the kite is generally stronger or weaker, according as the string is longer or shorter; but it does not keep any exact proportion to it. The electricity, for instance, brought down by a string of 100 yards, may raise the index of the electrometer to twenty, when, with double that length of string, the index of the electrometer will not go higher than twenty-five. (7.) When the weather is damp, and the electricity is pretty strong, the index of the electrometer, after taking a spark from the string, or presenting the knob of a coated phial to it, rises surprisingly quick to its usual place; but in dry and warm weather it rises very slowly. (8.) The principal use of the electrical kite is to show the electricity of the atmosphere; and it is perhaps the only instrument that will do this at all times with certainty, though several others have been invented for that purpose. But another use to which electrical kites have been applied, is to bring down quantities of the electric fluid from the upper regions of the atmosphere, for the purpose of supplying that deficiency of electricity, which is supposed to be hurtful to vegetation.'

350. From numerous experiments on the spontaneous electricity of the atmosphere made by Mr. Read, he has drawn the following conclusions:—(1.) 'That in moderate weather it is uniformly positive, and experiences an increase and a decrease in the degree of its intensity twice in twenty-four hours. (2.) That the electricity is strongest about two or three hours after sun-rise, and some time both before and after sun-set; and is in general in the weakest state between noon and four o'clock. (3.) And that this periodical electricity is obviously influenced by heat and cold.'

351. The latest experiments that have been made on this subject, on a large scale, are those by Andrew Crosse, Esq. of Broomfield, near Taunton. They were made by means of an apparatus the most extensive ever constructed. It consisted of a copper wire, one-sixteenth of an inch in thickness, stretched and insulated between two strong upright poles measuring from 100 to 110 feet in height.

352. No pains was spared to render this apparatus the most extensive and perfect that has been constructed. The insulated wire was one mile and a quarter in length, but having been exposed to various depredations, and liable to injury from other causes, it was shortened to 1800 feet. Every contrivance was tried to insulate this wire, but Mr. Crosse could not succeed in preserving the insulation during a dense fog, or a driving snow. A contrivance was adopted to lower the insulators, for the purpose of freeing them from spiders' webs; and it was necessary to fix the wire very securely, in order that it might be able to resist the weight of the great numbers of swallows that often perched upon it, and of wood-pigeons and owls that flew against it with considerable force. This apparatus has been in use for some years, and has enabled Mr. Crosse to draw the following conclusions, which confirm the observations of preceding authors.

353. (1.) 'The electricity is invariably positive during the usual state of the atmosphere, and subject to a regular increase and decrease, as stated in some of the preceding observations.

354. (2.) 'Fogs, rain, snow, hail, and sleet, produce changes in the electrical state of the wire. The electricity is negative when they first appear. It frequently changes to positive, increasing gradually in strength; and then decreasing in a similar manner, and changing from positive to negative every three or four minutes. Those phenomena have been so constantly observed, that, whenever the wire appears negatively electrified, it is considered as a certain indication, that either rain, snow, hail, mist, or a thunder-cloud, is approaching.

355. (3.) 'The approach of a charged cloud at first is sometimes found to produce positive, and sometimes negative electricity; but, whatever be the kind of the electricity which first appears, its intensity increases to a certain degree, then diminishes, and finally disappears, and is suc-

ceeded by the opposite electricity; which increases to a higher degree than the first had done; it then diminishes, and vanishes, and is again succeeded by the electricity which first appeared. These alternations of positive and negative electricity are often exceedingly numerous, and on different occasions succeed one another with different degrees of rapidity. The electricity, in general, becomes more intense at every repetition, till a copious and dense stream of sparks issues from the atmospherical conductor to the receiving-ball, stopping at intervals, and returning with redoubled force.

356. (4.) 'In this state of things, a strong current of air flows from the wire, and the apparatus with which it is connected. At every flash of lightning an explosive stream, attended by a very peculiar noise, passes between the balls and the apparatus, and brilliantly illuminates the surrounding objects, while the effects on the spectator are heightened by the successive peals of thunder, and the consciousness of being so near their cause.

357. 'When the electricity becomes too powerful to allow the observer to operate in safety, he connects the insulating wire with the ground; along this the whole passes off silently and harmlessly to the ground.

358. (5.) 'During a driving fog, or a smart rain, the wire is electrified almost as powerfully as during a thunder-storm, and the electricity exhibits similar changes.

359. (6.) 'A weak positive electricity generally prevails in cloudy weather. It often changes to negative when rain falls; but the positive electricity re-appears when the rain has ceased to fall.

360. (7.) 'The electricity is always stronger in clear frosty weather than during a fine summer's day.'

361. The following table, drawn up by Mr. Crosse, exhibits the intensity of the electrical appearances of the atmosphere in different states, commencing with those in which it is most powerful:—

(1.) During the occurrence of regular thunder clouds.

(2.) A driving fog, accompanied by small rain.

(3.) A fall of snow, or a brisk hail-storm.

(4.) A smart shower, especially in a hot day.

(5.) Hot weather succeeding a series of wet days.

(6.) Wet weather following a series of dry days.

(7.) Clear frosty weather, either in the night or day.

(8.) Clear warm summer weather.

(9.) A sky obscured by clouds.

(10.) A mackerel back, or mottled sky.

(11.) Sultry weather, the sky covered with light hazy clouds.

(12.) A cold damp night.

362. For common purposes, and occasional observations, Mr. Singer says, very simple contrivances may be employed. A common jointed fishing-rod, having a glass stick covered with sealing-wax substituted for the smallest joint, may be occasionally projected from the upper window of a house. A pair of pith-balls must be attached to a cork, in which the end of the glass stick is thrust; and this part of the apparatus is to be occasionally uninsulated, by placing a pin in the cork, connected with a thin wire held in the hand. In this uninsulated state, the fishing-rod and its attached electrometer are to be held for a few seconds projecting from the window, and, whilst in this position, the pin is to be withdrawn by pulling the thin wire; this insulates the electrometer, which may be then drawn in and examined. Its electricity will be found to be contrary to that of the atmosphere.

363. The last circumstance which we shall notice respecting the electricity of the atmosphere, is its effects on the vegetable kingdom. Much has been said relative to the merits of the question, whether the electricity of the atmosphere has or has not an influence on the process of vegetation. It is remarkable that this should ever for one moment have been matter of doubt with any one, since it is well known that light and heat, and, in one word, the free access of the air of our atmosphere, are all essential to the general process of vegetation. Where difficulties have occurred in the course of experiment on the subject, we are firmly persuaded that they relate entirely to the management of the apparatus employed; we can readily manage the regulations of warming, watering, and airing a small house, in which we wish to accelerate the growth of vegetable substances; but when we attempt to take, as it were, the management of the atmosphere in our own hands, and to regulate the general process of vegetation in our fields or gardens, we must expect to meet that disappointment which is ever attendant on quitting the sphere of action allotted to mortals. No series of experiments, how nicely soever conducted, can ever be expected to equal the silent, the invisible, but unerring operations of nature.

364. The first electrician who seems to have attended to this subject was Mr. Maimbray of Edinburgh, who, in the year 1746, electrified two myrtles, during the whole month of October, for some hours every day. The consequence was, that, in the following summer, these electrified myrtles put forth buds and blossoms sooner than those which had been left to nature.

365. Mr. Maimbray was followed by the abbé Nollet, who made some comparative experiments on the germination of seeds under similar circumstances, except that one plot was electrified three or four hours every day during the space of fifteen days. His experiments were attended with results similar to those obtained by Mr. Maimbray.

366. Experiments of a similar nature were repeated by others, and, as was to be expected, were in general followed by the like results. Hence the effect of electricity in promoting vegetation became universally acknowledged, till a series of well-conducted experiments, made by Dr. Ingenhousz, staggered the faith of philosophers in general on the subject

367. Several electricians, however, labored hard to support the credit of the abbé Nollet's system, although but with little success. Among these, the chief was the abbé Bertholon, who wrote a work which was entirely confined to the subject. The reasoning of this author, however incorrect it may appear to many, has certainly

the recommendation of ingenuity; and, although he carried his notions relative to the effects of electrical influence much farther than most are desirous of doing, we cannot perceive why these circumstances should be considered, as they have been by some, as the ground of ridicule.

368. But that our readers may form their own judgment on this subject, we shall here introduce the abbé's own account of the instrument with which his experiments were chiefly made, and of his method of procedure.

369. M. Bertholon commences his account by observing that there is continually and universally diffused in the atmosphere, and particularly in the higher regions, a considerable quantity of the electric fluid. 'This principle,' says he, 'being granted; in order to remedy the deficiency of electric fluid, which is supposed hurtful to vegetation, we must erect on the spot which we want to fecundate the following new apparatus, which has had all possible success, and which I shall call by the name of the electro-vegetometer. This machine is as simple in its construction as efficacious in its manner of acting; and I doubt not but it will be adopted by all those who are sufficiently instructed in the great principles of nature.'

370. The apparatus which the abbé here denominates his electro-vegetometer, consists of a mast or long pole firmly fixed into the ground to be able to resist the force of the wind; at the upper extremity of this pole is fixed a wire which terminates in one or more points, for the purpose of collecting the electricity of the air, and with which is connected a long insulated conductor, terminating in five or six points directed to the ground.

371. After having described at great length the construction of this apparatus, he proceeds to observe.—'The construction of this electro-vegetometer once well understood, it will be easy for us to conceive its effects. The electricity which prevails in the aërial regions will soon be drawn down by the elevated points of the upper extremity. This effect of the points is proved by the most decisive experiments, and is called by philosophers the power of the points.

372. 'By means of the electro-vegetometer just now described, one may be able to accumulate at pleasure this wonderful fluid, however diffused in the regions above, and conduct it to the surface of the earth, in those seasons when it is either scantily supplied, or its quantity is insufficient for vegetation, or, although it may be in some degree sufficient, yet it can never produce the effects of a multiplied and highly increased vegetation. So that by these means we shall have an excellent vegetable manure or nourishment, brought down as it were, from heaven, and that, too, at an easy expense; for, after the construction of this instrument, it will cost nothing to maintain it: it will be, moreover, the most efficacious you can employ; no other substance being so active, penetrating, or conducive to the germination, growth, multiplication, or reproduction, of vegetables. This heavenly manure is that which nature employs over the whole habitable earth, not excepting even those regions which are esteemed barren, but which, however, are often fecundated by those agents which nature knows so well to employ to the most useful purposes. Perhaps there was nothing wanting to bring to a completion the useful discoveries that have been made in electricity, but to show this so advantageous an art of employing electricity as a manure.

373. 'Consequently, that all the effects which we have already mentioned depend upon electricity alone; and, lastly, that all these effects, viz. acceleration in the germination, the growth, and production of leaves, flowers, fruit, and their multiplication, &c., will be produced even at a time when secondary causes are against it; and all this is brought about by the electric fluid, which we have the art of accumulating over certain portions of the earth, where we want to raise those plants that are most calculated for our use.

374. 'By multiplying these instruments, which are provided at little expense (since iron rods, of the thickness of one's finger, and even less, are sufficient for the purpose), we multiply their beneficial effects, and extend their use ad infinitum.

375. 'This apparatus having been raised with care in the midst of a garden, the happiest effects were perceived, viz. different plants, herbs, and fruits, in greater forwardness than usual, more multiplied, and of better quality. These facts are analogous to an observation which I have often made, viz. that plants grow fast, and are most vigorous, near thunder-rods, where their situation favors their development. They likewise serve to explain why vegetation is so vigorous in lofty forests, and where the trees raise their heads far from the surface of the earth, so that they seek, as it were, the electric fluid at a far greater height than plants less elevated; while the sharp extremities of their leaves, boughs, and branches, serve as so many points granted them by the munificent hand of nature, to draw down from the atmosphere that electric fluid which is so powerful an agent in forwarding vegetation, and in promoting the different functions of plants.'

376. It may be proper here to add, that others who succeeded Bertholon in his experiments, and with all his experience at their service, do not seem to have thrown any light on the subject. M. Achard, of Berlin, tried the effects of electricity on a small quantity of fermented rye, which was intended for distillation. He electrified one-half of it; and after five hours the vinous fermentation had ceased in the electrified portion, while in that which was not so treated it did not cease till after the lapse of eight hours. He then tried the effect of strong sparks upon a quantity of rye; which, excepting in one case, which he notices, he found to accelerate the process of fermentation.

Miscellaneous Experiments, &c.

377. *Illuminated phosphorus*, or the Bolognian stone. Among the numerous methods devised for exhibiting the effects of electrical light, perhaps the most curious is that made with the real, or more easily with the artificial Bolognian stone, or Canton's phosphorus. This phosphorus

is a calcareous substance, generally used in the form of a powder, which has the property of absorbing light when exposed to it, and afterwards appearing lucid when brought into the dark. Take some of this powder, and, by means of spirits of wine or ether, stick it all over the inside of a clear glass phial, and stop it with a glass stopper, or a cork and sealing-wax. If kept in a room perfectly darkened, it will give no light; but let two or three sparks be drawn from the prime conductor, when the phial is kept at about two inches from the sparks, so that it may be exposed to that light, and this phial will receive that light, and afterwards will appear illuminated for a considerable time. The powder may be stuck upon a board by the white of an egg, so as to represent figures of planets, letters, or any thing else; and these may be illuminated in the dark, in the same manner as the phial. A beautiful method to express geometrical figures with the above phosphorus, is to bend small glass tubes of about the tenth part of an inch diameter, in the shape and figure desired, and then fill them with the phosphoric powder. These may be illuminated in the manner described, and they are not so subject to be spoiled as the figures represented upon the board frequently are. The best method of illuminating this phosphorus, and which Mr. W. Canton generally used, is to discharge a small electric jar near it.

378. *The tourmalin.*—The tourmalin, or the *lapis electricus* of Linnæus, is a hard semi-pellucid fossil, and was first observed to exhibit electrical phenomena, on being heated and cooled. This stone is found in abundance in the East Indies, and is named the electrical stone from its possessing many singular electrical properties. The properties of this stone seem to have been known to the ancients: Theophrastus mentions a stone which he terms the *lyncurium*, and describes it as being very hard; susceptible of a high polish, very useful for making seals, &c.; and possessing the property of attracting light substances. Hence there can be little doubt as to its being the tourmalin of the moderns. The Dutch seem to have discovered the properties of the tourmalin by observing that when placed in the fire it attracted the ashes; hence they gave it the name of aschen-trikker.

379. But by increasing its heat it becomes electrical, and still more so by diminishing it. Its electricity appears, not over its whole surface, but only on two opposite sides, which have been styled its poles, as they are in a line with its centre, and in the same direction with its strata; in which direction it is opaque, though semi-transparent in the other.

380. During the process of heating, the tourmalin has one of its sides electrified positively, and the other negatively; but, while cooling, the former becomes negative and the latter positive. If heated and allowed to cool without either side being touched, the former will be positive and the latter negative, all the time it is heating or cooling. If excited by rubbing, each of its sides, or both at once may be rendered positive. I heated or cooled upon an insulated substance that substance will become possessed of the electricity contrary to that of the side of the tourmalin, which was laid on it. The electricity of both sides, or of either, may be reversed by heating or cooling the stone, in contact with other bodies.

381. If a tourmalin be cut in pieces, each piece will have its positive and negative poles, as well as the whole stone. All the above properties are observable in vacuo. If this stone be covered over with wax, oil, or any similar electric, it will exhibit the same electric signs as without the covering.

382. In making experiments with the tourmalin, Mr. Canton observed a vivid light upon it, while heating in the dark, by which he could determine which end of the tourmalin was positive or negative. When excited, it emits very strong flashes in the dark, from the positive to the negative end. Mr. Canton has also observed the Brasilian emerald emit light while heating in the dark. Mr. Cavallo 'imagines that every other precious stone will show it if its electric power be sufficiently strong; since the light is a consequence of the passage of a sufficient quantity of electricity through the air, or other partly resisting medium.'

383. The electrical power of the tourmalin is sometimes improved, sometimes injured, sometimes not in the least affected by a strong fire. Most of the above properties, which were supposed to be peculiar to the tourmalin, are possessed by several hard precious stones, which are capable of becoming electrical by heating and cooling, and have their positive and negative sides lying in the direction of their strata, &c.

384. *Evaporation produces electricity.*—This appears to have been a discovery of Signor Volta, who observed that the evaporation of water and some other fluids, as well as certain effervescences, generated electricity. His experiments seem to prove that fluids, or other bodies, reduced to vapor, become electrified positively, and leave the bodies from which they evaporated, electrified negatively; and that on the other hand, when the vapors are condensed into a fluid, they become electrified negatively, and leave the bodies with which they were last in contact electrified positively.

385. The common method of illustrating this is the following:—Place on the cap of a gold-leaf electrometer a metallic dish containing a few lighted coals, and project on them a few drops of water, whilst an insulated funnel is held about a foot or eighteen inches above. Under these circumstances the electrometer is found to be negatively electrified, and the insulated funnel positively. On this experiment Mr. Walker observes, that the vapor carries off the latent electricity from the electrometer; the leaves diverge, and fly to the slips of tin-foil to supply their loss. He adds, perhaps the vapor derives its volatility from its union with electricity, for it is observable, that if insulated pith-balls be suspended in a fog or mist, they separate spontaneously with positive electricity.

386. *To electrify the air of a room.*—This is an experiment which may be easily performed with a powerful machine. The room ought to be very clean, and as free as possible from

pointed metallic substances. These things being observed, place a few pointed wires in the prime conductor of the machine; put the machine in action, and after the lapse of a few minutes the air of the room will become so impregnated with electricity as to be very perceptible to the sense of smelling, and will readily affect a delicate electrometer, particularly if brought into the vicinity of the machine. The odor perceived on this occasion very much resembles that of oxygen gas, or of the atmospheric air in a very clear and frosty night.

387. *The charge of a jar is retained in the electric.*—This is proved in a very satisfactory manner by the following experiments, which show that the coating of the Leyden jar has not quite so much to do with the charge as is generally supposed. The first is given by Mr. Walker in his System of Familiar Philosophy, and is in substance as follows :—Lay a plate of tin or brass on your hand, and on it a plate of glass (rather larger than the metallic plate); on the glass lay another metallic plate, and let this communicate with the prime conductor: thus the glass may be charged. By the edge of the glass disengage it from the two plates, and place two other plates in the same situation, upon and under the glass. If now one knob of the discharging-rod be made to touch the under plate, and the other knob the upper plate, a discharge will ensue the same as if the first plates had remained in their place.

388. The same principle is thus illustrated by the Leyden jar; we give the process as directed by Mr. Singer :—Procure a jar with a double set of moveable tin-coatings, either of which may be adapted to it at pleasure; the outer coating being a tin can large enough to admit the jar easily within it; and the inner coating a similar can sufficiently small to pass readily in the inside of the jar. The charging wire of the inner coating should be surrounded by a glass tube covered with sealing-wax, to serve as an insulating handle, by which the inner coating may be lifted from the jar when that is charged, without communicating a shock to the operator. Arrange the jar with its coatings, and charge it; it will act in every respect as an ordinary coated jar. Charge the jar, and, without discharging it, remove the inner coating by its insulating handle; if this coating, when removed, be examined, it will be found not at all, or but slightly electrified: lift the jar carefully from within its outer coating, and examine that; it will evince no signs of electricity.

389. Let the jar be now fitted up with the other pair of moveable coatings; apply the discharger, and an explosion and spark will follow, which clearly proves that the accumulation is retained by the attractive power of the glass, and that the coatings are only useful as conductors to the charge.

390. *Velocity of the electric fluid.*—Although we have already made some passing remarks on this subject, the following detail will, we doubt not, be found interesting to the admirers of the electrical science. Several electricians of distinguished merit have made experiments on the velocity of the electric fluid; those to which we here particularly refer were made under the direction and superintendence of Mr. Watson, who, as an eye-witness of them, drew up the account to lay before the Royal Society.

391. The first attempt of these electricians was to convey electric shocks across the river Thames, availing themselves of the water of the river as one part of the circuit through which the charge was to pass. This they accomplished on the 14th and 18th of July, 1747, by fastening a wire all along Westminster-bridge, at a considerable height above the water. One end of this wire communicated with the coating of a charged phial, the other being held by an observer, who, in his other hand, held an iron rod, which he dipped into the river. On the opposite side of the river stood a gentleman, who likewise dipped an iron rod in the river with one hand; and in the other held a wire, the extremity of which might be brought into contact with the wire of the phial.

392. When the discharge was made, the shock was distinctly felt by the observers on both sides of the river, but more sensibly by those who were stationed on the same side with the machine; part of the electric fire having gone from the wire down the moist stones of the bridge, thereby making several shorter circuits to the phial, but still all passing through the gentlemen who were stationed on the same side with the machine. This was, in a manner, demonstrated by some persons feeling a sensible shock in their arms and feet, who only happened to touch the wire at the time of one of the discharges, when they were standing upon the wet steps which led to the river. In one of the discharges made upon this occasion, spirits were kindled by the fire which had gone through the river. The gentlemen made use of wires in preference to chains, as communicating a stronger degree of electricity.

393. Their next attempt was to cause the electrical fluid to make a circuit of two miles, at the New River at Stoke Newington. This they performed on the 24th of July, 1747, at two places; at one of which the distance by land was 800 feet, and by water 2000: in the other, the distance by land was 2800 feet, and by water 8000. The disposition of the apparatus was similar to what they had before used at Westminster-bridge, and the effect answered their utmost expectations. But as, in both cases, the observers at both extremities of the chain, which terminated in the water, felt the shock as well when they stood with their rods fixed into the earth twenty feet from the water, as when they were put into the river; it occasioned a doubt, whether the electric circuit was formed through the windings of the river, or a much shorter way, by the ground of the meadow; for the experiment plainly showed that the meadow-ground, with the grass on it, conducted the electricity very well.

394. From subsequent experiments they were fully convinced that the electricity had not in this case been conveyed by the water of the river, which was two miles in length, but by land, where the distance was only one mile; in which space, however, the electric matter must neces-

sarily have passed over the New River twice, and have gone through several gravel-pits, and a large stubble-field.

395. On the 28th of July, they repeated the experiment at the same place, with the following variation of circumstances:—The iron wire was, in its whole length, supported by dry sticks, and the observers stood upon original electrics; the effect was, that they felt the shock much more sensibly than when the conducting-wire had lain upon the ground, and when the observers had likewise stood upon the ground, as in the former experiment. Afterwards, every thing else remaining as before, the observers were directed, instead of dipping their rods into the water, to put them into the ground, each 150 feet from the water. They were both smartly struck, though they were distant from each other above 500 feet.

396. Their next object was to determine whether the electric virtue could be conveyed through dry ground; and, at the same time, to carry it through water to a greater distance than they had done before. For this purpose they pitched upon Highbury Barn, beyond Islington, where they carried it into execution on the 5th of August, 1747. They chose a station for their machine almost equally distant from two other stations, for observers upon the New River, which were somewhat more than a mile asunder by land, and two miles by water.

397. They had found the streets of London, when dry, to conduct very strongly for about forty yards; and the dry road at Newington about the same distance. The event of this trial answered their expectations. The electric fire made the circuit of the water, when both the wires and the observers were supported upon original electrics, and the rods dipped into the river. They also both felt the shock, when one of the observers was placed in a dry gravelly pit, about 300 yards nearer the machine than the former station, and 100 yards distant from the river: from which the gentlemen were satisfied, that the dry gravelly ground had conducted the electricity as strongly as water.

398. From the shocks which the observers received, when the electric power was conducted upon dry sticks, they were of opinion, that, from the difference of distance simply considered, the force of the shock, as far as they had yet experienced, was very little if at all impaired. When they stood upon electrics, and touched the water on the ground with the iron rods, the shock was always felt in their arms or wrists; when they stood upon the ground, with their iron rods, they felt the shock in their elbows, wrists, and ankles; and, when they stood upon the ground without rods, the shock was always felt in the elbow and wrist of that hand which held the conducting wire, and in both ankles.

399. The last investigation which these gentlemen made on this subject, and which required all their sagacity and address in the conduct of it, was to try whether the electric shock was perceptible at twice the distance to which they had before carried it, in ground perfectly dry, and where no water was near; and also to distinguish, if possible, the respective velocity of electricity and sound. For this purpose they fixed upon Shooter's Hill, and made their first experiments on the 14th of August, 1747; a time when, as it happened, but one shower of rain had fallen during five preceding weeks. The wire communicating with the iron rod which made the discharge, was 6732 feet in length, and was supported all the way upon baked sticks: as was also the wire which communicated with the coating of the phial which was 3868 feet long, and the observers were distant from each other two miles.

400. The result of the explosion demonstrated to the satisfaction of the gentlemen present, that the circuit performed by the electric matter was four miles, viz. two miles of wire and two of dry ground, the space between the extremities of the wires; a distance which, without trial, as they justly observed, was too great to be credited. A gun was discharged at the instant of the explosion and the observers had stop-watches in their hands, to note the moment when they felt the shock: but as far as they could distinguish, the time in which the electric matter performed that vast circuit might have been instantaneous. In all the explosions where the circuit was made of considerable length, it was observed that though the phial was very well charged, yet that the snap at the gun barrel, made by the explosion was not near so loud as when the circuit was formed in a room: so that a by-stander, says Dr. Watson, though versed in these operations, would not imagine from seeing the flash, and hearing the report that the stroke at the extremity of the conducting wire could have been considerable; the contrary whereof, when the wires were properly managed, he says, always happened.

401. Still, these philosophers were desirous to ascertain the absolute velocity of electricity at a certain distance; because though in the last experiment, the time of its progress was certainly very small, if any, they were desirous of knowing, small as that time might be, whether it was measurable: and Dr. Watson had contrived an excellent method for that purpose. Accordingly, on the 5th of August, 1748, the gentlemen met once more at Shooter's Hill; when it was agreed to make an electric circuit of two miles, by several turnings of the wire in the same field. The middle of this circuit they contrived to be in the same room with the machine, where an observer took in each hand one of the extremities of the wires, each of which was a mile in length. In this excellent disposition of the apparatus, in which the time between the explosion, and the shock might have been observed to the greatest exactness, the phial was discharged several times; but the observer always felt himself shocked at the very instant of making the explosion. Upon this the gentlemen were fully satisfied, that through the whole length of this wire, which was 12,276 feet, the velocity of the electric matter was instantaneous.

402. Notwithstanding all this surprising velocity, it is certain, that both sides of a charged phial may be touched so quickly, even by the best conductors, that all the electric matter had not time to make the circuit, and the phial will

remain but half discharged. If the upper plate of an electrophorus also is very suddenly touched with the finger, or any other conductor, a very small spark will be obtained on lifting it up; though a very strong one would be got if the finger was kept longer upon it. But how this seeming slowness can be reconciled with the immeasurable velocity above mentioned, does not appear. It is certain, indeed, that this fluid is considerably resisted in its passages through or over every substance. It will even prefer a short passage in the air where it is violently resisted to one along a wire of very great length; but here, as in every other case, it seems to divide its force, and to break through several different passages at once.

403. The amazing velocity of the electric fluid has recently given rise to some speculations on the subject of constructing electrical telegraphs; this idea, however, appears altogether chimerical, as has been proved by some experiments made by professor Barlow, of the Royal Military Academy. By employing wires of different lengths up to 840 feet, and measuring the energy of the electric action by the deflection produced in the magnetic needle, he found that the intensity rapidly diminishes, and very nearly as the inverse square of the distance. Mr. Barlow also ascertained that the effect was greater with a wire of a certain size than with a finer one; but at the same time, that no advantage was gained by increasing the diameter beyond a certain limit.

404. We have thus gone through what we consider as the essentials of electricity in general; we have omitted several things which we consider as being now obsolete, and some also that are of too trifling a nature to deserve a place in any work pretending to respectability. It has been our aim to produce the most useful information on every part of the subject, and to give the whole as much interest and life as the nature of a subject, purely philosophical, would admit. It may, however, be adviseable, prior to closing the present article, to furnish our readers with the latest facts in the science of electricity, and many that follow are discoveries that are due to the period that we are now writing.

On Paratonnerres, or Conductors of Lightning.

405. A very interesting report on the subject of paratonnerres, has been presented to the Royal Academy of Sciences by M. Gay Lussac. The paper is divided into two parts; one theoretical, and the other practical, and the information contained in it may be regarded as the most perfect we possess on the subject.

406. The theoretical part is introduced with some general observations on electric matter, and of conductors; that its velocity is at the rate of about 1950 feet per second; that it penetrates bodies, and traverses their substance, with unequal degrees of velocity; that the resistance of a conductor increases with its length, and may exceed that which would be offered by a worse but shorter conductor; and that conductors of small diameter conduct worse than those of larger. The electric matter also tends always to spread itself over conductors, and to assume a state of equilibrium in them, and becomes divided among them in proportion to their form, and principally to their extent of surface; and that hence a body that is charged with the fluid being in communication with the immense surface of the earth, will retain no sensible portion of it.

407. Gay Lussac defines a paratonnerre to be a conductor which the electric matter prefers to the surrounding bodies, in order to reach the ground, and expand itself through it; and commonly consists of a bar of iron elevated on the buildings it is intended to protect, and descends without any divisions or breaks in its length, into water or moist ground. When a paratonnerre has any breaks in it, or is not in perfect communication with a moist soil, the lightning, having struck it, flies from it to some neighbouring body, or divides itself between the two, in order to pass more rapidly into the earth.

408. The most advantageous form that can be given to the extremity of a paratonnerre is that of a sharp cone, and the higher it is elevated in the air, other circumstances being equal, the more its efficacy will be increased, as is proved by the experiments of M.M. de Romas and Charles.

409. It has not been accurately ascertained how far the sphere of action of a paratonnerre extends; but, in several instances, the more remote parts of large buildings on which they have been erected, have been struck by lightning at the distance of three or four times the length ot the conductor from the rod. According, however, to the opinion of Charles, a paratonnerre will effectually protect from lightning a circular space, whose radius is twice that of the height of the conductor. By increasing, therefore, the altitude of a conductor, the space also which it will protect is augmented in proportion.

410. A current of electric matter, whether luminous or not, is always accompanied by heat, the intensity of which depends on the velocity of the current. This heat is sufficient to make a metallic wire red hot, or to fuse or disperse it, if sufficiently thin; and hence we may perceive the absurdity of some attempts which have been lately made, to protect ships, by thin slips of copper nailed to the masts. The heat of the electric fluid scarcely raises the temperature of a bar of metal, on account of its large mass; and no instance has yet occurred of an iron bar, of rather more than half an inch square, or of a cylinder of the same diameter, having been fused, or even heated red hot by lightning. A rod of this size would, therefore, be sufficient for a paratonnerre; but, as its stem should rise from fifteen to thirty feet above the building, it would not be of sufficient strength at the base to resist the action of the wind, unless it were made much thicker at that part. An iron bar, about three-quarters of an inch, is sufficient for the conductor of the paratonnerre.

411. According to Gay Lussac, a paratonnerre consists of two parts, the stem which projects in the air above the roof, and the conductor,

which descends from the foot of the stem to the ground. The stem he proposes to be a square bar of iron, tapering from its base to the summit, in form of a pyramid, and for a height of from twenty to thirty feet, which is the mean length of the stems placed on large buildings; the base should be about two inches and a half square. Iron being very liable to rust by the action of air and moisture, the point of the stem would soon become blunt; and therefore, to prevent it, a portion of the top, about twenty inches in length, should be composed of a conical stem of brass or copper, gilt at its extremity, or terminated by a small platina needle, two inches long. Instead of the platina needle, one of standard silver may be substituted, composed of nine parts of silver, and one of copper. The platina needle should be soldered with a silver solder to the copper stem; and to prevent its separating from it, which might sometimes happen, notwithstanding the solder, it should be secured by a small collar of copper. The copper stem is united to the iron one, by means of a gudgeon, which screws into each; the gudgeon is first fixed in the copper stem by two steady pins at right angles to each other, and is then screwed into the iron stem, and secured there also by a steady pin.

412. The conductor should be about three-quarters of an inch square, and, as before stated, reach from the foot of the stem to the ground. It should be firmly united to the stem, by being tightly jammed between the two ears of a collar, by means of a bolt. The conductor should be supported parallel to the roof, at about six inches distance from it, by forked stanchions, and after turning over the cornice of the building, without touching it, should be brought down the wall, and to which it should be fastened by means of cramps. At the bottom of the wall, it is bent at right angles, and carried in that direction twelve or fifteen feet, when it turns down into a well.

413. Since iron buried in the ground in immediate contact with moist earth soon becomes covered with rust, and is by degrees destroyed, the conductor should be placed in a trough filled with charcoal, in the following manner. Having made a trench in the earth, about two feet deep, a row of bricks is laid on their broad faces, and on them others on edge; a stratum of bakers' ashes (braise de boulanger) is then strewed over the bottom bricks, about two inches thick, on which the conductor is laid, and the trough then filled up with more ashes, and closed by a row of bricks laid along the top. Iron thus buried in charcoal, will undergo no change in thirty years. After leaving the trough, the conductor passes through the side of the well before alluded to, and descends into the water to the depth of at least two feet below the lowest water line. The extremity of the conductor usually terminates in two or three branches, to give a readier passage to the lightning into the water If there be no well at hand, a hole must be made in the ground, with a six-inch auger, to the depth of about ten or fifteen feet, and the conductor passed to the bottom of it, placing it carefully in the centre of the hole, which is then to be filled up with bakers' ashes, rammed down as hard as possible, all round the conductor. In a dry soil, or on a rock, the trench to receive the conductor should be at least twice as long as that for a common soil, and even longer, if thereby it be possible to reach moist ground. Should the situation not admit of the trench being much increased in length, others, in a transverse direction, should be made, in which small bars of iron, surrounded by ashes, are placed and connected with the conductor. In general, the trench should be made in the dampest, and consequently lowest spot near the building, and the water gutters made to discharge their waters over it, so as to keep it always moist. Too great precautions cannot be taken to give the lightning a ready passage to the ground, for it is chiefly on this that the efficacy of a paratonnerre depends.

414. As iron bars are difficult to bend according to the projections of a building, it has been proposed to substitute metallic ropes in their stead. Fifteen iron wires are twisted together, to form one strand, and four of these form a rope, about an inch in diameter. To prevent its rusting, each strand is well tarred, separately, and, after they are twisted together, the whole rope is tarred over again with great care. Copper or brass wire is, however, a better material for their construction than iron. If a building contain any large masses of metal, as sheets of copper or lead on the roof, metal pipes and gutters, iron braces, &c., they must all be connected with the paratonnerre, by iron bars of about half an inch square, or something less. Without this precaution, the lightning might strike from the conductor to the metal (especially if there should be any accidental break in the former), and occasion very serious injury to the building, and danger to its inhabitants.

415. *Paratonnerres for Churches.*—For a tower, the stem of the paratonnerre should rise from fifteen to twenty-four feet, according to its area; the domes and steeples of churches, being usually much higher than the surrounding objects, do not require so high a conductor as buildings with extensive flat roofs. For the former, therefore, their stems, rising from three to six feet above the cross or weather-cock, will be sufficient, and being light they may easily be fixed to them without injuring their appearance, or interfering with the motion of the vane.

416. *Paratonnerres for Powder-Magazines.*—These require to be constructed with the greatest care. They should not be placed on the buildings, but on poles at from six to ten feet distance. The stems should be about seven feet long, and the poles of such a height, that the stem may rise from fifteen to twenty feet above the top of the building. It is also advisable to have several paratonnerres round each magazine. If the magazine be in a tower, or other very lofty building, it may be sufficient to defend it by a double copper conductor, without any paratonnerre stem. As the influence of this conductor will not extend beyond the building, it cannot attract the lightning from a distance, and will yet protect the magazine, should it be struck.

417. *Paratonnerres for Ships.*—The stem of a paratonnerre for a ship, consists merely of a

copper point, screwed on a round iron rod, entering the extremity of the top-gallant mast. An iron bar, connected with the foot of the round rod, descends down the pole, and is terminated by a crook or ring, to which the conductor of the paratonnerre is attached, which, in this case, is formed of a metallic rope, connected at its lower extremity with a bar or plate of metal, and which latter is connected to the copper sheathing on the bottom of the vessel. Small vessels require only one paratonnerre; large ships should have one on the main-mast and another on the mizen-mast.

418. The late ingenious Mr. George Sing r in his excellent work on electricity, proposed to have conductors fixed to the surfaces of masts, and the electric fluid conveyed by means of strips of metal, over the deck and the sides of the vessel; but this arrangement on many accounts is highly objectionable, and the mode proposed by Gay Lussac, or perhaps that commonly adopted in the British navy, of conveying the electric fluid from the mast-head to the surface of the water, in a direct line, by means of a series of long copper links, is the best which has hitherto been devised.

419. It is allowed from experiment, that the stem of a paratonnerre effectually defends a circle of which it is the centre, and whose radius is twice its own height. According to this rule, a building sixty-feet square, requires only a stem of fifteen or eighteen feet raised in the centre of the roof. A building of 120 feet, by the same rule, would require a stem of thirty feet, and such are sometimes used; but it is better, instead of one stem of that length, to erect two of fifteen or eighteen feet, one placed at thirty feet from one end of the building, the other at the same distance from the other end, and consequently sixty feet from each other. The same rule should be followed for three or any greater number of paratonnerres. A plate is given in the Annals of Philosophy to illustrate this interesting subject more particularly.

Electro-motive Action of Water on Metals.

420. M. Becquerel has endeavoured to ascertain experimentally the electrical effects produced by the contact of water and metals. The effect is so small as to be easily mistaken for, or confounded with, those due to electricity produced accidentally during the performance of the experiments, by contact of various parts of the apparatus, or in other ways: but taking every possible precaution, and testing his results in all ways, he arrived at the conclusion that zinc, iron, lead, tin, copper, &c., communicated positive electricity to water; whilst platina, gold, silver, &c., gave it negative electricity. Water is therefore positive with the metals which are most positive, and negative with those which are least positive. It operates, therefore, upon oxidable metals as alkalies do in their conduct with acids, when there is no chemical action. The same phenomena take place even when a little sulphuric acid is present, and the iron and zinc are acted upon; so that chemical action in this case did not prevent the production of electricity by the contact of metals and water

421. By certain changes of the surface, it was found that the inten ıty of electricity produced was much affected. A plate of gold, plunged in nitric acid for a few moments, and then washed in several fresh portions of water, produced a development of electricity much greater than before, the water still becoming negative. The same plate, plunged into a solution of potassa and then washed, lost in a great measure its power of becoming electrified by contact with water. A plate of platinum offered similar results. It is supposed, that these effects may have a distant analogy with the facts observed by M. M. Thenard and Dulong, that a new platina wire, which would not heat in a current of hydrogen gas and air, acquired this property by being previously plunged for a few minutes in nitric acid, and then washed. The property of the wire continued for above twenty-four hours; and M. Becquerel says, that the plate of gold preserved its power of becoming strongly electrified in contact with water, for several hours.

On the Electrical Actions produced by the Contact of Flames and Metals.

422. In place of making a complete metallic circuit, as in Seebeck's experiment; or one in which the circuit was by water or acid, as in the Voltaic pile; the metals used were connected by a flame only, and their states ascertained by the electrometer. The flames used were those resulting from the combustion of alcohol, hydrogen gas, or a sheet of paper. When a plate of platina was placed on the cap of the electrometer, and heated by one of the flames before mentioned, if the temperature was a red heat or above, the metal became negative, but below a red heat it became positive. On trying the electricity of the flame, by making it rise from a piece of wet wood on the cap of the instrument, and holding the platina in it, the reverse, as expected, was found to be the case.

423. A copper wire gave the same results, and generally it appeared that all the metals had the property just described; thus any metal, plunged into a flame of hydrogen gas, becomes negative or positive according as the temperature is higher or lower, and communicates the contrary electricity to the flame.

424. If the flame by which the plate of metal on the cap of the instrument is heated, be touched by a piece of wet wood instead of being insulated, the effects are more distinct: but if, instead of touching it with wet wood, it be touched with a plate of the same metal as that on the electrometer, the two portions of metal are found in different states: that heated to redness being negative, and the one heated to a less degree positive. The same effects are obtained if the two plates be of different metals. They are also produced if the flame urged by a blow-pipe be used.

425. These phenomena may be supposed to result either from the friction of the flame on the metals, or from an electro-motive action. M. Becquerel inclines to the latter opinion, conceiving it improbable that the tranquil flame of alcohol can produce friction sufficient to suffice for the

effect; and not being able to account by friction for the circumstance of two pieces of metal acquiring different electricities in the same flame, according to the temperature. That the effect was not due to the difference of temperature existing in various parts of the same piece of metal, was proved by the entire absence of any electrical phenomena, when a plate of platinum was heated to redness in the focus of M. Fresnel's strong burning-glass. These experiments have some relation to that of M. Volta on the combustion of a piece of amadou at the extremity of a rod communicating with the condensing plate of an electrometer. M. Volta found, that when the apparatus was distant from habitations, the amadou became positive by taking electricity from the circumambient air, from which he concluded that the atmosphere had always an excess of positive electricity.

Electrical Phenomena accompanying Combustion.

426. M. Becquerel found, that on rolling up a sheet of paper, placing it in the electrometer, inflaming it, and touching the flame with a piece of wet wood that the electricity might flow away more rapidly, the paper became positively electrical. If the experiment were inverted, the paper being held in the hand, and the flame made to touch the piece of wet wood placed on the electrometer, it was found that the flame took negative electricity. Hence it may be concluded, that when paper is burnt, the paper becomes positive, and the flame negative.

427. If alcohol be burnt in a copper capsule, it is found by the condenser that the capsule becomes electrified positively.

On the Electro-motive Force of certain Substances.

428. *Carburet of iron.*—In electro-motive power it yields only to certain oxides of manganese. It is augmented by immersion into acidulated water, if the plate be not wiped when withdrawn. This increase of power is not dissipated spontaneously, but is easily lost by the action of an inferior metal, as zinc. When the latter action diminishes that belonging to the carburet, it is resumed spontaneously in a few minutes. The Passau crucibles contain much plumbago, and possess the same properties if the clay has not been too much vitrified; a crucible having an internal surface of 100 square inches, and a vessel of similar form made of thin lead, produced a very useful apparatus. A small interval was left between the leaden vessel and the crucible, and the interval filled with a strong acid solution. By heating the crucible, and cooling the interior of the leaden vessel, important effects, dependent upon the difference of temperature, could be observed.

429. *Mercury.*—This metal ranges between sulphuret of lead and silver; when impure it becomes inferior even to brass, but distillation restores it to its place.

430. *Iron.*—Its electro-motive power is changed by oxidation, but not much. Its place is always between tin and brass.

431. *Tin* is superior to lead, but the least degree of oxidation renders it inferior. *Lead*, with zinc, gives greater deviations than tin, iron, brass, or copper. There is no arrangement formed with substances so near to each other, which produces so energetic a current, and it is in this respect opposed to that presented by zinc, with gold or platina.

432. *Charcoal*, heated until it ceases to yield flame and slowly cooled, is equal to the metals in electro-motive and conducting power. It does not retard the feeblest electric current. Its electro-motive power is variable, according to the manner in which it is cooled, and also to its exposure to air.

433. *Oxide of tin*, crystallised, produces currents, with all the metals inferior to it, as zinc, lead, tin, &c.; but none when in communication with bodies having a superior electro-motive force, as gold, silver, carburet of iron, gray manganese, &c.—*Annales de Chimie*, XXXIII., 136.

434. List of good conductors, arranged in the order of their electro-motive power, the most powerful being first.

Charcoal after long exposure to air.
Gray radiated manganese.
Oxide of manganese.
Uncrystallised iron pyrites.
Magnetic iron pyrites.
Crystallised arsenical pyrites
Carburet of iron.
Cubic iron pyrites.
Auriferous tellurium.
Gold.
Platina.
Copper pyrites.
Lamelliform tellurium.
Gray cobalt.
Gray copper ore.
Arsenical nickel.
Charcoal slowly cooled.
Sulphureted protoxide of iron.
Sulphuret of lead.
Red silver ore (bright).
Arsenical silver, and arsenic slightly oxidised.
Mercury.
Silver.
Tarnished antimony.
Arsenic.
Sulphuret of molybdena.
Crystallised oxide of tin.
Tarnished copper.
Antimony (bright).
Charcoal extinguished in water.
Nickel.
Tarnished bismuth.
Brass much oxidised.
Bright copper.
Brass.
Crystallised protoxide of iron.
Iron.
Tarnished lead.
Manganese.
Tin.
Bright lead.
Charcoal, instantly after extinction in water.
Zinc.

Insulation of Electricity.

435. M. Haüy, in his method of distinguishing precious stones, &c., joins the electric indications given by a gem when rubbed or pressed to its other physical characters. That these indications may be obtained more readily, M. Haüy has invented two small instruments, very portable, and ready to furnish the two kinds of electricity. One of them is a small bar of Iceland spar, fixed to the end of a needle or lever, which is then suspended by the middle so as to be balanced by a thread of silk. When the spar is pressed between the fingers, it becomes positively electric, and then the electricity of another body, however excited, as of a gem by friction, is ascertained by its attraction or repulsion of the spar. The second instrument is formed of a piece of sealing-wax, flattened at one end so that it may stand on a table, and at the other supporting the point of a needle; a needle of silver or copper, terminated at the extremities by beads, moves on this as on a centre. To charge this apparatus, a piece of amber or sealing-wax is to be excited negatively by friction, and then by touching the needle it becomes similarly electrified, and is then ready to indicate by attraction or repulsion the kind of electricity possessed by another body.

436. M. Haüy has also noticed the extreme permanency of the electrical states of these two apparatuses. His attention was drawn to this circumstance, from the perfection of their action during extremely moist weather, and he was induced to make a few experiments on the subject. The permanency of the electricity excited on the spar depends on the difficulty of adhesion between it and water. In damp weather no moisture deposits on it, so that electricity given to it is perfectly retained. Even if it be dipped in water, and afterwards pressed without wiping, it becomes strongly electric, because no water adheres to its surface to conduct the power away; and M. Haüy at last ascertained that immersion in water was not sufficient to remove electricity previously communicated to it. The permanency, therefore, of its electrical state in the atmosphere, and the value of this property may easily be conceived. If the water be rubbed on the surface of the crystal so as actually to wet it, then no electricity is generated by pressure, and what may have previously been generated is of course dissipated.

437. M. Haüy has observed also, that fluate of lime and the euclax also acquired electricity by pressure, though not so powerfully as Iceland spar; and he found them also to possess similar relations to water.

438. During his experiments on the electricity of minerals, M. Haüy found that the second apparatus also had the power of preserving its electric state unimpaired for a long time; a circumstance scarcely to be expected from its construction. In examining the apparatus, this power was found to depend on the sealing-wax foot, for if that were removed and the needle hung by silk, though it readily took electricity from other bodies, yet it also soon lost it; whereas, on its pivot and foot of sealing-wax, it retained it in damp weather for hours. This appears to depend on a portion of electricity, which, when the needle is first charged, passes on to the surface of the sealing-wax, and, remaining there for a while, gradually returns to the needle, as its state is reduced by the action of the moist air, and supports, as it were, its electricity at a higher tension than it otherwise would have. M. Haüy expresses this by saying that the sealing-wax has the power both of conducting and insulating; by the first it receives a part of the electricity given to the needle, by the second it retains it, and then by the first it gives it back again to the needle when the air has taken away its own portion. The evident conclusion from the experiments is, that the apparatus is always ready for use, and will act in any weather.

Plate Electrical Machines.

439. A variation in the construction of plate electrical machines has been devised and practiced by M. Metzger, of Siblingen, in Schaffhouse, which seems to be a real improvement. Considering that the effect desired in using the machine was first highly to excite the glass, and then to collect the electricity from it, M. Metzger concluded that the distance between the rubber and the points of the conductor, in machines of the common construction, was injurious in its effects, not only by causing the dispersion in part of the electricity excited, but by uselessly wasting the exciting surface. Plates were, therefore, mounted in a very compact and perfect manner, with three pairs of rubbers, placed at equal distances from each other; the conductor also had three arms furnished with points a little in advance of each pair of rubbers, to collect the electricity in the usual manner; and the rubbers were not attached to a surrounding frame, but to brass arms, which, proceeding from a socket through which the axis passes, diverged at equal distances from each other towards the periphery of the plate: the machine has a very compact and neat appearance, and its various smaller parts are contrived with much judgment.

440. In some comparative experiments, made with a plate twenty-two inches in diameter, the superiority of three pairs of cushions over two pairs was very manifest. In the following table the first column expresses the length in inches of the rubbers; the second the length of the spark when two pairs of rubbers were used, and the third the length of the spark when three pairs of rubbers were on the machine.

Inches.	Inches.	Inches.
6	12	18
7	14	21
8	16	24
9	18	27
10	20	30

Experiment with a Tourmaline.

441. That the tourmaline possesses electrical properties dependent on its temperature has been long known: the most elegant mode, however, of exhibiting these phenomena has been suggested by Mr. Sivright. If a slice be cut from this mineral, perpendicular to the axis of the prism, and then placed upon a piece of well-polished glass, on being heated to a temperature of 212° it will be

found to adhere so firmly as to support the weight of the slice. The two poles of a tourmaline may also be connected in such a way as to exhibit the effects of attraction and repulsion. To effect which, the oppositely electrified poles are furnished with metallic caps and wires, resembling a horse-shoe magnet; and a light pith-ball, placed between these metallic conductors, is made to vibrate till the electric equilibrium is restored.

Electricity of a Cat.

442. The electricity, upon rubbing the back of a cat, is well known; and that it is rendered evident by a snapping noise and sparks of light. Mr. Glover, in a letter to the editor of the Philosophical Magazine, describes so intense an action of this kind, as to enable the animal to give a very sensible electric shock. This effect was obtained at pleasure by Mr. Glover, and by some friends. When the cat was sitting on the lap of the person, if the left hand was placed under the throat with the middle finger and the thumb gently pressing the bones of the animal's shoulder, and the right hand was placed along the back, shocks were felt in the left hand; and when the right hand was placed under the throat, whilst the left hand rubbed the back, the shocks were felt in the right hand. When the atmosphere has been favorable, and the cat had lain some time before the fire, the experiment always succeeded.

Bohnenbergen's Electrometer.

443. This instrument is intended to indicate at once the nature, as well as presence, of electricity. The exterior is formed of a cylinder of glass, about two inches and a half wide: it is closed at the top by a brass plate, from which descend two of De Luc's electric columns, each containing about 400 discs of gilt and silvered paper, about three lines in diameter, and terminated below by brass rings; these tubes are an inch and a half distant from one another, and between them is placed a tube of glass, which, passing through the cover, in the manner of Singer's insulation, supports a wire, terminated below by two gold leaves, and above by a metallic plate. It is easy, from this disposition, to perceive that when the leaves are unelectrified they will hang midway between the tubes; but when affected by the approach of electrified bodies, they will diverge and indicate by the attraction of the leaf on the one side, on the other the nature of the charge.

Electricity produced by Congelation of Water.

444. When water is frozen rapidly in a Leyden jar, the outside coating not being insulated, the jar receives a feeble electrical charge, the inside being positive, the outside negative. If this ice be rapidly thawed, an inverse result is obtained, the interior becomes negative, and the outside positive.—*Grothus.*

Improvement of the Leyden Jar.

445. M. Metzger has varied the construction of Leyden jars, so as to augment their capacity without increasing their apparent volume. For this purpose, having two jars of proper dimensions, he simply places one within the other, so that they shall apply pretty correctly, and thus have a capacity of charge nearly proportional to the whole surface of coating, without increasing the volume of the whole beyond that of the larger jar. Jars made slightly conical would answer well for this purpose.

Electricity on Separation of Parts.

446. In the water-proof cloths manufactured by M. Mackintosh of Glasgow, where two pieces are cemented together by caoutchouc dissolved in coal, tar, or oil, the adhesion is such, that when the two are torn asunder in the dark, there is a bright flash of electric light, similar to that produced by separating plates of mica, by breaking Rupert's drops, or by breaking barley-sugar, or sugar-candy. Upon trying this experiment with different substances, it was found that flashes of light were distinctly produced by tearing quickly a piece of cotton cloth.

Electric Light.

447. Having a metallic wire covered with silk, form it into a close flat spiral, taking care that the revolutions touch each other: their number may be arbitrary, more than twenty-four have not been used. The properties of this spiral, when it forms part of the Voltaic circuit, are well known; but pass through it a charge of common electricity, such as may be taken by two square feet of coated surface, moderately charged, and a vivid light, something resembling that of an artificial fire-work, will occur, originating from the centre of the spires: it may be seen very distinctly without darkening the chamber where the experiment is made. M. Leopold de Nobili, who describes this experiment, considers the phenomenon as perfectly new. If the wire be folded backwards and forwards, so as to form a rectangular surface, then the electric discharge only produces a faint light at each corner, and this he considers as the light produced by the escape of the electricity into the atmosphere; but the light from the spiral is said to be so vivid and distinct, that once seen, its dissimilarity from the former must be instantly evident; he has therefore called it electro-magnetic light, because of its relation to the magnetic state of the spiral, thinks that it might be made continuous if a sufficiently powerful Voltaic battery were used, and has little doubt but that the aurora borealis is such a light, elicited by the magnetic state of the earth.

Electricity excited by the Burning of Paper and Alcohol.

448. M. Becqueral has found, as the result of numerous experiments, that when a roll of paper is set on fire at one end, the flame thereof becomes negatively electrified, and the paper positively. He also found that when alcohol is burned in a copper dish, the latter becomes positively electrified.

Hare's Single Gold-leaf Electrometer.

449. This instrument consists of a glass vessel, fixed by a foot to a wooden stand, and having an aperture at the top, and also another at one side. The top is closed by a metal cap,

finished externally by a horizontal zinc disc, six inches in diameter, and connected internally with a single leaf of gold, cut into an acute triangular form, and hanging on the centre of the instrument, with the point downwards. Opposite to the lower end of this leaf of gold, is a ball attached to a horizontal wire, and which, passing through a screw cap fixed in the lateral opening of the glass vessel, can be made to approach to, or recede from, the leaf at pleasure, the distance being estimated by a graduation of the screw into $\frac{1}{50}$ of an inch. A plate of copper, six inches in diameter, and furnished with a glass handle, generally accompanies the instrument.

450. The electricity produced by the contact of copper and zinc, is rendered sensible in the following manner :—Place the disc of copper on the disc of zinc; take the micrometer screw in one hand, touch the copper disc with the other, and then lift this disc from the zinc. As soon as the separation is effected, the gold leaf will strike the ball, usually if the one be not more than $\frac{1}{100}$ of an inch apart from the other. 'That the phenomenon arises from the dissimilarity of the metals, is easily shown by repeating the experiment with a zinc disc, in lieu of a disc of copper. The separation of the homogeneous discs will not be found to produce any contact between the leaf and the ball.'

451. 'It is probable that the sensibility of this instrument is dependent on that property of electricity which causes any surcharge of it, which may be created in a conducting surface, to seek an exit at the most projecting termination or point connected with the surface;' this disposition being increased, of course, by the proximity of the ball. These effects are not to be expected in weather unfavorable to electricity; but in favorable circumstances they have been produced by a smaller instrument, the discs being only two inches and a half in diameter.

Pyro-Electricity of Minerals.

452. M. L'Abbé Haüy has remarked, with regard to the electricity produced in certain crystals by an alteration of temperature, that it is of two kinds. The accidental circumstances which led to the discovery took place whilst he was examining some crystals of the oxide of zinc, from Limbourg, near Aix-la-Chapelle, and fragments of the acicular variety of the same mineral from Brisgau. Having placed a piece of one of these substances in a very cold window for a few moments, it was found, on examination, to be electrical. Its poles were ascertained, and the mineral then placed in a milder temperature, when the electricity soon become null; but, being approached to a fire-place, the power was greatly renewed, but the poles were inverted.

453. These results have been verified by M. Haüy on other crystals, especially those of the tourmaline. In taking them for examples, he has endeavoured to bring under one point of view all that passes with respect to them in the interval comprised between the limits of temperature, beyond which the electric action disappears without return. He has given the name of ordinary electricity to that produced by heat, and extraordinary electricity to that produced by cold. If, therefore, commencing at the point where the excess of heat destroys in the tourmaline the effects of the ordinary electricity, that mineral be left to cool, it will soon give signs of ordinary electricity. The action of the poles at first feebly augments to a certain degree, beyond which it gradually diminishes, and at last disappears. With a temperature a little lower, however, the extraordinary electricity appears, and the poles resume their power, but in an inverted order, so that the pole at first positively electrified becomes negative, and the negative pole becomes positive.

Electricity of the Atmosphere.

454. M. Bourdet, an ex-captain in the French service, has described in a letter, a very singular electric phenomenon which he witnessed in Poland, December 24th, 1826. The weather, according to the Poles, had never been milder at that season of the year, no snow had been seen, nor had the usual cold weather of the north, which generally set in early in that country, then commenced. Rains and storms, however, were frequent. 'I was,' says M. Bourdet, 'with the advanced guard of light cavalry; the commander gave me an order to halt in the rear and see that my guns were disembarrassed, and then to rejoin, as quickly as possible, the light brigade. In spite of the efforts of my men, the guns were not cleared from the marshy ground in which they were entangled, without great labor. We were advancing across the field about nine o'clock in the evening, when a strong gust of wind suddenly arose, the sun had shone brightly during the day, and, in a few minutes after, the night became so dark that we could not see the heads of our horses. The wind blew so violently that the horses stopped. At that moment the extremity of the hair on their ears became luminous, as well as all the longer hairs on their bodies except the locks on their manes and tails. All the metallic extremities of their harness, and all the metallic sharp points of the carriages of our guns, were studded with luminous points, so that one might have supposed, had it been spring, that a swarm of glow-worms had covered our horses and guns. Our quarter-master observed that the points of my mustachios were luminous. The same phenomenon was seen on some of the cannoneers, but none of us had our eye-lashes or hair rendered luminous. These lights remained as long as the gust of wind lasted, namely, for three or four minutes. Their color was a soft violet, and they terminated in a bright white. The horses held their heads high, their ears were erect and moving, their nostrils open and respiring, their manes and tails erected, their fore legs thrown forward and their hind ones back. Their attitude, in general, was that of animals seized with terror. During the time the wind blew, they remained at a full stop, and, when feeling the spur, some stood stock still, and others kicked, as if they had been reluctant to advance. When the wind ceased the lights disappeared, and a deluge of rain, mingled with hail, fell. But, though the obscurity continued, our horses moved on, shaking themselves at times, panting forcibly, and neighing; but they continued on their march. On arriving at the advanced post, I mentioned

to my comrades the phenomenon we had witnessed, and though they had been only three leagues from us, they felt nc wind, but experienced much rain. The wind we encountered had an opposite direction to the rain.

Relation of a remarkable electrical Phenomenon.

455. The following relation is made by M. Allemand, of Fleuvier Neufchatel, to M. Pictet, and is published in the Bib. Univer. M. Allemand, states that on the 3d of May, about ten o'clock in the evening was caught in a violent storm of wind and rain. The thunder becoming frequent and strong, he thought it proper to close an umbrella he had with him, and hold the upper metallic point in his hand, lest it should attract the lightning. The night, dark of itself, was made more so by the great rain. Suddenly he perceived a light from above, and looking upwards found the edge of his hat luminous. Supposing at the moment the hat was on fire, he, without reflection, passed his hand over the light to extinguish it. It, however, only shone more strongly, a circumstance which caused some confused ideas on the nature of the light. The hand being filled with water from the hat, on shaking it, M. Allemand saw that the interior of it shone as if it were a polished metal reflecting a strong light.

456. Being at this time near the farm of Chaux, about ten or twelve minutes' walk from Fleurin, and fifteen or twenty from Motiers, M. Allemand considered for a moment what he had best do, and concluded on continuing his progress. Having once filled his hand with the electrified water with impunity, he ventured to repeat the experiment, and did it fifteen or twenty times, endeavouring to ascertain whether it had odor, or produced any decrepitation or sound; but nothing of this kind could be perceived; nothing but the bright light, which seemed like a brilliant varnish on the hand. The light remained for an instant only. At a few hundred paces farther on, the light on the hat still continuing, M. Allemand was surprised by the appearance of another light, less bright than the former, on the smooth surface of the umbrella handle, at the place where generally a plate of metal is placed for the name, but which plate had been removed from this umbrella. At first the finger was passed over it to extinguish it, but the phenomena were just as before, and both the rubbing and rubbed surface shone brightly. Afraid of the metal about the umbrella, it was thrown down, and M. Allemand went on his way, rubbing his hat on the sleeve of his coat; but in this way only rendering the light brighter. The thunder was more frequent than before, but still at some little distance. The crown of light continued until M. Allemand arrived near Motiers, and he attributed its cessation to the high poplar trees in the neighbourhood of that place. Stopping at Motiers only a short time, he took a guide with a lantern to find the umbrella. Having done so he sent back the man, and went on himself towards Fleurin. As the tempest had diminished, he used the umbrella; and, as soon as the light of the lantern was sufficiently removed, he again remarked luminous appearances. These occurred at each end of the whalebone ribs, on the metal point which terminates them: the light was not so bright as the electric star, but they were brilliant points like a yellow red metal, highly polished, and would, M. A. remarks, have appeared very beautiful if he had been collected enough to admire them. M. Allemand explains these effects by supposing the atmosphere sursaturated with electricity, and that a portion of it was continually passing to the ground, through his hat, umbrella, and himself.

Illumination by Electricity.

457. Professor Meinecke of Halle, has, in a late number of Gilbert's Annals, proposed to illuminate halls, houses, and streets, by the electric spark, and expresses his strong persuasion that one day it will afford a more perfect and less expensive light than gas-illumination, and ultimately replace it. His plan is to arrange, what are called in electricity, luminous tubes, glasses, &c., i. e. insulating substances, having a series of metallic spangles at small distances from each other, along the place to be illuminated; and then by a machine send a current of electricity through them: sometimes also partially exhausted glasses, as the luminous receiver, conductor, &c., are used. In this way professor Meinicke obtained from a two feet plate machine a constant light in his apartment, equal to that of the moon, and even surpassing it; and by enclosing his system of sparks in tubes filled with rarefied hydrogen gas, in which gas it is assumed that the electric spark is more than doubled in brilliancy, thinks it will be easy to enlarge the plan to any extent.

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ELECTRO-GALVANISM.

1. ELECTRO-GALVANISM, or VOLTAIC ELECTRICITY, may be said to owe its origin to the discoveries of an ingenious Italian philosopher, named Galvani, who published a Latin treatise on the subject at the close of the last century.

2. In the preceding article we have examined the various phenomena resulting from the friction of dry bodies, which, by their mutual action on each other, tend to destroy their electrical equilibrium; and we now propose to furnish our readers with an outline of that branch of electricity which has led to some of the most important discoveries and splendid triumphs connected with the progress of chemical science.

3. In the year 1790 L. Galvani, professor of anatomy at Bologna, accidentally discovered that the passage of a small quantity of electricity, through the nerve of a frog that had been recently killed, had the property of exciting distinct muscular contractions. He produced the same effect with atmospherical electricity; and afterwards by the mere contact of two different metals. His discoveries were published in 1791: he proved the phenomena to be electrical, and says, 'it you lay bare the sciatic nerve of a frog, and remove the integuments, then place the nerve on a piece of zinc, and a muscle on a plate of gold, and connect these metals by any conducting substance, contractions are produced; but, if non-conductors are used to connect the metals, contractions are not excited.' The experiments of Galvani received considerable attention; they were varied and extended with the greatest perseverance and address by professor Volta, Dr. Valli, Humboldt, Fowler, Monro, Robison, and many others.

4. The effects obtained in the experiments of these naturalists may be illustrated by very simple experiments. The most important facts they establish are, first, that the passage of a small quantity of electricity through the nerve or nerves of any animal, occasions a tremulous motion or contraction of the contiguous muscles, and sometimes an extension of the limbs. This effect takes place both in living animals and such as have been recently killed, and even in the detached limbs of these last. It is produced when the transmitted electricity is too weak to affect the most delicate electrometers, and obtains in all animals for some time after death; their susceptibility being greatest at first, and gradually diminishing as the limbs stiffen. Animals with cold blood, as frogs and fishes, retain the power of action after death longer than others, sometimes for many hours, or even days.

5. Secondly, The same effects that are produced by the passage of electricity, also result from the contact of different metals with the nerves and muscles. If a communication be formed between any nerve and muscle by a single metal, contractions are but rarely produced, and when they appear are very feeble; but if two metals are employed, in contact with each other, motion is always obtained, and the effects are most considerable when the metals are most essentially different; thus zinc and gold or zinc and silver, form a very active combination.

6. Thirdly, By the same means that muscular motion is excited in these trials, some of the senses are remarkably affected, as will be evident when the experiment is made on living animals.

7. The demonstration of these facts is easily effected. For the excitation of muscular motion any small animals may be employed; the most convenient are frogs and fishes. Frogs are peculiarly susceptible. If one of these animals be employed alive, a piece of tin-foil may be pasted on its back, and the frog being then placed on a plate of zinc, spasmodic convulsions will be produced whenever a communication is made by a wire between the zinc and the tin-foil. This experiment will succeed either in the open air or under water.

8. M. Valli, an Italian physician, was one of the earliest to enter on a series of Galvanic experiments, which he began by those that relate more immediately to animal electricity. The results of these experiments he communicated in 1792 to the French Academy of Sciences, by the members of which the experiments themselves were so much approved, that the greater part of them were shortly after repeated in the chemical laboratory of Fourcroy. They were as follows:—

9. Experiment I.—Two metallic coatings, one of lead the other of silver, were placed on a frog fastened to a table, the former on the belly of the animal, the latter on the pelvis. These metallic coatings having been brought into union by the means of an exciting arc of copper, very powerful convulsive movements were produced in the animal.

10. Experiment II.—The small sheet of lead, employed as one of the coatings in the former experiment, having been removed, so as to leave the abdomen bare, and the exciting arc applied in the same way as before, the convulsive movements took place but were not so sensible as in the other case.

11. Experiment III.—In employing two coatings of the same metal, silver or gold for instance, it was found that the effects produced by the exciting arc of copper were much weaker. When these coatings were not only of similar metals, such as copper, lead, tin, zinc, &c., but the exciting arc also, no effect was produced.

12. Experiment IV.—The coating placed on the abdomen having received an horizontal direction, insomuch that the points of contact were less numerous, the effects were proportionably diminished. As soon, however, as the coating was brought into full contact with the surface of the abdomen, they became as powerful as before.

13. Experiment V.—A frog having been skinned, and cut transversely through the middle, the nerves of the thighs were laid bare, united, and placed on a piece of gold, at the same time that the thighs themselves were brought in contact with a piece of silver. On the application of the exciting arc of copper, slight movements

were produced; as they also were when both the coatings were of silver. But when a coating of tin, lead, or copper, was substituted for the one of silver, in which the nerves were enveloped, the movements became very violent. The following gradation was, however, observed in the action of the metals: the lead produced the most powerful movements; next the tin; and, lastly, the copper. In proportion as the vitality of the frog was diminished, the metals also lost the power of governing the direction of the progress of the electric fluid in the animal. The lead, tin, and zinc preserved this property the longest.

14. Experiment VI.—Plumbers' lead, placed on each side as a coating, produced no effect when employed with an exciting arc of the same description of lead; but when different qualities of this metal were selected, such, for instance, as the lead of the assayer, and plumbers' lead, an exciting arc of either of these descriptions of metal produced very singular effects. When these two kinds of lead, in changing the different metals, were no longer productive of any effect in one of these coatings, by substituting for the lead either silver, gold, bismuth, antimony, or zinc, movements of so powerful a nature were obtained, as to enable the animal to be susceptible of slight convulsions, when the above-mentioned pieces of lead, each of them of a distinct kind, were again applied.

15. Experiment VII.—A short interval of repose having been allowed to the frog, it was found to be susceptible of convulsive movements of a forcible nature, when again subjected to the same trials.

16. Experiment VIII.—The electric power being nearly exhausted in this animal, it was found that the different metals, when they produced by their contact new convulsions, did not, on this effect ceasing, leave to the animal the faculty of displaying fresh movements with the coatings of the different kinds of lead.

17. Experiment IX.—Lastly, the electric action disappeared totally in the following order, the plumbers' lead invariably forming one of the coatings: the assayers' lead first ceased to determine the action; next the tin; next the antimony; next the zinc; next the copper; next the gold; and finally, the silver. It ought here to be noticed, that the iron had lost its exciting quality before the antimony; but it was not ascertained whether it had likewise been deprived of that quality before the lead and the tin.

18. Experiment X.—The zinc, in losing the exciting property by which convulsions had been produced on the frog, which had been subjected to the experiment for the space of an hour, was not capable of determining any farther movements when the leaden exciting arc was placed on it. It was however remarked, that movements were still produced by this metal, the moment the person engaged in the experiment removed the exciting arc, and destroyed the communication. This singular experiment was so often repeated, as not to leave any doubt respecting the result.

19. Experiment XI.—The upper part of a frog, skinned and intersected transversely, having its crural nerves armed with a piece of lead, as in the preceding experiments, was placed in a glass filled with water, while the inferior part of the animal was placed in another glass. The different parts displayed very powerful movements when the communication was established, by the means of a chain formed by the persons present, two of the persons present having been selected to touch, each of them, the water in one of the glasses. One of these individuals held in his hand a bit of metal, which he brought in contact with the coating of lead.

20. Experiment XII.—When one of the company withdrew himself in such a way as to interrupt the chain, the movements were no longer perceptible.

21. Experiment XIII.—The parts of the frog having been placed in the two glasses, as in Experiment XI., the operator could not excite any movement by establishing the communication with his two fingers. He was equally unsuccessful when, with one hand armed with a piece of metal, he touched the body of the frog, while he placed a finger of the other hand on the metallic coating of the crural nerves. But when, having a finger placed on the inferior part of the frog, he presented the piece of metal to the coating of the nerves, very powerful movements were excited in the animal.

22. Experiment XIV.—When the frog was touched with a metallic exciting arc, in an insulated state, no sensible effect was produced; but, when the metal ceased to be insulated, the effect was invariably very considerable.

23. Experiment XV.—One of the fore legs of a rabbit having been detached from the body, the brachial nerves were denudated, and armed with a piece of sheet-lead. A piece of silver, which was to act as an exciting arc, was afterwards laid on an adjacent muscle; and the result was, that very violent convulsive motions were produced in the animal. In this experiment on the rabbit, as it was afterwards varied, one of the coatings being of plumbers' lead, and the other of assayers' lead, the movements were no longer excited. When they consisted, the one of lead, and the other of iron, they produced as little effect; but when the lead, as one of the coatings, was tried with another coating, either of silver, gold, copper, zinc, or antimony, convulsive movements were produced. Combined with a coating of bismuth, the coating of lead produced but very slight movements.

24. Experiment XVI.—To ascertain the state of the electricity inherent in the animal subjected to the experiment, it was plunged into a vessel containing one of Coulomb's electrometers, and successively electrified both positively and negatively. In either of these cases the animal influenced the balls of the electrometer, so as not only to evince that the electricity was in a perfect state of rest, as well before as during the experiment, but also, that the system of the body on which it was made, presented in the most marked and striking manner, the phenomenon of a Leyden phial.

25. Experiment XVII.—The left crural nerve of a living frog having been bound by a strong

ligature, the animal lost the faculty of moving, in a natural way, the part beneath the point where the ligature was tied. The nerve, however, having been armed in the same manner as in the preceding experiments, the movements were excited as soon as the communication was established between the muscle and the part above the ligature.

26. Experiment XVIII.—The ligature having been made on the left crural nerve, sufficiently near to the muscle to be in contact with it, and on the right crural nerve in such a way as to render it disengaged and visible, the left part of the animal being in a palsied state, remained perfectly motionless, whilst the convulsive movements excited by the communication were all of them confined to the right side. The above-mentioned left crural nerve having been afterwards more effectually denudated, and separated from the muscular substance by which it was surrounded, recovered its quality as a conductor, and permitted the movements which were communicated to display themselves with considerable energy. When the ligature was forced back against the muscle, the limb again lost the faculty of motion.

27. Experiment XIX.—One of the crural nerves having been armed with a piece of sheet-lead, a communication was established between this nerve and the other crural nerve in an unarmed state. The result was, that very powerful convulsive movements were produced.

28. Experiment XX.—One of the above nerves, coated with two pieces of lead, at different intervals of the muscle, was violently agitated as soon as a communication was established between the two parts by the means of an exciting arc. The same effects were observed, notwithstanding every part of the nerve was laid bare, and separated from the surrounding muscle.

29. The earliest experiments undertaken by M. Humboldt were made in the presence of M. Venturi, professor of natural philosophy at Modena, and several medical students. The brain and spinal marrow of several frogs having been laid bare, and the animals properly armed, powerful contractions were produced, by the application of the galvanic arc, in the muscles of the thorax and abdomen, together with slight contractions of those of the thigh. Violent convulsive movements of the eyes were at the same time perceived. The diaphragm, a muscle which is in all cases extremely sensible to galvanic irritation, was also powerfully contracted. As soon as the femoral and sciatic nerves had been irritated, violent contractions were produced in the thigh. The experiments on the heart and stomach were attended by but little effect. When, however, they were made on the heart of a dog, separated from the animal, and which had ceased to contract, that action was, in a certain degree, renewed; and, in the case of the stomach, a feeble motion was induced in the parts touched by the zinc. These experiments were afterwards repeated with pretty nearly the same results.

30. As the efficacy of the different substances calculated to bring about the galvanic phenomena, and the modifications they induce, had attracted the attention of naturalists much more than the effects of galvanism itself on the animal economy, Humboldt determined to direct his experiments more particularly towards the latter. The cause of galvanism appearing to him to reside in the body of living animals, and to be merely excited to action by extraneous substances, he was of opinion that the strongest light would be thrown on this subject by observing the phenomena the animal should present. Seeing that the magnetic and electric fluids, which are neither peculiar to the living body, nor secreted in its organs, as the galvanic fluid appears to be, have, notwithstanding, a decisive influence on the human body, as well in a healthy condition as in a diseased state, ought it not, he argued, to be concluded that galvanic researches are equally interestng to the physician and to the naturalist, insomuch that the former has a right to hope that galvanism may one day be usefully employed in the cure of particular diseases? and he adds, 'In the science of galvanism, as well as in every branch of natural philosophy, facts alone are stable and certain.'

31. The following are the conclusions drawn by Humboldt from his early experiments.

32. (1.) That the effects of galvanism are almost invariably different on different parts of animals; and that multiplied and well combined experiments on this subject may furnish a tolerably correct appreciation of the respective forces of the different extensor and flexor muscles.

33. (2.) That in animals with warm blood, the diaphragm is, of all the muscles, if not the most powerfully, at least the most easily irritable, it being the only one which constantly contracts with violence in the experiments without a chain. This may lead to a knowledge of the respective degrees of irritability residing in the different muscles.

34. (3.) That the living nerves and muscles are surrounded by an active and sensible atmosphere; and that the action of the nerve extends beyond the points at which they are distributed.

35. (4.) That galvanism is capable of exciting movements in the organs which are altogether independent of the will, such as the heart and stomach.

36. (5.) That the galvanic fluid, proceeding from an animal with warm blood, may act efficaciously on the human nerves.

37. (6.) That the galvanic phenomena take place without the intervention of any external body, which proves that the cause by which they are produced resides in the living animal economy.

38. (7.) That these phenomena may be made apparent by the means of a chain established between two points of one and the same nerve, as well as in the organs brought in contact with any part of the chain.

39. (8.) and lastly. That by the discovery of galvanism, anatomists are supplied with the means of ascertaining, in small animals, the nervous distributions which are too minute for dissection. From a comparison between many of the phenomena of living bodies with those of dead matter, Humboldt conceived the idea of

instituting a series of experiments by which vitality should be, as it were, subjected to a chemical analysis.

40. M. Humboldt's attention having been directed to other objects for more than two years, he did not think of publishing his experimental observations, until the work of our countryman, Fowler, on the galvanic influence, enlightened him as to the result of his experiments, which he had hitherto apprehended to be peculiar to himself, at the same time that similar ones were made by other naturalists; such, for instance, as the experiment of Mr. G. Hunter of York, which consisted in perceiving the flash of light without any contact of metals with the eyes. Humboldt now began to collect all that had appeared on this subject, from the origin of the discovery, and to compare this information with what he had himself observed. On reading the excellent production of Pfaff on animal electricity and irritability, he found, in the very considerable number of experiments it contains, and in the important observations by which they are accompanied, results exactly similar to those with which his own experiments had supplied him, notwithstanding a very different mode of investigation had been pursued by their author. He was now obliged to renew his labors, and to suppress at least one-half of his experiments.

41. By the observations of Messrs. Jurine, Pictet, Scarpa, Tralles, and Volta, in whose presence they were made, he corrected his ideas; and their reflections conducted him to new researches. After having collected all the observations on irritation, and on the incitability of the sensible and irritable fibre, he began with the history of galvanism, as it led to the other researches. Finding it unnecessary to go into any length of detail, in penning down his observations, the results alone being of importance, he has contented himself with pointing out the principal ones, in a loose way, and in the order in which they presented themselves to him. This work is divided into ten sections, which, after the introductory matter already given in substance, form a kind of table of the subjects they discuss, and of which the following is a brief, but faithful, analysis.

42. In the first section the author expatiates, in general terms, on the relation between galvanic irritation and incitability, and on the different degrees of the former, which, he observes, act exclusively on organic parts provided with sensible fibres. The indirect effects on inanimate matter, connected with incitable bodies, have not, as yet, been experimentally demonstrated. Humboldt, with great care and attention, caused the galvanic fluid to pass through colored liquors, and through other liquors saturated with salt. These experiments he repeated with great assiduity, but could never observe the smallest alteration in the color, temperature, evaporability, or crystallisation of the fluids in question, on the chemical combination of which he could not perceive any change to have been effected. It did not produce any sensible effect either on the electrometer, or on the intermediate rings of the galvanic chain, so as to indicate its strict analogy with the electric fluid.

43. In his investigation of the effects of a metallic stimulus on the irritable and sensible fibre, Humboldt was very solicitous to ascertain the degree of irritability and incitability, which has as powerful an influence on the success or failure of the experiments, as the degree of force of the stimulus itself. In experimenting, he therefore made choice of the most incitable animals, and found that the frogs best calculated for his purpose were young and vigorous females, taken immediately after their winter slumber, and fed, together with other frogs, for some days in a warm room. By the help of art he contrived to carry the incitability to a higher degree than is remarked in the natural state; and this discovery may be considered as one of the most important that he made. By bathing the nerves of animals with a solution of alkaline salts, or with the oxygenated muriatic acid, he not only obtained results which had not previously been known; but also noticed phenomena, the possibility of which had been denied.

44. A short time after the appearance of Humboldt's great work, M. Pfaff published an interesting memoir on the subject. 'It cannot be questioned,' says this writer, 'but that vital chemistry, which appears to be the favorite object of the meditations of the physiologists of the present day, has been elucidated, as well as greatly extended in its limits, by Humboldt's experiments on the excitability of the muscles and nerves. The indefatigable zeal employed by that writer, together with the sagacity and spirit of observation of which he has given so many conspicuous proofs, in a multitude of researches on physiology, must necessarily have led him to very interesting results. The inferences, however, which he draws from his experiments, as well as the explanation he gives of the phenomena he has observed, are not invariably fixed on a solid basis.'

45. The very remarkable effects produced by chemical substances on the sensible and irritable fibre, are, according to M. Pfaff, susceptible of an explanation different from the one adopted by M. Humboldt. It is for this reason that the former proposed another, which he thought more just, and, at the same time, more coincident with the different phenomena of galvanism. The following are his reasonings on this head, together with the experiments on which they are founded.

46. 'A very important circumstance,' he observes, 'to which Humboldt did not pay attention, in his experiments relative to the influence of chemical substances, as exciters of irritability, is the effect of them as members of the galvanic chain. Among these substances may be enumerated the different alkaline substances, acids in general, the oxygenated muriatic acid in particular, and liver of sulphur. I have examined them, in the above point of view, in a series of experiments, and have found several of them to be as efficacious links of the chain, and as powerful exciters of galvanism, as metallic substances themselves.

47. 'The table published by M. Humboldt, of the intermediate links of the chain of his boasted exciters and conductors of animal elec-

tricity, should be entirely altered, if it be intended to represent the scale of the conducting and exciting forces of these substances, in whatever relates to galvanism. Liver of sulphur, the alkaline solutions, lime-water, and the oxygenated muriatic acid, ought to be ranked before all other substances, metals and charcoal excepted, and immediately after them. The blood also should be considered as possessing a great degree of energy. I have convinced myself, by repeated experiments, made attentively, and with the most scrupulous exactitude, that alkaline solutions, lime-water, the oxygenated muriatic acid, and, more particularly, liver of sulphur, produce, when brought into reciprocal action, effects equally powerful with those of two heterogeneous metals; and that, in all the cases in which the recurrence of the contractions is ascribed to an increase of irritability, produced by a chemical action, it would be much better to ascribe this effect to the irritating property of these substances, as they constitute a part of the galvanic chain.

48. 'They form, in a manner, a series of metallic exciting arcs; and ought to be ranked among those which have the greatest affinity with metallic substances, that is, with zinc and lead. It is on this account that their effects are so obvious, when they are combined with gold, silver, and metallic minerals. They are also very efficacious in the reproduction of the contractions, when, instead of being applied in an immediate way to the nerves, they are simply made to correspond with them by the means of conductors. The blood and the bile ought also to be comprehended in the same class, although their effect may not be equally powerful.

49. 'It is well known that it suffices, for the production of convulsive movements in a very irritable frog, to employ a homogeneous metal, for instance a silver discharger, by which a communication is formed between the muscles and the nerves. These convulsive movements are principally produced by the metals denominated noble; but, more especially, by metallic minerals, such as pyrites and galena, or sulphuric ore of lead. When I had formed a communication between the nerve and the prepared thigh of a frog, by the means of a piece of pyrites, the convulsions were produced, and were more particularly manifested when that substance touched the blood-vessels belonging to the nerves. When a chain was established in the thigh, and the mineral substance and nerve had ceased to produce any effect, the convulsions were reproduced, although feebly, by interposing in the chain a piece of moistened sponge, which formed, in a manner, a coating to the nerves. These effects were not usually, however, of any long duration. By moistening, afterwards, the nerve with a drop of blood taken from the frog subjected to the experiments, or, what amounts to the same thing, from any other, and afterwards touching the blood in question with a metallic exciter of silver or copper, placed on the thigh, very powerful convulsions were instantly produced.

50. 'Here the susceptibility of irritation was evidently augmented by the moistening of the nerve with the blood. It was even so to such a degree, that a galvanic irritation of the feeblest kind became very powerfully augmented. This augmentation of the contractions was not, however, to be ascribed to an immediate influence of the blood on the nerve, and on the irritability seeing that the same phenomena were manifested, precisely in the same way, when the blood, instead of being immediately applied to the nerve, was simply laid on a bit of sponge, or on any other conducting body, placed over it. The success of the above experiments depended entirely on the immediate contact of the blood; since, whenever the nerve, or the sponge, was touched at the parts distant from it, the effect did not ensue. To the presence of the blood ought more particularly to be ascribed the properties of animal substances, considered as members of the galvanic chain.

51. 'In this latter point of view, the heart of the frog, still replete with blood, displayed very singular effects, at a time when the irritability was extinguished to such a degree, that certain heterogeneous metals, such as gold and silver, or silver and copper, no longer produced any effect when brought in contact. I was enabled to reproduce very forcible contractions, by placing the heart of a frog on its nerve, and by forming a communication between it and the thigh of the animal, by the means of a metallic exciting arc either of gold or silver. In this manner I established a galvanic chain, in the composition of which one metallic exciter only was to be found. In another instance, it was very remarkable, that the moment the heart was touched, either by silver or by pyrites, it remained tranquil, notwithstanding the thigh of the animal was in a convulsed state, the regularity of the system of the pulsations not being in any degree interrupted. Other parts of the frog, for instance, portions of its liver, its bowels, &c., which contain a less proportion of blood, did not possess an equal efficacy; but the heart itself was surpassed by the blood presented in substance, and more particularly in a concrete state. It was surprising to see the mode in which I could, by the means of a drop of blood, bestow on the nerve its vital energy; and also to observe that this drop of blood, without undergoing any sensible diminution or change, still continued to render the same service.

52. 'Whatever may be the effect, however, which the blood produces, it is still surpassed by the alkalies, by the oxygenated muriatic acid, and, more particularly, by the liver of sulphur, when metallic exciters of the first class, that is, the minerals and noble metals, together with the other metallic substances, and the regulus of antimony, cease to produce any effect, in conjunction with the blood with which the nerve has been moistened. After having wiped it dry, and substituted for the blood a single drop of the deliquescent oil of tartar, very powerful convulsive movements may be produced, by a recurrence to the above metallic exciting substances. This galvanic chain, consisting of muscles, silver, pyrites, or regulus of antimony, and of an alkali and a nerve, is as efficacious as a chain formed by muscles, silver, iron, or tin, conjointly with a nerve. The deliquescent oil of tartar

may be considered as an active coating of the nerve. These phenomena present themselves agreeably to the same identical laws by which the metallic coatings of the nerves are regulated. In the above process, the deliquescent oil of tartar possesses nearly the same activity, whether the nerve, without being moistened in an immediate way, is made to communicate with the muscles by the means of any conducting body whatever, or is immediately touched by the metallic exciter applied to the thigh of the animal, the exciter in question being a bent silver probe.

53. Professor Pfaff goes on to say that 'the following experiments merit a particular notice. I laid a portion of muscular flesh on the nerve of a frog, on which two heterogeneous metals, silver and copper, had ceased to produce any effect, and having touched the nerve with a silver probe, which was applied to the thigh, was not enabled to produce any contractions. I now poured a drop of the deliquescent oil of tartar on the muscular flesh, and, as soon as the silver probe was brought in contact with this alkaline substance, very strong convulsive movements were displayed. I laid another portion of muscular flesh on the preceding one, and brought the exciter towards it, but without being enabled to produce the contractions. Scarcely, however, had this latter portion of muscle been moistened and touched, as in the former instance, than they were renewed. In this way I was enabled to form several layers of a different nature; and the effect above pointed out took place as often as the silver, or, what was still better, the pyrites and the regulus of antimony, came in immediate contact with the alkali. The nerve having been moistened with the deliquescent oil of tartar, a very feeble galvanic irritation, produced either by gold and silver, or by silver and copper, became highly exalted, even when the convulsions had not been previously excited. It remains, however, to be ascertained, whether, in this case, the deliquescent oil of tartar did not act as the most efficacious coating of the nerve. It is in this way that silver and copper produce fresh contractions, when, after the nerve has been coated with zinc, and the thigh of the animal laid on silver, a communication is formed between them by the means of copper. In such a case, indeed, the effect is not owing to the joint operation of the copper and silver, but, on the other hand, to that of the silver and zinc, by which the humid animal parts are immediately coated. Would not an effect exactly similar be produced, if the nerve were to be moistened with the deliquescent oil of tartar? Does not this alkali, in surrounding the nerve, become a more efficacious coating than the zinc; and, on the application of feeble exciters, such as copper and silver, does not the zinc itself act more powerfully by the means of an alkali, with which it is simply connected by the copper, as an intermediate conductor?

54. 'These doubts are very far from being removed by M. Humboldt's experiments. Supposing the deliquescent oil of tartar to act by producing an augmentation of irritability, this effect ought also to be produced when the nerve has been carefully dried, before the application of a weaker galvanic irritation is made. This, however, is what I have not found in any of my experiments. M. Humboldt constantly applied his weakest exciters, whilst the nerves were still moistened with the deliquescent oil of tartar, or with any other chemical substance calculated to augment the susceptibility of irritation. On this head, let the different parts of his work in which he treats of the increase of this susceptibility by the alkalies, be compared. He sets out by saying: 'I showed the galvanic flashes to several persons who could not perceive them in the experiments made by Mr. G. Hunter, by rubbing their gums, on the upper jaw, with an alkaline solution. Two pieces of gold, applied to wounds on the back, were found to possess great efficacy, when the wounds had been touched with the deliquescent oil of tartar.' A little farther he observes: 'When the principal trunks of the nerves of an organ are carefully prepared, and enveloped in moist bits of bladder, in such a way as that the irritating humidity simply moistens the muscular flesh, and the few fine nervous filaments it contains, an increase of irritability is rarely to be observed, at the same time that it is constantly produced, when the above principal trunks are moistened beneath the muscles.' Again, he says in the following page: 'The vital principle will be restored in the thighs of frogs exhausted by galvanic experiments, by the means of the oxygenated muriatic acid, in such a way as that the irritation of metals will again produce its effect. It is remarkable, that the contractions become more powerful, when a great portion of the nerve is moistened, and touched directly by the silver.' Such are the extracts I have chosen to cite from Humboldt's work. Now, let it be observed, that, in all the above cases, and more particularly in the experiments relative to the influence of chemical substances on the irritability of the animal fibre, the nerves were constantly moistened by these substances. They must consequently, whenever the metals were applied, operate likewise as links, or members, of the galvanic chain. The consequences must therefore be uncertain at the least.

55. 'I could not observe any remarkable difference in the alkalies, considered as links of the galvanic chain. The deliquescent oil of tartar appeared, however, to be somewhat more efficacious than the other substances of this nature. The effects of lime-water were not so powerful: it appeared, as it were, to preserve a medium between the alkalies and the substances to which an inferior rank is assigned. The oxygenated muriatic acid appeared to be pretty nearly as active as the deliquescent oil of tartar. In a few cases only the latter fluid produced spasmodic contractions of a longer duration. I observed likewise, in several instances in which I employed the oxygenated muriatic acid, a phenomenon which the metallic coatings of the nerves had often displayed, namely, that the contractions were manifested at no other time than when the contact of the nerve, moistened with a drop of the oxygenated muriatic acid, ceased. Here, likewise, the effects seemed to depend entirely on the immediate presence and application of

the oxygenated muriatic acid. As soon as a drop of this liquid is poured on a portion of muscular flesh, laid on the nerve, the movements are invariably reproduced.'

56. Having entered into this detail of the objections of M. Pfaff to the theory of Humboldt, we may now proceed to the analysis of a very curious memoir, read by M. Lehot at the French National Institute. Its object is to demonstrate particularly, not only the circulation of a very subtile fluid in the galvanic chain, but likewise that, in the application of the different chains to the animal arcs, there are unequivocal signs of the direction of the motion of that fluid, insomuch that it is possible to determine a priori, in a considerable number of different chains, the direction of the current. Being acquainted with this direction, as well as with the nature of the different parts of the chain, the author of the memoir in question observes, that it is reciprocally possible, in certain cases at least, to determine their respective position; and also, by the interposition of new substances in the chain, or by a change in the disposition of the parts of which it is composed, to give a particular direction to the galvanic fluid, and even to bring it into a state of repose.

57. The comprehension of these phenomena is connected with a fact which seemed to have escaped the notice of the different physiologists, namely, that the galvanic fluid is accumulated in the passage from the organs to the coatings. By a due attention to this fact, the nature of the metallic substances may likewise be distinguished at the distance of several yards. The galvanic influence will be sufficient to determine this. The following are the principal results of the interesting experiments made by M. Lehot.

58. Experiment I.—If the thigh of a frog recently prepared be held in one of the hands, and the nerve be brought in contact with a piece of zinc, the extremity of which is immersed in mercury, the moment the fingers of the other hand are dipped in that fluid powerful contractions will be manifested in the thigh of the animal. The same result will be obtained as often as one of the following substances, namely zinc, lead, tin, mercury, bismuth, copper, silver, or plumbago, is employed as a coating to the fingers; and one of those by which it is preceded, in the foregoing series, as a coating to the nerve. With respect to the precaution of moistening the fingers, it is absolutely indispensable; for which reason, whenever they are described as terminating one of the extremities of the arc, they are to be constantly supposed to be in a humid state.

59. Experiment II.—If, on the other hand, the nerve be brought in contact with the mercury, and if that metal be touched with a piece of zinc, held in the moistened hand, either the contractions will not be produced, or they will be extremely feeble, provided there still be a certain share of susceptibility in the part. By separating, however, the nerve from the mercury, or, in general, by breaking the chain at any given point whatever, the contractile movements will take place. The same results will be obtained, as often as one of the metals belonging to the series pointed out in the preceding experiment, is employed as a coating to the fingers; and one of those by which it is followed in that series, as a coating to the nerve. Thus, if the nerve be coated with lead, and the fingers with zinc, there will not be any contraction when these two metals are brought in contact; but, if the chain be destroyed at any given point, the contractions will be manifested. If, on the other hand, the nerve being still coated with lead, the fingers be coated with silver, when the chain is formed, the galvanic contractions will take place.

60. Experiment III.—If a flat surface of zinc be laid on the tongue, and touched with a piece of silver, held between the moistened fingers, a particular savor will instantly be perceived. Much has been said on the subject of this phenomenon, but it has been nowhere noticed, that it likewise takes place whenever the tongue is coated with any one of the metallic substances pointed out in the first experiment, and the fingers with one of those by which it is followed in the series. If, however, after the chain has been formed, it be interrupted, the savor will be no longer manifest.

61. Experiment IV.—If a piece of silver be laid on the tongue, and a portion of zinc be held between the moistened fingers, as soon as the latter is brought in contact with the silver, there will not be any distinguishable sensation, or, at the least, it will be very slight. As often, however, as the chain is interrupted in any given point whatever, the savor will be perceptible. It will not in this case be so strong as in the preceding experiment, and will be more slowly communicated.

62. The same result will be obtained, as often as one of the metals pointed out in the first experiment is employed as a coating to the tongue, and one of those by which it is preceded in the list, as a coating to the fingers. Thus, by coating the tongue with lead, and the fingers with zinc, and by bringing the two metals in contact, the savor will not ensue; but, by interrupting the chain at any given point, it will be very perceptible. On the contrary, if, the tongue being still coated with the lead, the fingers be coated with silver, instead of zinc, and the chain established, the sensation will be instantly perceived.

63. Experiment V.—If the thigh of a frog be laid on a plate of silver, and the nerve on a surface of zinc or lead, the moment the coatings are brought in contact, powerful contractions will be produced. The same thing will happen whenever the coating of the nerve is made to consist of a metal selected from among those which are pointed out in the first experiment; and that of the muscle, of another metal following it in the series.

64. Experiment VI.—If the muscle be armed with zinc, and the nerve with silver, the contractions will not ensue until the moment the chain is interrupted. When portions of copper, iron, bismuth, and lead are substituted for the silver, the same results are obtained.

65. In the first, third, and fifth, of the preceding experiments, it must have been observed, that

the phenomena were manifested the moment the galvanic circle was formed. The fluid contained in the part of the chain was put in motion, and penetrated instantly either to the tongue or to the nerve. By reversing the chain, a contrary direction must have been given to the current, seeing that the phenomena which were manifested in the second, fourth, and sixth experiments, that is, those in which the galvanic influence was not perceptible until the instant when the chain was interrupted, were to be ascribed to a portion of the fluid, accumulated either in the tongue or in the nerves, at the points of contact of these organs with their coatings. Now, to the end that the fluid should have been thus accumulated, it was necessary that it should have penetrated the above organs in the direction of the muscle towards the nerves, or of the fingers towards the tongue. It is thus demonstrated, that the accumulation of the fluid is a sure characteristic of the direction of the current, by the help of which it may in all cases be determined.

66. In conformity to the experiments which have been detailed above, and to the galvanic facts previously known and established, it would appear that the following principles may be laid down.

67. (1.) That all exciting substances contain the galvanic fluid; but that its quantity is very considerable in humid substances, and in the organs of animals, which have a very small capacity for that fluid, when compared with metallic substances.

68. (2.) That, when two exciting substances are brought together, a new distribution of the galvanic fluid takes place; the substance which has the least capacity losing a portion of the fluid, on which the other substance seizes. Metallic and carbonated substances, disposed in the following order,—zinc, lead, tin, mercury, bismuth, copper, silver, and plumbago, act in such a manner as that any one of them, when brought in contact with one of those by which it is followed, seizes on a portion of the fluid the latter contains.

69. (3.) When the galvanic fluid penetrates the tongue, in directing itself from its extremity towards its root, it causes in the latter part a particular savor, which is more or less strong, according to the greater or less quantity of the fluid, and to the susceptibility of the organ. But when its direction is such, that it tends to flow out of the animal arc by the tongue, it occasions a much weaker savor, which differs from the former in proportion as the quantity of the fluid put in motion is less. As the fluid, however, finds some difficulty in quitting the tongue, it partly accumulates in that organ; and when the cause that has given rise to this accumulation ceases, then the fluid, in returning towards the root of the tongue, occasions there the galvanic savor in question.

70. (4.) When the galvanic fluid, distributed by the nerves, penetrates into the muscular substance of the organs of living animals, recently separated from the animals themselves, contractions are produced in the parts it permeates. The susceptibility being exalted, if the fluid inherent in the organ should, from any cause whatever, be unequally distributed, and accumulated at the particular points, muscular movements will ensue. But if the susceptibility is weakened, the contractions can no longer take place, unless by the aid of a fluid extraneous to the organ.

71. At the earliest stage of the diminution of the susceptibility of the organs, the contractions are displayed, whatever may be the direction of the fluid by which they are permeated. But when the susceptibility is weakened still more, the direction of the current ceases to be indifferent. When the fluid is directed in such a way as to pass from the nervous ramifications to the nerves themselves, the contractile movements are much weaker than when it receives a contrary direction; and in the former case a portion of the fluid becomes accumulated at the point where it has a tendency to flow out from the nerve. This accumulation, and this difference in the effect of the current, by which the organ is penetrated in one direction or in another, are greater in proportion as the susceptibility is less, and as the quantity of the fluid put in motion is smaller. Thus, when the susceptibility is greatly enfeebled, notwithstanding the contractions may ensue, when the fluid penetrates into the organs, in the direction leading from the nerve to the muscle, they cease altogether when it permeates them in a contrary direction, it being then almost completely accumulated in the organ. The cause which has given rise to this accumulation having ceased, the fluid returns into its accustomed channel, and, having penetrated the organs in the most favorable direction, occasions in them the muscular movements.

72. (5.) If a communication be established between two points of an animal organ, with the help of a chain composed of different substances, disposed in such a way as that it may not be symmetrical, relatively to the nature of the parts of which it is composed, the fluid, being unequally solicited on the one hand and on the other, puts itself in motion, and forms a current directed towards the preponderating force.

73. (6.) If all the parts of the chain, by which a communication is established between two points of a system of organs either nervous or muscular, be reversed, a current will be produced having a contrary direction to the former.

74. (7.) When the chain is symmetrical, relatively to the nature of the parts of which it is composed, the fluid, being equally solicited on all sides, will forbear to display any movement.

75. (8.) and lastly. When a chain, which is calculated by its nature to give motion to the galvanic fluid, is destroyed, that is, when an insulating body is interposed, the fluid, which had been accumulated in the organ by the formation of the chain, returns to its original situation, and a current is formed into a contrary direction to the first.

76. These principles, which form the basis of M. Lehot's theory of galvanism, are likewise confirmed by the following experiments :—

77. If the thigh of a frog be held in one of the hands, and the nerve coated with zinc, at the same time that the person who makes the experiment has his tongue armed with silver, the

thigh of the frog will contract as soon as the two metals are brought in contact; but the experimenter will not be sensible of any savor, or of a very slight one at the most. By interrupting, however, the chain, he will perceive a very distinct savor, and the thigh of the frog will cease to contract. If, on the other hand, he coats his tongue with zinc, and the nerve with silver, the peculiar taste will be manifested at the moment of the contact; and the thigh, provided its incitability has been weakened, will preserve a state of perfect immobility.

78. By the interruption of the chain, the muscular movements will be again apparent, without any manifestation of the galvanic taste. It will appear that this ought necessarily to happen, when it is considered that, as soon as the chain is formed, the current of the fluid takes a direction from the silver to the zinc, and, having penetrated in a direct and immediate way into the nerve, produces contractions in the muscle, at the same time that it crosses the body of the person by whom the experiment is made, and accumulates on his tongue, without his being sensible of any particular savor. When, however, the chain is interrupted, the accumulated fluid returns to the parts it had quitted, and the savor on the tongue becomes manifest. If the tongue be coated with zinc, and the nerve with silver, the current being impelled in a contrary direction, the phenomena which take place are diametrically opposite.

79. If two persons, holding each other by the hand, arm the tongue, one of them with zinc, and the other with silver, as soon as they bring the two metallic substances in contact, the one who has the tongue coated with zinc is sensible of the savor; but this does not happen to the other. If they afterwards separate the zinc from the silver, the one who felt the savor at the time when the chain was formed, will cease to be sensible of it on its being thus interrupted; at the same time that it will be rendered manifest on the tongue of the other.

80. Finally, the animal arc may be terminated by two nerves. Thus, by placing the two thighs of a frog on a plate of glass, and establishing a communication between their muscles, by the help of a flat piece of metal, coating, at the same time, the nerve of one of them with zinc, and the other with silver; the thigh which is armed with zinc will contract the moment a communication is established between the two coatings, by the means of a rod of zinc or silver; the incitability of the other thigh having been weakened, the limb will remain motionless. By interrupting the chain, however, the muscular movements will be displayed in the latter, and the former will resume a state of repose.

81. The same disposition being made as in the second experiment, and the chain established, if a given point of the muscle be brought in contact with the mercury, without deranging the contact of the nerve; or if a communication be established between the muscle and the mercury, or between the muscle and the zinc, by the means of a metallic substance, the muscular movements will be instantly manifested. These phenomena are occasioned by the fluid accumulated at the point of contact between the nerve and its coating, which fluid returns into the muscle, and there gives rise to the contractions. This is shewn in the following manner:—If, while the communicating metallic substance still touches the muscle and the mercury, or the muscle and the zinc, the latter be detached from the mercury, the contractions will not ensue, as would have happened if the fluid accumulated by the original chain, at the point of contact of the nerve and its coating, had remained there.

82. If the thigh of a frog, prepared in the customary manner, be held in one of the hands, and the nerves, as well as a few points of the muscle, be brought in contact with the mercury, the moment that fluid is touched by a bar of zinc, held in the other hand, previously moistened, violent contractions will be produced in the limb of the animal. This experiment consequently presents phenomena entirely different from those which were the result of the second experiment. The fluid, instead of having been accumulated in the nerve, appears to have flowed out by the muscle, and to have there occasioned the contractions. Such a degree of incitability may be induced, that the contractions may be altogether subdued by the double contact of the nerve and the muscle, as well in forming as in interrupting the chain.

83. If the same disposition having been made as in the sixth experiment, not only the nerve, but likewise the muscle, be made to touch the piece of silver, leaving it, however, in constant contact with the zinc, violent contractions will be manifested as soon as a communication is established between the zinc and the silver, by the means of a conducting substance. By substituting for the silver either copper, plumbago, or lead, the same phenomenon will be obtained.

84. The current which is formed in a chain composed of three metallic substances, is constantly directed towards the extreme metal stationed in front of the metal at the other extremity of the chain. The direction of the current cannot therefore depend, in any degree, on the metal by which the middle space is occupied.

85. In the chain composed of metallic and humid substances, where there are only two or three heterogeneous metals in immediate contact, the current is directed in the same way as it would be if these metals were to be regarded as independent of the rest of the chain.

86. Having placed a thin plate of zinc at the bottom of a vessel filled with water, and brought the tongue in contact with the extremity of a bar of tin, the other extremity of which is made to touch the plate of zinc; if another bar of the same metal, of the same dimensions with the preceding one, be held in one of the hands, and its extremity plunged in the water, there will not be any perceptible savor. In reality, the current is, in this instance, directed in such a way as to pass through the fingers, crossing the body of the person by whom the experiment is made, to accumulate itself on the tongue. But as soon as the second bar of tin is plunged more deeply in the water, so as to touch the zinc, the savor becomes perceptible. This phenomenon, which had not hitherto been noticed, is, according

to M. Lehot, a natural result of the principles he has laid down. By bringing, he observes, the second bar of tin in contact with the zinc, a symmetrical chain is formed, of such a nature, that the fluid it contains must necessarily be in equilibrio. Consequently, the quantity of the fluid which had been accumulated in the preceding disposition, must, unavoidably, have been dispersed, and have occasioned the sensation or flavor which was noticed. On detaching the bar of tin from the plate of zinc, without taking it out of the water, the sensation ceases to be perceptible, on this account, that a current is formed which is directed in such a way as to penetrate the fingers. If the bar of tin be withdrawn from the water, the flavor will be perceptible, in consequence of the dispersion of the accumulated fluid.

87. Thus, to render a chain symmetrical, or to destroy it by the interposition of an insulating substance, will have the same effect relatively to the motion of the galvanic fluid. By the explanation which has just been given, it seems evident that if, after rendering stationary the bar which touches the tongue, and the one which is held in the hand moveable, the operation be performed inversely, the savor will be felt in contrary circumstances; seeing that the current will, in every such case, take an opposite direction.

88. When the extremity of the moveable bar is plunged in water, the one which is held in the moistened hand being fixed, and in contact with the plate of zinc at the bottom of the vessel, the sensation is perceptible on the tongue. But if the former be plunged still deeper, so as to be brought to touch the zinc, the savor will be no longer manifested. On detaching it from the plate of zinc, without, however, withdrawing it from the water, the sensation is again produced; but ceases as soon as the bar is taken out of the water.

89. If the extremity of each of the two bars of tin be laid on a particular point of the tongue, the savor will be felt at the extremity of the moveable bar, the moment its other extremity is plunged in the water, that of the fixed bar being in contact with the plate of zinc. Secondly, by plunging the moveable bar still more deeply in the water, and bringing it in contact with the plate of zinc, the savor will be felt at the point of the tongue where it is touched by the other bar. Thirdly, the instant either of the bars is separated from the plate of zinc, without being, however, taken out of the water, the galvanic savor will be distinguishable at its point. Lastly, the one which was stationary in the first instance, still continuing so, if the moveable one be taken out of the water, the savor will be felt at the extremity of the former.

90. From the principles which have just been laid down, it is not difficult to conclude that, if a metal, taken from the given series, be employed as a bar, and one of those by which it is followed in that series as a communicator plunged in water, the phenomena which take place in the preceding experiments will be entirely changed. Consequently, the cases in which, in the first and second of the above experiments, the sensation was manifested, are precisely those in which there should not be any sensation, under the circumstances above stated, and vice versa. It also follows that, in the third experiment, the cases in which the savor was perceptible at the extremity of the moveable bar, are those in which, under these circumstances, it should be felt at the extremity of the fixed bar, and vice versa; the current then invariably taking a contrary direction.

91. Having placed the nerves of the thigh of a frog on a plate of tin, terminated by a small cavity filled with water, and the muscles on another plate of tin exactly similar, if one of the extremities of an arc of zinc be brought in contact with the bottom of the cavity formed in the coating of the nerve, and if the other extremity of the arc be immersed in the water contained in the cavity of the coating of the muscle, the susceptibility of the organs will be found to be such, that the contractions will not ensue. By plunging the communicator, however, still more deeply in the water, in such a way as that it may touch the bottom of the latter of the above cavities, the contractions will be instantly manifested in the animal arc. Having afterwards detached the arc of zinc from the bottom of the cavity of the coating of the nerve, without, however, withdrawing it from the water, the organ becomes motionless; but, as soon as the arc ceases to be immersed in the water, it being, at the same time, still in contact at its other extremity, the contractions are again produced. This experiment was frequently repeated by our author, and was constantly attended by the same result. In the latter instance, however, the contractions were invariably weaker than in the former.

92. If the arc of zinc be brought in contact with the coating of the muscle, at the same time that its other extremity is plunged in the cavity of the coating of the nerve, the thigh of the frog will be forcibly contracted. By immersing it still deeper, so as that it may reach the bottom of the cavity, the contractions will cease. In detaching it, the muscular movements are usually perceptible; but there are occasions in which the organs remain motionless.

93. The same results will be obtained as often as a more oxydizable metal is employed, to establish a communication between two homogeneous coatings, formed of a weaker metal. If coatings of a metallic substance, possessing a greater capacity, be employed in conjunction with a communicator or arc, which has a less capacity, the effects which will be produced will be diametrically opposite.

94. The experiments which have been thus detailed, lead to a very singular result, namely, that one metal may be distinguished from another without being either directly seen or felt. In reality, by composing a chain in such a way as that it may be terminated by one of the metals described above, a current being formed which takes a particular direction, totally different from the one which it takes when the chain is terminated by another metal, it is easy to recognise any one given metallic substance. In this way M. Lehot was enabled to distinguish a portion of zinc from a piece of silver, at the extremity of metallic threads several yards in length.

95 About this period professor Volta took up the subject, and philosophy has to rejoice that his mode of theorizing, although not strictly true, has contributed principally to its rapid advancement. He set out with the idea, contrary to Galvani, that the electricity in question did not belong to the animal, but to the different metals employed. Galvani, therefore, was unlikely to produce any greater effect than what two pieces of metal could effect, because he believed the electricity to be in the animal. Volta was led to the discovery of the battery by combining a number of pieces of metal together, because he was persuaded that the electricity was in the metals and fluids employed.

96. He repeated the experiments of Galvani, and found that when two pieces of metals of different kinds were placed in different parts of an animal at the same time that the metals were brought in contact, or were connected by a metallic arc, as often as the contact was made, convulsions were observed. He found that the greatest effect was produced when the metals were zinc and silver. When several pairs of metals were employed, having pieces of moist cloth between them, the effect appeared to increase as the number of pairs.

97. This important discovery of accumulating the effects of this species of electricity was made by Volta, in 1800, and thence has been denominated the Voltaic pile. The apparatus, as first made by Volta, consisted of a certain number of pairs of zinc and silver plates, separated from each other by pieces of wet cloth. Hence the arrangement was as follows: zinc, silver, wet cloth; zinc, silver, wet cloth, and so on. The silver plates were chiefly silver coins, the plates of zinc and the pieces of cloth being of the same size. He found this pile much more powerful when the pieces of cloth were moistened with a solution of common salt instead of pure water. A pile, consisting of forty pairs of plates, he found to possess the power of giving a very sharp shock, similar to that of a small electric jar; and that this effect took place as often as a communication was made between each end of the pile, and as long as the pieces of cloth remained moist.

98. An account of this discovery was communicated to the Royal Society, and published in the Philosophical Transactions. We do not find that this celebrated philosopher made any considerable discoveries after the invention of the pile.

99. The galvanic pile invented by M. Zamboni, and which he has called a binary pile, is composed only of two elements, namely, a metal and a fluid. The metallic elements of the pile are twenty-nine small squares of tin-foil, about half an inch long on each side, and terminated by a very fine tail, from two to three inches in length; and the fluid element is distilled water, placed in thirty watch glasses, arranged circularly on a table. The water in every two adjoining glasses is connected with one of the elements of tin, by placing the square portion of the tin in one glass, and the tail in the adjoining one in such a manner that the square portion is wholly immersed, while the tail merely touches the fluid. When the metallic elements are all arranged in a similar manner, and when the first and last glasses communicate only by means of all the intermediate ones, it will be found by making a communication between the first glass and the ground, and between the last and a good condenser, that the pile has two poles, one vitreous and the other resinous, the former corresponding to the small squares, and the latter to the long tails.

100. If the pile is constructed with elongated rectangular pieces of tin, no electricity is developed when the two extremities of the rectangles are equally immersed in the distilled water of the watch glasses; but, whenever they are immersed unequally, the electricity exhibits itself at the poles, as in the construction already described; the vitreous pole always corresponding to the larger surface immersed, and the resinous one to the smaller surface, so that the same pole may be rendered alternately vitreous and resinous, by immersing more or less of the nearest ends of the rectangles of tin.

101. When elements of zinc or copper are substituted in place of the tin, the same effects are produced; but no indications of electricity are obtained from oxide of manganese.

102. A pile constructed in the preceding manner does not charge the condenser instantaneously. The electricity does not appear till about the end of half a minute, and often longer, and it then gradually increases. This effect might be ascribed to oxidation, as the pile would then have three elements; but at the end of several days the development of electricity was as powerful as at the moment when the apparatus was arranged, although not the slightest trace of oxidation could be perceived. When zinc was substituted for tin, the electricity diminished as the oxidation increased; it then disappeared and afterwards reappeared, with an opposite character. Hence it would appear that the development of electricity in the binary pile is not owing to the oxidation of the metal.

103. A pile constructed with ten discs of tinned paper, without any other substance, produced, in about half a minute, a deviation of a third of an inch in Bennet's electrometer, furnished with a condenser. The tinned face possessed vitreous, and the paper face resinous, electricity. This effect invariably increased with the number of the discs.

104. Another pile of discs of tinned paper, having the paper face covered with a film of honey, in order to keep up a constant humidity, likewise gave signs of electricity, but it required from forty to fifty discs to produce the same degree of electricity as the preceding pile of ten discs of tinned paper; and the electricity was besides of an opposite character, the honey being vitreously, and the tin resinously, electrified. On the following day the electricity had rapidly diminished, and at last it completely disappeared, the paper having been penetrated throughout with the honey, and the tin being equally in contact by its two surfaces with the latter substance.

105. A pile of discs of tinned paper, in which all the discs had been glued together, gave no electrical indications, because the metal was equally in contact with the paper at each of its faces.

106. When a binary pile, like any of the preceding, has become inactive, its energy may be restored, by simply raising the discs, which, by the action of the air, will diminish the influence of humidity upon one of the faces of each disc. The binary piles, indeed, do not produce any effect, unless the touching surfaces of the metallic and the fluid element are unequal.

107. The energy of the binary piles is much influenced by the conducting power of the fluid which forms the humid element. A few drops of a solution of sal ammoniac added to the distilled water, augments a little the electricity of the pile; but if we continue to add more, a diminution of action takes place, and at last the energy of the pile is destroyed. Hence it follows, that the humid element must be an imperfect conductor.

108. Mr. Singer, in his first experiments, cut a number of thin slips of sheet copper, and bent them into the form of the letter U, so as to form a series of simple springs. He then introduced both legs of one of these springs into each cell of a Voltaic battery, so that it pressed forcibly against the copper surface on one side of the cell, and the zinc surface on the other. Having, in this manner, made a regular metallic communication between every pair of plates in a battery containing fifty of three inches square, Mr. Singer filled the cells with a diluted acid, and found that, notwithstanding the total absence of insulation, water was decomposed with great rapidity, a vivid spark produced by charcoal points, and gunpowder inflamed; and, on applying the condenser, a charge was communicated which occasioned the gold leaves of the electrometer to strike the sides of the glass.

109. This phenomenon appears the more extraordinary at first view, because it is well known that, if the plates are all connected together by a thin wire, the effect is almost totally destroyed; but in such case, the opposite copper and zinc surfaces of each pair of plates are made to communicate with each other, and consequently their electricities circulate individually, instead of being propelled forward from one cell to the other. But, in the arrangement above described, the metallic springs are in contact with the zinc surface of one pair of plates, and the copper surface of another; there is consequently no communication between the opposite surfaces of any individual pair, but what arises from the association of the copper and zinc; and, as their mutual contact produces a motion of the electric fluid from the copper to the zinc, it cannot operate as a conductor in the contrary direction. The effect is therefore only diminished in proportion as the copper spring, by placing part of the zinc plate between two copper surfaces, diminishes its electro-motive energy. This experiment appears a satisfactory proof of the electro-motive power produced by the association of the metals, and of its tendency to produce a current of electricity from one extremity of the battery to the other, and consequently a circulation of electric fluid when the opposite extremities are connected: it also proves that the electro-motive power is influenced by the nature of the substance interposed between the different pairs of metals, and thus accounts in some measure for the different effect produced by different fluids. This last circumstance is an interesting subject of enquiry; some instructive facts respecting it have been detailed by professor Berzelius, in an account of an ingenious experiment made to prove that oxidation is not the cause of the electricity of the Voltaic apparatus. The following is extracted from his description. 'I took twelve tubes of glass, half an inch diameter and three inches in height, and closed at one end. I half filled them with a strong solution of submuriate of lime (such as is obtained from the residue after the preparation of caustic ammonia), and above this fluid I poured diluted nitric acid, with the precaution not to mix the liquids. I arranged these tubes in succession, and then took copper wires, round one of the extremities of each of which I had melted zinc, in order to attach a knob of that metal to that end. I immersed the zinc-coated ends of each into one of the tubes to the bottom of the submuriate, and then bent the upper ends of the respective wires so as to immerse them in the middle of the acid of each nearest tube. This arrangment consequently formed a series in the order following: copper, zinc, submuriate of lime, nitric acid; copper, zinc, &c. It is evident that the chemical affinity which produces oxidation at the common temperature, was here at the surface of that part of the copper which was in contact with the nitric acid; and that, if this oxidation had been the primary cause of the electricity of the apparatus, the pole of copper in this construction, ought to have possessed the same electricity (namely, the positive) as the zinc pole in the common pile. Before the extremities of this small apparatus were connected, the copper continued to be constantly dissolved in the acid, which it turned blue, and the surface of the zinc remained metallic and without any perceptible change. And lastly, I combined the poles, by means of silver wires, passed into a tube filled with a solution of muriate of soda. But I was greatly surprised to find the effect directly contrary to what the theory, which considers oxidation as the cause of the electricity of the pile, had led me to expect. The solution of the copper instantly ceased, and the zinc became covered with a mass of white oxide, vegetating on all sides in the form of wool. The pole of the copper produced hydrogen gas as usual, and the zinc pole caused an abundant precipitate of muriate of silver. The electric state, therefore, produced in this case an affinity, which at the ordinary temperature of the atmosphere is inactive, and caused another very active affinity to cease, which was already in operation; and this could be effected by no other cause than that of the electricity produced by contact, which occasions the electric charge of the pile, and disposes the affinities which shall be put into activity. This little apparatus was very powerful, and disengaged so large a quantity of gas, as would not have been exceeded by 100 pairs of plates. But what could be the cause of this? I exchanged the submuriate for neutral muriate; it then produced a very moderate effect, corresponding with the number of pairs; and, lastly, I substituted neutral muriate

of zinc instead of the muriate of lime, and then the effect was scarcely perceptible, though it continued sufficient to prevent the oxidation of the copper in the nitric acid, and to show that the conductor of the zinc pole continued always to be oxidized.' This experiment demonstrates the influence of the interposed fluid on the chemical effects of the apparatus, which may probably arise from its action on the electro-motive power produced by the association of the metals. It indicates also, that the chemical action of the battery is never exerted but when the electric fluid circulates from one extremity to the other; and corresponds in this respect with an experiment by Sir H. Davy, in which forty compound arcs of zinc and silver were arranged in the usual order, in a series of glasses, filled with a solution of muriate of ammonia rendered slightly acid by muriatic acid; whilst the extreme parts remained unconnected, no gas was disengaged from the silver, and the zinc was scarcely acted upon; but when they were connected all the zinc wires were dissolved more rapidly, and hydrogen was disengaged from every silver wire. In simple Voltaic combinations, it appears essential to the production of chemical effects, that the e be a transition of the elements of the interposed fluid; and, as this may be presumed to take place also in each cell of a battery, it is perhaps one cause of the superior action of those fluids which are most readily susceptible of decomposition. When for instance a compound arc of zinc and platina is placed with the platina leg in a solution of silver, and the zinc leg in dilute muriatic acid, no precipitation of silver takes place unless the glasses are connected by some fluid medium, or by a metal which is soluble in the acid of the solution of silver. With arcs of platina, or gold, therefore, no effect is produced; but, with any other metal, a portion of the silver or copper of the solution is revived, and a corresponding portion of the simple connecting arc is dissolved, and occupies the place of the revived metal in the solution. Hence the corrosion of the zinc plates in the Voltaic battery, and the liberation of hydrogen at the copper surfaces. From the phenomena hitherto described, it appears that the primary source of the electric power of the Voltaic apparatus may be considered to be the association of the metals of which it is composed; but the chemical effects, though probably arising from the same cause, are obviously influenced by the nature and action of the interposed fluid. The relation of the various parts of a Voltaic apparatus (as usually constructed), to the various effects it produces, have been developed by the masterly experiments of M. De Luc. The ordinary apparatus consists of three constituent parts, namely, two metals and a fluid, being usually, when arranged in a pile, copper or silver, zinc, and wet cloth, following each other in successive groups. Now, if these be regarded attentively, without any regard to Volta's theory, they may be considered as divided into ternary groups under three different aspects. 1. Zinc and silver, with wet cloth between them. 2. Zinc and silver in mutual contact, with wet cloth on the side of the zinc. 3. Zinc and silver still in mutual contact, but the wet cloth on the side of the silver. Either of these ternary associations may be the cause of the action of the apparatus; but the really efficient groups may be ascertained, if each of the ternary associations are successively mounted as a pile, the different groups being separated from each other by some conductor that does not materially affect their electro-motive power. M. De Luc employed for this purpose small tripods, formed of brass wire, so bent as to touch the plates between which the tripod was placed, only at the three points of support.

110. The first dissection of the pile by this method was to form an arrangement of seventy-six groups of zinc and silver with wetted cloth between them; one group being placed first (suppose with the zinc plate lowest); then upon the silver plate a tripod of brass wire; upon that another group with the zinc plate lowest; again, upon its silver, a tripod, upon that a third group in the same order, and so on until the whole seventy-six groups were arranged.

111. Under these circumstances the same chemical and electrical effects were obtained, as when the apparatus was put together without the brass tripods. It therefore appeared that the efficient groups, for all the effects of the apparatus, were an association of silver and zinc, with wetted cloth between them. To ascertain the truth of this indication, a second dissection was made. In this the two metals were placed in contact with each other, and the wet cloth in contact only with the zinc plate. Suppose a pair of zinc and silver plates in contact with each other, placed on the base of the pile with the silver lowest, then a disk of wetted cloth upon the zinc, and a tripod upon the wetted cloth; then another group of zinc and silver, with wet cloth upon the zinc; then again a tripod, and so on, in regular order, until the seventy-six groups were arranged.

112. With this apparatus the electrical effects were produced as before; but, though these ceased when the usual glass tube for decomposing water was made to connect the opposite poles, not the slightest chemical effect was produced.

113. From this it appears, that the condition for the production of chemical and electrical effects is different; the latter requiring the arrangement of silver and zinc in mutual contact, the successive pairs being separated by a moist conductor, which may be in actual contact with the zinc only; the former requiring the association of silver and zinc, with wetted cloth between them.

114. A third dissection of the pile was thus arranged: silver and zinc in mutual contact, wetted cloth in contact with silver: seventy-six of these groups were placed in regular order, with a tripod upon the wet cloth of each group, as in the former experiment. With this arrangement neither chemical nor electrical effects were produced; the absence of electrical signs M. De Luc ascribed to the zinc plates being in contact on one side with the silver, and on the other with the brass of the tripod, which he regarded as a counteracting effect. The absence of chemical signs arose from the want of the condition for

their production, namely, successive associations of zinc and silver, with a fluid between them and in contact with both.

115. When either the continuous pile, or that composed of the efficient ternary groups, are put together with the pieces of cloth moistened with pure water, although chemical effects are produced, no perceptible shock can be felt; but, when the pieces of cloth are moistened by a solution of common salt, the shock is very distinct. Hence M. De Luc concludes, that for the production of chemical effects in the circuit it is essential that the zinc undergo oxidation, and for the production of the shock it is necessary that oxidation be effected by the action of an acid.

116. M. De Luc conceived the phenomena of the pile might arise from some modification of the electric fluid which pervaded it during the oxidation of the zinc; and as, in his experiments, he obtained more perceptible electrical indications by aid of the condenser, from wires immersed in water, when the chemical effects and the shock were produced, he concluded that this modification of the electric fluid was attended by a retardation of its course, by which a very small quantity was enabled to produce effects which are not obtained by a much larger quantity when set in motion by the electrical machine.

117. This idea, it may be observed, is the very converse of that which, from a very general and extended view of the phenomena of the Voltaic apparatus, Mr. Singer proposed.

It was indeed a natural inference at first view, from the experiment in question, when that alone was considered; but the increased rapidity of decomposition, which always attends the increased operation of that influence, which is here supposed to cause a retardation of the current that occasions decomposition, is very inimical to any such supposition; and the usual phenomena of electrical analysis are equally at variance with it.

118. When any fluid is decomposed by the action of the common electrical apparatus, the effect is always proportioned to the intensity of the current of electricity that passes through it; and in the decomposition of water, when the metallic surface in contact with it is of moderate extent, very strong shocks in rapid succession are required. It is to the acute intelligence of Dr. Wollaston we are indebted for the means of executing this analysis with a more moderate power. He enclosed the metallic conductor in glass, or wax, and exposed only a very small portion of its surface to the fluid. The current of electricity, being thus reduced in volume, was proportionably increased in force; and, by rendering the exposed surface very minute, a sufficient intensity was produced, by a moderate quantity of electricity.

119. When a circuit is made through water, by wires proceeding from the opposite extremities of a Voltaic battery, those wires can impart no charge to the condenser, unless the quantity of electricity evolved by the battery is greater than the water can transmit: therefore any cause that increases the quantity, will produce an augmentation of effect by this test, whilst the column of water remains the same: or if the velocity of the electro-motion of the apparatus be increased, whilst the same imperfect conductor is interposed between its extremities, a similar effect must take place; for the positive wire will receive electricity from the pile faster than it can transmit it to the water, and the negative wire yields electricity to the pile more rapidly than it can receive it from the water; so that a slight positive and negative charge will be given to the condenser by these wires respectively, whenever the electro-motion of the pile supplies electricity faster than the water can conduct it; and the charge will be highest when the supply is most rapid. Now, according to Mr. Singer's principle, the most rapid electro-motion of the apparatus will be produced when the different pairs of plates communicate with each other through the medium of the best conducting fluids: it is therefore obvious, that the result of M. De Luc's experiments, in which a more considerable charge was communicated to the condenser by wires immersed in water, when the pile was excited by a saline solution, than when it was excited by pure water, is conformable to the above principle; and the legitimacy of this inference is confirmed by a variation of the experiments; for if, when the apparatus is excited by a saline fluid, the tube that connects its extremities be filled with the same fluid instead of pure water, no increased charge will be given to the condenser by either of the wires, because the increased electro-motion of the apparatus is then compensated by the increased conducting power of the fluid by which its extremities are connected.

120. When different degrees of chemical action are excited in the Voltaic apparatus, by the introduction of various fluids, the more powerful the action that is produced the more transient is its duration. This circumstance is of importance in the practical application of the instrument, since it offers the means of judiciously applying various methods of experiments, and of continuing the action of the apparatus during any required time. When the battery is charged with water, its chemical action is feeble, but it appears to continue without diminution for any indefinite length of time; by the addition of a minute quantity of muriatic acid, $\frac{1}{300}$th part for instance, its chemical action is greatly augmented, and still continues for a considerable period. When the proportion of acid is increased to a thirtieth or twentieth part, the action is considerable, but comparatively of short duration. Mr. Singer says, he has found no solutions so advantageous as those of acids, and he prefers the muriatic acid to all others; the nitric is indeed rather more powerful in the same proportion, but its cost is four times as great, and it is found that it destroys the copper plates as well as the zinc. The nitrous gas evolved by its action is also much more offensive than hydrogen, which results from the employment of muriatic acid.

121. The experiments of M. De Luc induced him to conclude, with Volta, that the electrical effects of the apparatus result entirely from the successive association of the different metals,

separated into pairs by some conducting substance that does not interfere with their electromotive powers. To ascertain if a liquid was essential to this effect, he mounted a pile with pieces of cloth not moistened, and he found the electric effects were still produced, but somewhat weaker than with the wetted cloth. He then instituted a series of experiments, successively mounting the pile with different animal and vegetable substances, interposed between the pairs of metal, instead of wetted cloth. Of the various substances tried, he preferred writing paper, as the most convenient of those that were efficient. The apparatus constructed in this way was found to have the same electrical indications as the common Voltaic pile, but it produced no chemical effects, however numerous the pairs of plates; nor was any oxidation of the zinc produced by its most protracted action. These circumstances led to the idea, that, by the extension of the number of groups, a kind of perpetual electric machine might be formed; and, as in the previous trials, it had been found that the effect was rather increased by pasting the paper upon the silver or copper. Dutch gilt paper, which consists of thin copper leaf, laid upon paper, was employed instead of the usual silver, or copper plates, and moist conductors: 800 plates of tinned iron being put together with the same number of Dutch gilt paper between them, the copper sides being all turned in one direction, the combination was found to affect the electrometer more powerfully than any Voltaic battery had been ever observed to do; but on the application of the usual glass tube with water, no chemical effect was noticed. The apparatus was left for a considerable time, and its action on the electrometer continued without diminution; and subsequent experience has shown that it does so for any period during which the experiment has been continued. Thus was invented a new and important Voltaic arrangement, highly valuable both in a theoretical and practical view: in the former, as separating the pure electrical effects of the Voltaic battery from its chemical power, and demonstrating the permanence of its electro-motive faculty: in the latter, as providing a spontaneous and permanent electrical machine, in which the opposite electrical states perpetually exist, without any new excitement. Besides these properties, the new apparatus promises to become an important meteorological instrument; for the degrees of its electrical indications have been observed to vary with the different seasons of the year, and are probably influenced by some of the causes by which our atmospherical phenomena are produced.

122. To distinguish this instrument from the usual Voltaic apparatus, from which it differs in many respects, M. De Luc proposed to call it 'the Electric Column,' an appellation sufficiently appropriate, since the effects it produces are purely electrical.

123. Mr. Singer made very numerous experiments, on the constructions of such columns, and varied their combinations most extensively. The materials he preferred, are thin plates of flatted zinc alternated with writing or smooth cartridge paper, and silver leaf. The silver leaf is first laid on paper, so as to form silvered paper, which is afterwards cut into small round plates by means of a hollow punch. In the same way an equal number of plates are cut from thin flatted zinc, and from common writing or cartridge paper. These plates are then arranged in the order of zinc, paper, silvered paper with the silvered side upwards; zinc upon this silver, then paper, and again silvered paper, with the silver side upwards; and so on, the silver being in contact with zinc throughout, and each pair of zinc and silver plates separated by two discs of paper from the next pair. An extensive arrangement of this kind may be placed between three thin glass rods, covered with sealing-wax, and secured in a triangle, by being cemented at each end into three equi-distant holes in a round piece of wood; or the plates may be introduced into a glass tube previously well dried, and having its ends covered with sealing-wax, and capped with brass; one of the brass caps may be cemented on before the plates are introduced into the tube, and the other afterwards; each cap should have a screw pass through its centre, which terminates in a hook outside. This screw serves to press the plates closer together, and to secure a perfect metallic contact with the extremities of the column. To fill the tube with discs, it is necessary to employ a cylindrical rammer of baked wood with flat ends, and when a small number (as about half a dozen discs) are introduced, they should be thrust down, taking care to ensure their perfect contact; and the operation of the apparatus will be ensured.

124. Soon after the invention of the column, Mr. B. M. Forster discovered that, when a sufficiently extensive series was put together, its electric power was sufficient to produce a sort of chime by the motion of a small brass ball between two bells, insulated, and connected with the opposite extremities of the column. He constructed a series of 1500 groups, and by its agency kept a little bell-ringing apparatus in constant activity for a considerable length of time.

125. Mr. Singer contrived an arrangement which is well calculated to form a perpetual motion, by excluding, to a very considerable extent, the operation of extraneous causes of interruption, and it at the same time renders the disposition of the apparatus rather elegant. A series of from 1200 to 1600 groups are arranged in two columns of equal length, which are separately insulated in a vertical position by glass pillars constructed on his principle of insulation; the positive end of one column is placed lowest, and the negative end of the other; and, their upper extremities being connected by a wire, they may be considered as one continuous column. A small bell is situated between each extremity of the column, and its insulating support, and a brass ball is suspended by a thin thread of raw silk, so as to hang midway between the bells, and at a very small distance from each of them. For this purpose the bells are connected, during the adjustment of the pendulum, by a wire, that their attraction may not interfere with it; and, when this wire is removed, the motion of the pendu-

lumn commences. The whole apparatus is placed upon a circular mahogany base, in which a groove is turned to receive the lower edge of a glass shade with which the whole is covered.

126. If a column of about 1000 series is placed horizontally, with each of its extremities resting on a gold leaf electrometer, the electrometers will each diverge; that connected with the zinc extremity of the column will be positive, that connected with the silver extremity will be negative. If the column be very powerful, the gold leaves of the electrometer will alternately strike the sides of the glass, but this motion is soon stopped by their adhering to it. If the simple divergence only is produced, on touching either extremity of the column, the electrometer connected with it closes, and that at the opposite extremity has its divergence increased. This is analogous to the effect of the Voltaic battery when disposed in a similar manner; but the motion in the column is slower, which arises from the more imperfect conductors of which it is composed.

127. There is some cause, not yet perfectly developed, that appears to influence the power of the column to produce the motion of light metallic pendula. In the bell-ringing apparatus, for instance, though the motion always continues, it is much more rapid at one period than another, and the oscillations of the pendulum, though usually as uniform as that produced by mechanism, is on some occasions singularly wild and irregular. The frequency with which the gold leaves of an electrometer strike the sides of the glass, when connected with an electric column, is also different at different times; the variations observed in some experiments of M. De Luc are much more considerable than we have yet noticed, with the more powerful columns of Mr. Singer's construction.

128. De Luc proposed, as an interesting object of enquiry, to make regular observations on the action of the column, and the number of oscillations it would produce in a given time, at each observation. For this purpose a single column of from 1000 to 2000 series may be supported vertically on an insulating pillar. A bent wire, with a ball at its lower end, is to be connected with the upper extremity of the column, so as to hang parallel with, and at some distance from it; the ball at its lower extremity being diametrically opposite to a similar ball that is screwed into the lower cap of the column. To the same cap there is also screwed a brass fork with a fine silver wire stretched between its extremities; this is placed above the ball and projects farther from the column, so that when the pendulum moves towards the ball it strikes this wire first, and receives a kind of jerk, which prevents it from sticking. The pendulum consists of a gilt pith-ball suspended by a very fine silver wire, which hangs parallel to the bent brass wire, to which it is fastened at top; the arrangement is such, that the gilt pith-ball would be always in contact with the brass ball that proceeds from the upper extremity of the column, if the apparatus had no electrical power; it therefore always returns to this situation, when, after being attracted to the lower extremity of the column, it discharges its electricity by striking against the cross silver wire.

129. There appears every reason to believe, that the action of a well-constructed column would be permanent. There is, however, a precaution necessary to their constant and immediate action; the two ends of a column should never be connected by a conducting substance for any length of time; for if, after such continued communication, it be applied to an electrometer, it will scarcely affect it for some time. It is, therefore, necessary, when a column is laid by, that it be placed upon two sticks of sealing-wax so as to keep its brass caps at the distance of about half an inch from the table, or other conducting surface on which it is laid. And if a column, which appears to have lost its action by laying by, be insulated in this way for a few days, it will usually recover its full power.

130. There is another cause of deterioration which is more fatal; it is the presence of too much moisture. If the paper be perfectly dry it is a non-conductor, and will not therefore produce any action in the column; but this perfect dryness can only be obtained by exposing the paper to a heat nearly sufficient to scorch it, and in its dryest natural state the paper will be found sufficiently a conductor, even when, by exposing the paper discs to the heat of the sun, they have been so dried as to warp considerably. When the paper is sufficiently dry, the action of the column continues without diminution; and on taking such an apparatus to pieces after it had been constructed thirty months, no trace of oxidation was evident on the zinc plates.

131. The size of the plates in the column need not be large; Mr. Singer has constructed them of various sizes, and finds no proportionate advantage by extending the diameter beyond five-eighths of an inch; they may even be constructed much smaller, and yet found to act with the greatest precision.

132. By connecting the extremities of a column of at least 1000 series, with the opposite coatings of a Leyden jar, during a period of from one to five minutes, a charge is usually communicated to it capable of affording a small but distinct spark, when the discharge is made by a wire that is not very thick.

133. Mr. Singer observes that the most extensive series he had ever made experiments with, consisted of 20,000 groups of silver, zinc, and double discs of writing paper. Its power was considerable. Pith-ball electrometers, with balls of one-fifth of an inch diameter, and threads of four inches long, diverged to the distance of two inches and upwards, when connected with its opposite extremities. An electrometer in the centre was not affected. When either extremity of the column was connected with the ground, the electrometer attached to that extremity closed, and the central electrometer opened with the same electricity, whilst that connected with the opposite extremity had its original divergence considerably increased; but the electro-motion was so slow, that some minutes were required to produce the full effect.

134. By connecting one extremity of the series with a fine iron wire, and bringing the end of

this near the other extremity, a slight layer of varnish being interposed, a series of minute bright sparks were obtained by drawing the point of the iron wire lightly over the varnished surface.

135. A jar containing fifty square inches of coated surface was charged by ten minutes contact with the column, so as to convey a disagreeable shock, felt distinctly in the elbows and shoulders, and by some individuals across the breast.

136. The charge from this jar could perforate thick drawing paper, but not a card. It had just power to fuse one inch of platina wire, of the $\frac{1}{5000}$th of an inch diameter.

137. Notwithstanding the considerable electric power of this combination, it had not the slightest chemical action; neither the best nor worst conducting media were affected. Saline compounds, tinged with the most delicate vegetable colors, were exposed under the most favorable circumstances to its action, and in some instances for many days, but no chemical effect was produced.

138. It therefore appears indispensably necessary to the chemical power of the Voltaic apparatus, that a liquid be interposed between each pair of its plates, whilst, for the pure electrical effects, the only condition appears to be the association of the two metals, and the connexion of the different pairs, by some conductor that does not interfere with their electro-motive power.

138*. The first experiments made upon the moist pile in this country appear to have been performed by Messrs. Nicholson and Carlisle. After observing the effects then ascribed to the piles on bringing the wires from each end of the column in contact with a drop of water, they observed a disengagement of bubbles of some elastic fluid.

139. On closer examination they found the gas to be hydrogen. They then took a glass tube, about half an inch in diameter, into each end of which a cork was inserted, the tube being filled with water. Through each cork was introduced a brass wire, so that the ends of the wires in the glass were about an inch and three-quarters of an inch. The pile employed consisted of thirty-six half-crowns, and as many similar pieces of zinc, and wet pasteboard. The zinc end of the pile was then connected with one of the wires in the tube, and the silver end with the other, so that the circuit formed by the pile was separated by the water in the tube placed between them. A stream of bubbles was observed at the end of the wire, in the tube connected with the silver end of the pile. No gas was disengaged from the opposite wire, but it speedily became tarnished, first of an orange color, and ultimately black. The tube was then reversed, when it was observed that the wire, which in the first experiment became tarnished, gave out bubbles, while that which had before given out gas, in its turn became tarnished.

140. The emission of gas from the wire connected with the silver end of the pile was constant and uniform, except when a metallic circuit was formed between the ends of the pile, during which no gas whatever appeared. It was observed that, when this metallic conductor was removed, the appearance of the gas was not immediate, since there was an interval of about two seconds between the removal of the wire and the appearance of bubbles. After the process had continued two hours and a half, a bulk of gas was produced equal to two-thirds of a cubic inch. This gas was mixed with an equal bulk of common air, and exploded on the application of a lighted taper.

141. These ingenious experimenters, supposing the phenomena in question to arise from the decomposition of the water, thought it surprising that the hydrogen should make its appearance at a distance of an inch and three-quarters from the point where the oxygen was disposed of.

142. They then made the same experiment with a tube thirty-six inches in length, but no gas was observed. When they introduced an infusion of litmus instead of pure water, they observed that the fluid in the vicinity of the wire connected with the zinc end of the pile became red, and hence were led to suppose that an acid had been produced. The fluid at the other wire was not changed, but gas, as usual, was evolved.

143. It may be proper to state that, in every apparatus constructed for practical purposes, there is a combination of three different substances in contact with each other, in successive groups; in general it is an arrangement of copper, zinc, and some conducting fluid. It is demonstrable that the primary source of the electrical power of the apparatus is the association of the two metals; and, according to Volta, the interposed fluid serves only as a conductor of the effect of one pair of metals to another. As far as electricity is concerned, this opinion appears to be correct, for the electrometer is acted on, whatever be the nature of the interposed fluid, and the degree of divergence is proportioned to the number of the plates. The electrometrical effects prove also, that, the arrangement of a series of zinc and copper plates, with an interposed fluid, forms a conducting column, which, in its insulated state, is positive at one extremity, negative at the other, and neutral in the middle. This may be easily shown by three gold-leaf electrometers, connected at the same time with an apparatus of 300 or 400 pairs of plates. The electrometer, connected with the copper extremity, will diverge with negative electricity; that connected with the zinc end will separate to the same distance positively; while that connected with the central plate of the series will not be affected. But, if either extremity of the battery be connected with the ground by means of a wire, the leaves of the electrometer connected with it will close; and those of the central electrometer will open with the same electricity, and to the same extent, whilst those of the opposite extremity will have their original divergence increased.

144. Hence it appears that there is a real electro-motive property in the apparatus, by which the zinc end constantly tends to become positive, and the copper end negative; and it is also obvious, that the extent of this operation,

at either extremity, is increased by connecting the opposite end with the ground. This last experiment, by which the central plate may be rendered either positive, negative, or neutral, at pleasure, proves also that the interposed fluid never acts as an insulator, for if it did so these changes could not possibly occur.

145. As the contact of either surface of the battery with the ground increases the electrical state of the opposite extremity, the same circumstance may be presumed to take place with every pair of associated metals, when their surfaces are in contact with a conducting fluid. Whilst the apparatus is insulated, the first zinc plate can only act on the electricity of its associate, the first copper plate; but the second zinc plate, through the conducting interposed fluid, can act on both these, besides its companion, the copper, and may therefore become more highly positive; and it is easy to conceive that such a repetition of action would be attended with an increase of effect, proportioned to the number of plates; and that the electrical tension of either end must be increased by connecting the other with the ground.

146. To ascertain if this principle really operated with a single combination, Mr. Singer took a pair of circular plates six inches diameter, very clean and smooth, one being formed of zinc and the other of copper, and each provided with an insulating handle. When both plates were held by their insulating handles, and the zinc was successively applied to the flat surface of the copper, and after each contact made to touch the insulated plate of a condenser of six inches diameter; twenty contacts were required to communicate such a charge to the condenser as would occasion the leaves of a very delicate electrometer to separate to a quarter of an inch. But when the copper plate, instead of being held by its insulating handle, was simply laid on the hand, or on any similar conducting body, ten successive contacts of the insulated zinc plate, communicated a charge to the condenser, which occasioned the gold leaves to separate to the distance of more than half an inch. On repeating these experiments, with the variation of touching the condenser with the copper plate, held by its insulating handle, and brought in contact with the zinc plate, first insulated, and then uninsulated, similar results were obtained, but with the contrary electrical state. Hence the similarity of action in a single pair of metals, and a combined series, is sufficiently proved; and the preceding statement of the manner in which the electrical power is supposed to increase with the number of associated plates, is rendered highly probable.

147. So far the phenomena are sufficiently simple and consistent, for those described are not materially influenced by the nature of the interposed fluid, nor do they occur, but when the extremities of the apparatus are unconnected with each other, and consequently capable of maintaining the opposite electrical states. But the chemical effects, the shock, and the power of ignition, take place only when the extremities of the apparatus are connected by some conductor, and are also materially influenced by the nature of the interposed fluid. If these effects then, are produced by electricity, they can only result from its circulation in the apparatus; and, as there is no reason to suppose that the electro-motive power of the associated metals ceases when there is a conducting communication between their opposite surfaces, but rather that it is accelerated by such a circumstance; that very acceleration may be the cause of the phenomena, and the effects observed correspond very nearly with such an idea; for, if it be admitted that the connexion of the opposite ends of the Voltaic battery by a conductor, occasions a current of electricity from the positive to the negative, that current must be more rapid, in proportion as the conductor is more perfect. Now it is found that the chemical effects are most considerable, and more promptly produced in fluids of the highest conducting power; thus the quantity of gas liberated in a given time from common water, is greater than from distilled water; saline fluids furnish more than common water; solutions of alkali more than saline fluids, and acids more than alkalies: and, as the effects of a simple combination are influenced by the same causes as those that operate with a series, the fluids that are susceptible of the most rapid decomposition are also most active in exciting the chemical effects of the battery, when employed as the connecting medium between its plates.

148. Acids are of all other fluid bodies, excepting metals, the most perfect conductors, and the chemical effect of the battery is more powerfully excited by them than by any other substances; it is possible that their chemical action on the zinc may have some share in modifying the quantity of electricity, or the rapidity of its motion; but it is certain that the effects are not in proportion to the chemical action; sulphuric acid, for instance, acts as powerfully on the zinc as nitric or muriatic acid, but it is not so active in producing the chemical agency of the battery: in like manner the alkalies, which exert a very trifling action on the battery, excite its powers with greater energy than many saline fluids which are more efficient as chemical agents.

149. The ignition of wire, and of charcoal in the Voltaic circuit, is conformable to this view; these substances are the most perfect conductors known, and, when made the medium of communication between the opposite ends of a battery, must accelerate its electro-motive power to the greatest extent. The rapid circulation of electricity, thus obtained, produces ignition, if the conductor be not too large in proportion to the quantity of electricity; but, within this limit, the effect will be greatest with the thickest wire, because the acceleration will be more considerable in proportion to the facility of transmission. There is, perhaps, no other view on which the continued ignition of wire, and the increased action of large plates is so intelligible.

150. The cessation of chemical agency, and igniting power, as the chemical action of the acids or other menstrua declines, may arise from the total change which then occurs in the nature of those fluids; their conducting power is much diminished, and they may possibly, by the change

in their chemical properties, acquire some faculty of electro-motion subversive of the effect of the combined metals.

151. The extensive experiments of Messrs. Hisinger and Berzelius, confirmed by the researches of Sir H. Davy, had demonstrated the constant separation of oxygen, and compounds in which it prevailed, at the wire proceeding from the zinc surface, and of hydrogen and other inflammable matter, at that connected with the copper surface; and, at this latter, alkali was also frequently found, and, from analogy, it was in consequence concluded, that the alkalies probably contained a considerable proportion of some inflammable substance.

152. This conjecture was confirmed by Sir H. Davy in 1807: he found that a thin piece of potassa or soda, slightly moistened by exposure to the air, and placed between two conductors of platina, proceeding from the opposite sides of a powerful Voltaic apparatus, was resolved into a peculiar metallic substance highly inflammable, which appeared at the negative surface; and oxygen gas, which was evolved at the positive surface. By an extensive series of experiments, it was shown that these bodies are, in reality, metallic oxides, and that the proportion of their constituent parts is somewhat different, being in round numbers, for potassa six parts of metallic base to one part of oxygen, nearly; or it may be stated that potassa is composed of eighty-six parts of metal, and fourteen of oxygen in each 100 parts. The proportions in soda are nearly seven parts metal to two of oxygen; or seventy-eight metal and twenty-two oxygen, in each 100.

153. The metal obtained from potassa is called potassium; it is lighter than water in the proportion of eight to ten. At common temperatures it is solid, but soft and plastic. At a temperature of 150° it becomes fluid, and evaporates at a heat rather below redness. In color it nearly resembles silver, but it tarnishes immediately when exposed in the open air, and can only be preserved under naphtha. Its attraction for oxygen is so powerful, that it will detach that substance from almost all its combinations; and the result of this action is its consequent oxidation and reconversion into potassa. If thrown into water it immediately inflames, floats upon the surface, and burns with a mixed flame of white, red, and violet; rendering the water, in which the experiment is made, alkaline. Similar phenomena ensue when it is brought in contact with ice. When moderately heated in oxygen gas it inflames and reproduces potassa. Its action on water is always attended by the decomposition of that fluid; hydrogen is evolved, and the oxygen combines with the potassium to form potassa. By measuring the quantity of hydrogen separated from water, by the action of a given weight of potassium, the quantity of oxygen that metal combines with to form potassa may be readily learnt. Each grain of potassium detaches about 1·06 cubic inch of hydrogen gas, and consequently combines with half that quantity of oxygen.

154. The metal obtained from soda is named sodium; it is rather lighter than water, nearly as 0·9348 to 1000. It has the color of silver; is less fusible than potassium, but tarnishes in air in the same way. It is fluid at the temperature of 200°, and passes into vapor at a strong red heat. At common temperatures it is a soft metal, and a globule of it may be easily spread into a thin leaf by the action of a knife. It decomposes water violently, and floats on its surface, but does not inflame; the water is rendered alkaline, and, when examined, is found to contain pure soda. It acts nearly in the same manner as potassium, but with less energy, on most substances, and must consequently be preserved under naphtha. When thrown on the surface of nitric acid it inflames, and burns with great brilliance; it also occasionally scintillates when thrown upon hot water. The proportion of oxygen with which it combines to form soda, may be learnt by noting the quantity of hydrogen evolved from water by a given weight of the sodium.

155. Both these new metallic substances unite with mercury in various proportions, and form amalgams which decompose water, but more slowly than the metals themselves; these amalgams act upon all other metals, even platina and mercury.

156. The decomposition of the alkalies may, by care and attention, be effected with a battery of fifty pairs of plates of three or four inches square; but the results are rather uncertain: 200 plates form a very efficient arrangement; they should be excited by a weak acid mixture (about one part strong muriatic or nitrous acid, to thirty parts of water). A plate of silver or platina being connected with the negative side of the battery, a thin piece of pure potassa or soda is to be placed upon it, and a platina or silver conductor, proceeding from the positive side of the battery, is to be brought in contact with the upper surface of the alkali, which soon fuses at the points of contact: metallic globules shortly appear near the negative surface, and gradually increase in size, until a crust of alkali begins to form on their surface; at this moment they should be removed by the point of a knife, and instantly plunged under naphtha; or, if the experiment be merely intended to demonstrate their production, they may be brought in contact with the surface of water or nitric acid. It sometimes happens that no globules appear; but if the contact be preserved for some time, and the alkali be afterwards raised, several will be found imbedded in its under surface. If the action of the battery be strong, it also sometimes happens that the globules inflame, and even detonate at the moment of their production; it is therefore advisable not to bring the eyes too near during the experiment, or else to cover them with glasses. These experiments always require great care to insure their success, which a trifling variation in the power of the battery, purity of the potassa, or moisture of the atmosphere, may prevent.—Soda is rather more difficult to decompose than potassa, and therefore requires to be employed in thinner pieces; the pieces of potassa should rarely exceed a quarter of an inch in thickness, and those of soda one-eighth of an inch.

157. To prevent the loss of the alkaline bases during their separation, by the powerful action of the air upon them, it has been proposed to effect

the decomposition under naphtha: the moist potassa being placed between two plates of platina in a proper vessel, which is to be filled with naphtha as soon as the contact with the battery is established; in this way the action of the air is prevented, but the naphtha decomposes, and hydrogen and charcoal are liberated, which renders the result less satisfactory than in the more simple form of the experiment. The most essential precautions are to preserve the alkali as dry as is consistent with a sufficient degree of conducting power, and to employ the battery in a moderate state of action, in which it does not produce a very intense heat, for that would destroy the metallic base at the moment of its production.

158. The amalgam of potassium, or sodium, with mercury, is easily procured; and may be obtained by a very moderate power. A glass tube, one-fourth of an inch diameter and three inches long, having a short platina wire sealed in one end, is to have mercury poured into it until the end of the platina wire is covered; the rest of the tube is to be filled with a concentrated solution of alkali, either pure or carbonated. The platina wire, surrounded by mercury, is then to be connected with the negative end of a Voltaic battery, and the circuit completed by bringing a platina wire from the positive end, in contact with the solution of alkali. Gas will be evolved from this wire, and the surface of the mercury will be greatly agitated; when the action grows weaker, the mercury may be poured into a glass of water, and the presence of the alkaline metal will be immediately indicated by the evolution of a cloud of minute bubbles of hydrogen gas, which may be collected by inverting over the mercury a small closed glass tube filled with water. This result has been frequently obtained with a battery of thirty pairs of plates of only two inches square.

159. The amalgam may be obtained more highly charged with the alkaline metal by employing a solid piece of alkali, with a small cavity on its surface, in which a globule of mercury is to be placed. The alkali is to be connected with the zinc surface of a battery, and the mercury with the copper surface; the mercury soon becomes more tenacious, and sometimes is converted into a soft solid mass, and in this state, if thrown into water, it produces a rapid decomposition.

160. The strong attraction of the metals of the alkalies for oxygen, renders them most active agents of chemical decomposition; by the strongest Voltaic power they can only be obtained in small quantity; and for the purpose of experiment they are now usually procured by another process first devised by the French chemists. A gun-barrel is bent nearly in the form of the letter S. An iron tube of the capacity of two cubic inches, having a small hole at the lower extremity and an iron stopper at the top, is ground into one end of the gun-barrel, and a tube of safety is fitted to the other. The iron tube is to be filled with pure dry potassa, and the bent part of the gun-barrel nearest to it, with clean iron turnings: this part of the barrel is to be luted and placed in a small blast furnace; the iron tube projecting out on one side, and the vacant part of the gun-barrel, with its attached tube of safety, charged with clean oil, or naphtha on the other. A strong heat is then to be raised in the furnace, and, when the iron turnings have attained an intense white heat, a small furnace is to be applied to the tube containing the potassa, which, being readily fused, will flow through the small hole at the bottom of the tube upon the iron turnings. The oxygen of the potassa combines with the heated iron, and the potassium condenses in brilliant laminæ in the vacant part of the gun-barrel, which must be kept cool by ice during the process. As potassa always contains water, that is also decomposed, and hydrogen escapes during the experiment, from the tube of safety; the cessation of this liberation of gas is the sign for removing the small furnace from the tube, and the heat being raised in the blast furnace for a few minutes, as high as possible, to expel the last portions of potassium from the iron, the whole apparatus is suffered to cool. The gun-barrel is then to be cut at the commencement of the part which has been kept cool, for there the greatest portion of potassium is usually found; it must be detached by a chisel in as large pieces as possible, and introduced quickly into naphtha, a portion of which fluid it is expedient to pour into the barrel as soon as it is first opened.

161. This process is attended with some difficulty, but it has been repeated successfully by many chemists in this country: a more detailed account of it may be consulted in the thirty-second volume of the Philosophical Magazine, pp. 89, and 276.

162. The composition of the fixed alkalies was entirely unknown before these experiments, but the volatile alkali, or ammonia, had been shown to consist of hydrogen and nitrogen, in the proportion of three of hydrogen to one of nitrogen by volume. Now it is singular, that of three bodies, whose properties are so analogous, two should be metallic oxides, and a third a compound of two gases; but there are experiments that seem to prove that either one or both of these gases contain a metallic substance, and that consequently ammonia may be, like the other alkalies, a metallic oxide.

163. Messrs. Berzelius and Pontin of Stockholm, discovered that when mercury is placed in a Voltaic circuit with a solution of ammonia, the mercury being connected with the copper-extremity of the battery, and the ammonia with the zinc, the mercury gradually expands to four or five times its original volume, and becomes a soft solid, nearly of the consistence of butter, having its metallic character quite unimpaired. It is very remarkable, that by this change it gains only about $\frac{1}{12000}$ part of its weight; yet has its specific gravity so much diminished, that, from being thirteen or fourteen times heavier than water, it becomes only three times heavier. By a short exposure to the atmosphere, it regains its original size and fluidity, absorbing oxygen and reproducing ammonia. When thrown into water a similar effect is produced, the water being decomposed and hydrogen liberated.

164. These phenomena are very analogous to those observed with the fixed alkalies; some substance combines with the quicksilver and alters its properties materially, without imparing its metallic character; now, according to all existing analogies, this substance must be a metal, and this metal, in returning to the state of alkali, absorbs oxygen, as is seen by its action on water. Hence it appears that ammonia consists of oxygen and a peculiar metal which may be called ammonium; but its analysis by other means evinces only the two gases, hydrogen and nitrogen; the former of these being the lightest of all gravitating bodies, is most probably a simple or elementary substance; and, on such a view, it would seem that nitrogen, though a gaseous body, is a compound of oxygen and a metal.

165. The amalgam of ammonium may be formed most readily by making a cavity in a moistened piece of muriate, or carbonate of ammonia, connected with the positive side of a Voltaic battery, and inserting in it a globule of mercury connected by a platina wire with the negative surface; in a few minutes a soft amalgam is formed; it must be transferred into water as quickly as possible when its action on that fluid is to be observed, as it changes by the shortest possible contact of the air.

166. Sir H. Davy has observed, that the strong attraction of potassium for oxygen, enables it to decompose ammonia even more rapidly than the Voltaic battery; and if an amalgam of potassium and mercury be placed in a cavity in moistened muriate of ammonia, it immediately increases in size, and becomes more consistent.

167. As some of the substances called earths resemble the alkalies in various properties, it was conjectured, that they also were metallic oxides; and this conjecture has been partly verified by the experiments of Messrs. Pontin and Berzelius, and Sir H. Davy. If a paste be formed with water, and either barytes, strontites, lime, or magnesia; and this paste be connected with the positive side of a Voltaic battery, and touched with an iron wire proceeding from the negative surface, the wire obtains the property of decomposing water.

168. If a globule of mercury be placed in a cavity in the earthy body, and touched with a wire proceeding from the copper end of the battery (the paste being connected with the zinc), an amalgam will be soon formed, which has the property of decomposing water, and forming with it a solution of the earth employed. If this amalgam be introduced into a little tube made of glass, and bent in the form of a retort, then filled with the vapor of naphtha and hermetically sealed; on the application of heat to the end of the tube containing the amalgam, the mercury will distil over and leave the pure metal of the earth behind. This process is rather difficult, and requires great care.

169. The amalgam from barytes, strontites, and lime, may be obtained with a battery of from 100 to 200 four-inch plates, in a moderate time; that from magnesia requires a longer continuance of the action of the battery, and the other earths do not readily yield to its powers. These metals are named from the earths of which they appear to be the bases, as follows: namely, that from barytes, barium; strontites, strontium; lime, calcium; magnesia, magnesium; alumine, aluminum; silex, silicum, &c.

170. The decomposition of the alkalies and earths which had previously resisted every attempt at analysis, are a monument of the importance of the Voltaic apparatus as an instrument of chemical research; and a proof of the ability with which it has been employed, which will be regarded with admiration and applause as long as science shall continue to be cultivated.

171. The phenomena that have been described as the consequences of Voltaic decomposition obtain in every variety of experiment. Sulphuric acid introduced into the Voltaic circuit gives off oxygen gas, and sulphur is deposited. Phosphoric acid evolves oxygen gas, and phosphorus combines with the negative wire. Ammonia separates into hydrogen and nitrogen with a small proportion of oxygen. Oils, alcohol, and ether, when acted on by a powerful battery, deposit charcoal, and give off hydrogen, or carborated hydrogen. And professor Brande has shown, that when animal fluids containing albumen, are placed in the Voltaic circuit, the albumen is separated in combination with alkali at the negative wire, and in combination with acid at the positive wire; and that, with a powerful battery, it separates at the negative wire in the solid form; and with a less power, in the fluid form, so that it is probable animal secretion may depend on some such power.

Prior to an examination of the Voltaic apparatus there are some simple experiments that should be noticed.

172. If a wire of silver, and another of zinc, be immersed in a glass containing dilute muriatic acid, so as to remain at a little distance from each other, the zinc will give off hydrogen gas rapidly, but the silver will produce no effect. Bring the ends of the wires that are out of the acid in contact, by twisting them together; the quantity of hydrogen given off by the zinc will be diminished, and bubbles will be evolved from the silver.

173. If zinc, iron, or copper, are employed in the same way with gold, in dilute nitric acid, similar phenomena ensue, but the gas produced is nitrous gas.

174. If a wire of iron and another of silver are immersed in a solution of copper, the iron will soon become coated with copper, but the silver will remain unchanged. Bring the wires in contact, by twisting their upper extremities together, and the silver will be soon covered with a coat of copper.

175. Similar experiments may be made with a zinc and a silver wire, in solutions of lead or tin.

176. Dr. Wollaston, to whom we are indebted for the last two experiments, thus accounts for the result:—'We know that when water is placed in the circuit of conductors of electricity, between the two extremities of a pile, if the power is sufficient to oxidate one of the wires of communication, the wire connected with the opposite extremity affords hydrogen gas.

177. 'Since the extrication of hydrogen in this instance is seen to depend on electricity, it is probable, that in other instances, electricity may be also requisite for its conversion into gas. It would appear, therefore, that in the solution of a metal, electricity is evolved during the action of the acid upon it; and that the formation of hydrogen gas, even in that case, depends on a transition of electricity between the fluid and the metal.

178. 'We see moreover, in a former experiment, that the zinc, without contact of any other metal, has the power of decomposing water; and we can have no reason to suppose that the contact of the silver produces any new power, but that it serves merely as a conductor of electricity, and thereby occasions the formation of hydrogen gas.

179. 'In the last experiment, also, the iron by itself has the power of precipitating copper, by means of electricity evolved during its solution; and here likewise the silver, by conducting that electricity, acquires the power of precipitating the copper in its metallic state.'

180. The experiments of this ingenious philosopher, by which the attraction of alkali, and the precipitation of copper on the surface of silver, were produced by the influence of negative electricity, excited by the ordinary machine, were considered by him as favoring the preceding explanation, and proving that oxidation must be the primary cause of electric phenomena. To Mr. Singer, who furnishes the quotation, they did not appear to favor any such supposition, but rather the contrary; for in the experiment with two different wires, touching each other, both produced the same chemical effects, yet, observes Mr. S., 'if they are electrical at all, the one is positive and the other negative, as all experiments on the association of different metals prove; and if two wires that have no chemical action on the fluid in which they are immersed, be rendered respectively positive and negative, they are well known to produce different chemical effects.'

181. But it is said the chemical effect produced by the silver wire, arises from electricity communicated to it by the zinc; and that we have no reason to suppose that any new power is produced by the contact of the metals. Now, if this were the case, the mere conducting communication of the metals would be the only condition necessary to give the silver its chemical power; but the case is widely different, the communication must be not only conducting, but metallic, and even then no chemical effect will be produced, unless the extremities of the wires are immersed in the same liquid, or in two separate portions of liquid that have a conducting communication with each other.

182. Place two glasses filled with a solution of copper near each other. Make a compound arc, by twisting together the end of a wire of zinc, with the end of a similar wire of silver. Connect the two glasses by placing the silver leg of the arc in one, and the zinc in the other. The zinc will immediately attract copper from the solution, but it does not communicate that power to the silver, though they are both closely connected. Whilst the compound arc remains, connect the two glasses by a second arc, formed of a piece of bent wire of any kind, except gold or platina. The silver will be immediately covered with a coating of copper, and will continue to separate copper from the solution as long as the disposition of the apparatus remains the same. Now the only difference in the arrangement, that appears to have operated as a condition to the chemical power of the silver, was the provision of another conducting communication between the glasses, in addition to that established by the compound arc; it therefore appears, that the associated metals cannot serve as conductors to the effect produced; and indeed, if they did, it would be scarcely possible any accumulation of power could result from the increased number of plates in a Voltaic battery.

183. This experiment does not display any of the electric powers of a Voltaic combination; but it shows that the association of three different substances is essential to the chemical agency of such a combination; and the phenomena will be found to correspond with some experiments of M. De Luc, on the efficient groups in the Voltaic pile. This celebrated philosopher found that no chemical effects were produced by any Voltaic arrangements, unless two metals were employed with a liquid between them; and, in the experiment last described, zinc, silver, and a metallic solution were inactive, though in contact with each other, until the fluid was made the medium of conducting communication between the free extremities of the combined metals.

184. The experiment last described will succeed, when the two glasses containing the metallic solution, are connected by any moistened conductor; but the chemical power of the silver wire will be evinced slower, in proportion as the length of the moistened conductor is increased; and in all experiments of the kind, the less the interval between the extremities of the compound arc, the more rapid is its action on the interposed fluid. Hence, in the arrangements of Voltaic apparatus, for the purpose of chemical decomposition, the ends of the conducting wires are placed at a greater or less distance from each other, in proportion as their action is required to be more or less intense.

185. The arrangement of a simple Voltaic combination, by Mr. Sylvester, in which this effect is apparent, may be referred to. It consists of a tall glass jar filled with very dilute muriatic acid. Through a cork, placed in the neck of this jar, two wires are inserted; the one a short straight wire of zinc, the other a long bent wire of platina, or silver; by turning this last round, its upper end may be brought in contact with the zinc, or separated from it at pleasure. When they are separate, the zinc only is acted on; but, as soon as they are brought in contact, the platina or silver becomes covered with bubbles of gas, which appear soonest, and are evolved in the greatest quantity, from the projecting point.

186. Notwithstanding this circumstance, the power of a simple Voltaic combination con-

tinues to exert its effect, when the stratum of interposed fluid is considerable. If a tube of three feet long be filled with dilute muriatic acid, and a wire of platina be inserted through a cork in one of its extremities, and a wire of zinc in the other; on connecting the wires, gas will be soon evolved from the silver. If the tube be bent the effect will take place more slowly. Mr. Singer took two similar tubes of eighteen inches long, and connected them by a short piece of flexible pipe, so as to form together a tube of three feet in length, with a joint in the middle, which admitted of its employment either as a straight tube, or as a siphon with a bend of any required inclination. In the open ends of this tube he placed respectively a zinc, and a platina wire; and found that, whenever their outer ends were connected by a wire, hydrogen was soon evolved from the platina; but this effect took place soonest when the tube was straight, and hence it appears that the power put in motion by these combinations, can pass more readily through any given column of a fluid in a straight line, than in any other direction.

187. It has been seen, that, when any metal is in solution in the interposed fluid, it is revived by the wire which in other cases evolves hydrogen; and it has been shown, by the effect of the silver and the platina wire, that metals which have no chemical action on the interposed fluid alone, may decompose it when combined with another metal. These facts, though far from being perfectly understood, may serve to explain some chemical effects which were before rather obscure. If a zinc wire, for instance, be immersed in a solution of lead, the latter metal will be revived in the form of a metallic vegetation, which increases gradually by additions to its extremities. The first separation of the lead is sufficiently intelligible; the acid in which that metal is dissolved, having a stronger attraction for the zinc, dissolves a portion of it, and deposits on its surface an equal portion of lead. But the lead, so revived, continues to revive more, and to receive additions at its remote extremities, whilst it would have been rather expected these additions would have been made on the zinc, and the vegetation that had been first formed protruded further into the fluid by that means. The contrary result is now understood to be obtained, by the revived particles of lead forming a Voltaic combination with the zinc and the surrounding fluid. This effect is analogous to that which obtains in various other instances.

188. Spread a few drops of a solution of silver upon a pane of glass, and place a small piece of platina, and a similar piece of copper wire upon it, at a little distance from each other. A vegetation will take place about the copper wire; but no effect will be produced by the platina. Bring the wires in contact with each other, and the Voltaic combination thus formed will occasion a beautiful vegetation of metallic silver to surround the platina wire.

189. With a solution of tin, and wires of zinc and platina, similar phenomena occur; but a considerable time elapses, after the contact, before the vegetation appears round the platina. The immediate contact of the oxidable metal with the metallic solution is not absolutely necessary to the success of these experiments; it is only essential that a regular Voltaic circle, consisting of two different metals and a moist conductor be established.

190. If we take a glass tube having a piece of bladder tied over its lower extremity water tight, and a cork inserted in its upper end with a platina wire passing through it; and the tube be filled with acetate of lead, and placed in a small cup of zinc containing dilute muriatic acid; we shall find that, when a metallic communication is formed between this cup and the platina wire, the latter will become studded with brilliant crystals of metallic lead. In this case the oxidable metal has no connexion with the metallic solution but through the medium of the platina wire on the one side and moist bladder on the other.

191. Fill two similar glasses, the one with a solution of silver, the other with dilute muriatic acid; connect them by a compound wire arc of zinc and platina; the zinc being plunged in the muriatic acid, and the platina in the metallic solution. Immerse a second arc, formed of a bent silver wire, in the two glasses, one of its legs being in each; after some time the zinc wire will be entirely dissolved, and the platina will be found covered with minute crystals of metallic silver, displaying a very beautiful appearance under the microscope.

192. Copper and zinc are the metals most usually employed in the construction of Voltaic apparatus, for their effects are greater, in proportion to the value of the metals, than those of any other combination. Silver and zinc, or gold and zinc, would be more powerful, but not so much so as to compensate for the increased expense.

193. As the effects produced by a single pair of metals, of any size, are still exceedingly feeble, attempts were made to combine the action of several pairs. Professor Robinson arranged a series of zinc and silver plates, about the size of a shilling, so as to form a rouleau; and on applying his tongue to the edge of this, the sensation experienced was more manifest than by a simple pair of metals; but its power in other respects did not appear more considerable. In this arrangement every zinc plate was necessarily between two silver plates, and every silver plate between two of zinc, with the exception of the first and last. Now it has been stated, that the contact of zinc with silver, or copper, occasions some electric fluid to flow from either of those metals to it; and, consequently, when a single pair of metals are associated, the outer surface of the zinc appears positive, and that of the silver or copper negative. But if both surfaces of the zinc are in contact with copper or silver, electricity will flow into it in contrary directions, so that neither surface can exhibit the effect; and the same circumstance occurs, in a contrary order, when both surfaces of a silver or copper plate are in contact with zinc. Hence every arrangement of this kind, however numerous the pairs of metal, will exhibit at its opposite extremities the powers of a single pair of metals only.

194. Volta had the penetration to ascertain the cause of this defect in the rouleau of professor Robison; and his ingenuity supplied a means of obviating it. His experiments on the combination of two metals with an imperfect conductor (as water or saline fluids) had taught him that the electro-motive power of these fluids interfered but little with the more powerful energy of the combined metals; and that in fact they acted principally as conductors to that energy. He therefore interposed imperfect conductors of this kind between a series of pairs of metal, and thus combined their power without producing a counteracting current; for the zinc and silver, or zinc and copper, were then in contact with each other at one surface only, but the conducting communication existed throughout.

195. To construct an apparatus of this kind, procure a number of plates of zinc and copper, or zinc and silver, either round or square, of any size; and an equal number of pieces of cloth, leather, or pasteboard, of the same form, but rather smaller. Soak these last in salt water, until they are thoroughly moistened; place a plate of silver, or copper, upon the table, then upon that place a piece of zinc, and on the zinc one of the moistened discs; upon this a second series of silver, zinc, and moistened cloth (or pasteboard) in the same order; and thus consecutively until a series of fifty or sixty repetitions have been placed one upon the other. Particular care must be taken to place the plates in regular order; if in the first group silver is placed lowest, zinc next, and then the moistened disc, the same disposition must be observed throughout.

196. The Voltaic pile being thus formed, let the operator moisten both his hands with brine, and grasp a silver spoon in each. If the top of the pile be then touched with one spoon, and the bottom with the other, a distant but slight shock will be felt at every repetition of the contacts. This shock resembles very nearly the sensation produced by a very large electrical battery weakly charged; it is greater in proportion to the number of groups of which the pile is composed. If the communication is made with any part of the face near the eyes, or with a silver spoon held in the mouth, a vivid flash of light is perceived at the moment of contact, and that whether the eyes be open or shut.

197. The power of an apparatus of this kind continues for some time, but gradually diminishes, the zinc surfaces becoming oxidated by the action of the moisture; it therefore requires to be taken to pieces and cleaned, an operation that is very troublesome when the number of plates is considerable. This inconvenience was diminished by soldering each pair of zinc and copper plates together, instead of simply laying them on each other; and a further improvement was devised by Mr. Cruickshanks, which consisted in cementing the pairs of plates in regular order, in grooves made in the side of a mahogany trough, so as to form water-tight cells between each pair. These cells being filled with water, or any conducting fluid, served as a substitute for the moistened discs used in the pile; and, as the fluid could be easily poured out and replaced, it required considerably less time to keep it in proper order. This form of the apparatus, which is called the Voltaic trough, or battery, has been much used in this country; it is perhaps, on the whole the best arrangement hitherto devised, and its construction is sufficiently simple.

198. The zinc plates are made by casting that metal in an iron or brass mould; they may be about an 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.

199. 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 size, otherwise the apparatus will be inconvenient from its weight. When the plates are not more than three inches square their number in one trough may be fifty, and the distance of the grooves from three-eighths to half an inch. The trough must be made of very dry wood, and put together with white lead or cement. The plates being placed to the fire, the trough is to 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 they are then to be quickly slided into the grooves and pushed firmly to the bottom, so as to bed themselves securely in the cement. In this way the plates are very perfectly cemented at the bottom, and, when this cement is sufficiently cool, a slip of thin deal is to be slightly nailed on the top 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 top 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 torn off, and the trough inclined so as to admit 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. The instrument will then be cemented in the most perfect manner, and it may be cleaned off and varnished.

200. We may notice the preparation of electrical cements. The various cements employed in the construction of electrical apparatus are formed principally of resin, with the addition of some substances to render it more adhesive, and less brittle. Five pounds of resin, one pound of bees'-wax, one pound of red ochre, and two table spoonfuls of plaster of Paris, when melted, and well incorporated together, form a very good cement for general purposes. One that is well adapted for cementing large Voltaic batteries, and which is cheaper, may be formed of six pounds of resin, one pound of red ochre, half a

pound of plaster of Paris, and a quarter of a pint of linseed oil. Other cements in great variety, more or less fusible, &c., may be formed by combining the preceding ingredients in various proportions. The ochre and plaster of Paris should be well dried, and added to the other ingredients when they are well melted.

201. It must have occurred to those engaged in a series of Voltaic experiments, to observe the early exhaustion of power and the inequality of the action under the usual construction and management of the apparatus. The lecturer on this subject has more particularly felt such inconvenience; as during the progress of his experiments of elucidation he is obliged frequently to pause for explanation, during which time the power is on the decline.

202. To obviate these difficulties, Mr. Pepys has constructed a table, with drawers containing a suite of troughs, all the plates of which may be either raised out of the acid, or immersed into it, simultaneously. By means of a lever and counterpoise weight, the whole of the plates are as easily elevated as one series; all the communications with the prime conductors being, as in the same gentleman's Voltaic discharger, completed by quicksilver.

203. The troughs being enclosed within the table or chest, prevents the free escape of the acid vapors; and, where an opportunity offers of communication with a chimney or window, a pipe may be usefully added to carry them off.

204. Fig. 1, plate I., Electro-Galvanism, represents the external figure of the case.

205. Fig. 2. The internal arrangement of the whole contents (except the communication), the front being removed.

206. Fig. 3. Side view of the same, the side of the case, and drawers being removed.

207. Fig. 4. One of the drawers, with the spring supports, or props for the plates.

208. Fig. 5. Front view of the communications.

209. Fig. 6. Side view of ditto.

210. The Voltaic series consists of sixty pairs of plates, four inches square, each plate presenting its whole surface to the action of the acid; they are arranged in two drawers A, A, one above the other, each drawer containing three porcelain troughs *a, a, a*, and each trough ten pair of plates *b, b, b*; the plates are suspended from rods *c, c, c*, connecting each set of ten pairs together, and these rods drop into a square frame *d, d*, made to the full size of each drawer inside: the action of these frames lowers or raises the whole of the plates together, and is thus contrived.

211. B, B, are two rods passing through the upper board or table, and resting upon the short arm of the levers C, C, fig. 2, which are of wood; these rods have each two pairs of pins *e, f*; and which in fig. 2 are represented as employed, the plates being in action; but in fig. 3 the contrary, the lower drawer being open, and the frames, with plates supported by their props D, D. The drawers being first shut, the handles E, E, of the rod B, are to be turned inwards, as in fig. 2, when the pins *e, e*, enter the openings cut in the sides of the drawers at *g*, fig. 4, and stop in the grooves *h, h*, fig. 2, cut in the square frame *d*, to receive them; in the mean while, the shorter pins *f, f*, bearing upon the lower sides of the spring props D, press their upper end or points entirely within the thickness of the drawer on each side, and release the frames *d, d*. The whole weight of the plates, now bearing only upon the rods, is counterpoised by the weight *w*, which connects the two levers C, C; they are gradually let down into their several partitions, and the action of the battery commences; at the conclusion of the experiment the rods are again raised by the handles E, E, and when stopped, the pins *e*, having reached the top of the groove *g*, fig. 4, the handles are to be turned back into their former position, as in fig. 3; the props D, being now first released, shoot into the drawers, and support the frames when the pins *e, e*, have quitted them.

212. The communications between each trough are effected in the usual manner; but those which conduct the fluid from one drawer to the other, and from the opposite ends of the series to the upper board or table, are capable of being disengaged, and their connexions are effected under mercury, as in the Voltaic discharger.

213. They are thus arranged: *i, i, i*, are ivory cups containing mercury, and fixed to the drawers; *j, j, j*, are platina wires depending from them, and entering the troughs; *k* is a ring and wire, which effects the communication between the two drawers; and *l, l*, are the two wires which conduct the fluid from the opposite ends of the battery to the table, C being the copper, and Z the zinc end of the series.

214. We have stated that when the opposite extremities of a powerful Voltaic apparatus are connected by a wire, at the moment of contact a distinct spark is perceived, which occurs every time the contact is alternately broken and renewed. If the contact is made with a wire terminated at the end by a piece of well-burnt charcoal, the spark is considerably more vivid. And if two wires proceeding from the opposite ends of the battery are armed with charcoal points, and brought in contact with each other, the light evolved is more brilliant and intense than any that has been procured by other artificial arrangements. When the battery is powerful, the emission of light may be kept up for a considerable time; it is so dazzling as to fatigue the eye even by a temporary glance, and, when it ceases, leaves the most brilliantly illuminated room in apparent darkness.

215. This light appears to be principally derived from the immediate action of the Voltaic apparatus, and not from the combustion of the charcoal; for, though that is partly ignited, it suffers but comparatively little waste, and the light is evolved with equal splendor when the experiment is made in gases which contain no oxygen; and will even take place, though with diminished energy, under water, alcohol, ether oils, and other fluids whose conducting power is not too great.

216. The influence of the Voltaic spark on various gases may be ascertained by the apparatus represented at fig. 1, plate II., Electro-Galvanism, the wires within the globe being ter-

minated by pointed pieces of charcoal, instead of balls. When a globe of this kind has been exhausted and filled with sulphureted hydrogen, on taking the Voltaic spark in it, the sulphur is separated, and deposited on the interior of the globe, and produces, during its separation, a very beautiful appearance.

217. Some other compound gases are similarly affected; phosphorus separates from phosphureted hydrogen, and arsenic from arsenureted hydrogen.

218. With the most powerful Voltaic batteries the striking distance of the spark, or interval at which it passes from one conductor to another, is very considerable. Mr. Children measured this effect by means of a micrometer, attached to two polished points of platina, which were inserted in a receiver containing very dry air. With 1250 pairs of plates the points were brought within one-fifteenth of an inch of each other before the spark took place. With a large apparatus employed at the London Institution, which extends to 2000 pairs of four-inch plates, points of charcoal were brought within a thirtieth or fortieth of an inch of each other before any light was evolved; but, when the points of charcoal had become intensely ignited, a stream of light continued to play between them when they were gradually withdrawn even to the distance of nearly four inches. The stream of light was in the form of an arch, broad in the middle and tapering towards the charcoal points; it was accompanied by intense heat, and immediately ignited any substance introduced into it; fragments of diamond, and points of plumbago disappeared, and seemed to evaporate, even when the experiment was made in an exhausted receiver; though they did not appear to have been fused. Thick platina wire melted rapidly, and fell in large globules; the sapphire, quartz, magnesia, and lime, were distinctly fused.

219. In rarefied air, the discharge took place at a greater distance, and the beam of light was made to pass through an interval of six or seven inches.

220. These phenomena may be exhibited on a smaller scale by means of 100 pairs of plates, of six inches square, an apparatus which is well suited for all experiments of fusion and ignition.

221. The arched form of the stream of light, passing between two charcoal points, is often very perceptible when the distance of the points does not exceed half an inch.

222. From the low intensity of the most powerful Voltaic apparatus, but little attention to insulation is required in the transmission of its effects. The conductors employed for this purpose consist of copper wires passed through a short piece of glass tube, which serves as an insulator to hold them by. Such conductors are represented attached to the battery, and placed on a glass plate to inflame gunpowder, at fig. 2.

223. As the charcoal points usually become ignited when the battery has moderate power, almost any combustible substance may be inflamed, if placed between them. Oils, alcohol, ether, and naphtha, are decomposed when the points are plunged into them, and inflamed when they are brought near each other upon the surface.

224. Some of the most pleasing effects of the Voltaic apparatus result from its action on metals; if these substances, in thin leaves, are made the medium of communication between the opposite ends of a powerful battery, they inflame, and by continuing the contact may be made to burn with great brilliance. The best method of performing these experiments, is to suspend the metallic leaves to a bent wire proceeding from one extremity of the battery, and to bring in contact with them a broad metal plate connected with the opposite extremity; the brilliancy of the effect may be increased by covering the plate with gilt foil. Gold leaf burns with a vivid white light tinged with blue, and produces a dark brown oxide. Silver leaf emits a brilliant emerald-green light, and leaves an oxide of a dark gray color. Copper produces a bluish-white light attended by red sparks; its oxide is dark brown. Tin exhibits nearly similar phenomena; its oxide is of a lighter color. Lead burns with a beautiful purple light; and zinc with a brilliant white light, inclining to blue, and fringed with red. For the distinct appearance of these colors it is essential to make the contacts with the metal; for, if charcoal be used, the brilliant white light it evolves absorbs the colors produced by the combustion of the metals.

225. If a fine iron wire be connected with one extremity of a powerful battery, and its end be brought to touch the surface of some quicksilver connected with the other extremity, a vivid combustion both of the wire and the quicksilver results, and a very brilliant effect is produced.

226. If a fine iron wire of moderate length be made the medium of connexion between the extremities of the battery, it becomes ignited, and may be fused into balls; or if a platina wire is employed, it may be kept at a red, or even white, heat, for a considerable length of time; which seems to prove that some power is continually circulating through it; but however powerful the battery, wires are never dispersed by it, as they are by the action of a charged surface.

227. If the slender wire be inserted in any fluid, and then introduced into the Voltaic circuit, the fluid may be made to boil.

228. It has been noticed, that, if any two wires of different thicknesses are taken, on either of which a certain battery can produce ignition, a greater length of the thickest wire will be ignited than of that which is thinner. This effect may probably arise from the cooling influence of the air, for the surface of the thin wire is most extensive in proportion to its quantity of metal; and that the surrounding medium has an influence on the degree of ignition may be proved by another experiment.

229. Stretch a fine wire of platina, withinside a glass receiver, placed upon an air-pump, so that the air surrounding the wire may be removed or restored at pleasure. Ignite the wire to a dull red heat, by connecting its opposite extremities with the wires from a Voltaic battery, of sufficient power for that purpose.

Rarefy the air by the action of the pump; and as the rarefaction proceeds, the ignition of the wire will become more vivid, until at length it obtains a glowing white heat. Admit air into the receiver, and the wire will lose its intense heat, and appear more dull than at first. Rarefy the air again, the ignition will increase. Restore it to its original density, it will again diminish. These effects may be repeated many times, and will maintain the same proportion to each other, though they are less intense at each repetition.

230. The power of a Voltaic apparatus increases with the number of plates it contains, within certain limits, but the limit is different for the various effects it produces, and varies also with the manner of employing the apparatus.

231. The effects have been stated by Volta to be in the simple ratio of the numbers, but very limited series only had been put together at the time this statement was made, and there appears to be a loss of power when very extensive arrangements are employed. The pure electrical effects, and the force of the shock, are found to increase with the number, and an arrangement of 1500 may be employed. The power of chemical decomposition, and transfer, also continues to increase with the number when the battery is excited by dilute acid; but, if it be charged with river water, the power does not increase after 400 or 500 plates. The powers of ignition have increased in exact proportion to the numbers within the limit of 100 plates, beyond that limit there appears to be a loss of power; for Sir H. Davy found that 100 plates ignited three inches of platina wire, one-seventieth of an inch diameter, and 1000 similar plates, charged in the same way, ignited only thirteen inches.

232. The French chemists have investigated the ratio of increase for different numbers of plates, as indicated by the quantity of gas liberated by the decomposition of water; and they announce that the increase is as the cube root of the number of plates. The apparatus they employed, was arranged in the form of troughs of a particular construction, being part of a large apparatus constructed by order of the French government. Sir H. Davy states, that he has made similar experiments with the large combination of porcelain troughs, employed in the Royal Institution, and the results he obtained indicate an increase nearly as the squares of the numbers.

233. The result of every experiment of the kind must be uncertain if a series of minute attentions are not observed, which appear to have been overlooked in those already instituted. The vessels employed for the decomposition should be of the same size and form; the wires of the same length and thickness, and placed at equal distances from each other, in a fluid of uniform conducting power.

234. When the size of the plates is increased, their effects on perfect conductors, such as metals, charcoal, and strong acid solutions, are greatly augmented; but their action on imperfect conductors, as water, and various weak saline solutions, remains unaltered. If a battery, for instance, of thirty pairs of plates of two inches square, be compared with another battery of thirty plates, of six inches square, charged with diluted acid of the same strength; there will be no material difference in the shock they produce, or the quantity of water they decompose in a given time; but the small battery will not melt wire, or burn metals, and will scarcely produce a spark between two points of charcoal; whilst the large battery will evolve a brilliant light between the charcoal points, deflagrate metallic leaves with rapidity, and ignite several inches of wire.

235. This remarkable fact, which appears to have been first noticed by the French chemists, is susceptible of some explanation (on the supposition that the phenomena are electrical). If a Leyden jar, for instance, having a square foot of coated surface, be applied to an electrical machine with another jar, whose coated surface is equal to four square feet; after a certain number of turns of the machine, they will both be charged, and to the same intensity, for they will equally affect an electrometer. But the large jar will contain four times the quantity of electricity that the small one does, and will fuse sixteen times the quantity of wire.

236. Now, suppose an imperfect conductor, capable of transmitting only such a quantity of electricity as is adequate to the charge of half a square foot; and it is obvious either of the jars before mentioned would produce the same effect on such a substance; for they both contain more than it can transmit, and its conducting power, which remains the same in both cases, limits the effect that can be produced by either. It is consequently found, that, if several different sized jars are charged to the same degree, the shock is nearly equally painful when received from either of them.

237. Mr. Cavendish has stated, that 'iron wire conducts 400,000,000 times better than rain or distilled water; that is, the electricity meets with no more resistance in passing through a piece of iron wire 400,000,000 inches long, than through a column of water of the same diameter only one inch long. Sea water, or a solution of one part of salt in thirty of water, conducts 100 times, and a saturated solution of sea salt about 720 times better than rain water.' It is therefore probable, that the power excited by a Voltaic apparatus, with plates of two inches square, is in quantity equal or superior to the conducting capacity of most aqueous fluids, and consequently no increased effect can be produced on such fluids by larger plates, which increase the quantity of that power, but not its intensity. But if a conductor be presented to the large plates, which is capable of receiving the increased quantity furnished, the effect must necessarily be greater on such conductors, in proportion to the increased impulse it may be supposed to receive. These facts are capable of easy illustration.

238. Let two wires, proceeding from the extremities of a battery of fifty or 100 plates of two inches square, be plunged in separate glasses of water, if the glasses are connected by putting a finger into each of them, a shock will be felt at the moment of contact. Connect the water

in the glasses by some fibres of moistened cotton, or by an inverted syphon filled with water; on repeating the contact with this arrangement, either no shock, or a very slight one will be felt. Make a similar experiment with another battery of the same extent, but with plates of six inches square. The shock will be nearly as great when the glasses are connected by moistened fibres, as when no connexion exists between them; and whilst the circuit exists through the moistened fibres, and the human body, if a third circuit be formed through a fine wire, several inches of it may be ignited. The imperfect conductors being incapable of conducting more than a small portion of the power excited by the large plates.

239. Whatever be the cause of the power of the Voltaic apparatus, the quantity of that power excited by any given number of plates under similar circumstances, will be in direct proportion to the size of the plates; and if the power be electricity, or should obey the same law that operates with charged surfaces, the comparative action of different sized batteries, containing the same number of plates, should be, with regard to their power of igniting wire, in the proportion of the square of the increased surface; thus if two batteries are taken, one containing fifty plates of twenty square inches surface, and the other fifty plates of forty square inches, the latter ought to ignite four times the length of wire the former can ignite. From some experiments with plates of four inches square, and others with plates of eight inches square, made many years since, it has been stated by Dr. Wilkinson, 'that the power of ignition, in batteries of the same total surface, but with plates of different sizes, increases in the proportion of the squares of the surfaces of the elementary plates, singly taken in each.' It was afterwards shown by Mr. Harrison of Kendal, that when the total surfaces are not equal, the rate of ignition must be as the sixth power of the diameters of the elementary plates, or as the cubes of their respective surfaces.

240. It appears also from some experiments with large plates, mentioned by Sir H. Davy, that the power of ignition, for equal number of plates, probably increases in a higher proportion than the squares of their surfaces; for twenty double plates, each exposing a surface of eight square feet, ignited more than sixteen times as much wire as twenty double plates, having each a surface of two square feet.

241. Several curious galvanic experiments and observations have been published by M. Bichat, author of a very celebrated work on anatomy. In speaking of the influence of the destruction of the brain on that of the heart, after having proved, conformably to observation and experience, that it is not immediately by the interruption of the cerebral action that the heart ceases to act, he confirms this fundamental datum of physiology and pathology, by a series of galvanic experiments, which demonstrate that the heart is in all cases independent of the brain.

242. 'These experiments,' he observes, 'were made by me with the most scrupulous attention, because several very respectable authors have recently advanced an opinion contrary to mine and have endeavoured to prove that the heart, together with the other muscles of organic life, do not differ, as to their susceptibility to the galvanic influence, from the different muscles of animal life. I shall begin by a detail of the observations I have made on animals with red and cold blood.

243. (1.) 'In several experiments made on frogs, I coated the brain, on the one hand with lead, and the heart and muscles of the inferior extremities, on the other, with a long lamina of zinc, the upper end of which touched the heart, and the lower end the muscles. Having, by the means of silver, established a communication between the coatings of the muscles and those of the brain, the movements of the limbs constantly followed; but I could not perceive any acceleration in the contractions of the heart, when it still continued to beat; and, when its action had entirely ceased, it did not display the smallest movement. Whichever may be the voluntary muscle that is coated at the same time with the heart, with a view to a comparison of the phenomena they exhibit at the moment of the metallic communication, there is constantly a marked and decided difference.

244. (2.) 'In the case of other frogs, I coated, with a common metallic wire, on the one hand, the cervical part of the spinal marrow, in the upper region of the heart, to the end that the coating might be above the part where the nerves which proceed from the great intercostal nerve, and thence to the heart, originate; and, on the other hand, the heart, and any one of the voluntary muscles. I constantly noticed a result similar to the one which attended the preceding experiment, whenever the communication was established. There were invariably violent agitations in the voluntary muscles, without any visible alteration in the contractile movements of the heart.

245. (3.) 'I endeavoured to denudate the nerves which lead to the heart of frogs. Several grayish filaments, scarcely perceptible, with the nature of which I must acknowledge I am not positively acquainted, were coated with a metallic substance, at the same time that the heart was made to rest on a substance of a similar nature. When the communication was established by the means of a third metal, not the smallest sensible effect was to be perceived.'

246. Dr. Wilson Philip has made some curious experiments on the influence of the Voltaic battery in obviating the effects of the division of the eight pairs of nerves. In some experiments in which the nerves of the eighth pair were divided in the neck of a rabbit, and the ends not displaced, and the animal was allowed to live some hours, it was found that food swallowed immediately before the division of the nerves, was considerably digested, even when the divided ends of the nerves had separated to the distance of a quarter of an inch from each other.

247. In other experiments in which, after the division of the nerves, the divided ends had been turned completely away from each other, little or no perfectly digested food, when the animal

was allowed to live some hours, was found in the stomach: and the longer the animal lived, the smaller was the proportion of digested food in the stomach, the great mass having the appearance of masticated food, which was not sensibly lessened in quantity, however long the animal lived. In an experiment in which, under some circumstances, the stomach was exposed, from the time of the division of the nerves, to the influence of a Voltaic battery sent through the lower portion of the divided nerves, its contents were apparently as much changed as they would have been in the same time in the healthy animal. The change was also of the same kind, the contents of the stomach assuming a dark color, and those of the pyloric end being more uniform, and of a firmer consistence than those of the central and cardiac portions of the stomach, while the whole contents became less in quantity.

248. The division of the nerves, in both ways, produced difficulty of breathing and efforts to vomit; neither of which occurred, when the stomach and lungs were brought under the influence of a Voltaic battery, sent through the lower portion of the divided nerves.

249. When, under the foregoing circumstances, the lungs had not been exposed to the Voltaic influence, and the animal had been allowed to live for five or six hours, they were found much affected: in the rabbit which had been submitted to this influence, they seemed quite healthy.

250. An account of some very interesting experiments performed by Dr. Ure, on the body of a criminal executed in the north, was read before the Glasgow Literary Society. The paper commences with some appropriate general physiological views relating to the application of galvanism, in which the author notices particularly the researches of Dr. Wilson Philip on the relation between Voltaic electricity and the phenomena of life. The author gives the following detail of his experiments.

251. 'The subject of these experiments was a middle-sized, athletic, and extremely muscular man, about thirty years of age. He was suspended from the gallows nearly an hour, and made no convulsive struggle after he dropped; while a thief executed along with him, was violently agitated for a considerable time. He was brought to the anatomical theatre of the University of Glasgow in about ten minutes after he was cut down. His face had a perfectly natural aspect, being neither livid nor tumefied; and there was no dislocation of his neck.

252. 'Dr. Jeffrey, the distinguished professor of anatomy, having on the preceding day requested me to perform the galvanic experiments, I sent to his theatre with this view, next morning, my minor Voltaic battery, consisting of 270 pairs of four-inch plates, with wires of communication, and pointed metallic rods with insulating handles, for the more commodious application of the electric power. About five minutes before the police officers arrived with the body, the battery was charged with a dilute nitro-sulphuric acid, which speedily brought it into a state of intense action. The dissections were skilfully executed by Mr. Marshall, under the superintendence of the professor.

253. 'Experiment I.—A large incision was made into the nape of the neck, close below the occiput. The posterior half of the atlas vertebra was then removed by bone forceps, when the spinal marrow was brought into view. A considerable incision was at the same time made in the left hip, through the great gluteal muscle, so as to bring the sciatic nerve into sight; and a small cut was made in the heel. From neither of these did any blood flow. The pointed rod connected with one end of the battery was now placed in contact with the spinal marrow, while the other rod was applied to the sciatic nerve. Every muscle of the body was immediately agitated with convulsive movements, resembling a violent shuddering from cold. The left side was most powerfully convulsed at each renewal of the electric current. On moving the second rod from the hip to the heel, the knee being previously bent, the leg was thrown out with such violence as nearly to overturn one of the assistants, who in vain attempted to prevent its extension.

254. 'Experiment II.—The left phrenic nerve was now laid bare at the outer edge of the sterno-thyroideus muscle, from three to four inches above the clavicle; the cutaneous incision having been made by the side of the sterno cleido-mastoideus. Since this nerve is distributed to the diaphragm, and since it communicates with the heart through the eighth pair, it was expected by transmitting the galvanic power along it, that the respiratory process would be renewed. Accordingly, a small incision having been made under the cartilage of the seventh rib, the point of the one insulating rod was brought into contact with the great head of the diaphragm, while the other point was applied to the phrenic nerve in the neck. This muscle, the main agent of respiration, was instantly contracted, but with less force than was expected. Satisfied, from ample experience on the living body, that more powerful effects can be produced in galvanic excitation, by leaving the extreme communicating rods in close contact with the parts to be operated on, while the electric chain or circuit is completed, by running the end of the wires along the top of the plates in the last trough of either pole, the other wire being steadily immersed in the last cell of the opposite pole, I had immediate recourse to this method. The success of it was truly wonderful. Full, nay laborious breathing instantly commenced. The chest heaved, and fell; the belly was protruded, and again collapsed, with the relaxing and retiring diaphragm. This process was continued, without interruption, as long as I continued the electric discharges.

255. 'In the judgment of many scientific gentlemen who witnessed the scene, this respiratory experiment was perhaps the most striking ever made with a philosophical apparatus. Let it also be remembered, that, for full half an hour before this period, the body had been well nigh drained of its blood, and the spinal marrow severely lacerated. No pulsation could be perceived meanwhile at the heart or wrist; but it may be supposed that, but for the evacuation of the blood, the essential stimulus of that organ, this phenomenon might also have occurred.

256. 'Experiment III.—The supra-orbital nerve

was laid bare in the forehead, as it issues through the supra-ciliary foramen, in the eye-brow: the one conducting rod being applied to it, and the other to the heel, most extraordinary grimaces were exhibited every time that the electric discharges were made, by running the wire in my hand along the edges of the last trough, from the 220th to the 227th pair of plates; thus fifty shocks, each greater than the preceding one, were given in two seconds: every muscle in his countenance was simultaneously thrown into a fearful action; rage, horror, despair, anguish, and ghastly smiles, united their hideous expression in the murderer's face, surpassing far the wildest representations of a Fuseli or a Kean. At this period several of the spectators were forced to leave the apartment from terror or sickness, and one gentleman fainted.

257. 'Experiment IV.—The last galvanic experiment consisted in transmitting the electric power from the spinal marrow to the ulnar nerve, as it passes by the internal condyle at the elbow; the fingers now moved nimbly, like those of a violin performer; an assistant, who tried to close the fist, found the hand to open forcibly, in spite of his efforts. When the one rod was applied to a slight incision in the tip of the fore-finger, the fist being previously clenched, that finger extended instantly; and, from the convulsive agitation of the arm, he seemed to point to the different spectators, some of whom thought he had come to life!'

258. An hour was spent in these experiments, when an experiment was made with the view of determining the quantity of residual air in the lungs; after the detail of which, the author proceeds as follows.

259. 'In deliberating on the above galvanic phenomena, we are almost willing to imagine, that if, without cutting into and wounding the spinal marrow and blood-vessels in the neck, the pulmonary organs had been set a-playing at first (as I proposed), by electrifying the phrenic nerve (which may be done without any dangerous incision), there is a probability that life might have been restored. This event, however little desirable with a murderer, and perhaps contrary to law, would yet have been pardonable in one instance, as it would have been highly honorable and useful to science. From the accurate experiments of Dr. Philip, it appears that the action of the diaphragm and lungs is indispensable towards restoring the suspended action of the heart and great vessels, subservient to the circulation of the blood.

260. 'It is known that cases of death-like lethargy, or suspended animation from disease and accidents have occurred, where life has returned, after longer interruption of its functions than in the subject of the preceding experiments. It is probable, when apparent death supervenes from suffocation with noxious gases, &c., and when there is no organic defect, that a judiciously directed galvanic experiment will, if any thing will, restore the activity of the vital functions. The plans of administering Voltaic electricity hitherto pursued in such case, are, in my humble apprehension, very defective. No advantage, we perceive, is likely to accrue from passing electric discharges across the breast, directly through the heart and lungs. On the principles so well developed by Dr. Philip, and now illustrated on Clydsdale's body, we should transmit along the channel of the nerves, that substitute for nervous influence, or that power which may perchance awaken its dormant faculties. Then, indeed, fair hopes may be formed of deriving extensive benefit from galvanism; and of raising this wonderful agent to its expected rank, among the ministers of health and life to man.

261. 'I would, however, beg leave to suggest another nervous channel, which I conceive to be a still readier and more powerful one to the action of the heart and lungs than the phrenic nerve. If a longitudinal incision be made, as is frequently done for aneurism, through the integuments of the neck at the outer edge of the sterno-mastoideus muscle, about half way between the clavicle and angle of the lower jaw; then, on turning over the edge of this muscle, we bring into view the throbbing carotid, on the outside of which the par vagum and great sympathetic nerve lie together in one sheath. Here, therefore, they may both be directly touched and pressed by a blunt metallic conductor. These nerves communicate directly or indirectly with the phrenic, and the superficial nerve of the heart is sent off from the sympathetic.

262. 'Should, however, the phrenic nerve be taken, that of the left side is the preferable of the two. From the position of the heart, the left phrenic differs a little in its course from the right. It passes over the pericardium, covering the apex of the heart.

263. 'While the point of one metallic conductor is applied to the nervous cords above described, the other knob ought to be firmly pressed against the side of the person, immediately under the cartilage of the seventh rib. The skin should be moistened with a solution of common salt, or, what is better, a hot saturated solution of sal ammoniac, by which means the electric energy will be more effectually conveyed through the cuticle, so as to complete the Voltaic chain.

264. 'To lay bare the nerves above described, requires, as I have stated, no formidable incision, nor does it demand more anatomical skill, or surgical dexterity, than every practitioner of the healing art ought to possess. We should always bear in mind that the subject of experiment is at least insensible to pain; and that life is at a stake, perhaps irrecoverably gone. And assuredly, if we place the risk and difficulty of the operations in competition with the blessings and glory consequent on success, they will weigh as nothing with the intelligent and humane. It is possible, indeed, that two small brass knobs, covered with cloth moistened with solution of sal ammoniac, pressed above and below on the place of the nerve and the diaphragmatic region, may suffice, without any surgical operation. It may first be tried.

265. 'Immersion of the body in cold water accelerates greatly the extinction of life arising from suffocation; and hence less hopes need be entertained of recovering drowned persons after a considerable interval, than when the vital heat has been suffered to continue with little abate-

ment. None of the ordinary practices judiciously enjoined by the Humane Society, should ever, on such occasions, be neglected. For it is surely criminal to spare any pains which may contribute, in the slightest degree, to recall the fleeting breath of man to its cherished mansion.'

266. We have hitherto confined ourselves to the effects of small batteries, but we must not omit to notice the powerful Voltaic apparatus constructed by Mr. Children, as well as the results obtained by it, or the more portable as well as powerful arrangement by Mr. Pepys. In the first of these arrangements, the copper and zinc plates of the apparatus were connected together, in the usual order, by leaden straps, six feet long by two feet eight inches broad, each plate presenting thirty-two square feet of surface. All the plates being attached to a strong wooden frame suspended by ropes and pulleys, which, being balanced by counterpoises, was easily lowered and elevated, so as to immerse the plates in the acid, or raise them out of it at pleasure. The cells of the battery were twenty-one in number, and their united capacities amounted to 945 gallons. To each pole of the battery a leaden pipe, about three-fourths of an inch in diameter, was attached by solder, and the opposite end of each pipe immersed in a basin of mercury (a separate basin for each pipe), by means of which the circuit was completed, and a perfect contact ensured. The battery was afterwards improved at the suggestion of Dr. Wollaston, and the copper coiled completely round each zinc surface. See fig. 3, plate II. The first experiments we shall mention were made on the comparative facility with which different metals are ignited when placed in the electrical circuit. For this purpose, in each experiment, two wires of dissimilar metals were taken, of equal diameter and length; one end of each was in contact with one of the basins of mercury communicating with the poles of the battery, and the other end bent to an angle, and the wires connected continuously by hooking them together. The length of each wire was eight inches, and the diameter one-thirtieth of an inch. The battery was moderately excited by a charge of one part acid diluted with forty parts of water.

267. Experiment I.—A platina and a gold wire being thus connected, and introduced into the electrical circuit, the platina was instantly ignited, the gold remained unaffected.

268. Experiment II.—A similar arrangement of gold and silver wires. The gold was ignited, the silver not.

269. Experiment III.—The same with gold and copper. No perceptible difference in the state of ignition; both metals were heated red.

270. Experiment IV.—Gold and iron. The iron was ignited; the gold unchanged.

271. Experiment V.—Platina and iron. The iron ignited instantly at the point of contact next the pole of the battery. Then the platina became ignited through its whole extent. After this the iron became more intensely heated than the platina, and the ignition of the latter decreased.

272. Experiment VI.—Platina and zinc. The platina was ignited: the zinc was not; but melted at the point of contact. In a subsequent experiment, the zinc did not melt; but the platina ignited as before.

273. Experiment VII.—Zinc and iron. The iron was ignited: the zinc bore the heat without fusing.

274. Experiment VIII.—Lead and platina. The lead fused at the point of contact.

275. Experiment IX.—Tin and platina. The tin fused at the point of contact. No ignition of either wire took place in the two last experiments.

276. Experiment X.—Zinc and silver. The zinc was ignited before it melted: the silver was not ignited.

277. The results in every case were the same to whichever pole of the battery either wire was presented. These experiments were varied by introducing several alternations of different wires continuously connected, into the circuit, and obtained in every instance analogous results. Thus,

278. Experiment XI.—Alternations of platina and silver, three times repeated: all the platina wires were ignited, and none of the silver.

279. Experiment XII.—One zinc wire between two platina: both the platina wires were ignited, the zinc not.

280. Experiment XIII.—One iron between two platina. Both the latter first ignited; then the iron, which soon became fully heated, and fused.

281. It is unnecessary to enter into a farther detail of these experiments; it will be sufficient to say generally, that when wires of several different metals were introduced at once into the circuit, the order of their ignition was precisely that of the former experiments. In one experiment the copper was decidedly most heated.

282. To explain these phenomena, Mr. Children supposes that when a perfect communication is established between the poles of the battery, the electricity circulates without producing any visible effect; but, if it meet with resistance in its passage, it manifests itself by chemical action, by the evolution of heat, or both. Thus, if a bar of metal be connected with one pole of the battery, and its extremity immersed in a basin of mercury connected with the other pole, at the instant the surfaces come in contact, heat and light are evolved, which cease as soon as the bar, if it be of sufficient size, is fairly plunged beneath the surface of the quicksilver. If the circuit be completed by two pieces of charcoal, the evolution of heat and light is permanent, as long as their surfaces remain in contact, because that contact can never be so perfect, as to oppose no resistance to the electricity; whereas, in the case of the bar of metal and the mercury, it soon becomes complete, and the current is then uninterrupted. Resistance, therefore, appears to occasion the development of heat (whatever be the ultimate cause of the phenomenon), and as this must be inversely as the conducting power, when any two of the wires connected continuously are placed in the circuit, that which is the worst conductor must be most heated; and thus platina, having the lowest conducting power, is ignited before all

the rest; and silver, which conducts best, is not heated red when connected with any of the other metals.

283. The following experiments were made with the battery in a high state of excitation; and Mr. Children considers them as representing nearly the maximum of effect which it is capable of producing. As the quantity of acid was increased from time to time, and that previously added often almost spent before fresh was put in, it is not easy to say exactly what proportion it bore to the water; perhaps the largest may be stated at about $\frac{1}{20}$th. On this, as on former occasions, he found a mixture of nitrous and sulphuric acids, to produce the most powerful and permanent effects.

284. Experiment I.—Five feet six inches of platina wire, $\frac{11}{100}$ of an inch in diameter, were heated red throughout, visible in full daylight.

285. Experiment II.—Eight feet six inches of platina wire, $\frac{44}{100}$ of an inch in diameter, were heated red.

286. Experiment III.—A bar of platina $\frac{1}{8}$ of an inch square, and $2\frac{1}{4}$ inches long, was also heated red, and fused at the end; and,

287. Experiment IV.—A round bar of the same metal, $\frac{278}{1000}$ of an inch in diameter, and $2\frac{1}{2}$ inches long, was heated bright red throughout.

288. Experiment V.—Fine points of boxwood charcoal intensely ignited in chlorine, neither suffered any change, nor produced any in the gas. The result was similar when heated in azote.

289. Mr. C. next tried the power of the battery to fuse several refractory substances. The subject of experiment was placed in a small cavity, made in a piece of well burnt boxwood charcoal, floating on the surface of the mercury in one of the basins before mentioned, and the circuit completed by another piece of charcoal, communicating by stout copper wire with the other basin.

290. Experiment I.—Oxide of tungsten, which (as well as other metallic oxides operated on) had been previously intensely ignited in a charcoal crucible, in a powerful furnace, fused, and was partially reduced. The metal grayish white, heavy, brilliant, and very brittle.

291. Experiment II.—Oxide of tantalum. A very small portion fused. The grains have a reddish-yellow color, and extremely brittle.

292. Experiment III.—Oxide of uranium; fused, but not reduced.

293. Experiment IV.—Oxide of titanium; fused, not reduced. When intensely heated, it burnt, throwing off brilliant sparks like iron.

294. Experiment V.—Oxide of cerum; fused, and when intensely heated it burnt with a large, vivid white flame, and was partly volatilised, but not reduced. The fused oxide, on exposure for a few hours to the air, fell into a light brown powder, containing numerous shining particles of a silvery lustre interspersed amongst it, and exhaled an odor, similar to that of phosphureted hydrogen.

295. Experiment VI.—Oxide of molybdena; readily fused and reduced. The metal is very brittle, of a steel gray color, and soon becomes covered with a thin coat of purple oxide.

296. Experiment VII.—Compound ore of iridium and osmium; fused into a globule.

297. Experiment VIII.—Pure iridium; fused into an imperfect globule, not quite free from small cavities, and weighing 7·1 grains. The metal is white, very brilliant, and in its present state its specific gravity is 18·68, which must be much too low, on account of the porous state of the globule. In the Minutes of the Experiments, in July 1813, mention is made of the fusion of a small portion of pure iridium into a globule weighing $\frac{88}{100}$ of a grain, which had been previously submitted to the action of a battery of 2000 plates, of four inches square, without melting.

298. Experiment IX.—Ruby and sapphire, were not fused.

299. Experiment X.—Blue spinal ran into a slag.

300. Experiment XI.—Gadolinite, fused into globules.

301. Experiment XII.—Magnesia was agglutinated.

302. Experiment XIII.—Zircon from Norway was imperfectly fused.

303. Experiment XIV.—Quartz, silex, and plumbago, were not affected.

304. In the year 1796 M. Clouet converted iron into steel, by cementation with the diamond, with the view of confirming the nature of that substance, and of ascertaining the exact state in which carbon exists in steel. Clouet had also previously formed steel by cementation with carbonate of lime. Mr. Mushet repeated this experiment, using, instead of the carbonate, caustic lime, and obtained also what he considered to be cast steel; whence he concluded that the carbon necessary to convert the iron into steel had not been furnished, as Clout supposed, by decomposition of the carbonic acid, but that it had found its way from the ignited gas of the furnace to the iron. This result occasioned suspicions of the accuracy of the deductions from the experiment with the diamond; and Mr. Mushet accordingly, at the suggestion of the editor of the Philosophical Magazine, repeated the experiment made at the Polytechnic School, only keeping out the diamond. The results (for he made several experiments), uniformly gave him good cast steel, whence he concludes that we are still without any satisfactory or conclusive proof of the steelification of iron solely by means of the diamond; and adds that he doubts whether the diamond afforded even one particle of carbon to the iron. The details of both Clouet's and Mushet's experiments, may be found in the fifth volume of the Philosophical Magazine. Sir George M'Kenzie repeated both results confirming the conclusions of the French chemist. The labors of this gentleman would at first view appear conclusive; but, if a doubt should remain, it occurred to Mr. Pepys, that the battery would afford an experimentum crusis on the subject; and his ingenuity readily suggested a mode of making it, every way unobjectionable. He bent a wire of pure soft iron, so as to form an angle in the middle, in which part he divided it longitudinally, by a fine saw. In the opening, so formed, he placed diamond powder, securing it in its situa-

tion by two finer wires, laid above and below it, and kept from shifting, by another small wire, bound firmly and closely round them. All the wires were of pure soft iron, and the part containing the diamond powder was enveloped by thin leaves of talc. Thus arranged, the apparatus was placed in the electrical circuit, when it soon became red hot, and was kept so for six minutes. The ignition was so far from intense, that few who witnessed the experiment expected any decisive result. On opening the wire, however, Mr. Pepys found that the whole of the diamond had disappeared; the interior surface of the iron had fused into numerous cavities, notwithstanding the very moderate heat to which it had been exposed; and all that part which had been in contact with the diamond was converted into perfect blistered steel. A portion of it being heated red, and plunged into water, became so hard as to resist the file, and to scratch glass. This result is conclusive; for as the contact of any carbonaceous substance, except the included diamond, was effectually guarded, to that alone can the change produced in the iron be referred. This experiment will also probably be deemed fatal to the opinion of those mineralogists (if any do still maintain that opinion), who class the diamond with substances of the siliceous genus.

305. When dry caustic potassa was exposed to the intense heat between the two pieces of charcoal, it fused, and appeared to decompose, throwing off a large flame of the peculiar purple color, that attends the combustion of potassium. When moist caustic potassa was placed in the circuit, the water only was decomposed.

307. The second apparatus was constructed under the immediate direction of Mr. Pepys for the London Institution, and the great portability of this gigantic galvanic spiral gives it an especial claim to the notice of the scientific world. The apparatus is shown at fig. 4.

308. The two tubs, T, T, are somewhat larger than the metallic coil. The one beneath the weight is intended as a receptacle for water, while the other is charged with dilute acid.

309. The spiral M is suspended by a cord, and balanced by the weight W; the beam over which the cord passes being moveable on a central axis at the top of the upright piece of timber.

310. The coil consists of two plates, each fifty feet in length and two feet in width; the one copper, and the other zinc, making a superficial surface of 400 feet. They are rolled or wrapped round a cylinder of wood, with three strands or ropes of horse-hair between each plate, to prevent contact of the metals; and, to maintain these in their situation, notched sticks are occasionally introduced in the rolling. Two conductors of copper, near three-fourths of an inch in thickness, are firmly attached to the end of each plate, from which the power is dispensed upon immersion in the acid.

311. Rather more than fifty gallons of dilute acid are requisite to charge the receptacle intended for the metallic spiral; and, to put the apparatus in operation, the coil is gradually lowered into the tub beneath. The immersion of the spiral, however, displaces a certain portion of water; so that it is necessary to restore the equilibrium by withdrawing one of the balance-weights. In the apparatus actually employed in the theatre of the London Institution, there is but one tub employed; but in the improved form, represented in the diagram, it may be removed to a vessel of water, and its maximum effect produced by a subsequent immersion in the dilute acid.

312. As a mere electrical battery, the effect to be derived from this pair of plates is comparatively small; but its powers as an agent for illustrating the connexion between magnetism and electricity are truly astonishing.

313. Magnetic needles, placed at a distance of several feet from the apparatus, were readily put into motion, and deflected from their previous position. The most singular phenomenon, however, which resulted from the series of experiments with this extraordinary instrument, remains to be noticed:—A spiral of wire was connected with the two poles of the battery shown at C, C, and, being placed in a perpendicular direction, a steel cylinder was dropped from the upper end, and this, instead of obeying the ordinary laws of gravitation, was found, after a few oscillations, to take a position somewhere midway between the two extremities of the tube.

ELECTRO-MAGNETISM.

314. The connexion between galvanism and magnetism must now be examined. The term electro-magnetism has been employed to designate a science which has originated since the commencement of the present century, and which has received no ordinary attention from the continental philosophers, as well as from those of our own country. Amongst those who have done most towards the development of electro-magnetism, we may especially enumerate M. Oersted, Sir Humphry Davy, and professor Barlow, and the latter of these gentlemen has published a very valuable work illustrative of the science.

315. M. Oersted, professor of natural philosophy, and secretary to the Royal Society of Copenhagen, was for many years engaged in enquiries respecting the identity of chemical, electrical, and magnetic forces; and, as early as 1807, proposed to try 'whether electricity the most latent had any action on the magnet.' At that time no experimental proofs of the peculiar opinions he entertained were known; but his constancy in the pursuit of his object, both by reasoning and experiment, was well rewarded in the winter of 1819, by the discovery of a fact o. which no previous notice had been taken; but which, when once known, instantly drew the attention of all those who were at all able to appreciate its importance and value.

316. M. Oersted's own account of this discovery has been published in volume xvi. of the

first series of the Annals of Philosophy. It is full of important matter, and contains in few words the results of a great number of observations; and, with his second paper, comprises a very large part of the facts that are as yet known relating to this subject.

317. Upon the excitation of the Voltaic apparatus, by the proper arrangement of its plates and fluid, it is known that certain powers are given to its poles or extremities which enable them, when attached to an electrometer, to show by their divergence a certain tension of electricity; or when connected together by fluids, wires, or other conducting substances, to decompose or heat them. These effects have been known for several years, and are generally attributed to electricity produced by the apparatus; the effects of tension belonging to the insulated state of the poles; those of decomposition and heating to their connected state.

318. When the two poles of such a battery or apparatus are connected by conductors of electricity, the battery is discharged; that is, the tension of the electricity at the poles is lessened, and that, according as the conducting power of the substance is more or less powerful. Good conductors, discharge it entirely and instantly; bad conductors with more or less difficulty; but as the instrument has within itself the power of renewing its first state of tension on the removal of the conducting medium, and that in a very short space of time, it is evident that the connecting substance is continually performing the same office during the whole time of its contact that it did at the first moment, and this whether it be a good or a bad conductor; and it is also evident that it must be in a different state in this situation than when separated from the apparatus. It is important at present rather to consider the action of a good conductor in discharging the battery, as the phenomena to be considered are in that case more energetic. A metallic wire, therefore, may be used to connect the two poles; it will discharge a powerful apparatus; and, consequently, whatever takes place in the connecting medium is here compressed into a very small place. Those who consider electricity as a fluid, or as two fluids, conceive that a current or currents of electricity are passing through the wire, during the whole time it forms the connexion between the poles of an active apparatus. There are many arguments in favor of the materiality of electricity, and but few against it; but still it is only a supposition; and it will be as well to remember, while pursuing the subject of electro-magnetism, that we have no proof of the materiality of electricity, or of the existence of any current through the wire.

319. Whatever be the cause which is active within the connecting wire, whether it be the passage of matter through it, or the induction of a particular state of its parts, it produces certain very extraordinary effects. If small, it becomes heated; and as the size of the wire is diminished, or that of the apparatus increased, the heat rises to an intense degree apparently without any limitation, except from the influence of external circumstances, or the alteration of the wire. Another effect, and it is that to which M. Oersted, here calls attention is, that, if brought towards a magnetic needle, it has the power of attracting and repelling it in a constant manner, and in obedience to certain simple laws.

320. If a magnetic needle be left to take its natural direction, and then a straight portion of the connecting wire be brought above it, and parallel to it, that end of the needle next the negative pole of the battery moves towards the west; and that whether the wire be on the one or the other side of the needle, so that it be above and parallel to it. If the connecting wire be sunk on either side the needle, so as to come into the horizontal plane in which the needle is allowed to move, there is no motion of the needle in that plane; but the needle attempts to move in a vertical circle; and but for the imperfect suspension, and the influence of the earth's magnetism, would do so. When the wire is on the east of the needle, the pole of the needle next the negative end of the battery is elevated; and when on the west of the needle it is depressed. If the connecting wire be now sunk below the level of the needle, similar attractions and repulsions take place, but in opposite directions to those followed when it is above. The pole of the needle opposite the negative end of the battery now moves eastwards, whatever the position of the wire, so that it be restricted as above.

321. That these positions of the magnetic needle may be retained with more facility in the memory, professor Oersted proposed the following formula: 'The pole above which the negative electricity enters is turned to the west; under which, to the east.'

322. M. Oersted subsequently pointed out, what it is easy to see from the above experiments, that the movement of the needle took place in a circle round the connecting wire; and though, in the description of his first experiments, the quantity of declination given to the needle from the wire is expressed by an angle of so many degrees, yet it is afterwards stated to vary with the power of the battery. Whenever the needle is moved in a horizontal or any other circle from the position it naturally assumes, the power of the earth over it tends to restore that position, and is consequently an active force in the present instance opposed to the power of the connecting wire; it therefore lessens the declination the needle would otherwise have. Also when the wire is brought into the same horizontal circle with the needle, its effect over it is shown by the elevation and depression of its opposite ends; and it is the mode of suspension combined with the earth's magnetic power that prevents it from traversing in a vertical circle. But if those interfering circumstances be removed, viz. if the suspension be such as to allow of free motion to the needle in every direction, and the earth's magnetism be rendered null, or counteracted either by the position of the needle, or by the vicinity of another magnet, then a much simpler idea of the relative movements of the wire and needle may be obtained.

323. It is not, perhaps, easy to obtain this perfect state of apparatus, but it is not difficult so to arrange it as to examine the movements first

in one direction, and then in another. It will then be found, if the connecting wires of a sufficiently powerful apparatus be placed near a magnetic needle so as to pass near its centre, that the needle will arrange itself directly across the wire, whatever the previous position of the two; that if the wire be carried round the centre of the needle, or the centre of the needle round the wire, the same relative position of the two will continue; and that the direction of the needle across the wire is not indifferent, but has its poles always in a constant position to the poles of the battery. If the positive pole of a battery be on the right hand, and the negative pole on the left, and a wire be stretched between, connecting them, then a needle above the wire will point the north pole from, and the south towards us; or if below, the south pole from, and the north towards the experimenter. See fig. 5, plate II.

324. If the connecting wire and the needle be represented by two small rods named accordingly, and fastened permanently together, then they will represent the wire and the needle in all positions; for, however one be placed, the other will correspond with it: or if, on the under side of a small square piece of glass, a line be drawn from top to bottom, the upper end being called negative, and the lower positive; and on the upper surface a line be drawn from left to right, the left termination being named south, the right north; then the lower line will always represent the connecting wire, and the upper the needle. Fig. 6.

325. The needle and wire being in this position, if the wire be moved along the needle towards either extremity, strong attractions will take place between it and the pole, notwithstanding the same part of the wire be employed; and the poles in the two positions are contrary to each other. In this case it appears that the same point in the wire has the power of attracting both the north and south pole of the needle. If while the wire is thus situated near the end of the needle, the latter be turned round, so that the pole before there be replaced by the opposite pole, strong repulsions will take place; and that to whichever pole the wire has in the first instance been carried, so that the same point which before attracted both poles will now repel them both. If, when the wire is near the extremity of the needle where the attraction is strongest, it be moved round the end so as to go from one side to the other, keeping the same point constantly towards the needle, its attractive power over the needle will be found to increase as it approaches the end, but remains on one side of it; will diminish as it turns the end; will become null when exactly opposed to the pole; and, as it passes on the other side, will resume repulsive powers, which will be strongest at the extremity of the pole on the opposite side to where the wire was situated at first. Fig. 7.

326. In all these cases the positions assumed by the wire and needle, whether the result of attraction or repulsion, are the same as those before described, except that the wire is now near the end of the needle instead of the middle; and it will be found that all the attractions and repulsions may be reduced to four positions of the needle to the wire, in which it forms tangents with it. In fig. 8, the north pole; in fig. 9, the south pole; if in either of them the poles of the needle be reversed, the tangents remaining in the same direction, repulsion will take place. Hence it is easy to see how any individual part of the wire may be made attractive or repulsive of either pole of the magnetic needle by mere change of position.

327. The magnetic property does not depend upon the metal employed or its form, but is exerted by any of them which forms the circuit between the poles: even a tube filled with mercury is effectual: the only difference is in the quantity of effect produced. It continues also, though the conductor be interrupted by water, unless the interruption be of great extent.

328. The magnetic influence of the wire extends through all sorts of substances, and acts on the needle beyond, just as in common magnetism. It does not act on needles of brass, glass, or gum lac.

329. In a second paper on this subject, M. Oersted shows that not intensity, but quantity, is wanting in the Voltaic apparatus, to produce this effect most eminently. A single galvanic arc is sufficient for the purpose. A plate of zinc, six inches square, placed in a trough of copper, filled with diluted acid, enabled the wire which connected the two metals to act powerfully; and, with a similar arrangement, the zinc plate having a surface of 100 square inches, an effect was produced on the needle at the distance of three feet. He also, in this paper, describes the construction of a Voltaic combination so light, that being suspended, it moved on the approach of a magnet: the motions were in accordance with what has been said, and may easily be conceived.

330. The results obtained by M. Oersted were immediately repeated and confirmed by a great number of philosophers in various places. Of these no one was more active than M. Ampere, in varying experiments, making new ones, and applying to them the most judicious theory.

331. The facts discovered by M. Ampere, though not numerous, are of great importance. He described an experiment, proving that the Voltaic pile itself acted in the same manner as the wire, connecting its two poles; and constructed an instrument which, at the same time that it proved this action, was found to be of great use in experiments on currents of electricity. This was merely a magnetic needle, but from the uses to which it was applied was called a galvanometer. When placed near a pile, or trough, in action, having its poles connected either by a wire, or by introducing them into one cell, it immediately moved, becoming obedient to the battery in the same manner as to the connecting wire; and the motions were such as if the battery were simply a continuation or part of the wire. In consequence of this action, the needle becomes an instrument competent to indicate that state of an active Voltaic pile, and the wire connecting it, which is supposed to be occasioned by currents of electricity, and in which only, magnetism has yet been most perfectly discovered.

332. M. Ampere also announced the fact of the attraction and repulsion of two wires connecting the poles of a battery; and showed, that the magnetic needle, which had previously been used to prove the magnetic attractions and repulsions of the wire, could be replaced by another connecting wire like the first. This discovery seemed to liberate the phenomena of magnetism from any peculiar power resident in the magnet, and to prove its production by electricity alone. When by Oersted's discovery it had been shown that a wire connecting the poles of a Voltaic battery would act on a magnet, attracting and repelling it, just as another magnet would do, it was fair to assume that the wire possessed the powers of the magnet it supplied; and when the second magnet was replaced by another connecting wire, as in Ampere's experiment, and the powers and actions still remained as before, it was perfectly correct to consider these powers and actions as magnetical; so that it became evident that magnetism could be exerted independent of magnets, as they are usually called, and of any of the means of excitation usually employed, but wholly by electricity, and in any good electrically conducting medium.

333. The phenomena with two conductors situate between the poles of the battery are as follows:—When they are parallel to each other, and the same ends of them are similarly related to the battery; viz. when the supposed currents existing in them are in the same direction, then they attract each other; but if the opposite ends be connected with the battery, so that the currents conceived to exist in them are in opposite directions, they repel each other. If also, the one being fixed the other moveable, the currents be sent, or the connexions be made, in opposite directions, then the moveable one will turn round until they are in the same direction. The contrast between these attractions and repulsions, and those usually called electrical, are very striking. The one take place only when the circuit is completed: the other only when it is incomplete. The attractions take place between the similar ends of the wires, and the repulsions between the dissimilar ends; but the electrical attractions take place between dissimilar ends, and the repulsions between similar ends. These take place in vacuo, but those do not. When the magnetic attraction brings the two wires together, they remain in contact; but when electrical attraction brings two bodies together, they separate after the contact.

334. These experiments were varied in several ways by M. Ampere; and the apparatus with which they were made appears, from the plates and description published, to be very delicate, ingenious, and effectual. The general results drawn up by M. Ampere himself from them are, (1.) That two electrical currents attract when they move parallel to each other, and in the same direction; and repel when they move parallel to each other in a contrary direction. (2.) That when the metallic wires, traversed by these currents can only turn in parallel planes, each of the currents tends to direct the other into a situation in which it shall be parallel, and in the same direction. (3.) That these attractions and repulsions are entirely different from the ordinary electrical attractions and repulsions.

335. M. Arago stated to the Royal Academy of Sciences that he had ascertained the attraction of iron filings by the connecting wire of the battery exactly as by a magnet. This fact proved not only that the wire had the power of acting on those bodies already magnetised, but that it was itself capable of developing magnetism in iron that had not previously been magnetised. When the wire in connexion with the poles of the battery was dipped into a heap of filings, it become covered with it, increasing its diameter to the size of a goose-quill; the instant the communication was broken at either pole, the filings dropped off; and when it was re-established, they were re-attracted. This attraction took place with wires of brass, silver, platina, &c., and was so strong as to act on the filings when the wire was brought near them without actual contact. It was shown not to belong to any permanent magnetism in the wire or filings by the inactivity of both when the connexion was not made with the battery; and it was proved not to be electrical attraction by the connecting wire having no power over filings of copper, or brass, or over saw-dust. When soft iron was fused, the magnetism given was only momentary; but on repeating the experiment, with some modification, M. Arago succeeded completely in magnetising a sewing-needle permanently.

336. The theory which M. Ampere had formed, to account for the magnetic phenomena of magnets by electrical powers only, assumed that magnets were only masses of matter, around the axes of which electrical currents were moving in closed curves. This theory led him, when informed by M. Arago of his experiments, to expect a much greater effect if the connecting wire were put into the form of a spiral, and the piece to be magnetised were placed in its axis. According to the theory, in a needle or magnet, pointing to the north, the currents were in the upper part from east to west. In consequence of these expectations, M.M. Ampere and Arago made experiments with spirals or helices, and the results are mentioned in M. Arago's paper, on the communication of magnetism to iron filings in the fifteenth volume of the Annales de Chimie.

337. On twisting a wire round a rod, it may be made to pass either in one direction or the other, giving rise to two distinct but symmetrical helices, which have been named by botanists dextrorsum and sinistrorsum. Though their diameters be equal, and the spirals which compose them have equal inclinations, yet they can never be superposed; for, however they are turned about, their direction is the same. The dextrorsum, or, as we may call it, the right helix, proceeds from the right hand downwards towards the left above the axis; the tendrils of many plants exhibit instances of it, and it is almost exclusively used in the arts: the sinistrorsum, or left helix, proceeds from the left hand downwards towards the right above the axis.

338. Having made some of these helices, one

was connected by its extremities with the poles of a Voltaic battery, and then a needle wrapped in paper placed within it; after remaining there a few minutes, it was taken out, and found to be strongly magnetised; and the effect of a helix above that of a straight connecting wire was found to be very great.

339. Then, with regard to the position of the poles in the magnetised needle, it was found that, whenever a right helix was used, that end of the needle towards the negative end of the battery pointed to the north, and that towards the positive end toward the south; but that with a left helix, that end of the needle towards the positive, pointed north; and the other end south.

340. In order to establish this point, the connecting wire was sometimes formed into one helix, sometimes into two or three, which was readily done by twisting it round a glass tube, or rod, first in one direction, then in another; and when needles previously enclosed in glass tubes were then placed in these helices, the magnetic poles they received were always in accordance with the statement just given. In one case, also, where the connecting wire had been formed into three consecutive helices, the middle one being of course different to the other two, a single piece of steel wire sufficiently long to pass through all three of them being enclosed in a glass tube was placed within them. On being again removed and examined, it was found to have six poles; first, a north pole, a little further on a south pole, then another south pole, a north pole, another north pole, and at the further end a south pole.

341. M. Boisgeraud read a paper to the Royal Academy of Sciences, containing the detail of numerous experiments, most of which, however, are variations of Oersted's first experiments. He remarked, that connecting wires, or arcs, placed any where in the battery, would affect the needle, a result that follows as a consequence from Oersted's and Ampere's experiments. He notices the difference of intensity in the effects produced when bad electrical conductors were employed to complete the circuit, a difference which Oersted himself had pointed out in the case of water. M. Boisgeraud, however, proposed to ascertain the conducting power of different substances by placing them in one of the arcs, cells, or divisions of the battery, and bringing the magnetic needle, or Ampere's galvanometer, towards another arc, viz. to the wire, or other connecting body, used to complete the circuit in the battery. With regard to the positions, M. Boisgeraud's notices of the needle and wire, they are all confirmatory of Oersted's statements.

342. M. Ampere read another memoir on the phenomena of the Voltaic pile, and on the method he intended to pursue in calculating the action of two electrical currents. He also showed the mutual action of two rectilinear electrical currents; viz. of two straight portions of the connecting wires; for it appears that the phenomena of attraction, repulsion, &c., were first observed with spiral wires. These actions, however, are exactly similar; and the view already given of them, as it relates to straight wires, is consequently more simple than the description of the effects with spiral wires can be; viz. considering it as a matter of experiment only, and not of theory.

343. In consequence of the view which M. Ampere had taken of the nature of magnetism as dependent simply upon currents of electricity, it became an important object with him to ascertain the action of the earth upon such currents excited by the Voltaic battery; for, from his theory, he expected that it would be equally efficient in directing these currents as in directing those supposed to exist in the magnetic needle. After some trials, he succeeded in overcoming the obstacles to delicate suspension, contact, &c., and constructed an apparatus in which a part of the wire connecting the two poles of a battery was rendered so light and mobile as to move immediately; the connexion was completed with the pole, and took a direction which, with regard to the earth, was always constant, and in accordance with M. Ampere's theory. An account of these experiments, with the apparatus used in them, was read to the Royal Academy. The first consisted of a wire bent so as to form almost a complete circle of about sixteen inches in diameter; the two extremities were made to approach, and were placed one just beneath the other; and being attached to two steel points, were connected by them with two little basins of platina containing mercury, fixed so as to receive them; only one of the points touched the bottom of the cup in which it was placed; so that the friction was scarcely any, and the mercury secured a good contact. The cups were connected with other wires that passed off to the Voltaic battery; so that it was easy to make this moveable circle connect either one way or the other between the poles; and being enclosed in a glass case, any movement it might receive was readily observed without danger of its resulting from any other cause than the electric action.

344. When the extremities of this apparatus were connected with the poles of a battery, the circle immediately moved, and after some oscillations placed itself in a plane perpendicular to the magnetic meridian of the earth; and, on every repetition of the experiments, the same effect took place. The direction in which it moved depended upon the way in which the connexion had been made with the battery; and if it be assumed that there is a current passing through the wire, from the positive to the negative end, the curve so arranged itself that that current always passed downwards on the eastern side, and upwards on the west. This circle moved round a perpendicular, and, therefore, only represented the direction of the magnetic needle: in order to represent the dip, a wire was formed into a parallelogram, and being fixed to a glass axis was suspended by fine points, and connected as before, so as to move round a horizontal axis, then this axis being placed perpendicular to the magnetic meridian, and the wires being connected with the poles of a battery, the parallelogram immediately moved towards a position in the plane perpendicular to the dipping-needle; when the communication was broken, it returned towards its first position; and when renewed, it resumed the second, evidently indicating the

magnetic influence of the earth over it. In consequence of the difficulty of placing the centre of gravity in the centre of suspension, and keeping it there, this conductor did not take its position exactly in a plane perpendicular to the dipping needle, but approached towards it till in equilibrium between the magnetic and the gravitating power of the earth.

345. M.M. Biot and Savart read a memoir to the Academy of Sciences, the object of which was to determine the law by which a connecting wire acted on magnetised bodies. Small rectangular plates, or cylindrical wires, of tempered steel, were made magnetical by the double touch, and being then suspended by silk-worm threads were placed in differed positions with, and at different distances from, the wire connecting the poles of the battery. The terrestrial magnetism was sometimes combined with that of the wire, sometimes opposed to it, and sometimes neutralised by the vicinity of another magnet. The different positions of equilibrium, and the number of oscillations of the needles, were then observed, and data gained, by which M.M. Biot and Savart were conducted to the following result, which expresses the action exerted by a molecule of austral or boreal magnetism, placed at any distance from a very fine and indefinite cylindrical wire, rendered magnetic by the Voltaic current. Let a line pass from this molecule perpendicularly to the axis of the wire, the force which draws the molecule is perpendicular to this line and to the axis of the wire; its intensity is reciprocal to the distance. The nature of the action is the same as that of a magnetised needle placed on the surface of the wire in a direction determinate and constant in its relation to the direction of the Voltaic current; so that a molecule of boreal magnetism, and a molecule of austral magnetism, would be drawn in different directions, though constantly according to the preceding expression.

346. M. Ampere noticed an effect produced by the connecting wire bent into a helix. This may be easily understood from considering that the direction of the magnetic power is always perpendicular to the conducting wire. When, therefore, the conducting wire is parallel to the axis of the helix, the power is perpendicular to that axis; when the wire forms a circle round the axis, in a plane perpendicular to it, the power is in the direction of the axis; but when, as in the helix, it passes round the axis in a direction intermediate between parallelism and perpendicularity, the direction of the power is of course inclined accordingly. In this case the power may be considered as composed of two portions, one perpendicular to the axis, the other parallel to it. As M. Ampere considered magnets to be assemblages of currents perpendicular to their axes, he wished, in his imitation of them, to do away with that effect due to the extension of the wire in the direction of the axis of the helix, and succeeded in this by making the wire at one end return through the helix so as not to touch it in any part; for, in this position, its magnetic effects being contrary to those belonging to the length of the helix, and also near to them, they neutralised or hid each other. An imitation of a magnet was made by forming a helix, and making the wires at the two extremities return through the centre of the helix half way, and then pass out upwards and downwards, so as to form a perpendicular axis on which the whole might move. The extremity of a battery being connected with these two ends of the wire, the helix became magnetical, and was attracted and repelled by a magnet precisely as a real magnet would have been.

347. M. Biot's examination of the effects of magnetism, as impressed by electricity in motion, is too excellent to be passed unnoticed in our chronological account of discoveries in this science.

348. 'When the electric current, evolved from a Voltaic battery, is transmitted through any metallic bodies whatsoever, it gives them instantaneously a magnetic virtue; they become then capable of attracting soft and unmagnetised iron. This curious fact was discovered by M. Oersted. If we expose to these metallic bodies, a magnetic needle, they attract one of its poles, and repel the other, but only relative to the parts of their surface to which the needle is presented. Needles of silver or copper are not affected, but merely those susceptible of being magnetised. These effects subsist only under the influence of the electrical current. If we suspend the circulation of the electricity, by breaking off the communications established between the opposite poles of the Voltaic apparatus, or even if we retard considerably its velocity, by joining its poles with bad conductors, the magnetic power instantly ceases, and the bodies which had received it return to their usual state of indifference.

349. 'This simple sketch already displays many new properties. All the processes hitherto employed to magnetise bodies had produced an effect on only three pure metals, iron, nickel, and cobalt, and on some of their compounds, steel for example, which is merely a carburet of iron. Till now it was never possible to render silver, copper, or the rest of the metals magnetic. But the electric current gives all of them this property; it bestows it transiently by its presence; and, as we shall presently see, it diffuses it through the whole mass, in a manner equally singular, and which has no resemblance to what is produced, when we develope magnetism by our ordinary processes, which consist in longitudinal friction with magnetic bars.

350. 'To produce these novel phenomena in the simplest manner, we must, with M. Oersted, establish a communication between the two extremities of the Voltaic apparatus, by a simple metallic wire, which may be easily directed and bent in all directions. We place afterwards, in the neighbourhood of the battery, a very sensible magnetic needle, horizontally suspended. As soon as this is settled in the direction due to the magnetic force of the terrestrial globe, we take a flexible portion of the conducting, or conjunctive wire, as M. Oersted calls it, and having stretched it parallel to the needle, we bring it gently near it, either from above, from below, from the right, or from the left. We shall see an immediate deviation of the needle; but, what is not the least remarkable circumstance, the direction of this

deviation differs according to the side by which the conjunctive wire approaches it. Duly to comprehend this astonishing phenomenon, and to fix its peculiarities with precision, let us suppose that the conjunctive wire is extended horizontally from north to south, in the very direction of the magnetic direction in which the needle reposed, and let the north extremity be attached to the copper pole of the trough, the other being fixed to the zinc pole. Imagine, also, that the person who makes the experiment looks northward, and consequently towards the copper or negative pole. In this position of things, when the wire is placed above the needle, the north pole of the magnet moves towards the west; when the wire is placed underneath, the north pole moves towards the east; and, if we carry the wire to the right or the left, the needle has no longer any lateral deviation, but it loses its horizontality. If the wire be placed to the right hand, the north pole rises; to the left, its north pole dips; and in thus transporting the conjunctive wire all around the needle, in directions parallel to one another, we merely present it to the needle, by the different sides of its circular contour, without affecting in the least the proper tendency of the needle towards the terrestrial magnetic poles. Since then the deviations observed in these successive positions are first of all directed from right to left, when the wire is above the needle; then from above downwards, when the wire is to the left; from the left to the right, when the wire is beneath; and, finally, from below upwards when it is to the right hand, we must necessarily conclude from these effects, that the wire deranges the needle, by a force emanating from itself, a force directed transversely to the length of its axis, and always parallel to the portion of its circular contour, to which the needle is opposite. M. Oersted drew this inference from his first observations.

351. 'Now this revolutive character of the force, and revolutive according to a determinate direction, in a medium which like silver, copper, or other pure metal, seems perfectly identical in all its parts, is a phenomenon very remarkable, of which we had heretofore only one singular example in the deviations which certain bodies impress on the planes of polarisation of the luminous rays. The first fact of the magnetism, transiently impressed upon the conjunctive wire by the Voltaic current, might have offered itself to a vulgar observer. I do not know whether some traces of this property may not have been previously perceived and indicated; but to have recognised this peculiar character of the force, and to have delineated it, agreeably to its phenomena, without hesitation and uncertainty, is the praise which truly belongs to M. Oersted, and which constitutes a condition entirely new in the movement of electricity.

352. 'As soon as this beautiful discovery was known in France, England, and Germany, it excited the most lively sensation among men of science. One of our colleagues, in particular, M. Ampere, ardently verified it in all its circumstances. Seizing with sagacity the revolutive character of the force impressed on the conjunctive wire, he directed it with judgment, and skilfully developed the consequences which flowed from this property. His researches, which preceded those of the other French philosophers, have considerably occupied the Academy; but as the order of exposition, occasioned by the mutual dependence of the phenomena, hinders me from beginning with them, I have endeavoured to compensate for this inversion by rendering justice at once, to labors which have anticipated and facilitated others.

353. 'In the above experiments which M. Oersted had made, the conjunctive wire is presented to steel needles, previously magnetised. It may be asked, if the action then exercised is proper to the conjunctive wire, as the action of a bar of steel tempered and magnetised is proper to this bar, or if the action is communicated to the wire by the presence of the magnetic needle, as we see soft iron, which exercises no magnetic power of itself, acquire transiently this power in the presence of magnets? To decide this question it was necessary to examine whether a body, not magnetic in itself, but capable of becoming so by influence, soft iron for example, would experience a sensible action at the approach of a conjunctive wire, traversed by the Voltaic current. This was effected by M. Arago, who showed that filings of iron are attracted by these wires; a simple but important fact, which defines clearly one of the characters of the force by which the phenomenon is produced.

354. 'The first thing which we must determine, is the law according to which the force emanating from the conjunctive wire decreases at different distances from its axis. This enquiry has been the object of experiments which I made along with M. Savart, already known to the Academy by his ingenious discoveries in acoustics. We took a small needle of magnetised steel in the form of a parallelogram, and, to ensure its perfect mobility, we suspended it under a glass bell, by a single fibre of the silkworm, and gave it at the same time a horizontal direction. Then, in order that it might be entirely at liberty to obey the force emanating from the conjunctive wire, we screened it from the action of the magnetism of the earth, by placing a magnetised bar at such a distance, and in such a direction, that it exactly balanced this action. Our needle was thereby placed in the same freedom of movement as if there did not exist any terrestrial globe, or as if we had been able to transport ourselves with it to a great distance in space. We now presented it to a conjunctive cylindrical wire of copper, stretched in a vertical direction, and to which we had given such a length, that its extremities necessarily bent in order to attach them to the poles of the electric apparatus, should have, in consequence of their distance, so feeble an action on the needle that it might be neglected with impunity. This disposition represented therefore the effect of an indefinite vertical wire, acting on a horizontal and independent magnetic needle. As soon as the communication of the Voltaic current was completed, the needle turned transversely to the axis of the wire, conformably to the revolutive character indicated by M. Oersted; and it set itself to oscillate around this direction, as a

clock pendulum, moved from the perpendicular, oscillates round the vertical by the effect of gravitation. We counted with an excellent seconds watch of M. Breguet, the time in which a certain number of these oscillations, twenty for example, were performed; and by repeating this observation, when the wire and needle were at different distances, we inferred the decreasing intensity of the force, precisely as we determined, by the oscillations of the same pendulum, the variations of gravity at different latitudes. We thus found that the force exercised by the wire was transverse to its length, and revolution, as M. Oersted had observed; but we discovered besides that it decreased in a ratio exactly proportional to the distance. However, the force which we thus observed was in reality a compound result; for on dividing in imagination the whole length of the conjunctive wire, into an infinity of segments of a very small altitude, we perceive that each segment ought to act on the needle, with a different energy according to its distance and direction. Now these elementary forces are precisely the simple result which it is important to know; for the total force, exercised by the whole wire, is merely the sum of their actions. Calculation enables us to pass from this resultant to the simple action. This has been done by M. Laplace. He has deduced, from our observations, that the individual law of the elementary forces, exercised by each section of the conjunctive wire, was the inverse ratio of the square of the distance; that is, precisely the same that we know to exist in ordinary magnetic actions. This analysis showed that, in order to complete the knowledge of the force, it remained to determine if the action of each section of the wire was the same, at an equal distance, in all directions; or if it was more energetic in a certain direction than in others. I have assured myself by delicate experiments that the last is the case.

355. ' What we now know of the law of the forces, is sufficient for explaining and connecting together a multitude of results, of which I now proceed to indicate briefly some of the most curious. For example, let us conceive as we have done above, an indefinite conjunctive wire, stretched horizontally from south to north. Let us present laterally to it a magnetic needle, of a cylindrical shape, and suspended so that it can take no movement but in the horizontal direction. For greater simplicity, let us withdraw it from the influence of the terrestrial magnetism, by neutralising this influence with the action of a magnet suitably placed. This being done, when the needle rests at the same height as the wire, so as to point exactly to its axis, it is neither attracted nor repelled; but, if we raise it above the wire, it presents one of its poles to it, and makes an effort of approximation. If, on the contrary, we sink it below, the needle turns about, to present its other pole, and is then attracted anew. But, if we constrain it to present the same pole as at first, the needle is repelled, and the effects are precisely inverse on the right and on the left hand of the wire.

356. ' If, instead of transmitting the electrical current across a simple wire, we make it pass through tubes, plates, or other bodies of a sensible breadth, whose surfaces are composed of parallel right lines, we find that all these bodies act on the magnetic needle, as bundles of wires parallel to their length would do; which proves that the power developed in them by the electrical current is exerted freely through their very substance, and is not weakened by their interposition, as the radiation of heat through hot bodies is enfeebled and intercepted by the interposition of these very bodies.

357. ' Instead of leaving the needle in the preceding experiment at liberty to move, fix it invariably, but render the conjunctive wire moveable, by suspending it on two points; then it will be the latter which will move towards the needle, or recede from it. In fact, it is a general law of mechanics, that re-action is always equal to action. If the wire attract or repel the needle in certain circumstances, the needle ought in the same circumstances to attract or repel the wire. This experiment belongs to M. Ampere.

358. ' Now, let us operate no longer with a magnetic needle on the wire placed in its position of mobility, but let us expose it to the magnetic action of the terrestrial globe, which is known to be perfectly similar to that of a common magnet whose poles are very distant. This force will likewise make the conjunctive wire move according to the same laws, at least if it be sufficiently freely suspended, and it will impress on it a determinate direction relative to the plane of the meridian, just as it would direct any other magnetic body. This result was realised by M. Ampere.

359. ' Finally, instead of presenting a conjunctive wire to a magnet, present two conjunctive wires to one another, in parallel positions. Then if the revolutive direction of the force be the same for the two wires, they will both concur in giving one direction to a magnetic needle placed between them; but, if the direction of the revolutive movement be opposite in each, they will tend to turn the needle in opposite directions. These are simple consequences of the law of the forces. Now, on trying these two arrangements, M. Ampere has found that in the first the two wires come together, and that in the second they mutually repel each other. Thence we must make two inferences; first, that the wires exert on each other actions perfectly analogous to those which they exercise on magnetic needles; and next that the distribution of these forces in each of their particles is analogous as to direction, with what it is in magnetic needles themselves. These two new conditions relative to the nature of the force, render this experiment very important.

360. ' In the different arrangements which we have just described, the conjunctive wires and the magnets attract or repel principally by their most contiguous parts; for, with regard to the rest, their distance rapidly diminishes their action. Hence it is evident that we should augment the energy of the effects, if we approximate together the different parts of the conjunctive wire, preserving to them, however, the same general line of action. M. Ampere has also verified this position, by coiling the conjunctive wire in the form of a flattened spiral, on the

plane of whose contours he acts with magnets, as on the side of a single wire.

361. 'Among the arrangements which he has thus formed, one of the most remarkable consists in winding the conjunctive wire around a cylinder of wood or glass, forming an elongated spiral. Then the force emanating from each point of the thread, being always directed transversely to its length, becomes in each element of the spiral perpendicular to the place of the coils, and consequently parallel to the length of the spiral itself. Farther, on account of the revolutive character of the force, all the inner points of the different rings exercise, in the interior of the spiral, forces which are equal, and operate in the same direction: whilst in their action exteriorly, the forces emanating from the different points of each ring, oppose and weaken each other gently by their obliquity. Thus the result of all these actions ought to be much more energetic within the spiral than outside of it; a consequence which actually happens. If we place in the interior of a spiral, unmagnetic steel needles, they will acquire in a few instants a permanent and very perceptible longitudinal magnetism; whereas, if we place them without the spiral, they suffer no change. This experiment is due to M. Arago. Sir H. Davy, without being acquainted with it, has since succeeded in magnetising small steel needles, by rubbing them transversely on a single conjunctive wire, or even without contact, by placing them at some distance from it. This process does not differ from the preceding, except in using the force of only one wire, a force which the spiral multiplies.

362. 'Since the electricity developed by the friction of our ordinary machines, differs in no other respect from that evolved from the Voltaic apparatus, than that the former is retained and fixed, while the latter is in motion; we find that, whenever we cause the electricity of our machines to flow in a continuous current, it has produced absolutely the same effects as the Voltaic battery. The similarity, or rather the identity, of these two forms of electricity, is manifested likewise in the production of the electro-magnetic phenomena. This has been shown by M. Arago, who transmitted along the spirals of M. Ampere, no longer the Voltaic current, but a succession of very small sparks, drawn from a common electrical machine. Small steel needles, placed in the interior of these spirals, were thus magnetised in a few instants, and the direction of their magnetic polarity was found to be determined in reference to the surfaces charged with the resinous or vitreous electricity, precisely as happens with the copper and zinc poles of the Voltaic apparatus.'

363. We must now revert to the discoveries that were rapidly proceeding in this country. Sir Humphry Davy found, in repeating the experiments of M. Oersted with a Voltaic apparatus of 100 pairs of plates of four inches, that the south pole of a common magnetic needle placed under the communicating wire of platinum was strongly attracted by the wire, and remained in contact with it, so as entirely to alter the direction of the needle, and to overcome the magnetism of the earth. This he could only explain by supposing that the wire itself became magnetic during the passage of the electricity through it, and direct experiments, which were immediately made, proved that this was the case. He threw some iron filings on a paper, and brought them near the communicating wire, when immediately they were attracted by the wire, and adhered to it in considerable quantities, forming a mass round it ten or twelve times the thickness of the wire: on breaking the communication they instantly fell off, proving that the magnetic effect depended entirely on the passage of the electricity through the wire. The same experiment was tried on different parts of the wire, which was seven or eight feet in length, and about the twentieth of an inch in diameter, and the iron filings were found every where attracted by it; and, making the communication with wires between different parts of the battery, iron filings were attracted, and the magnetic needle affected in every part of the circuit.

364. It was easy to imagine that such magnetic effects could not be exhibited by the electrified wire without being capable of permanent communication to steel. Sir Humphry fastened several steel needles, in different directions, by fine silver wire to a wire of the same metal, of about the thirtieth of an inch in thickness, and eleven inches long, some parallel, others transverse, above and below in different directions; and placed them in the electrical circuit of a battery of thirty pairs of plates, of nine inches by five, and tried their magnetism by means of iron filings: they were all magnetic; those which were parallel to the wire attracted filings in the same way as the wire itself, but those in transverse directions exhibited each two poles, which, being examined by the test of delicate magnets, it was found that all the needles that were placed under the wire (the positive end of the battery being east) had their north poles on the south side of the wire, and their south poles on the north side; and that those placed over had their south poles turned to the south, and their north poles turned to the north; and this was the case whatever was the inclination of the needles to the horizon. On breaking the connexion, all the steel needles that were on the wire in a transverse direction retained their magnetism, which was as powerful as ever, while those which were parallel to the silver wire appeared to lose it at the same time as the wire itself.

365. He attached small longitudinal portions of wires of platinum, silver, tin, iron, and steel, in transverse directions, to a wire of platinum that was placed in the circuit of the same battery. The steel and the iron wire immediately acquired poles in the same manner as in the last experiment; the other wires seemed to have no effect, except in acting merely as parts of the electrical circuit; the steel retained its magnetism as powerfully after the circuit was broken as before; the iron wire immediately lost a part of its polarity, and in a very short time the whole of it.

366. The battery was placed in different directions as to the poles of the earth; but the effect was uniformly the same. All needles placed transversely under the communicating

wires, the positive end being on the right hand, had their north poles turned toward the face of the operator, and those above the wire their south poles; and on turning the wire round to the other side of the battery, it being in a longitudinal direction, and marking the side of the wire, the same side was always found to possess the same magnetism; so that in all arrangements of needles transversely round the wire, all the needles above had north and south poles opposite to those below, and those arranged vertically on one side, opposite to those arranged vertically on the other side.

367. It was found that contact of the steel needles was not necessary, and that the effect was produced instantaneously by the mere juxtaposition of the needle in a transverse direction, and that through very thick plates of glass: and a needle that had been placed in a transverse direction to the wire merely for an instant, was found as powerful a magnet as one that had been long in communication with it.

368. Sir Humphry placed some silver wire of one-twentieth of an inch, and some of one-fiftieth, in different parts of the Voltaic circuit when it was completed, and shook some steel filings on a glass plate above them: the steel filings arranged themselves in right lines, always at right angles to the axis of the wire; the effect was observed, though feebly, at the distance of a quarter of an inch above the thin wire, and the arrangement in lines was nearly to the same length on each side of the wire.

369. He ascertained, by several experiments, that the effect was proportional to the quantity of electricity passing through a given space, without any relation to the metal transmitting it: thus, the finer the wires the stronger their magnetism.

370. A zinc plate of a foot long, and six inches wide, arranged with a copper plate on each side, was connected by a very fine wire of platinum; and the plates were plunged an inch deep in diluted nitric acid. The wire did not sensibly attract fine steel filings. When they were plunged two inches, the effect was sensible; and it increased with the quantity of immersion. Two arrangements of this kind acted more powerfully than one; but when the two were combined, so as to make the zinc and copper plates but parts of one combination, the effect was very much greater. This was shown still more distinctly in the following experiment:—Sixty zinc plates with double copper plates were arranged in alternate order, and the quantity of iron filings which a wire of a determinate thickness took up observed: the wire remaining the same, they were arranged so as to make a series of thirty; the magnetic effect appeared more than twice as great; that is, the wire raised more than double the quantity of iron filings.

371. The magnetism produced by Voltaic electricity seems (the wire transmitting it remaining the same) exactly in the same ratio as the heat; and however great the heat of a wire, its magnetic powers were not impaired. This was distinctly shown in transmitting the electricity of twelve batteries of ten plates each of zinc, with double copper arranged as three, through fine platinum wire, which, when so intensely ignited as to be near the point of fusion, exhibited the strongest magnetic effects, and attracted large quantities of iron filings, and even small steel needles from a considerable distance.

372. As the discharge of a considerable quantity of electricity through a wire seemed necessary to produce magnetism, it appeared probable that a wire electrified by the common machine would not occasion a sensible effect; and this was found to be the case, on placing very small needles across a fine wire, connected with a prime conductor of a powerful machine and the earth. But, as a momentary exposure in a powerful electrical circuit was sufficient to give permanent polarity to steel, it appeared equally obvious, that needles placed transversely to a wire at the time that the electricity of a common Leyden battery was discharged through it, ought to become magnetic, and this was actually the case, and according to precisely the same laws as in the Voltaic circuit; the needle under the wire, the positive conductor being on the right hand, offering its north pole to the face of the operator, and the needle above exhibiting the opposite polarity.

373. So powerful was the magnetism produced by the discharge of an electrical battery of seventeen square feet, highly charged, through a silver wire of one-twentieth of an inch, that it rendered bars of steel two inches long, and from one-twentieth to one-tenth in thickness, so magnetic, as to enable them to attract small pieces of steel wire or needles; and the effect was communicated to a distance of five inches above or below, or laterally from the wire, through water, or thick plates of glass, or metal electrically insulated.

374. The facility with which experiments were made with the common Leyden battery, enabled Sir Humphry Davy to ascertain several circumstances which were easy to imagine, such as that a tube filled with sulphuric acid, of one-fourth of an inch in diameter, did not transmit sufficient electricity to render steel magnetic; that a needle placed transverse to the explosion through air, was less magnetised than when the electricity was passed through wire; that steel bars exhibited no polarity (at least at their extremities) when the discharge was made through them, as part of the circuit, or when they were placed parallel to the discharging wire; that two bars of steel fastened together, and having the discharging-wire placed through their common centre of gravity, showed little or no signs of magnetism after the discharge, till they were separated, when they exhibited their north and south poles opposite to each other, according to the law of position.

375. These experiments distinctly showed, that magnetism was produced whenever concentrated electricity passed through space; but the precise circumstances, or law of its production, were not obvious from them. When a magnet is made to act on steel filings, these filings arrange themselves in curves round the poles, but diverge in right lines; and in their adherence to each other form right lines, appearing as spicula. In the attraction of the filings round the

wire in the Voltaic circuit, on the contrary, they form one coherent mass, which would probably be perfectly cylindrical, were it not for the influence of gravity. In first considering the subject, it appeared to Sir Humphry, that there must be as many double poles as there could be imagined points of contact round the wire; but when he found the north and south poles of a needle uniformly attracted by the same quarters of the wire, it appeared to him that there must be four principal poles corresponding to these four quarters. Dr. Wollaston has, however, pointed out that there is nothing definite in the poles; that the phenomena may be explained, by supposing a kind of revolution of magnetism round the wire, depending for its direction upon the position of the negative and positive sides of the electrical apparatus.

376. To gain some light upon this matter, and to ascertain correctly the relations of the north and south poles of steel, magnetised by electricity to the positive and negative state, Sir Humphry Davy placed short steel needles round a circle made on pasteboard, of about two inches and a half in diameter, bringing them near each other, though not in contact; and fastening them to the pasteboard by thread, so that they formed the sides of a hexagon inscribed within the circle. A wire was fixed in the centre of this circle, so that the circle was parallel to the horizon, and an electric shock was passed through the wire, its upper part being connected with the positive side of a battery, and its lower part with the negative. After the shock all the wires were found magnetic, and each had two poles; the south pole being opposite to the north pole of the wire next to it, and vice versa; and when the north pole of a needle was touched with a wire, and that wire moved round the circle to the south pole of the same needle, its motion was opposite to that of the apparent motion of the sun.

377. A similar experiment was tried with six needles arranged in the same manner, with only this difference, that the wire positively electrified was below. In this case the results were precisely the same, except that the poles were reversed; and any body, moved in the circle from the north to the south pole of the same needle, had its direction from east to west.

378. A number of needles were arranged as polygons in different circles round the same piece of pasteboard, and made magnetic by electricity; and it was found that in all of them, whatever was the direction of the pasteboard, whether horizontal or perpendicular, or inclined to the horizon, and whatever was the direction of the wire with respect to the magnetic meridian, the same law prevailed; for instance, when the positive wire was east, and a body was moved round the circle from the north to the south poles of the same wire, its motion (beginning with the lower part of the circle) was from north to south, or with the upper part from south to north; and when the needles were arranged round a cylinder of pasteboard so as to cross the wire, and a pencil-mark drawn in the direction of the poles, it formed a spiral.

379. It was perfectly evident from these experiments, that as many polar arrangements may be formed as chords can be drawn in circles surrounding the wire.

380. Supposing powerful electricity to be passed through two, three, four, or more wires, forming part of the same circuit parallel to each other in the same plane, or in different planes, it could hardly be doubted that each wire, and the space around it would become magnetic in the same manner as a single wire, though in a less degree; and this was found to be actually the case. When four wires of fine platinum were made to complete a powerful Voltaic circuit, each wire exhibited its magnetism in the same manner, and steel filings on the sides of the wires opposite attracted each other.

381. As the filings on the opposite sides of the wire attracted each other in consequence of their being in opposite magnetic states, it was evident, that if the similar sides could be brought in contact, steel filings upon them would repel each other. This was very easily tried with two Voltaic batteries, arranged parallel to each other, so that the positive end of one was opposite to the negative end of the other. steel filings upon two wires of platinum joining the extremities strongly repelled each other. When the batteries were arranged in the same order, viz. positive opposite to positive, they attracted each other; and wires of platinum (without filings) and fine steel wire (still more strongly) exhibited similar phenomena of attraction and repulsion under the same circumstances.

382. As bodies magnetised by electricity put a needle in motion, it was natural to infer that a magnet would put bodies magnetised by electricity in motion, and this was found to be the case. Some pieces of wire of platinum, silver, and copper were placed separately upon two knife edges of platinum, connected with two ends of a powerful Voltaic battery, and a magnet presented to them; they were all made to roll along the knife edges, being attracted when the north pole of the magnet was presented, the positive side of the battery being on the right hand, and repelled when it was on the left hand, and vice versa, changing the pole of the magnet. Some folds of gold leaf were placed across the same apparatus, and the north pole of a powerful magnet held opposite to them; the folds approached the magnet, but did not adhere to it. On the south pole being presented, they receded from it.

383. Sir Humphry Davy, in continuing his researches on the magnetic phenomena produced by electricity, found that these phenomena were precisely the same, whether the electricity was small in quantity, and passing through good conductors of considerable magnitude; or, whether the conductors were so imperfect as to convey only a small quantity of electricity; and in both cases they were neither attractive of each other, nor of iron filings, and not affected by the magnet, and the only proof of their being magnetic was their occasioning a certain small deviation of the magnetised needle.

384. Thus, a large piece of charcoal placed in the circuit of a very powerful battery, being a very bad conductor compared with the metals,

would not affect the compass needle at all, unless it had a very large contact with the metallic part of the circuit; and if a small wire was made to touch it in the circuit, only in a few points, that wire did not gain the power of attracting iron filings; though, when it was made to touch a surface of platinum foil coiled round the end of the charcoal, a slight effect of this kind was produced. And in a similar manner fused hydrate of potassa, one of the best of the imperfect conductors, could never be made to exert any attractive force on iron filings, nor could the smallest filaments of cotton, moistened by a solution of hydrate of potassa, placed in the circuit, be made to move by the magnet; nor did steel needles floating on cork on an electrised solution of this kind, placed in the Voltaic circuit, gain any polarity; and the only proof of the magnetic powers of electricity passing through such a fluid, was afforded by its effect upon the magnetised needle, when the metallic surfaces, plunged in the fluid, were of considerable extent. That the mobility of the parts of fluids did not interfere with their magnetic powers, as developed by electricity, was proved by electrifying mercury and Newton's metal fused in small tubes. These tubes, placed in a proper Voltaic circuit, attracted iron filings, and gave magnetic powers to needles; nor did any agitation of the mercury or metal within, either in consequence of mechanical motion or heat, alter or suspend their polarity.

385. Imperfect conducting fluids do not give polarity to steel when electricity is passed through them; but electricity passed through air produces this effect. Reasoning on this phenomenon, and on the extreme mobility of the particles of air, Sir Humphry Davy concluded, as M. Drago had likewise done from other considerations, that the Voltaic current in air would be affected by the magnet.

386. Mr. Pepys charged the great battery of the London Institution, consisting of 2000 double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid, and twenty-five parts of sulphuric acid; the poles were connected by charcoal, so as to make an arc, or column of electrical light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced; and a powerful magnet being presented to this arc, or column, having its pole at a very acute angle to it, the arc, or column, was attracted or repelled with a rotatory motion, or made to revolve by placing the poles in different positions, being repelled when the negative pole was on the right hand, by the north pole of the magnet, and attracted by the south pole, and vice versa.

387. It was proved by several experiments that the motion depended entirely upon the magnetism, and not upon the electrical inductive powers of the magnet; for masses of soft iron, or of other metals, produced no effect.

388. The electrical arc, or column of flame, was more easily affected by the magnet, and its motion was more rapid when it passed through dense than through rarefied air, and in this case, the conducting medium or chain of aeriform particles was much shorter.

389. We must now again revert to the continental philosophers. M. Von Buch, of Utrecht, while engaged in repeating the experiments of Oersted and others, obtained results according with them, except in one instance of difference with Oersted. M. Oersted says, that 'if the uniting wire be placed perpendicularly to the plane of the magnetic meridian, whether above or below it, the needle remains at rest, unless it be very near the pole; in that case, the pole is elevated when the entrance is from the west side of the wire, and depressed when from the east.' M. Von Buch points out that this state of rest does not continue in two of the four positions of the wire. When the connecting wire is beneath the centre of the needle, and the positive current is from east to west, the needle remains unmoved. When the current is from west to east, it performs half a revolution. On the contrary, the connecting wire being above the current from east to west, makes the needle turn half way round; while that from west to east leaves the needle unmoved. M. Von Buch conceives the difference of his results and M. Oersted's to depend upon the superior power of his apparatus; and indeed it is sufficiently evident that the incompleteness of Mr. Oersted's results depended upon the weakness of his pile. The attractions and repulsions, or the elevations and depressions, he speaks of when the wire was brought near the poles proves the existence of that action which, in M. Von Buch's experiments, was strong enough to turn the needle round; and, if the position of the wire and needle in these experiments be compared with the positions deduced from M. Oersted's experiments, it will be found that, in two of the cases, those pointed out by M. Von Buch, it was necessary a half revolution of the needle should take place to bring it into a state of equilibrium with the wire in those positions.

390. M. Von Buch, also, appears to have ascertained the effect of common electricity in producing magnetism without a previous knowledge of what had been done by others in that way, and succeeded in producing the effect by a smaller power than had before been used for that purpose. He found that a strong discharge was not necessary, nor even a Leyden phial; but, fixing a helix between the prime conductor of a machine and another insulated conductor, placing a steel needle in it, and then drawing sparks from the latter conductor, the needle became magnetic. One single turn of a machine, with two discs, eighteen inches in diameter, was sufficient to make the needle evidently magnetic.

391. In Italy, many experiments relating to magnetism by electricity had been made, and which, though new at the time to those who made them, had been previously made by others. A series was made by M.M. Gazzeri, Ridolfi, and Antinori, at Florence. The results are as follows: needles placed in helices connected with the poles of the battery received their full magnetisation in one minute. Needles on the outside of the helices would receive no magne-

tism, unless there was one or more also within, and then they became magnets with their poles in opposite directions to the poles of the inner magnet. The helix was changed into a square form, by having its wire wrapped round a parallelopiped; the magnetising effect remained the same. A needle and a long wire of platina were wrapped in a sheet of tin-foil, and that part which contained the needle introduced into a spiral of copper wire; the circuit was then made by the platina wire without the copper spiral; being in connexion with either pole, the needle became magnetised. A spiral of copper wire, with a needle in it, was placed on the surface of a basin of mercury, and the mercury then made part of the circuit: the needle became feebly magnetic. Sparks from a common machine, taken through a helix containing a steel needle, made the needle magnetic. These philosophers appear to have found that the connecting wire placed in other parts of the battery than from end to end would not magnetise needles. There was however, probably, some mistake in this.

392. M. la Borne, in repeating Arago's experiments, varied the use of the helix, by making it of iron, and putting it round the straight wire, through which an electrical discharge was made. The helix in this case became the needle to be magnetised, and it was found to be a strong magnet, the poles being in the positions so often referred to. Such a magnet is flexible and elastic, and may be doubled, lengthened, or shortened: on bringing the two poles together, its action on a magnetic needle was much diminished.

393. M. Berzelius described an experiment, which consisted in placing a thin leaf of tin, eight inches long and two inches wide, parallel to, and in the plane of, the meridian, and in that position connecting it with the elements of a Voltaic circle. A magnetic needle brought near the lower edge of this plate was thrown 20° from the magnetic meridian. On moving it slowly upwards, it took its natural position, when level with the middle of the plate, except that it was raised at one end, and depressed at the other; and, when near the upper edge, it moved 20° from the magnetic meridian in the opposite direction to what it did below. When the needle was moved up and down on the opposite side of the plate, the same deviation and effects took place, but in opposite directions. A small portion of the upper edge of the leaf was cut, and turned upwards, forming a projection above the edge. The needle, brought within equal distance of this projection and the edge, was more affected by the former than the latter.

394. Then, using a square plate of tin, and forming the connexion at opposite angles, it was found on examination that the intervening angles acted more powerfully on the needle than any other parts—'a circumstance which proves,' M. Berzelius says, 'that the magnetic polarity of the current goes to opposite extremities, as happens with electric polarity, and in artificial magnets.'

395. The tin band, or leaf, placed in a horizontal plane, and in the magnetic meridian, acted on the needle just as a wire would have done. The greatest deviation of the needle was immediately under or above the middle of the leaf, and the edges acted as in the former position. The positions assumed by the needles in these experiments was exactly what would be expected. The experiments received all their interest from the way in which their maker applied them to support his particular opinion, and apart from that had not much new in them. M. Berzelius thought that a round wire, when made the conductor, presented a more complicated case than when a square one, or a parallelopiped, was used.

396. In 1823 a paper was published by Sir Humphry Davy on the subject of electro-magnetism, which is of too important a character to admit of abridgment. He says, 'Immediately after Mr. Faraday had published his ingenious experiments on electro-magnetic rotation, I was induced to try the action of a magnet on mercury connected in the electrical circuit, hoping that, in this case, as there was no mechanical suspension of the conductor, the appearances would be exhibited in their most simple form; and I found that when two wires were placed in a basin of mercury perpendicular to the surface, and in the Voltaic circuit of a battery with large plates, and the pole of a powerful magnet held either above or below the wires, the mercury immediately began to revolve round the wire as an axis, according to the common circumstances of electro-magnetic rotation, and with a velocity exceedingly increased when the opposite poles of two magnets were used, one above, the other below.

397. 'Masses of mercury, of several inches in diameter, were set in motion, and made to revolve in this manner, whenever the pole of the magnet was held near the perpendicular of the wire; but, when the pole was held above the mercury between the two wires, the circular motion ceased, and currents took place in the mercury in opposite directions, one to the right, and the other to the left, of the magnet. These circumstances, and various others which it would be too tedious to detail, induced me to believe that the passage of the electricity through the mercury, produced motions independent of the action of the magnet; and that the appearances which I have described were owing to a composition of forces.'

398. Sir Humphry says, 'I endeavoured to ascertain the existence of these motions in the mercury, by covering its surface with weak acids; and diffusing over it finely divided matter, such as the seeds of lycopodium, white oxide of mercury, &c.; but without any distinct result. It then occurred to me, that from the position of the wires, currents, if they existed, must occur chiefly in the lower, and not the upper surface of the mercury: and I consequently inverted the form of the experiment. I had two copper wires, of about one-sixth of an inch in diameter, the extremities of which were flat and carefully polished, passed through two holes, three inches apart, in the bottom of a glass basin, and perpendicular to it; they were cemented into the basin, and made non-conductors by sealing-wax, except at their polished ends; the basin was then filled with mercury, which stood about a tenth or twelfth of an inch above the wires. The wires were now placed in a powerful Voltaic circuit. The moment the contacts were made, the phe-

nomenon, which is the principal object of this paper, occurred: the mercury was immediately seen in violent agitation; its surface became elevated into a small cone above each of the wires; waves flowed off in all directions from these cones; and the only point of rest was apparently where they met in the centre of the mercury between the two wires. On holding the pole of a powerful bar-magnet at a considerable distance (some inches) above one of the cones, its apex was diminished and its base extended: by lowering the pole further, these effects were still further increased, and the undulations were feebler. At a smaller distance the surface of the mercury became plane; and rotation slowly began round the wire. As the magnet approached, the rotation became more rapid, and, when it was about half an inch above the mercury, a great depression of it was observed above the wire, and a vortex, which reached almost to the surface of the wire.

399. 'In the first experiment which I made, the conical elevations or fountains of mercury were about the tenth or twelfth of an inch high, and the vortices apparently as low; but, in the experiments made at the London Institution, the mercury being much higher above the wire, the elevations and depressions were much more considerable, amounting to the fifth or sixth of an inch. Of course the rotation took place of either pole of a magnet, or either wire, or both together, according to the well-known circumstances which determine these effects.

400. 'To ascertain whether the communication of heat diminishing the specific gravity of the mercury, had any share in these phenomena, I placed a delicate thermometer above one of the wires in the mercury, but there was no immediate elevation of temperature; the heat of the mercury gradually increased, as did that of the wires; but this increase was similar in every part of the circuit. I proved the same thing more distinctly, by making the whole apparatus a thermometer terminating in a fine tube filled with mercury. At the first instant that the mercury became electro-magnetic, there was no increase of its volume.

401. 'This phenomenon cannot be attributed to common electrical repulsion; for, in the electro-magnetic circuit, similar electrified conductors do not repel, but attract, each other; and it is in the case in which conductors in opposite states are brought near each other on surfaces of mercury that repulsion takes place.

402. 'Nor can the effect be referred to that kind of action which occurs when electricity passes from good into bad conductors, as in the phenomena of points electrified in air, as the following facts seem to prove. Steel wires were substituted for copper wires, and the appearances were the same in kind, and only less in degree; without doubt, in consequence of a smaller quantity of electricity passing through the steel wire: and by comparing the conducting powers of equal cylinders of mercury and steel in glass tubes, by ascertaining the quantity of iron filings they attracted, it was found that the conducting powers of mercury were higher that those of steel; the first metal taking up fifty-eight grains of iron filings, and the second only thirty-seven.

403. 'Again, fused tin was substituted for mercury in a porcelain vessel, into which wires of copper and steel were alternately ground and fixed; the elevations were produced as in the mercury, and the phenomena of rotation by the magnet: and it was found by direct experiment, that the conducting powers of the tin, at and just before its point of fusion, did not perceptibly differ, and that they were much higher than those of mercury. Lastly, the communication was made from the battery by two tubes having nearly the same diameter as the wires, filled with mercury, so that the electricity, for some inches before it entered the basin, passed through mercury; and still the appearances continued the same.

404. 'From the rapidity of the undulations round the points of the cones, I thought they would put in motion any light bodies placed above the mercury; but I could not produce the slightest motion in a very light wheel hung on an axle; and when fine powders of any kind were strewed upon the surface, they merely underwent undulations, without any other change of place; and fine iron filings, strewed on the top of the cone, arranged themselves in right lines at right angles to the line joining the two wires, and remained stationary, even on the centre of the cone. The effect, therefore, is of a novel kind, and in one respect seems analogous to that of the tides. It would appear as if the passage of the electricity diminished the action of gravity on the mercury. And that there is no change of volume of the whole mass of the mercury, appears from the experiment; and this was shown likewise by enclosing the apparatus in a kind of manometer terminating in a fine tube containing air enclosed by oil; and which, by its expansion or contraction, would have shown the slightest change of volume in the mercury: none, however, took place when the contacts were alternately made and broken, unless the circuit was uninterrupted for a sufficient time to communicate sensible heat to the mercury.'

405. We may now direct the reader's attention to professor Barlow's admirable collection of experimental illustrations of this science. Mr. Barlow published a very interesting Treatise on Magnetic Attractions in 1823, but a new edition has since appeared. We shall only advert to the last section of the third part, referring our readers to the work itself for the fullest information on the subject.

406. We may commence with the most simple experiment, and show Mr. Barlow's mode of magnetising a steel bar. Take a piece of steel wire, as for example a sewing needle, and dip its ends first into steel or iron filings, in order to ascertain that it has no magnetism already in it, which will be the case if the particles of iron do not adhere to it; if they do, another needle must be tried, till one is found free from every species of magnetic action; this being done, connect the ends of the battery by the conducting wire, C Z and place the needle, N S, across it, fig. 10, plate II., drawing the latter backward and forward a few times, and it will be found to have acquired the magnetic property; for, on

immersing its extremities again in the filings, they will be found to adhere to it, in the same manner as to a needle magnetised in the usual way.

407. This very interesting experiment is strictly conformable to professor Barlow's hypothesis; for, according to this, the action of the galvanic particles in the wire, being tangential, will act upon the latent magnetic particles in the needle, in the direction of its length, and cause a displacement of them, precisely in the same manner as would be done by a magnet; and also, as in that case, the cohesive power of the steel preventing the return of the fluids to their natural state, the needle will remain magnetic.

408. This experiment was performed nearly at the same time by Sir H. Davy, and M. Ampere; but Sir H. Davy also succeeded in effecting the same with the common electrical machine, and showed that the magnetism might be excited at considerable distances, and consequently not only without rubbing the needle on the wire as we have described, but even without the contact. It requires, however, to effect this at the distances here alluded to, a very powerful apparatus.

409. If the needle be made a part of the galvanic circuit, or if it be placed lengthwise of the wire, no perceptible permanent magnetic power will be developed, which is also consistent with the hypothesis; because, in this case, the action of the wire will be transverse of the needle, which is the least favorable direction for the development of the magnetic power; the tendency of the action being to place the poles transversely, instead of lengthwise.

410. To ascertain the polarity of needles magnetised as in the last experiment, the wire and needle being placed as in the last figure, that is, the needle being above the wire, and Z denoting the zinc end of a battery of two plates only, it will be found that the extremity N will attract the south end of a compass needle, and the extremity S the north end; in short, that the north poles of the latent magnetic particles have been carried towards the left hand, and the south towards the right hand.

411. Let the needle now be placed under the wire, instead of being placed over it, and in other respects the process described in the last example repeated, and it will be found that the polarity of the needle will be exactly the reverse of that in the last experiment, which ought to be the case according to the principle of the preceding experiment; because by this the north polarity is always carried to the left hand of the observer, who conceives himself to form the galvanic circuit, his head being towards the zinc end, and his face towards the magnet; for thus, his position being now the reverse of what it was in the preceding experiment, the polarity ought to be the reverse also.

412. If we wish to magnetise a needle by placing it in a spiral conducting wire, let ZC (fig. 11) represent a conducting wire bent into a spiral form, and let the needle *ns* be placed either naked in the spiral, or enclosed in a glass tube, or in a tube of any other matter; make the connexion with the battery, and in an instant it will be found that the needle *ns* has become strongly magnetic, having its poles posited, as shown in the figure, viz. having its north end towards the zinc extremity of the battery.

413. This is of course precisely similar to the first experiment, the only difference being that, by means of the spiral form given to the wire, the action upon the needle is repeated as many times as there are spires of the wire covered by it; the power excited is therefore proportionably stronger, and the magnetism more quickly communicated. The explanation of the effect produced is exactly the same as in the last experiment. If the direction of the contact be changed, by supposing Z to communicate with the copper side of the battery, the effect will be in all respects the same, except that the polarity of the needle will be reversed. The end towards Z, in this case, becoming the south instead of the north pole. Or if a spiral, having its spires turned the contrary way, as shown in fig. 12, be used, and Z be supposed to communicate with the zinc side of the battery, the polarity will also be the reverse of that in the first case; viz. the poles will have the direction marked in the figure; and if here again the contact be changed by connecting Z with the copper side, the poles will be once more inverted, and have the same direction as at first. These facts, as we have stated above, are explained exactly in the same manner as those for the single wire.

414. In performing this experiment, Mr. Barlow employed a glass tube about five inches in length and half an inch in diameter; and it was observed, when the needle was placed in it, so that one half of it projected beyond the end, that the moment the plates reached the acid, the needle was drawn instantly to the middle of the tube, and while the contact was continued it was held suspended in the centre of the tube when the latter was held vertically, the suspending power of the spiral exceeding the power of gravity.

415. This effect is very curious, because the needle here remains suspended in the open space, directly in the axis of the tube, and not attached to either sides as in the usual cases of suspension by attraction.

416. To examine the effects of a spiral conducting wire on a floating magnetised needle, let a wire be wound about a glass tube of about half or three-quarters of an inch diameter, and hang it within a basin of water, as shown in fig. 13, so that the surface of the water rises to about the axis of the bore; then having pierced a small piece of cork with a needle previously magnetised, so as just to preserve it from sinking when immersed in the basin, make the connexion with the battery. The needle will instantly be agitated, and will soon arrange itself in front of the spiral in a direction parallel to its axis, and then suddenly dart into the interior of the tube with a force nearly sufficient to carry it to the other extremity; it then returns again towards the other end, and at length becomes stationary in the middle of the axis, arranging itself exactly parallel to it.

417. If the spirals have the direction shown in the figure, and Z communicates with the zinc side, the needle, if placed near the extremity of the tube A, will enter with its south

end; if placed near the other extremity it will enter with its north end; but, if the direction of the spiral be changed, the needle will enter in both cases the reverse way, as it will also if the direction of the spires remain the same, but the contact be changed. This experiment will succeed equally well if the tube be placed upright in the water; the needle will then dive like a fish, and remain below till the contact is broken.

418. This entertaining and instructive experiment is due to Mr. Faraday; the explanation of it by the previous hypothesis is obvious, for the north pole of the particles of the needle being carried to the left of an observer conceiving himself coinciding with the direction of the wire, and with his head towards Z, all the effects ought to take place precisely as above stated. M. Ampere had assimilated a spiral wire of this kind with an actual magnet, and Mr. Faraday instituted the above experiment to prove that there was not that identity which had been assumed; for, by suspending a hollow cylindrical magnet in the same way, the needle was always attracted to the nearest extremity of its edge, and indicated no tendency to enter the tube.

419. To show the effect produced by a galvanic wire on steel or iron filings, we must strew a quantity of iron dust or filings on a table, and bring the connecting wire near to them, when the filings will immediately be affected by the action of the wire, some few flying towards it, and adhering to it as a magnet; and, if the wire be brought into actual contact with them, a very considerable quantity may be taken up by it, exactly the same as at the extremity of a bar magnet; but the moment the contact is broken the filings fall.

420. In order to produce the best effect in this experiment, the wire intended to be operated upon should be smaller than the conducting part of the circuit. This latter, in all cases, is the better for being stout, at least three-sixteenths of an inch in diameter; but in this, as in several other experiments, it is best to have the extremities of the wires terminated by a much smaller wire, wound round the former as a spiral, or by simple contact; for by this means, the transmission being made through a smaller space, the intensity of action is proportionably increased.

421. This experiment is due to M. Arago, and it seems at first sight somewhat at variance with Mr. Barlow's hypothesis; because we have here an appearance of actual attraction between the iron and the wire, whereas we have supposed that there is no attraction between them. A little consideration will, however, show, that instead of contradicting, this fact will serve to confirm the hypothesis in question.

422. Let us, for example, conceive W, fig. 14, to denote the section of our conducting wire descending vertically from the zinc end of the battery; then, the first and direct action of this wire will be to excite magnetism in any small particle of iron, *n s*, according to the direction indicated by the letters in the figure.

423. After which, the action of the wire will be to urge the point *n* in the line *n n*, perpendicular to *n* W, and the point *s*, in the line *s s*, perpendicular to *s* W; and, in consequence of the combined action of these forces, the particle *n s* ought necessarily to approach the wire in the same way as it would do by a direct attractive force. This effect is therefore still consistent with our hypothesis, and strongly confirmatory of it.

424. We have seen that, by giving the conducting wire a spiral form, its power of magnetism is much increased; and in the same way the power of the wire on the iron filings may be rendered very great. The best form for the spiral, however, here, is that in which the wire lies all in one plane, as was shown in a previous figure.

425. This, being connected by its two extremities with the poles of the battery, will take up an astonishing quantity of filings, which, by their reciprocal attraction towards each other, exhibit the most pleasing appearance.

425*. To exhibit the rotation of a magnet round a galvanic wire, let A B E D, fig. 15, represent a cup of glass, wood, or any other non-conductor, and N S a small magnet, having a hole drilled at S, whereby it may be fixed by a short piece of silk S *c'*, to the copper wire *c'* C, passing through the foot of the cup, and let mercury be poured into the latter till the needle floats nearly vertical. Conceive, also, Z *z'* to be part of the conducting wire, descending from the zinc side of the battery, and slightly immersed in the quicksilver. If now the contact be made at C with the copper side of the battery, the magnet N S begins to rotate about the wire Z *z'*, passing towards the left hand of the observer. This rotation will be greater or less according to the power of the battery, and will continue while there is sufficient force in the latter to overcome the resistance of the quicksilver to the motion of the magnet. If the descending wire proceed from the copper side of the battery, the motion will take place in a contrary direction, that is, from left to right.

426. Or, if the contact remain the same, and the magnet inverted, then also the motion will be reversed; but if the contact and magnet be both reversed, the rotation will be the same as in the first instance. This highly curious and important experiment, which is due to Mr. Faraday of the Royal Institution, is immediately explained by the same hypothesis; according to which, the extremity N of the magnet is always acted upon by two forces, one being the galvanic force, which is tangential to the wire, and the other the tension of the silk S *c'*, in the direction of the needle. Let this latter be resolved into two forces, one vertical and the other horizontal, and we shall find the extremity N under the influence of two horizontal forces, one always central and the other tangential. The result of which must be a rotation of that point about the wire; and it will be made with the position and arrangement shown in the figure from right to left.

427. To exhibit the rotation of a galvanic wire about the magnet, let A B D E, fig. 16, be a cup or vessel of wood or glass, and N S a magnet passing tight through its foot; Z *z* a conducting wire descending from the zinc side of the battery, and rendered free to move by the chain connexion at *g*. Let mercury be poured into the vessel till the extremity of the wire is slightly

immersed in it. Then the contact being made at C (which, by means of the wire DC, communicates with the quicksilver) the wire *g z* will immediately assume a rapid rotatory motion, much greater than in the former case, the resistance being very considerably diminished by the mode of suspension. The direction of the motion, according to the arrangement in the figure, being from left to right, to a person coinciding in position with the magnet. It may, however, be reversed by reversing the magnet, or by changing the contact, as in the preceding cases.

428. This experiment is also due to Mr. Faraday, and its explanation is the same as the last; for since when the magnet is free, it will, as we have seen, revolve about the wire from right to left, it follows that, when the magnet is fixed and the wire free, the latter will revolve in an opposite direction (the action and re-action between the wire and the magnet being reciprocal), which is still, however, towards the left of a person supposed now as coinciding in position with the magnet, and his head to the north.

429. The resistance being very inconsiderable in this experiment, it may be exhibited in a more simple manner. For instance, instead of piercing the foot of the cup, as in the figure referred to, it will be sufficient to use a tea-saucer, or any other shallow vessel, and to bring a strong magnet as near to it as possible under the table; when the motion will take place precisely in the same manner as above.

430. By this means also we may establish a most important fact, viz. that it is indifferent, as to the result of the experiment, what may be the position of the magnet; that is to say, if we keep the extremity of it as nearly as possible under the centre of the vessel, we may hold it either vertical or horizontal, or incline it in any angle, and at any azimuth, without greatly changing the rate of the rotation; it being always understood that the magnet should be of considerable length, in order that its other pole may not affect the motion of the wire.

431. The machine for the exhibition of these motions, according to Mr. Faraday's construction, is shown at fig. 1, plate III. ABCD is a stand of wood, EF a brass pillar, FG a fore arm or projecting piece of brass, through the extremity of which passes the wire LHK; at L there is a sort of ball and socket joint; the socket being in the upper part, and the ball fitting it, on the small wire L*m*. Both the socket and ball are amalgamated, and a piece of silk fixed to the ball, or head of the wire, passes through a hole drilled in the wire LH, and by which the smaller wire is suspended, thereby preserving the contact, and leaving to the latter a perfect freedom of motion: *ab* is a glass cup having a hole through its foot, into which is inserted a copper tube, soldered to a copper disc just the size of the bottom of the glass, and which disc is cemented to the foot of the latter.

432. The wire Z*z* is also soldered to another copper disc, upon which the glass rests; and by which the contact is carried on from Z to the quicksilver in the cup, and thence to the wire *m*L; lastly, a small magnet *ns* is inserted into the copper tube, passing through the stem of the glass above mentioned.

433. The foot of the cup *cd* is pierced, and discs of copper applied as in the cup *a b;* but the wire passing through the foot is solid, and to it is fixed, by a short string, the small magnet *ns,* which is thus free to revolve about the descending wire HK; quicksilver, as in the preceding cases, being poured into the cup, till the wire HK is slightly immersed in it at K. The contact with the battery being now made at Z and C′, the motions will take place as described in the last two experiments; viz. that the magnet *ns* in the one cup will revolve about the wire K, while the wire L*m* will at the same time be revolving about the other magnet *n s*.

434. If the cup *cd* be placed where the cup *a b* is represented, then the magnet and wire being both free, they will revolve about each other, and thus produce a pleasing variety in the experiment.

435. A section of this machine is shown at fig. 2.

436. Mr. Faraday also describes another apparatus, which requires a less galvanic action than the former to produce the rotation. This is shown at fig. 3; it consists of a piece of glass tube, the bottom part of which is closed by a cork, and through it is passed a small piece of soft iron wire, so as to project above and below the cork. A little mercury is then poured in, to form a channel between the iron wire and the glass tube. The upper orifice is also closed by a cork, through which a piece of platinum wire passes, being terminated within by a loop; another piece of wire hangs from this by a loop, and its lower end, which dips a very little way into the mercury, being amalgamated, it is preserved from adhering either to the iron wire or the glass. Things being thus arranged, a very minute galvanic power being applied by contact with the lower and upper end of the apparatus, and the pole of a strong magnet being applied to the external end of the lower iron wire, the moveable wire within begins rapidly to rotate round the temporary magnet thus formed; and which rotation may be inverted either by changing the contact or by inverting the magnet. Mr. Faraday states that this instrument is so sensible that a rotation has been produced in it by two plates, each only one inch square.

437. To exhibit the rotation of a magnet on its axis by the effect of a galvanic wire, let ABDE, fig. 4, represent a cup of glass or wood, NS a magnet, having at its lower extremity a fine steel point, inserted in the agate *a; b c* is a thin slip of brass or ivory, having a hole through which the magnet passes freely, and by means of which it is kept perpendicular: at the upper extremity N of the magnet is a thin cylinder, as a piece of quill, forming a cup or reservoir *z* to receive a small quantity of quicksilver; and into this is inserted the wire Z, amalgamated at its lower point; and C*c* is a stout wire passing through the side of the cup into the quicksilver. Then, the contact being made at C and Z, the magnet will begin to revolve on its axis, with a very astonishing velocity, and continue in motion while the power of the battery lasts.

438. This pleasing experiment is due to M.

Ampere, who employs only a piece of platinum attached to the magnet, to produce, by its superior gravity, a vertical position of the latter in the mercury; the upper wire being then inserted into the quicksilver in the cylinder *z*, and the other wire into the cup C, the motion is produced exactly as above described: the greatest freedom of motion is, however, given by the apparatus shown in the figure. The explanation of this rotation is very obvious according to the hypothesis we have adopted, for the tangential force of the wire, acting upon the magnetic particles on the surface of the magnet, must necessarily produce the rotation in question.

439. To exhibit the rotation of a galvanic wire on its axis by the action of a magnet, let N S, fig. 5, be a magnet, represented as broken in the figure, but which is fixed, in the experiment, in a foot, in order to keep it vertical, and let *a b c d* be a light hollow copper or brass cylinder, having a steel point passing downwards into the agate cup *f*, fixed to the upper end of the magnet, and let *e* be a small tube or quill fixed on the wire passing through the top of the cylinder, holding a little quicksilver, and receiving into it the descending conducting wire Z. A B is a piece of wood turned to fit on the cylindrical magnet N S, which has a hollow groove on its upper surface to receive a quantity of quicksilver, into which the lower edge of the cylinder *a d* is slightly immersed, the surface being covered with weak dilute nitric acid. A C is a wire passing into the quicksilver. It is obvious that thus (the contact being made at Z and C) the galvanic circuit is carried from Z through the cylinder *a b c d*, thence to the quicksilver, and hence again through the wire A E, to the other extremity of the battery, whereby the cylinder *a b c d* is made to become a part of the conducting wire; and it will be found to revolve on its axis with a great velocity, fully equal to that of the magnet in the last experiment; the direction of the motion, with the arrangement shown in the figure, being from left to right, to a person coinciding in position with the magnet.

440. To exhibit a quicksilver vortex by means of a galvanic wire and magnet, it is only necessary to take any shallow non-conducting vessel, and put into it a quantity of pure mercury, into which is to be inserted the conducting wires Z, C, proceeding respectively from the zinc and copper sides of the battery. And if now the north end of a strong magnet be brought under the vessel, the quicksilver round the wire C will begin to revolve about the same, forming a beautiful vortex; the direction of the motion being from left to right. If the magnet be removed under the other wire, the same kind of motion will be produced, but its direction will be reversed; and the same change of motion will take place, of course, in each case, by changing the end of the magnet.

441. The explanation here is precisely the same as in the last experiment; the moveable part of the conductor in this case owing its mobility to its fluid nature, whereas in the former it is due to the peculiar mode of suspension. This very elegant experiment was, as we have stated in another place, first made by Sir H. Davy.

442. To exhibit the rotation of the galvanic wire, independently of the galvanic battery, we must employ the apparatus exhibited in fig. 6, where A B C D is a small copper vessel about two inches and a half high, and the same in diameter; *a b c d* is another small cylinder of copper, of the same height, soldered to the former vessel at its lower end *d e*, a hole being left in the bottom of the former to receive it. The cylinder *a b c d* is therefore open, and will admit a cylindrical magnet to be passed up; and it will, at the same time, hold a quantity of dilute acid within the space A D, *d a b c*, B C: *z z'* is a zinc cylinder, very light, of rather less altitude than the copper one. To the cylinders *a b* and *z z'* are soldered two copper wires, as shown in the figure, the upper one having a steel point proceeding from E downwards, and resting in a small metal hole at F; and consequently the cylinder *z z'* will be free to move upon its point of suspension at F.

443. The apparatus being thus arranged, and the acid placed in the cell as above described, insert through the interior cylinder the north end of a strong cylindrical magnet, and balance the whole apparatus upon it, when immediately the zinc cylinder will begin to revolve with a greater or less velocity, according to the strength of the acid, the freedom of motion, and the power of the magnet. Mr. Barlow has frequently produced, with this simple apparatus, a motion, amounting to 120 rotations per minute. The only difference between this and the other rotations we have described is, that the galvanic power is here produced by the apparatus itself, instead of having recourse to the battery.

444. For it is obvious that the wire from Z Z' to E, may be considered as a conductor proceeding from the zinc; and the wire from *a b* to F, as one from the copper side of the battery; and consequently, the same effect is to be expected here as in the preceding cases. It is unnecessary to add, that, with the north end of the magnet upwards, the motion is from left to right, and the contrary with the magnet reversed. This experiment is due to M. Ampere.

445. A very pleasing addition has been made to this apparatus by Mr. J. Marsh. It consists in having a second point descending from F, which is made to rest in an agate cup, fixed on the top of the magnet, fig. 7, and upon which the whole machine is balanced, having a perfect freedom of motion; and, to preserve this balance, the magnet is placed vertically in a foot. The machine being now charged with acid, a compound motion takes place, the zinc cylinder revolving in one direction, and the copper vessel in another, producing thus a very pleasing effect; the latter, however, is by no means so rapid as the other, in consequence of the weight of the acid; and, in fact, that of the whole machine being supported on the lower point.

446. To show the effect of a horse-shoe magnet on a freely suspended galvanic wire, let Z *z*, fig. 8, denote a part of the galvanic wire, freely suspended by the chain connexion at *o*, proceeding from the zinc end of a battery, its lower extremity being amalgamated, and slightly immersed in a reservoir of pure mercury, having a

connexion at C with the other extremity of the battery. N S is a horse-shoe magnet, posited as shown in the figure.

447. The contact being now made at C and Z, the hanging part of the wire, *o z*, will be thrown out of the mercury into the position *o z'*; the contact being thus broken, it falls by its own gravity into the mercury; by which means, the contact being renewed, it is again projected, and so on with an extraordinary rapidity; and if the position of the magnet be reversed, or the contact be changed, the direction of the motion will be changed also, but the effect will be the same.

448. This singular motion may be still explained by the hypothesis that has been advanced; for the wire having a tendency to pass round the north end of the magnet to the right hand, and round the south end to the left hand, is urged by equal forces directly in a line with the open space of the magnet, the equality of the two forces preventing the rotatory motion about either, but both conspiring to give to the wire the rectilinear motion which has been described. This experiment is also due to Mr. J. Marsh.

449. If we wish to exhibit a wheel and axle rotation by means of a horse-shoe magnet, the machine represented in fig. 9 will produce this motion. A B is a rectangular piece of hard wood; C D an upright wooden pillar; D E a piece of stout brass or copper wire; and *a b* a somewhat smaller wire, soldered upon it at E, on the lower side of which the wheel W, of thin copper, turns freely; *h f* is a small reservoir for mercury, sunk in the wood; and *g i* a narrow channel running into it. H H is a strong horse-shoe magnet. Mercury being now poured into the reservoir *f g*, till the tips of the wheel are slightly immersed in it, and the surface covered with weak dilute nitric acid, let the connexion with the battery be made at *i* and D, and the wheel W will immediately begin to rotate with great velocity. If the contact be changed, or if the magnet be inverted, the motion of the wheel will be reversed; but, in general, the best effect is produced when the wheel revolves inwards. The suspension of the wheel is shown in fig. 10. This is a necessary consequence of the motion described in the last experiment, by which it was suggested, and is explained on the same principles.

450. The machine for exhibiting a compound wheel and axle rotation, with two horse-shoe magnets, is shown in fig. 11. A B G D is a rectangular piece of board, having two grooves about half an inch deep, cut in it parallel to its length. C *p*, Z *q*, are two wires, having cups for connexion at Z and C, and each passing into its respective groove, *a b*, *c d*, filled with mercury, into which are slightly immersed the points of the wheels W W'; these being fixed on an axle W W', and resting upon the two supports *m n*, *r s*, brought to a fine edge at *n* and *s*, in order to reduce the friction as much as possible, and to give the greater freedom of motion. N S are two horse-shoe magnets, posited as in the figure, with the like poles interior and exterior of the wheels.

451. The apparatus being thus prepared, and the contact made at Z and C, the wheels will begin to rotate, and in a very short time will acquire a velocity exceeding, very considerably, any of the motions hitherto described.

452. It is unnecessary to say, that by changing the contact, or by inverting the magnets, the direction of the rotation will be also changed. The usual precaution of covering the surface of the mercury with weak dilute nitric acid, will increase the rapidity of rotation; but it is not actually necessary in this case.

453. To exhibit the terrestrial directive quality of a galvanic wire, let A B, fig. 12, represent a piece of wood fixed to any convenient support, through which pass the two wires G, E, and where they remain fixed. At their upper and lower extremities are soldered the small metal cups, *a*, *b*, *c*, *d*. D H I K, &c., is a part of the conducting wire, bent into the form shown in the figure, having small steel points soldered upon it at *c* and *d*. These points are inserted into the cups *c*, *d*, the upper one only resting on the base of its cup, the other being merely brought into contact with *d*, by a little quicksilver placed in it for that purpose, by which means the rectangle has a great freedom of motion given to it, the only solid contact being on the point *c*. Mercury is also poured into the other cups, for the sake of a more perfect and certain communication than that afforded by the mere juxta-position of the wires.

454. The apparatus being thus prepared, the two wires proceeding from the copper and zinc sides of the battery, are inserted into the cups *a*, *b*, and thus the connexion is established; first by means of the wire G with the cup *c*, thence by means of the contact of the points with the cup and mercury; it is carried forward from *c* through the rectangle, to the cup *d*, whence it proceeds to the cup *a*.

455. We have already seen that of this connecting wire, the part from *c* to *d* has a perfect freedom of motion upon the point at *c*, and will therefore obey any exciting force. This force, in the experiment in question, is the magnetic influence of the earth; and in consequence of which the rectangle, immediately the contact is made, places its plane perpendicular to the plane of the magnetic meridian; and to which position it will always return, after a few vibrations, if it be drawn out of it by the hand or otherwise.

456. This arrangement of the moveable conductors is perfectly consistent with our hypothesis, as is obvious without any farther illustration than what has been given in several preceding experiments.

457. A differently formed wire, and a more simple mode of suspension, is shown in fig. 13. Here a brass or copper wire, A C, rests at its bent end A, in a cup containing a little mercury, and is very moveable in azimuth round this point. The other end passes through the centre of a circular piece of pasteboard, and then forms spiral turnings in the plane of this circular piece. The wire is attached by thread or silk to the pasteboard disc; and at the point B it turns and descends till its extremity reaches the quicksilver in the cup D. The communication being now made at A and D with the battery, the spiral will immediately arrange itself, as in the last

case, in a plane perpendicular to the magnetic meridian. This experiment is originally due to M. Ampere, but the mode of suspension described is that of professor Van den Boss.

458. A needle, upon a different construction, also due to M. Ampere, is shown in fig. 14.

459. The directive quality of the galvanic wire has been since exhibited in a variety of ways, much more simple than that above described, of which we shall only state the following:—

460. M. de la Rive's apparatus consists of a small galvanic combination attached to a cork; the plate of zinc is nearly half an inch wide, and extends about one and a half, or two inches, below its cork, its upper end passing through the same; the slip of copper is of equal width to the zinc, but passes round it, being thus opposed to both its surfaces, as in Dr. Wollaston's construction: its upper end also appears through the cork. A piece of copper wire, covered with silk thread, is coiled five or six times, and tied together, so as to form a ring about an inch in diameter; and the ends of the wire are connected by solder, one with the zinc, and the other with the copper slip above the cork. See fig. 15.

461. When this small apparatus is placed in water, slightly acidulated with sulphuric or nitric acid, the ring becomes highly magnetic, and will arrange itself in a plane perpendicular to the magnetic meridian, or it will at least indicate a tendency to take up that position; but the escape of the bubbles, arising from the decomposition of the water, prevents it from preserving a fixed direction.

462. Its magnetic qualities, however, are more obviously shown by bringing to it a strong magnet. Mr. Barlow used a cylindrical one, about three quarters in diameter, and eighteen inches in length. This being applied at the distance of several inches, the ring was immediately attracted or repelled accordingly, as one or the other of the poles of the magnet was presented, or accordingly as one or the other side of the wire was opposed to the latter. When the result of the application is attraction, the cork will advance towards the extremity of the magnet; and if the latter be held horizontally, and in a line with the centre of the former, this will continue to advance till the pole of the magnet is within the ring, and then proceed with considerable velocity till it reaches the middle of the magnet, where it remains perfectly stationary. If now the magnet be withdrawn, and changed end for end, and re-introduced into the ring, the latter will go off from the magnet, turn itself round when quite free from it; again advance, and settle itself as before in the centre.

463. This very simple apparatus, which may be made at the expense of about a shilling, throws great light upon the nature of the electro-magnetic action, and proves most satisfactorily, that notwithstanding the intimate relation between the electro-magnetic, and simple magnetic fluids, they are not identical; for no possible arrangement of simple magnets can be made that would lead one of them beyond the pole of another, to find its state of equilibrium in the middle of the latter. At the same time all the above facts will be found perfectly consistent with the hypothesis that has been advanced; for it will be seen, when the wire and cork are in equilibrium, as above stated, that an observer will have the north end of the magnet to his left hand, and the south to his right, at equal distances; and acting therefore with equal and opposite powers; consequently the wire itself ought to be in equilibrio, and, when disturbed from, it will have a tendency to regain it, and hence be subject to all the conditions and motions that have been described.

464. As the current of electricity, produced by a Voltaic battery when passing through a metallic conductor, powerfully affects a magnet, tending to make its poles pass round the wire, and in this way moving considerable masses of matter, it was supposed that a re-action would be exerted upon the electric current capable of producing some visible effect; and the expectation being, for various reasons, that the approximation of a pole of a powerful magnet would diminish the current of electricity, the following experiment was made:—The poles of a battery of from two to thirty four-inch plates were connected by a metallic wire, formed in one part into a helix, with numerous convolutions, whilst into the circuit, at another part, was introduced a delicate galvanometer. The magnet was then put, in various positions, and to different extents, into the helix, and the needle of the galvanometer noticed; no effect, however, upon it could be observed. The circuit was made very long, short, of wires of different metals and different diameters down to extreme fineness, but the results were always the same. Magnets more and less powerful were used, some so strong as to bend the wire in its endeavours to pass round it. Hence it appears, that however powerful the action of an electric current may be upon a magnet, the latter has no tendency, by re-action, to diminish or increase the intensity of the former.

465. M Prechtl has a very curious experimental illustration of the effects of a spiral wire. He coils round a glass tube or wooden cylinder, steel-wire covering the surface as with a continuous sheath. To one end of this cylindric spiral, he applies the south or north pole of a magnet, and draws it along the cylinder in a straight line, parallel to the axis. In this way a magnet is formed, which possesses the following properties:—

(*a*) Along its whole length, it has on one side the north, and on the opposite side, the south pole.

(*b*) These transversal magnetisms are in every point of the length of the wire-cylinder, equally strong.

(*c*) Both of its ends exhibit on the contrary no particular polarity, and they have no other magnetism than that which belongs to every individual point of the whole length. Thus the transversal magnet is in the same condition as the conjunctive wire of the Voltaic column.

(*d*) If we hold this transversal magnet over a magnetic needle in the declination-plane, it repels exactly like the conjunctive wire, the north pole of the needle to the right or to the left, ac-

cording as the effective north pole of its transversal magnetism lies to the left or to the right hand; and with greater or less force, according to the strength of its magnetism, even to 90°.

(*e*) If we draw the one pole of a magnet along this transversal-magnet, in a spiral direction, the wire becomes magnetised longitudinally; the transversal magnetism disappears, the two poles are found at the two extremities, and it now resembles an ordinary magnetised steel wire. The longitudinal and transversal magnetisms are not compatible with each other, in their full exhibition.

466. Besides this transversal magnetism, with single polarity, magnets may be easily made, possessing several transversal magnetisms. Take four magnetic bars, about a quarter of an inch thick; provide a small disc of wood, with an aperture of about an inch diameter in its centre, and four grooves, cut into one face of the disc, leading from the circumference, inwards: in these grooves the magnetic bars are to be fixed, with their narrow edge outwards, and their ends projecting into the aperture. Let a north pole alternate with a south pole in the circle, so that the ends of the bars right opposite to each other may be homogeneous; and adjust the whole, so that they may touch the circumference of a steel wire-coil, about half an inch diameter. We then draw this spiral wire through the opening, and between the four magnets, taking care that the cylindric coil does not revolve on its axis, but that the direction of each individual magnetic pole remains in the same plane with the axis; for otherwise the wire would acquire the longitudinal magnetism. Instead of the wire-coil, we may take a massive cylinder of steel. This will acquire, when treated in the same way, the compound transversal magnetism, without its extremities having a stronger magnetism than each of its cross sections. These transversal magnets with manifold polarities, have all the above enumerated properties of the single transversal magnets, but their phenomena are still more in unison with those of the electrical conjunctive wire; for, under this manifold polarised magnet, the deviation of the needle is the reverse of that above the magnet.

467. In the following manner we may produce a section of a manifold polarised transversal magnet in a larger rod, and with a proportionally greater number of poles. We take a ring of steel wire, from four to six inches diameter, and furnish it with as many poles as we can apply to its circumference. Lay the ring flat on a table, and apply to its outer edge the two poles of a horse-shoe magnet, that are as near each other as possible; then remove the magnet and apply it in succession all around, at distances equal to the width of its own poles. In this way it is easy to induce on a steel ring, of about five or six inches diameter, from twenty to thirty opposite poles.

468. This steel ring, which represents a section of the manifold polarised transversal magnet, exhibits, relatively to the greater extension and smaller number of the existing magnetisms, the phenomena which a conjunctive wire presents. In every part of it the magnetic needle, with its north end above, stands to the right hand; below it, to the left; and inversely. M. Prechtl thinks that these direct results leave no further doubt concerning the magnetical condition of the conjunctive wire.

469. Although success had attended the experiments made to magnetise steel needles and bars by ordinary electricity when in motion, yet every attempt to occasion the deviation of the magnetic needle by a current from the machine had failed, until M. Colladon instituted his experiments. Conceiving that the quantities of electricity operated with had been too small, he used a battery of thirty jars, containing 4000 square inches of surface for the previous accumulation of the electricity, and operated with a galvanometer constructed on Nobili's principle, having 100 revolutions of wire. The wire was covered with a double thickness of silk, and the instrument placed in a room away from that containing the battery. Two copper wires covered with silk, and suspended on silk cord, connected it with the electrical apparatus. A very fine point was soldered on to each of these wires, which were then named the extremities of the galvanometer.

470. The battery was charged: one galvanometer extremity was connected with the outer coating, and the other approached towards a ball in connexion with the inner coating. When at four or five centimetres' distance, (an inch and a half or two inches) the needle deviated; when at less than half that distance, the deviation was 23°, and, gradually diminishing, continued for five seconds. The direction of the deviation accorded with the course of the electricity. Every repetition of the experiment gave the same result, and when the points brought to the battery were changed, or the charge of the battery itself was altered, the direction of the deviation corresponded with it. The quantity of deviation varying with the distance of the points was often 40°; and the return of the magnetic needle to its original position, upon the cessation of the current, was in every instance ascertained.

471. On making experiments with a Nairn's machine, and also with a plate machine, no accumulative apparatus being used, deviations of the needle, amounting to 3° or 4°, were obtained in dry weather.

472. It was thus demonstrated that the electrical machine could, like the Voltaic pile, produce a current, competent to the deviation of the needle, and that the electricity accumulated in a given time in a battery, or even in a conductor, was a finite portion of that which circulated in the same time in a closed electro-motive circuit. To establish this comparison in a more definite manner, a wire of platina was soldered to the two extremities of the galvanometer, one of the junctions heated, and the other cooled; at 125°, C. (268° F.) the needle of the galvanometer deviated 45°, the same quantity which had been produced by the battery. Hence it appears that the galvanometer may, in certain cases, be a very useful indication of the quantities of ordinary electricity.

473. The insulation of the different turns of the galvanometer wire appearing to be an im-

portant point, M. Colladon prepared an instrument, in which the wire was covered with two folds of silk, made 500 turns round the box, and had each separated from the others by oiled silk. With this instrument the effects were nearly tenfold what they were before, and as, in the former case, the deviation of the needle, by the current from a machine, was only 3° or 4°, now it amounted to much larger quantities. When the point was at the distance of—

1 decimetre (3·937 inches) the deviation was 18°				
2	ditto	ditto	ditto	10
4	ditto	ditto	ditto	5½
8	ditto	ditto	ditto	3
1 metre (39·371 inches)			ditto	2;

so that it was rendered sensible at the distance of a metre from the conductor.

474. It should be remarked that the withdrawing action of a point is sensibly proportional to its distance from the conductor. This is constantly the case with a cylinder machine, but seemed to be interfered with in a plate machine by the presence of four cushions. Experiments, instituted to illustrate this point, proved the correctness of this conclusion. When the motion of the cylinder machine was regular, the deviation remained constant as long as the experiment was continued.

Operating with the battery, and slowly approaching the point, a constant deviation of 30° was obtained for sixty-five seconds. A jar, containing only two half-square feet of surface, deviated the needle 32°.

475. The ratios which these experiments establish between the action of currents produced by electrical machines, and those of a pile or a thermo-electric arrangement, afford the means of appreciating the absolute velocity with which the electricity moves in a closed electro-motive apparatus, when we know their electro-motive force, or the tension which may be produced by the contact of two metals, and the friction of cushions. In fact, in electrical machines, this velocity of circulation is determined by the motion of the glass plate, by which the electricity is transported to the conductors with a known velocity. If the tension of this electricity is ten thousand times stronger than the tension of a pair of Voltaic plates, having the same surface as the cushion, and nevertheless the effects produced by the two currents on a galvanometer are the same, the velocity of circulation of the electricity from the Voltaic arrangement would be evidently ten thousand times greater than that of the rubbed part of the plate; for it is an acknowledged opinion, that the deviation of the magnetic needle is proportional to the quantity of electricity which passes in the current.

476. Comparative experiments, made with piles and thermo-electric circuits, prove that the conductibility of metallic wires is not in the inverse ratio of their length. When the electro-motive force is small, a metallic circuit of moderate length is sufficient to stop the electric current almost entirely. The intensity of the current rapidly increases as the length of the circuit is diminished to a certain limit, dependent on the energy of the electro-motive force.

477. M. Colladon observes also, that although bad conductors, as pure water for example, cannot be made part of a Voltaic circuit without stopping the motions of the galvanometer; yet a layer of air, of more than a metre in thickness, does not always prevent this kind of action, and that the results depend upon the energy of the electro-motive force; so that this becomes an important element, not to be neglected in experiments on the conductibility of bodies.

478. Taking advantage of some stormy weather, M. Colladon was enabled to obtain deviations of the magnetic needle by currents of atmospheric electricity, and has shown that the instrument may become a very precise and useful indication of the state of this agent in the atmosphere. A metallic point being raised on the observatory of the college of France, and connected with the galvanometer, whilst the other extremity of the instrument wire was communicated with the stem of a lightning-rod, deviations were obtained of 32°, 34°, and 37°. The direction of the needle indicated negative electricity, and by dismounting the apparatus, and using an electrometer, this was found to be the case. On another occasion the deviation was from 10° to 22°, and, during the twenty minutes that the instrument was observed, the direction of the current changed two or three times. On another occasion the deviation amounted to 87°. These results were obtained with the first and least sensible galvanometer.

479. These experiments prove that the galvanometer may be very useful in researches on atmospheric electricity. If it should be demonstrated that electricity contributes to the formation of hail, this instrument would be the only one which could indicate in a precise manner the quantities of electricity withdrawn by points more or less acute and elevated, and communicating more or less with the soil.

480. M. Nobili's galvanometer is a curious instrument. Its construction is founded upon the fact discovered by Oersted, the deviation of a magnetic needle by a wire conveying a current of electricity; and, as in most other instruments of this kind, the wire is passed several times round the frame, within which the needle is suspended, that the effect may be proportionally increased. It differs, however, from all made before it, in the use of two needles instead of one: these are equal in size, parallel to each other, magnetised in opposite directions, and fixed on a straw, so that the contrary ends of the two needles point in the same direction. Their distance from each other on the straw is regulated by the construction of the frame with its covering wire, in and about which they are to move. The frame of M. Nobili is twenty-two lines long, twelve wide and six high. The wire is of copper covered with silk, it is one-fifth of a line in thickness, from twenty-nine to thirty-feet long. It makes seventy-two revolutions about the frame. The needles are twenty-two lines long, three lines wide, a quarter of a line thick, and they are placed on the straw five lines apart from each other. An aperture is made in the tissue formed by the turns of the wire on the upper surface of the galvanometer, by thrusting them from the middle towards each side; the lower

needle on the straw is introduced through this aperture into the interior, in consequence of which the upper needle remains a little above the upper surface of the wire. The aperture is retained open to a certain extent, to allow freedom of motion to the needles and straw, these being suspended in the usual way from the upper extremity of the straw. The graduated circle, on which the deviation is measured, is placed over the wire on the upper surface of the frame, having an aperture in its centre for the free passage of the needle and straw. The upper needle is the index, the lower being visible only from the sides of the instrument.

481. The sensibility of this instrument depends upon the addition of the upper needle. Being magnetised in an opposite direction to the lower one, it almost entirely neutralises the influence of terrestrial magnetism, leaving only so much of directive power as shall induce the whole arrangement to return to a constant position when uninfluenced by electrical currents, and yet combining with the lower needle, to cause deflexion when an electrical current is passing through the wire.

482. As an illustration of the delicacy of the instrument M. Nobili observes, that it is well known if Sebeck's combination of antimony and bismuth be attached to a common galvanometer, and the point of junction be cooled, only a very slight effect is observed on the instrument; whilst, if attached to the new galvanometer, the same influence is sufficient to make the needles revolve several times. If a piece of iron wire, five or six inches long, be used to connect the extremities of the copper wire of the instrument, by twisting the ends together, and one of the points of contact be warmed by touching it with the hand, the needle will move from 0°, and in the first oscillation extend to 90°. Even the mere approximation of the hand to the junction of the metals will produce a deviation of 20°.

483. It is necessary for the delicacy of the instrument that the needles used be magnetised as nearly as possible to the same degree, and two indications have been observed as useful in pointing out when this is the case; the first is the position taken up by the plane of the needles, when left to the earth's influence, this should not be in the plane of the magnetic meridian, but more or less inclined to it; the second is the manner in which the system oscillates about its line of equilibrium. These oscillations should be very slow compared with those of a common needle.

484. In consequence of the situation of the graduated circle above, and not within the frame, the folds of the wire may be brought much nearer to each other than in the common instrument, this renders it more compact, and, from the vicinity of the needle within to the wire, also more powerful. When fixing the graduation the zero should be placed so as to accord with the position of the needles, when left to the earth's influence; this will not be towards the true magnetic north, but will not be far from it, and will always be constant.

485. M. Nobili then offers a very curious illustration of the powers of the instrument:—'It is known,' he says, 'that water usually retains itself at a lower temperature than the ambient air, the difference being sometimes 2°, and resulting from the evaporation of the liquid. If a bar of bismuth be made to join the two extremities of the galvanometer wire, and one of the points of junction be plunged into a cup of water, the needle will immediately deviate several degrees; proving that the instrument is capable of measuring the small degree of refrigeration produced by the evaporation of the liquid. I have actually submitted one of my galvanometers for fifteen days to an experiment of this kind, the deviation was about 15° in the morning and evening, but more considerable in the course of the day. This first attempt has made me suppose that the galvanometer might become, in the hands of an attentive and skilful philosopher, a kind of *atmidometer*. If by means of a single couple of different metals, bismuth and copper, a deviation of 15° has been obtained, a much greater one would be produced by employing several pairs, conveniently immersed in the same vessel of water; and, perhaps, one might succeed by increasing the scale of observation, in ascertaining more exactly the diurnal rate of evaporation. I propose, also, to ascertain the effect of a current of air, excited by any means over the surface of the water used in the experiment; it would, without doubt, augment the evaporation, and, by increasing the difference between the temperature of the air and the water, increase the effect on the instrument.

486. The theory of electro-magnetism remains to be illustrated. The phenomena developed were, at first view, not a little perplexing; and it was not till after repeated investigation, that, in 1820, any tangible view of the matter was furnished. The conducting wire was found to exert a magnetic force, not in a direction parallel to the wire itself, nor even in any plane passing through that direction, but in one that was perpendicular to it; and which, if circles were described in this latter plane, having the point at which it intersects the wire for their common centre, would have the direction of tangents to those circles. The following is another mode of conceiving the same thing. Imagine a cylinder of any diameter to envelope the wire,—the wire itself being in the axis; and conceive the surface of the cylinder to be covered on all sides with an infinite number of short lines touching the surface at different points, and situated transversely, that is, at right angles to its length. Suppose these lines to represent magnets, with the northern polarity of each turned in one invariable direction, as we follow them round the cylinder. Then will these imaginary magnets indicate the direction and nature of magnetic forces, which emanate from the fire as long as the stream of Voltaic electricity is passing through it. The particular direction of the transverse, or, as it has been termed, tangential magnetic force will of course depend on that of the electric current in the wire, and may easily be traced in all cases by the recollection of the following fact. Supposing the wire to be in a vertical position—in which case the planes of the tangential forces will be horizontal—and supposing the stream of positive electricity to be

descending along the wire, which of course implies that the negative electricity is ascending, then that polarity which exists in the end of the magnetic needle, which naturally turns to the north, will be impelled round the wire in the circumference of a circle in a direction similar to the motion of the hands of a watch; that is, from the north to the east, and then to the south and west. The south pole of a magnet will of course be impelled in the contrary direction. A magnetic body in the vicinity of the wire will, by the influence of this force, tend to assume a position, shown in fig. 16, similar to one of the tangential lines we have been describing as placed on the cylinder. But further, the tendency of the electric current in the wire is to induce magnetism in soft iron or other bodies capable of receiving it; and the magnetism so reduced has the precise direction already indicated as that which a bar previously magnetised would assume by the influence of the wire. This direction is shown in the figure, where N and S denote respectively the north and south poles of steel bars, situated transversely with respect to a vertical conducting wire, in which the current of positive electricity is descending, as indicated by the arrows.

487. Most of the facts which have been brought to light by Oersted are the immediate consequences of the above general law. Mr. Barlow's enunciation of this law is as follows: he states 'that every particle of the galvanic fluid in the conducting wire acts on every particle of the magnetic fluid in a magnetised needle, with a force varying inversely as the square of the distance; but that the action of the particles of the fluid in the wire is neither to attract nor to repel either poles of a magnetic particle, but a tangential force, which has a tendency to place the poles of either fluid at right angles to those of the other; whereby a magnetic particle, supposing it under the influence of the wire only, would always place itself at right angles to the line let fall from it perpendicular to the wire, and to the direction of the wire itself at that point.'

488. The transverse, or tangential action, which we have been describing is one of so extraordinary a nature, that it can be assimilated to no other principle in nature, of which we have any knowledge. It is not, therefore, surprising that it eluded the observation of former enquirers; although in the keenness of research, they almost stumbled upon the discovery. The fact which occurred to Beccaria, of the production of transverse magnetism in an iron bar, by the electric discharge of a battery, had, in fact, pointed out the precise direction of this inductive force; and the hint, if pursued, would have infallibly led to the discovery which Oersted made fifty years afterwards. It is curious that a circumstance extremely similar is on record, with regard to the observation which conducted Galvani to the discovery of the science which bears his name; namely, the convulsive movements of the muscles of frogs, on taking sparks from a neighbouring prime conductor, charged with electricity. The very same fact had been noticed by Du Verney, about a century before, as appears from a memoir in the History of the French Academy of Sciences, for 1700; but was deemed of no importance.

489. The relation which this new magnetic power bears to the electrical, was also very singular and enigmatical. Considered as a magnet the conducting wire acted differently, according to the side to which magnetic bodies were presented to it. What was attracted by the one side was repelled by the other; and, if the power were conceived to be derived from the impulse of a fluid, that fluid must be circulating perpetually round the wire in a kind of vortex, of which the wire is the axis. The consequence of such a vertiginous motion, as Dr. Wollaston has termed it, in the magnetic fluid, would necessarily, under certain circumstances, produce rotatory motions in the parts of certain combinations of magnets and of wires. The suggestion thus thrown out by Dr. Wollaston was soon after realized, by Mr. Faraday's discovery of the rotatory movements which had been predicted, and which we have already pretty fully described. By employing mercury as part of the Voltaic circuit, and placed so as to allow of perfect freedom of motion in the conducting wire, or in the magnet, according to the nature of the experiment, and so as to obtain the action of one pole only, Mr. Faraday succeded in effecting a variety of rotations, both in the magnet and the wire, in conformity with the law above stated. If the positive electric current be descending along the wire, the north pole of a magnet in its vicinity will revolve round it in the direction indicated by the arrows. As action and re-action are equal and contrary, the wire was seen to revolve round a fixed magnet, in a direction contrary to that in which the magnet would have moved, if the wire had been stationary; but, since these motions are to be estimated on opposite sides of a common centre, the direction in the circumference will remain the same. Thus, as a north pole revolves round a descending positive electric current in the direction of the hands of a watch, a wire in which a similar current is descending, will revolve in the same circular direction round a north pole placed in the centre of its motion.

490. The experiments of Mr. Faraday and professor Barlow, confirmed and extended as they have been by Barlow, Biot, and others, appeared to have conducted us to the most general fact belonging to the science; namely, the tendency to a transverse rotatory motion in the magnetic and electric fluids, when acting freely on each other. This fundamental principle once admitted, all the phenomena that had hitherto been discovered appeared to be easily explicable, and most of them were the immediate and necessary consequence of that principle. There was, indeed, one particular fact, for the discovery of which we are indebted to M. Ampere, to which it was less directly applicable, and which might not, perhaps, have been deduced as one of its results. This distinguished philosopher observed, that when two conducting wires were so arranged as that one or both of them were allowed a certain freedom of motion, they either attracted or repelled each other, according as the electric current which they transmitted was moving in the same or in opposite directions in the two wires.

If, for example, two wires, which are transmitting currents of electricity, be situated within a certain distance, and parallel to each other; and if we suppose the currents of positive electricity to be passing from left to right in both the wires, they will manifest an attraction for each other. The same tendency of attraction will also appear when the positive currents are both moving in the contrary direction, that is, from right to left. But if the current in one wire is moving in a direction opposite to that of the current in the other wire, in that case a repulsive action will take place between the two wires. These were found to be constant and invariable effects of the transmission of electricity along conductors; and they were manifested equally, whether the two currents were obtained from separate Voltaic batteries, or were only two portions of the same current in different parts of its course.

491. To understand Ampére's theory, let us conceive a slender cylinder of iron intersected by an infinite number of planes, perpendicular to the axis, so as to divide it into as many circular discs, successively applied to each other, as represented in the engraving, at fig. 17: let us now imagine that, in consequence of some unknown action among the particles composing these circles, a current of electricity is perpetually circulating in their circumferences, as if they had composed a Voltaic circuit. Let us suppose the direction of these currents to be the same throughout the whole series of circles: the cylinder thus constituted may be considered as a magnetic filament; that extremity in which, when uppermost, the current of positive electricity is moving in a direction contrary to the hands of a watch, being the one which has the northern polarity, that is to say, which will, when suspended as in a compass-needle, point to the north. It is of course to be understood that the current of negative electricity revolves in the opposite direction. A magnet, then, is supposed to consist of an assemblage of similarly-constituted filaments; and, if these postulates be once granted, all the phenomena of magnetism will flow from them as corollaries; the magnetic power will be resolved into the electrical, and be henceforth erased from the list of original physical powers.

492. The facts belonging to the science of electro-magnetism may be classed under five heads:—the first relating to the reciprocal actions of two electric currents when traversing a conducting substance: the second, to the mutual action occurring between electric currents and magnets: the third, to the magnetic action of the earth on electrical currents: the fourth, comprising the actions of magnets on each other: the fifth, the action of the earth on magnets. These two last divisions of the subject constituted what was properly the province of the science of magnetism; the three former having sprung up in consequence of the discovery of Oersted, and being of an intermediate character, had received the name of electro-magnetism. Ampére proposes to comprehend them all under the title of electro-dynamics.

493. Setting out, then, from the primitive fact, that parallel currents attract one another when their directions are the same, and repel one another when opposite, we have to study the law of modification which these forces undergo when the currents deviate from strict parallelism, and are inclined to one another at various angles, and in different planes. It is evident that the whole action of the currents must be the combined result of the actions of all their parts; and that in order to obtain the former, in every possible case, with mathematical precision, it is necessary to ascertain the simple law which governs the action of those elementary portions.

494. It is evident, in the first place, that the action will be in proportion to the intensities of the currents from which that action is derived; and it has been also determined, that the quantity of each action in each element, follows the same law as that of gravitation—namely, that it is inversely proportional to the square of the distance. The action, estimated in the direction of the line drawn from the one elementary portion of electric current to the other, and which, for the sake of convenience, we shall term the line of junction, will be diminished by any obliquity in the direction of either of the currents—in the proportion of the radius to the sine of the angle which such direction forms with the line of junction. If, again, we consider the effects of a current, of which the direction deviates from the plane that passes through the line of junction, and through the direction of the other current, and is situated in another plane, also passing through the line of junction, we shall find that, from being at a maximum when these two planes coincided, it will be reduced to the proportion of the cosine of the angle they form between them. Taking all these considerations, then, into account, and combining them in one formula, we obtain the following, in which a and b denote the respective intensities of the two elementary portions of each current; d their absolute distance from each other, measured of course on the line of junction; α, β, the angles which their respective directions make with the line of junction, and γ the angle between two planes, each passing through the direction of the respective current and the line of junction. Then the action of the two currents on each other, estimated in the direction of the line of junction, being expressed by A,

$$A = \frac{ab}{d^2} (\sin. \alpha. \sin. \beta. \cos. \gamma.)$$

495. In the course of this investigation, Ampére found reason to conclude that the formula thus obtained was still only an approximation to the true law; for portions of the same, or o different currents, that were moving at very oblique angles, or even in the same continued line, were observed to exert a certain degree of repulsion on each other: he therefore introduced another term in the formula; and, as he was at first unable to ascertain the amount of its influence, prefixed to it the co-efficient k, the value of which was left for future determination. The whole formula will then stand thus:—

$$A = \frac{ab}{d^2} (\sin. \alpha. \sin. \beta. \cos. \gamma. + k. \cos. \alpha. \cos. \beta.$$

496. Ampère at first regarded the value of k as exceedingly small, and thought it might safely be neglected. Subsequent researches have led him to conclude that it was equal to $-\frac{1}{2}$, so that the whole of that term has a negative value when the cosines of the two angles are themselves positive.

497. The forces of electro-dynamical action, determined by the law above stated, are subject to the same laws of composition and resolution as all other mechanical forces, and afford, therefore, equal facilities for mathematical investigation. Many consequences important to the theory of particular facts are deducible from this consideration. Thus the action of a small portion of conducting wire, bent into any number of flexures and contorted forms, provided they do not extend to any great space, upon a distant current of electricity, will be equivalent to that of a similar wire proceeding in a straight course between the two extreme points of the contorted wire.

498. Another corollary deducible from the general law is, that the total action of a conducting wire of infinite length upon any portion of an electric current, moving in a direction parallel to the wire, is in the simple inverse ratio of the shortest distance intervening between the two currents—that is, of the line drawn from one to the other, which is perpendicular to both. This consequence had been already deduced by Laplace, and was verified by direct experiment by Biot, as well as by Ampère.

499. Setting out from the simplest case, where a simple attractive or repulsive power is manifested, namely, that in which two currents are rectilineal, and in parallel directions, and in which the action is at its maximum in point of degree, we proceed to consider the variations which a change of inclination will produce. Let us first suppose one of the rectilinear currents, or wire which conveys it, to be inclined, as is shown at fig. 18, at a certain angle, and in a plane which does not pass through the other wire, or channel in which the other current is moving. In this case, a compound force, or at least one that may be resolved into two forces, is called into action. Let us suppose a line $m\,n$, fig. 18, drawn between the points, in each wire, which are the nearest to each other; a line which will, of course, be perpendicular to both the wires, and which may be called the line of junction: the points m, n, where this line meets the wires, will divide each wire respectively into two portions. Those portions of the wires, as a and b, or c and d, in which the currents are both moving, either towards those points or from them, will be attracted towards each other,—an action which will at first tend to turn them on the line of junction $m\,n$, as an axis, in planes perpendicular to that axis, so as to diminish the angle which they form, and to bring them into the parallel positions indicated by the dotted lines; and will also tend to make the two wires approximate. The former portion of this force, which produces a rotatory action, may be termed a directive force; the latter, which tends to the approach of the wires in the direction of the line of junction, may be termed the approximate force. This last force commences when the two wires are at right angles, and attains its maximum when they are brought by the directive force into a parallel position. When the corresponding portions of the wires, on the contrary, form an obtuse angle, the approximative force is negative, and is so in the greatest degree when the wires are parallel, with their currents moving in opposite directions.

500. This action will be considerably modified if, instead of supposing the two currents to be of equal length, and crossing one another at the line of junction, we take only a very limited portion of a rectilineal current, situated wholly on one side of the other current, which is itself of indefinite length; and we may now, for the sake of greater simplicity, assume them to be both in the same plane. If we analyse the forces which act on each side, and on each part of the limited portion of the current, the one set being attractive and the other repulsive, we shall find that the resultant is a force which will impel it in a direction perpendicular to itself, in the plane common to the currents, and so as to preserve its parallelism; and this will happen, whatever be the angle of inclination of the less current to the greater. Indeed we might show by experiment the direction in which the shorter wires will tend to move by the action of the current in the lower wire, supposed to be of indefinite length. The direction of this progressive tendency will be determined by that of the currents. When they are parallel to each other, they tend to approach or to separate, according as the direction of the currents is similar or dissimilar. When at right angles to each other, and the positive current in the shorter wire is receding from the longer wire, the shorter wire will be urged forwards in the same direction as the positive current is moving in the longer wire; and, vice versâ, it will be urged in the opposite direction when the current of positive electricity is moving towards the longer wire. Such then would be its motion were it free to move in all directions; but, if its motion be limited, in that plane, to a movement of rotation round one of its extremities, the same force will produce its continual revolution, with a uniformly accelerated velocity round this axis; because the force itself is independent of the angle of inclination of the currents, and is, therefore, uniformly exerted during the whole period of its revolution. It is to be observed, however, that the two cases we have here supposed, in which the effect of a straight current of indefinite length can be limited to a small portion of another current on one side only, are such as are not easily realised in practice. The difficulty lies in disposing of the remaining portions of the current, so that they shall not interfere with the effects intended to be produced. The only mode of obtaining this object is to provide for their subdivision and branching off in different directions, at the end which is nearest to the current whose action we are studying; so that these different portions shall act in opposite ways, and thus neutralise each other's effects. This object may be accomplished most conveniently and effectually by allowing the ends of the smaller portions of

wire to dip in mercury; which will not only carry off the stream of electricity in various directions, but also allow of perfect freedom of motion.

501. Let us now investigate the action of currents moving in the circumference of a circle, which may be examined by means of a conducting wire bent into such a form, that its extremities come very near each other, but are prevented from touching by being covered with silk, or other insulating substances. The force acting on such a wire, while it is transmitting electricity by the influence of a rectilineal current in the vicinity, will tend to bring it into such a position, as that its plane shall coincide with that of the rectilineal current, and so that the direction of the currents in the adjacent portions may be the same. In this position, these adjacent portions attract each other, while a repulsion is exerted between the straight current and that in the remoter part of the circle, which moves in the opposite direction. These two forces are, therefore, opposed to each other; but the attractive force prevails, on account of the greater vicinity of the attracting than of the repelling portions. That portion of the original force which made the plane turn upon itself, so as to bring it into parallelism with the straight current, must be regarded as the directive force. It is here composed of two forces, the one attractive, the other repulsive, but which, acting on opposite sides of the axis of rotation, concur in their effect. Thus while the approximative force is the difference of the two forces, the directive force is equal to their sum.

502. It will be easily understood, that forces of a similar kind are the result of the action of the circular current on the straight wire; and that the latter is urged to assume a position in the same plane with the former, and so that the adjacent currents may be in similar directions.

503. The action of a circular current upon a small portion of a straight current at right angles, or otherwise inclined to the plane of the former, and lying wholly on one side of it, will be somewhat modified. If the direction of the straight current, when prolonged, pass near the centre, the forces which act upon it will be nearly balanced, and no re-action will result; if it be near to the circumference the action of the adjacent portion will predominate, and we shall obtain results analogous to those which we have traced with regard to straight wires. Revolving motions will result either in the straight wire or in the circular one, according to their positions, and according to the direction of the fixed points which may limit their movements. The direction of the motion is determined by the circumstances of the approach or recession of the current to or from the same point, as we have before explained.

504. Having considered the action of a circular on a rectilineal current, we may now study the reciprocal action of two circular currents. When the centre of the one lies in the plane of the other circle, a directive force will operate, tending to bring its whole circumference into that plane, and to assume a new position; and when, in this position, the resultant of all the forces which are in operation will be an attraction or a repulsion, according as the currents in the adjacent portions of the circumferences are moving in the same, or in opposite directions.

505. If the two circular currents be situated opposite to each other, so that the centre of the one be in a line perpendicular to the plane of the other, and passing through its centre, similar phenomena will take place with respect to the directive and approximative forces; which will produce, in the first place, a tendency to parallelism, and then either attraction or repulsion. For each position of the centres intermediate to the two former, we shall find a particular position of equilibrium in planes inclined at a certain angle, whose intersection is exterior to the circles themselves. This position of equilibrium is determinate, and excludes the possibility of any continued rotatory or revolving motion.

506. It is an important preliminary to the study of Ampère's theory to obtain correct ideas of the action of the two circular currents upon one another, because such currents are supposed, in his hypothesis, to be the elements of all magnetic action. This magnetic action may be regarded as the resultant of the forces exerted by every part of the circular currents; and as constituting two forces emanating from its centre, and being of an opposite species on each side of the plane of the circle. If we suppose the circle to occupy a vertical plane passing nearly through the eye of the observer, placed without the circle, and the current of positive electricity to be passing downwards on the side next to the spectator, and upwards on the remoter side, then the force exerted on the side to the right of the plane, considered as a magnetic force, will correspond to the northern polarity, or to a polarity belonging to that end of the compass which turns to the north. The force extending to the left, will, of course, correspond to the southern or opposite polarity. When two circular currents are brought together on the sides where similar polarities reside, they repel each other, because the two currents are then moving in opposite directions in each; but, when the dissimilar polarities are presented to each other, attraction takes place, because the currents are then similarly directed.

507. The intensity of all these forces is much increased when the powers of several circles are combined, which may be obtained by bending the conducting wire so as to compose a spiral; the successive coils of which will conspire together in producing the respective polarities on each side: spirals thus constituted act exactly as magnets whose poles might be supposed to be situated in the centre of each disc.

508. But the imitation of magnetic bodies is rendered still more complete, when the turns of the wire are made, not in the same plane, but on the surface of a cylinder, so as to form a helix instead of a spiral. If the wire, after having formed a helix, be bent back so as to return in a straight course in the interior of the cylinder, with the usual precautions against contact, we obtain a very perfect accordance with the theory already examined.

509. We come now to the subject of terrestrial magnetism. If we assume that the action of the solar rays on successive parts of the torrid zone, from east to west, produces currents of positive electricity in that direction, and which may be regarded as collectively circulating in what may be called the magnetic equator; attended, as they must always be, by counter-currents of negative electricity in the same equator, but in the opposite direction; and also that these currents have the same properties and modes of action with all other electrical currents,—then there must result, as a necessary consequence, a twofold polarity, apparently belonging to the earth, and directed to the poles of this magnetic equator.

510. It is to be observed, that as that polarity, which is situated near the north pole of the earth, results from a current moving in a direction similar to that of the hands of a watch, it will have the properties of a southern polarity, in the sense in which we have invariably used the term; that is, it will attract the north pole of a magnet, and repel the south pole; while actions the reverse of this will take place in the southern hemisphere. It is unnecessary to remark, how exactly this theory accords with all the known facts relative to the action of the earth on magnets. The directive power which acts on magnets on the surface of the earth, is the result, not of any real influence proceeding from that part of the earth to which their poles point, but of the action of the currents at the magnetic equator, and the tendency of the currents in the magnet itself to turn it, so that they shall attain the position of equilibrium we have already adverted to, in considering the mutual action of two circular currents. This position is precisely the plane which is perpendicular to the line of magnetic direction; that is, to the axis of the dipping needle: for as the electric currents in the needle are at right angles to its axis, it follows that when they arrange themselves in conformity with the equatorial currents of the earth, that are circulating east and west, that axis and the whole needle will point to the north and south —as we find they actually do.

511. The nature of this influence is more clearly discernible when it is exhibited in its simplest form, on a single circular current, which, as we have seen, may be regarded as the element of a magnet. A conducting-wire bent into the form of a circle, when free to move, always assumes, by the electro-magnetic action of the earth, a position in a plane descending to the south, intersecting the horizon in a line passing east and west, and inclined to it at an angle which is the complement to the dip; that is, in a plane which is perpendicular to the magnetic meridian. Its northern and southern polarities are equally real with that of a magnetic needle; but appertain to an imaginary axis passing through the centre of the circle and perpendicular to its plane. The direction of the currents on its south side, or that nearest the equator, is similar to those in the earth's equator—that is, from east to west (the positive current being always understood as defining the direction). All these circumstances are sufficiently illustrated in the theory we have been endeavouring to explain, and of which we shall furnish experimental data in referring to the apparatus contrived by Mr. Barlow, and employed in the theatre of the London Institution.

512. The same phenomena are observed, if the course of a moveable wire be that of a parallelogram; or, indeed, any plane figure which returns into itself, as well as if it were a circle. By varying these forms, we are enabled to observe and distinguish the effects of the earth's influence on wires which are parallel to the direction of the dip, and on such as are at right angles.

513. The action of the earth on spiral conducting wires is precisely similar in kind to that of single circles, but it is more powerful in degree. Helices are, in like manner, found to obey the terrestrial influence, just as magnets do when placed in similar circumstances as to freedom of motion, provided the electrical currents which they convey are of sufficient intensity. Continued progressive, or even rotatory motion may be obtained by the same influence, in conductors whose motions are limited to certain planes, either in parallel directions, or round an axis. So that, in fact, every experiment that has been tried, and a great variety has been devised by the ingenuity of numerous experimentalists, has served but to confirm the correctness of Ampère's views of the theory of magnetism. It is easy to distinguish whether the motion of any part of a Voltaic circuit is the effect of the influence of the earth, or merely of the other portions of the same circuit, by reversing the communications with the ends of the pile or battery employed: in the former case, the direction of the motion is immediately reversed by this change; and in the latter case, the action continues the same as before.

514. Ampère is far from supposing that the successive action of the solar rays on the equatorial regions of the earth is the sole cause of the electric currents that circulate in them. Internal changes, taking place in the earth itself, must also concur in producing them; for it would otherwise be impossible to account for the observed variations in their effects. The diurnal variations may, however, fairly enough be attributed to the alternate changes of temperature occurring in different parts of the torrid, and even of the temperate zones.

515. The phenomena of magnetic induction, whether effected by currents of electricity passing through a conducting body, or by a magnet in which such currents are assumed to exist, are also in perfect conformity with this hypothesis. A conducting wire tends to the determination of currents in the same direction as those which it conveys itself, in all the magnetisable bodies in its vicinity: these currents continue to circulate with more or less permanency, after the removal of the current which originally determined them. In soft iron they soon disappear: in steel they continue to maintain themselves, and give rise to permanent magnets. The polarities thus induced will have transverse directions with respect to that of the current to which they owe their

origin, for the reasons we have already so fully explained.

516. Numerous facts have induced Ampère to conclude, that the circulation of electric currents peculiar to magnets takes place round each particle of the magnetic body; he has also adopted the opinion that these currents pre-existed, in the bodies susceptible of magnetism, before this property was imparted to them; but, as they were moving in every variety of direction, they neutralised each other, and could produce no external effect. It is only when a determinate direction has been given to them, either by another magnet or by a Voltaic current, that they become capable of exerting any magnetic action.

517. By a very curious experiment, Ampère has proved, that a powerful electric current has a tendency to excite similar currents in neighbouring bodies, not generally susceptible of magnetism. A copper wire of considerable length was rolled round a cylinder, so as to form a coil, all the turns of which were separated from each other by silk riband. Within this spiral coil a ring of brass was freely suspended by a fine metallic thread, passing through a small glass tube, which was placed between the threads of the copper coil. The circumference of the ring, in every part, was thus brought very near to the copper wire, through which a powerful Voltaic current was made to pass. Under these circumstances the brass wire was attracted or repelled by a magnet, in the same way as it would have been had it formed part of the same Voltaic circuit. The action, indeed, was but feeble, and Ampère, in his first trials, failed in his endeavours to render it sensible; but, on persevering in the attempt, his success, at last, was complete and unequivocal.

518. A simple circular current, or what will act still more powerfully, a spiral coil, when presented to a magnet exhibits phenomena precisely analogous to those afforded by the ends of magnets; acting as north poles on one side, and as south poles on the other. If the currents in these spirals be reversed, the polarities on each side are in consequence immediately reversed; what was before a north, now becomes a south pole; and vice versâ.

519. But the simple circular conducting wire or ring exhibits, in consequence of the vacant space in its centre, phenomena which neither the spiral coil, of which the turns occupy the whole disc of the circle, nor any magnetised iron can produce. M. De la Rive contrived, upon this principle, a very pretty and instructive experiment, which is noticed in another part of this article. A floating conducting ring being placed so as to encircle a magnet, but in such a way as that the currents in each did not accord, was repelled along the magnet till it reached its end; when it spontaneously turned half round, and was then attracted by the magnet, again encircled it, and proceeded to settle itself round the middle of its length, where it remained in equilibrio.

520. A still more perfect accordance with magnetic phenomena is presented by the helical arrangements which we have denominated Voltaic magnets. These possess regular poles at both ends; the one being north, the other south: which poles are immediately changed into the opposite kinds, by merely reversing the course of the current. They obey the action of magnets which are presented to them, are attracted and repelled, and assume determinate positions with respect to the magnet, just as if they were ordinary magnets: of which, indeed, they possess all the essential properties, and for which they may be substituted in almost every form of experiment.

521. The phenomena of revolving motions, effected either in magnets or in wires, by their mutual action, as first discovered by Mr. Faraday, and as afterwards extended by Ampère, Barlow, Savary and others, and which have been regarded by most philosophers as indicative of the rotatory tendency being an ultimate fact, will be found, on attentive examination, to be not only in strict accordance with, but to be direct consequences of Ampère's theory. Instead of constituting objections to that theory, as was at one time supposed, they have proved, in fact, to be amongst the strongest confirmations of its truth. It would extend this article to too great a length were we to engage in the detail of the circumstances of each experiment, so as to follow all the particular applications of the theory, and trace their agreement with the observed results; but the general principles on which they are to be accounted for have already been sufficiently explained. It is also to be remarked, that Ampère ascertained, by suitable variation in the experiments, that these rotatory movements, although strictly deducible from his own theory of the constitution of magnets, where the action of the portion of conducting wire was alone taken into account, were generally, in a much greater degree, the effect of electric currents taking place in the mercury, into which the extremities of the wire were immersed, and the re-action of which on the wire produced a considerable repelling force. He found it, indeed, as impracticable in mechanism, as it was impossible in theory, to produce rotation without employing fluid conductors in some part of the Voltaic circuit.

522. To take one of the simplest cases of electro-magnetic action, let us suppose a vertical conducting wire, in which the positive current is descending, presented to a magnetic bar suspended by its centre, so as to move freely in a horizontal plane, and which has assumed its usual position in the magnetic meridian by the influence of the earth. In this position, all the currents contained in the magnet are ascending on its western, and descending on its eastern side. The former will therefore be repelled, and the latter attracted by the wire, and the magnet will so arrange itself that the middle of its attracting side shall be opposite to the wire.

523. When two magnets, on the other hand, are presented to each other, end to end, it will depend upon the direction of the currents being similar or dissimilar at the adjacent ends, whether attraction or repulsion will take place; the former happens when the north and south poles are opposite to each other: the latter when simi-

lar poles front each other. The first case may be illustrated by two watches laid the one above the other, so that the dial of the one may be in contact with the back of the other; the hands will then, in both watches, be moving in the same direction. The second case is represented by their being laid face to face, when it will be seen that the motion of the hands are now in opposite directions.

524. But the attractive or repulsive forces are not merely produced by currents at the ends of the mangets; they are the result of the action of all the currents from one end to the other of each magnet. We must regard the total action as composed of the attraction or repulsion of one whole side of the one to one whole side of the other; and of a similar attraction or repulsion between the two other sides: while the contrary action is excited between those respective sides which may be differently grouped. Thus, calling the east and west sides of a magnet the sides which face those points, when its axis is in its natural position in the magnetic meridian, the east side of the one will attract the east side of the other, and repel the west side: the west side will, in like manner, attract the west and repel the east. The tendency of this action is to bring the two eastern sides parallel, and as near to each other as possible: when this position has been attained, the north pole of each magnet will be adjoining to the south pole of the other, and the attractive action will be at its maximum. The same must be understood, mutatis mutandis, of the repulsive action, which is greatest when the east side of the one is parallel and adjoining to the west side of the other; in which case the two poles of the same name in each magnet are adjoining to each other.

525. The attentive consideration of these combinations of forces will explain a difficulty which at first might be apt to startle us. When the north end of one magnet is directly opposed to the south end of another, the adjacent currents run in similar directions, and there is, therefore no difficulty in understanding how attraction takes place: but if the one magnet be moved a little to one side, and brought in a parallel direction, till the two adjacent ends have just past one another, we then find that such a coincidence of adjacent currents no longer takes place: on the contrary the eastern side of the one, where the current is descending, is close to the western side of the other, having an ascending current. Repulsion therefore, as it would seem, should now take the place of attraction: whereas we find that, under these circumstances, the two poles still exert a powerful attraction. The reason, however, will appear when the actions of all the other currents, besides those that are immediately adjacent, are taken into account. It will then be found that the repelling positions belonging to the two magnets are, in consequence of the great obliquity of their actions, much less powerful than the attractive portions, which act at a greater angle.

526. Mr. Buxton has published a new theory of electro-magnetism in a work of Mr. Partington's, to which it may be advisable briefly to call the reader's attention. He says, 'I have at all times been particularly averse to the basis upon which the present theory of electro-magnetism is founded, where there is supposed to exist a strong analogy, if not a comple identity, between the electric and magnetic fluids; and also to the many unnatural modifications which have been resorted to in order to support the above position. I allude to the various routes which the electric fluid has been supposed to take in its transmission through a conductor connected with the two poles of a galvanic battery, in order to account for the deflection of a magnetised needle exposed to its influence, while it is a well-known fact that electricity invariably takes the most direct and shortest route in its transmission through any conducting substance.

527. 'Naturam expellas furcâ tamen usque recurret,' says Horace; and in this instance it is verified. For even with the assistance of these assumptions, and many others, which are not only irreconcileable with the known and established laws of nature, but even incongruous to each other, we are unable to account for many of the most interesting phenomena of the science. It would be wrong to reject any hypothesis without giving some grounds of objection, and I shall therefore endeavour to show, that though these two properties may, in an unqualified sense, be made to agree and to possess similar attributes, yet neither of these argues a physical identity, or even analogy. It is true, they may be made to agree, but this only in a bare definition, inasmuch as they may both be defined to be properties of natural bodies; but this must not be taken as a general definition, as it would lead to the presumption of a co-existence of these two properties in all bodies, whilst, in fact, the metallic bodies are those only wherein they are found in combination: the non-metallic bodies, though evidently possessing the electric principle, seem destitute of the magnetic. Hence we draw our primary distinction, that electricity is a general physical property of all bodies, and that magnetism is a particular property of metals.

528. 'If electricity and magnetism were identical, their phenomena should be similar, and should be exerted under similar circumstances.

529. 'Electricity is capable of exerting attractions and repulsions, and magnetism possesses the same attributes; but this parity exists merely in the unqualified ideas of mere attraction and repulsion, without adverting to the particular circumstances under which these phenomena are made sensible, or the particular objects upon which their influence is exerted.

530. 'Electricity appears to attract all bodies, but repels itself. Thus, when a body in its natural state of electricity is brought within the influence of another body which contains a quantity of the electric principle redundant to its natural capacity, the first body will abstract the fluid from the second, and be attracted by it until they both become similarly electrised, when they will be repelled.

531. 'From these premises, we draw the conclusion that the attractive and repulsive qualities of electricity are dependent upon the different relative proportions of this principle in each containing body, with respect to its capacity, and to the

different relative proportions contained in both bodies with respect to one another.

532. 'But in magnetism these qualities are exerted under a complete dissimilarity of circumstances; for, on two magnetic bodies being brought within the sphere of each other's action, we find that the different parts of the several bodies act differently upon each other; hence, that part of the magnetised body which we denominate the north pole, attracts that part of a similar body denominated the south pole, and, è converso, any two of these similar and corresponding parts in different bodies repel each other. From this we may infer, that the attractions and repulsions exerted by magnetic bodies are dependent upon different modes of action, being exerted in different situations in similar bodies, and not from any difference in the relative proportions of the magnetic principle existing in the different bodies, as is the case in electricity.

533. 'The dissimilar modes of action employed by electricity and magnetism, in exerting their attractive and repulsive qualities, may be elucidated by the following experiment: If a piece of steel, highly magnetised, be brought within a short distance of another piece of steel in its natural state, the latter will be powerfully attracted; and, until being drawn into close contact with the former, they will both exhibit a similarity of magnetic phenomena, and remain in that situation until disturbed by some extrinsic agent. Whereas, in order that these properties of attraction and repulsion exerted by magnetism should coincide in their modes of action with electricity, a mutual attraction should at first take place between the two bodies until both become equally magnetic, when they should be mutually repelled.

534. 'So far I have merely mentioned those properties of electricity which, from a too hasty observation, might appear also to obtain generally in magnetism; but I might adduce many properties in each of these which are not found in the other. This might, however, lead to a disquisition which would form an octavo volume, and I must therefore refrain from trespassing on your valuable pages.

535. 'Though the renouncement of the principle of identity of electricity and magnetism is a sufficient denial of the present theory, it will be found that, even with the admission of this principle, it would be incapable of accounting for many of its most brilliant phenomena. Among these are the interesting experiments of the attraction of two parallel galvanised wires, when the route of the electric fluid is similar; and their repulsion, when the electric fluid in each passes in a contrary direction. Another peculiarity which theorists have been unable either to reconcile or smother, is the fact, that if a piece of soft iron be placed in a tube of glass, and hermetically sealed, the whole being enclosed in a spiral conducting wire, on the galvanic stream passing through the spiral, the enclosed piece of iron will become strongly magnetic; if we admit this as the immediate effect of electricity, we must deny the impermeability of glass by the electric fluid, and with it the theory of the Leyden jar, and in fact endanger the whole science of electricity.

536. 'The admission of an analogy existing between electricity and magnetism, seems the effect of a too superficial observation and hasty conclusion, and the notion seems first to have arisen from the circumstance that lightning has been known sometimes to destroy the polarity of magnetised needles, at others to have magnetised pieces of steel which had not before any sensible magnetic properties. After the observation of these facts, and when the identity of lightning and electricity was afterwards established, it was presumed that common electricity would necessarily produce the same effects: this is found to be the case, and steel may be magnetised either by the Voltaic pile, or by the electric machine.

537. 'But, though electricity is thus capable of exciting magnetism in iron and other metals, still this property is not confined to electricity, for the same effect is produced by filing, drilling, twisting, and several other mechanical means. Electricity ought, therefore, merely to be considered as one of the various means which nature employs to excite the latent magnetic properties of metals.

538. 'Having so far premised, I shall now endeavour to show that the phenomena of electro-magnetism are merely some of the most simple operations of nature, and that they involve no difficulties but what are easily explained by her most simple laws.

539. 'If we admit of magnetism being an essential property of metals, as no magnetic phenomena are sensible to our observation, except under particular circumstances, we must necessarily infer that this property exists in a latent state, which must arise from the natural disposition of the parts of the metal being unsuitable to the circulation of the magnetic fluid; a necessary precedent to any magnetic phenomena.

540. 'That some metals are more easily magnetised than others is a well-known fact, and this frequently obtains in similar metals which have been differently operated upon; this must be ascribed to the above cause, viz.:—to the different organisation of different metals. Thus the latent magnetic principle in steel may not only be brought into action by means of electricity, but the same may be effected by a blow, twisting, &c., and by being rubbed upon an already excited magnet; whilst, to excite the latent magnetic principle inherent in gold, silver, brass, and other metals, the transmission of an electric stream across the metal seems invariably necessary: this, by disturbing the mutual cohesion of the parts of the metal, and by opening a free passage for its own circulation, at the same time, effects a similar arrangement for the circulation of the heretofore latent magnetic fluid.

541. 'If the electric force thus employed be but small, and the parts of the metal through which it has been transmitted not sufficiently removed without their mutual sphere of attraction, the magnetism excited will be but temporary; for, immediately upon the discontinuance of the electric stream, the parts of the metal by their natural attraction will resume their original arrangement, and the magnetic principle will again become quiescent. If, however, the elec-

tric stream, transmitted through the metal be sufficiently strong to effect a total alteration of the relative situation of its parts, the circulation of the magnetic stream will remain constant. However, the permanence of the circulation of the magnetic stream does not seem so much to depend upon the intensity of the electric stream, as to its direction, with respect to the internal structure of the metal through which it has been transmitted.

542. 'Under the impression that all metals contained the magnetic principle in some degree, and also that the conducting wire, connected with the two sides of a battery, is actually magnetic during the transmission of the electric fluid, as is demonstrated by several indubitable experiments, I was led to suppose, that the deflection of a magnetic needle, and the other phenomena of electro-magnetism, were not the immediate effects of electricity, but of the temporary magnetism excited in the conducting wire, during the transmission of the electric fluid.

543. 'With this view, I undertook a series of experiments with different conductors of galvanism (avoiding the metals as being capable of magnetic excitation), supposing that as these non-metallic conductors were incapable of exerting magnetic influence, they would produce no disturbance in the needle during their transmission of the electric fluid; and these expectations were very satisfactorily realised; for on attaching any of these conductors to the poles of the battery, and presenting the needle, not the least sensible deflection was produced; but, on removing these, and substituting metallic conductors, a deflection of 90° immediately ensued.

544. 'In applying this position to electro-magnetism, it will not be necessary to recapitulate the experiments which have not only appeared in most of the journals of science, but have also appeared compiled in a volume. Neither will it be necessary to apply it minutely to any of the experiments, as from its simplicity the experimenter may, by substituting artificial magnets upon a wire, instead of exciting its inherent magnetism by means of the transmission of the electric fluid, perform several of the most pleasing experiments; and this would obtain universally, were he capable of adjusting his magnets with as much precision as is effected by electricity.

545. 'It will, however, be necessary to mention one peculiarity which takes place with respect to the direction of the route of the magnetic fluid, in a piece of metal during the transmission of the electric by which it has been excited; the direction of the route of the magnetic fluid seems to be at right angles, or nearly so, with the direction of the route of the electric: thus, when the electric fluid is transmitted in the longitudinal direction of the metal, the magnetic will move at right angles with it, and consequently transverse of the metal; but if the electric stream take its course transverse of the metal, as by means of the spiral conducting wire, the magnetic stream will still move at right angles with the electric, and consequently in the longitudinal direction of the metal, each extremity of which will possess a different magnetic pole.'

546. When two electrified spheres are made gradually to approach each other, and when there does not exist between the species and the quantities of electricity which they possess, the particular relation which would be established by their contact, the thickness of the electric stratum at the points nearest each other, on the two surfaces, becomes greater and greater, and increases indefinitely as their distance diminishes. It is the same with the pressure exerted by the electricity against the mass of air intercepted between the two spheres; since the pressure, as we have mentioned above, is always proportional to the square of the thickness of the electric strata. It must at last then overcome the resistance of the air, and the fluid, in escaping under the form of a spark or otherwise, must pass, previous to the contact, from the one surface to the other. The fluid thus accumulated, before the spark takes place, is of a different nature, and of nearly equal intensity on each of the spheres. If they are electrified, the one vitreously and the other resinously, it is vitreous in the first and resinous in the second; but when they are both electrified in the same manner, vitreously for example, there arises a decomposition of the combined electricity upon the sphere which contains less of the vitreous fluid than it would have in the case of contact; the resinous electricity, resulting from this decomposition, flows towards the point where the spark is preparing, and, on the contrary, the other sphere, which contains more vitreous electricity than it would have after the contact, remains vitreous over its whole extent.

547. The phenomena are no more the same after the two spheres have been brought in contact together, and are then removed, however little, from each other. The ratio which then exists between the total quantities of electricity with which they are charged, causes to disappear in the expression of the thickness, the term which before became infinitely great for a distance infinitely small, and no spark takes place. The electricity of the points nearest each other upon the two spheres is then very feeble, for very small distances, according to a law which calculation determines, and its intensity is nearly the same on both spheres; but, when they are unequal, this electricity is vitreous on the one, resinous on the other; and it is always upon the smallest that it becomes of a nature contrary to the total electricity, which is conformable to the observations related above.

548. In general, all the varieties of these phenomena depend on the relation which we establish between the radii of the two spheres, and also between the quantities of electricity with which they are charged. We may even determine these proportions in such a manner, that, at a certain distance, the thickness of the electric stratum on the small sphere may be almost constant, so that this sphere may remain near the other, almost as if it were not exposed to any action, not from the weakness of the electricity on the other sphere, but in consequence of a sort of equilibrium which is then established between

its action upon the smallest, and the re-action of this upon itself. In this case, the electricity diffused over the large sphere is vitreous in certain parts, resinous in others, and its thickness in different points presents very considerable variations. M. Poisson has determined the proportions of volume and of electric charge necessary to produce these phenomena; and in this respect, as we have formerly observed, his analysis has anticipated the observations.

549. To complete the case of two electrified spheres, placed in presence of each other, M. Poisson has calculated the changes which the greater or less distance produces on the state of the points most distant from those where the contact takes place. In this respect, he has found, that, in proportion as the two spheres approach each other, the thicknesses of the electric stratum in these points tend more and more towards the values which they would have at the instant of contact. As they arrive at this limit, however, but very slowly, it hence follows, that even at very small distances, they differ yet much from what they would be, if the contact or the spark actually took place. Hence we conclude also, that the spark, when it takes place at a sensible distance, changes suddenly the distribution of the electricity over the whole extent of the two surfaces, from the point where it is produced, even to that which is diametrically opposite. This re-action is easily verified by experiment: we have only to fix, at certain distances from each other, a long and insulated conductor, couples of linen threads, with pith-balls suspended to them, and to communicate to this conductor a certain quantity of electricity, by which the threads may be made to diverge; if we then draw successively, several sparks by the contact of an insulated sphere, whose volume is not too small, all the threads will be observed to be disturbed, and shaken in a manner by each explosion, in whatever part of the conductor it is produced.

550. For the particular case in which the two electrified spheres are removed to a great distance from each other, in relation to the radius of any one of them, M. Poisson has discovered formulæ, which express in a very simple manner the thickness of the electric stratum, in any point of their surfaces. We shall here state these formulæ as they enable us to explain distinctly why conducting bodies, when they are electrified, seem to attract or repel each other, although from the manner in which electricity is distributed among them, and from its mobility in their interior, we cannot suppose that these phenomena indicate any sensible affinity which it has for their substance. Let r, r', represent the radii of the two spheres; call e, e', the thicknesses of the strata which the quantities of electricity they possess would form upon their surfaces if they were left to themselves, and exempt from all external influence; call a the distance of their centres, and place them so far from each other that the radius r' of one of them be very small compared with a, and with $a-r$. Lastly, let u, u', denote the angles formed with the distance a, by the radii drawn from the centre of each sphere to any point on their surfaces, then the thicknesses E, E′, of the electric stratum in these points will be expressed approximately by the following formulæ:—

$$E = e + \frac{e' r'^2}{a r} - \frac{e' r'^2 (a^2 - r^2)}{r (a^2 - 2 a r \cos. u + r^2)}$$

$$E' = e' - \frac{3 e r^2}{a^2} \cos. u' + \frac{5 e r^2 r'}{2 a^3} (1 - 3 \cos.^2 u')$$

551. Here, as in the experiments of Coulomb, the angles u, u', are reckoned from the points A and a, in which the surfaces of the two spheres would touch each other, if we brought them to the point of contact. The difference of symmetry in these expressions is owing to this, that the approximation from which they arise supposes the radius r' of the second, very small compared with the distance $a-r$, which separates its centre from the surface of the other.

552. If it is required, for example, from these formulæ to determine the state of an insulated, but not electrified sphere, which we present to the influence of another sphere charged with a certain quantity of electricity, we have only to suppose e' nothing in the equation of the second sphere, and it will then become

$$E' = \frac{-3 e r^2}{a^2} \left[\cos. u' + (3 \cos.^2 u' - 1) \frac{5 r'}{6 a} \right]$$

553. At the point a, on the line A a, between the two centres, the angle u' is nothing. In this point then we have

$$\cos. u = 1 \text{; and } E' = -\frac{3 e r^2}{a^2} \left(1 + \frac{5 r'}{3 a}\right)$$

554. The thickness E′, then, has always a contrary sign to that of e, that is to say, that the electricity on this point, in the sphere of which the radius is r', is of a nature contrary to that which covers the sphere of which the radius is r.

555. At the point d, diametrically opposite to the preceding, the angle u' is equal to 180°, which gives

$$\cos. u' = -1 \text{; and } E' = + \frac{3 e r'^2}{a^2} \left(1 - \frac{5 r'}{3 a}\right)$$

556. This value of E′ has always the same sign with that of e; for the factor $\frac{5 r'}{3 a}$ is a fraction far smaller than unity, since the distance a is supposed very great, compared with the radius r'; then the electric stratum will be in this point of the same nature as upon the other sphere.

557. Thus we see arising out of the theory the important result which we have until now only established by experiment, but while a sphere c, not electrified, is placed in presence of another sphere C, electrified vitreously, for example, the combined electricities of c are partly decomposed; the resinous electricity that results flowing towards the part of c which is nearest to C, and the vitreous electricity towards the part which is farthest from it.

558. The thicknesses of the stratum in these two points are to each other in the ratio of

$$1 + \frac{5 r'}{3 a} \text{ to } 1 - \frac{5 r'}{3 a};$$

they are nearly equal, then, since a is supposed very great in relation to r'.

559. Hence it may be conceived that there must be upon the sphere c a series of points, in which the thickness of the electric stratum is

nothing, and which form a curve of separation between the two fluids. The locus of these points will be found by putting the general expression of the thickness E' equal to zero, which gives the condition

$$0 = \cos. u' + (3\cos.^2 u' - 1)\frac{5r'}{6a}.$$

560. If the distance a were altogether infinite, compared with the radius r', the second member of this equation would be reduced to cos. u'; consequently, this cosine would be 0, which would give $u' = 90°$. The line of separation of the two fluids would then be the circumference of the great circle, of which the plane is perpendicular to the line of the centres.

561. But if a is not infinite, it is at least very great relatively to r'. Thus, the factor $\frac{5r'}{6a}$ will still be a very small fraction, and the true value of cos. u' will be equally so. We may, therefore, in calculating, neglect the product of $\frac{5r'}{6a}$ by $\cos.^2 u'$, compared with the product of this same quantity by unity. With this modification the equation resolves itself and gives

$$\text{Cos.}\, u' = \frac{5r'}{6a}$$

In this case the line of separation of the two fluids is still a circle whose plane is perpendicular to the line of the centres; but the distance of this plane from the centre of the sphere, in the place of being nothing, is equal to $r' \cos. u'$ or $\frac{5r'^2}{6a}$, this distance being taken from c to a, towards the electrified sphere C.

562. In considering only the degree of the equation which determines generally cos. u', there would seem to be two values of this cosine which would satisfy the conditions of our problem; but it will clearly appear, that one of those roots should necessarily be greater than unity, and, consequently, will not have here any real application, as it would correspond to an arc u', which is imaginary.

563. When we now consider how various, how delicate, and how detached from each other, are the phenomena this theory embraces; with what exactness, also, it represents them, and follows, in a manner, all the windings of experiment, we must be convinced that it is one of the best established in physics, and that it bestows on the real existence of the two electric fluids the highest degree of probability, if not an absolute certainty. But what is not less valuable for science, it teaches us to fix, by exact definitions, the true meaning which we must attach to certain elements of the electrical phenomena, which are too often vaguely enunciated, or even confounded, with others; although the knowledge of each of them, individually, is indispensable to form a correct and general idea of the phenomena.

564. The first of these elements is the *species*, vitreous or resinous, of the electricity which exists at the surface of an electrified body, and at every point of this surface. This is determined by touching it with the proof plane, and presenting this to the needle of the electroscope, already charged with a known species of electricity.

565. The second element is the *quantity* of this electricity accumulated on every point, or, what comes to the same thing, *the thickness of the electric stratum*. This we still measure by touching the body with the proof plane, and communicating the electricity acquired by this contact to the fixed ball of the electric balance; the moveable one having been previously charged with electricity of the same nature. The force of torsion necessary to balance the electric reaction communicated by the plane to the fixed ball, is at equal distances proportional to the quantity of electricity which it possesses, or, what is the same thing, to the thickness of the electric stratum on the element of the surface which it has touched.

566. The third element which it is of importance to consider in the phenomena, is the *attractive or repulsive action* exerted by each element of the electric stratum upon a particle of the fluid situated at its exterior surface or beyond this surface. This attraction or repulsion is directly proportional to the thickness of the electric stratum on the superficial element which attracts or repels, and is inversely proportional to the square of the distance which separates this element from the point attracted or repelled.

567. In fine, the last element to be considered, and which is a consequence of the preceding ones, is the *pressure* which the electricity exerts against the external air in each point of the surface of the electrified body. The intensity of this pressure is proportional to the square of the thickness of the electric stratum.

568. By adhering strictly to these denominations, there will be no risk of falling into error from vague considerations; and if we also keep in mind the development of electricity by influence at a distance, we shall then find no difficulty in explaining all the electric phenomena.

569. To place this truth in its full light, we shall apply it to some general phenomena which, viewed in this manner, can be conceived with perfect clearness, but which, otherwise, do not admit but of vague and embarrassed explications. These phenomena consist in the motions which electrified bodies assume, or tend to assume, when they are placed in presence of each other, and in which they appear as if they really acted upon each other by attraction or by repulsion. But it is extremely difficult to conceive the cause of these movements, when we consider that, according to the experiments, the attraction and repulsion are only exerted between the electric principles themselves, without the material substance of the body, provided it be a conductor, having any influence on their distribution or their displacement. We cannot hence admit, that the particles of the electric principles, whatever they may be, really attract or repel the material particles of the bodies. It is absolutely necessary, therefore, that the attractive and repulsive actions of these principles, whatever they are, be transmitted indirectly to the material bodies, by some mechanism which it is of extreme importance to discover, as it is the true

key to these phenomena. But we shall see that this mechanism consists in the re-action produced by the resistance which the air and non-conducting bodies in general oppose to the passage of electricity.

570. For the sake of greater simplicity, we may first confine ourselves to the consideration of two electrified spheres A and B; the one A fixed, the other B moveable. Three cases may arise which it is necessary to discuss separately.

1. A and B non-conductors.
2. A a non-conductor, B a conductor.
3. A a conductor, and B a conductor.

571. In the first case, the electric particles are fixed upon the bodies A and B, by the unknown force which produces the non-conductibility. Unable to quit these bodies they divide with them the motions which their reciprocal action tends to impress upon themselves.

572. The forces then which may produce the motion of B, are, (1.) The mutual attraction or repulsion of the fluid of A upon the fluid of B. (2.) The repulsion of the fluid of B on itself. But it is demonstrated in mechanics, that the mutual attractions and repulsions exerted by the particles of a system of bodies on each other, cannot impress any motion on its centre of gravity; the effects of this internal action then destroy themselves upon each of the spheres; there cannot result from it any motion of the one towards the other; and the first kind of force, therefore, is the only one to which we need pay any attention. If the electricity is distributed uniformly over every sphere, each of them attracts or repels the other as if its whole electric mass were collected in its centre. Thus, if we call a the distance of their centres; r, r', their radii; e, e', the thicknesses of the electric strata formed upon their surfaces by the quantities of electricity introduced into them; the electric mass of each of them will be $4\pi r^2 e$, $4\pi r'^2 e'$, π being the semi-circumference of which the radius is equal to unity, and the attractive or repulsive force will be expressed by $\frac{16\pi^2 K r^2 r'^2 e e'}{a^2}$, K being a co-efficient which expresses the intensity of the force when the quantities a, e, e', are each equal to the unity of their species. This force transmits itself directly to the two spheres, in consequence of the adhesion by which they retain the electric particles. We see, from this expression, that the force must become nothing, if e or e' be nothing, that is, if the one of the two spheres be not primitively charged with electricity. During the motion it suffers no alteration but what arises from the distance, because the two spheres being supposed of a perfectly non-conducting substance, their reciprocal action produces upon them no new development of electricity.

573. In the second case, where A is a non-conductor, and B a conductor, the sphere B suffers a decomposition of its natural electricities by the influence of A. The opposite electricities which result from this decomposition unite with the new quantity which has been introduced, and dispose themselves together according to the laws of the electric equilibrium. Here the motion of B towards A may be regarded under two points of view.

574. Suppose, first, that without disturbing the electric equilibrium of B, we extend over its surface an insulating stratum, solid, without weight, and which may remain invariably attached to it. The electricity of B, unable to escape, will press as it were against this stratum, and, by this means, transmit to the particles of the body the forces by which it is urged. The forces which then act upon the system will be, (1.) The mutual attraction or repulsion of the fluid of A on the fluid of B. (2.) The repulsion of the fluid of B upon itself, a repulsion, however, which cannot produce any motion upon the centre of gravity of B. (3.) The pressure of the fluid of B upon the insulating envelope, a pressure, again, which being exactly counterbalanced by the re-action of this coating, produces still no motion whatever. The first force, then, is still the only one to which we need pay any attention.

575. When the distance a of the two spheres is very great, relatively to the radii of their surfaces, the decomposed electricities of B, are distributed almost equally over the two hemispheres situated on the side of A, and on the opposite. In that case the actions which they suffer on the part of A are nearly equal, and destroy each other; all the force then is produced by the quantities of external electricity, $4\pi r^2 e$, $4\pi r'^2 e'$ introduced into the two spheres, which, acting as if they were wholly collected in their centres, the force becomes still $\frac{16\pi^2 K r^2 r'^2 e e'}{a^2}$.

576. When the two spheres are very far from each other, the co-efficient K may be considered as constant, and the attractive or repulsive force varies not but in consequence of a change in the distance a. But this is only an approximation; for, to consider the matter rigorously, the electrical state of the conducting sphere B varies in proportion as it approaches A, on account of the separation which this produces in its natural electricities. Hence also the reciprocal action of the two spheres ought to vary in a very complicated manner, and it is probably to this that we must ascribe the error which appears in the experiments of Coulomb, at very small distances, when calculated by the simple law of the square of the distance.

577. The supposition of an insulating envelope, without weight, serves here merely to connect the electric fluid with the material particles of the body B, and we may always regard as such the little stratum of air with which bodies are ordinarily enveloped, and which adheres to their surfaces. Yet the same result may be obtained without the aid of this intermediary; but, in that case, we must consider the pressures produced upon the air by the electricities which exist at liberty in B. These electricities, in effect, as well those that have been introduced, as those that are decomposed on it, move towards the surface of B, where the air stops them by its pressure, and prevents their escape; they dispose themselves then under this surface, as their mutual action and the influence of the body A require, resting, for this purpose, against the

air, which prevents them from expanding. But, reciprocally, they press this air from within outwards, and tend to fly off with a force proportional to the square of the thickness of the electric stratum in every point. Decompose these pressures in the direction of three rectangular axes of the co-ordinates x, y, z, the one x being in the direction of the straight line already alluded to, joining the centres of the two spheres, and add together all the partial sums; it will then be found, as we shall show presently, that, in the direction of the co-ordinates y and z, they amount to nothing, and there only remains, therefore, a single resulting force, directed in the straight line C c, that is, towards the centre of the sphere A. When the spheres are very distant from each other, compared with the radii of their surfaces, the decomposed electricities of B press the external air, in opposite directions, with a force nearly equal, and their effects destroy each other almost exactly. There only remains, then, the effect of the quantities e, e', introduced into the two spheres, and from this there results an excess of pressure in the direction of the lines of the centres, and expressed by $\frac{K e e'}{a^2}$, K being a constant quantity for the two spheres, that is, exactly the same as was obtained by the other method. It is evident, besides, that this expression is subject to the same limitation, since the pressures produced by the electric stratum against the external air, ought to vary with the quantity of natural electricity decomposed on B by the influence of A, in proportion as the two spheres approach each other.

578. The third case in which A and B are both conductors, is resolved exactly upon the same principles, either by imagining the two electrified surfaces covered with an insulating envelope, and calculating the reciprocal actions of the two fluids which are transmitted by means of this cover to the material particles; or in considering the pressures produced on the external air by the two electric strata, and calculating the excess of these pressures in the direction of the line which joins the two centres; only, in this case, the attractive or repulsive force of these two spheres will vary in proportion as they approach each other, not only by the difference which thence arises in the intensity of the electric action, but still farther by the decomposition of the natural electricities which will be going on in the two conducting bodies A and B.

579. To render the mathematical exactness of these considerations evident, we shall, for the preceding case, go through the calculation of the pressures exerted against the air by the quantities of electricity introduced or developed on the two spheres. For this purpose take, first, on the sphere A, any point whatever which we may denote by M. The pressure exerted at this point against the air, depends on the thickness of the electric stratum there. In this manner, the pressure for any point of either sphere calculated for the unity of the surface, will be represented by $k E^2$ upon the first, and $k E'^2$ upon the second, E E' being taken from the previous formulæ. We shall now develope, successively, these two expressions. In the first place, as the pressure $k E^2$ varies from one point to another with the thickness of the electric stratum, we cannot suppose it the same, but in a very small space all round the point M, a space which must be considered as a superficial element of the sphere, and which we shall call ω; thus the expression K E^2 being calculated for the unity of surface, the pressure upon the small superficial element ω will be K ω E^2. This pressure acts perpendicularly to the spherical surface A, in the direction of the radius C M; decompose it then into three others, parallel to three axes of the rectangular co-ordinates x, y, z, which have their origin at the centre C; the first, x, being in the direction of the straight line, C c, which joins the centres of the spheres, and the two others perpendicular to this line. To effect this decomposition, we must multiply the normal pressure K E^2 by the cosines of the angles which the radius C M forms with the co-ordinates x, y, z; that is, by $\frac{x}{r}$, $\frac{y}{r}$, $\frac{z}{r}$ since, in the formula of p. 84, we have represented by r the value of the radius C M of the sphere A. We shall thus have the three following component parts

parallel to the co-ordinates x; $K \frac{x}{r} \omega E^2$

parallel to the co-ordinates y; $K \frac{y}{r} \omega E^2$

parallel to the co-ordinates z; $K \frac{z}{r} \omega E^2$

But we must observe, first, that it is absolutely of no use paying any attention to the two last, because the efforts which each of them makes, on the whole extent of the surface, mutually destroy each other, on account of the symmetrical disposition of the electricity relatively to the axis of the co-ordinates x, which joins the two centres. If we consider, in effect, the force, for example, $K \frac{z}{r} \omega E^2$ for the point M, situated in the figure under the plane of the co-ordinates x, y, we shall find above this plane, another point M′ situated quite similarly, and of which the co-ordinates x, y, z, will consequently be the same, with this only difference, that z will there be negative, on account of its opposite situation relative to the origin of the co-ordinates. For this second point, the element ω, and the pressure K E^2, will be also absolutely the same; ω on account of the symmetry of the surface of the sphere A; E^2 on account of the symmetrical disposition of the electricity round the axis of the co-ordinates x, which joins the centres of the two spheres A and B; but the component force which proceeds parallel to the co-ordinates z, will be $- K \frac{z}{r} \omega E^2$, on account of the negative sign of z; this force and its analogous one $+ K \frac{z}{r} \omega E^2$ being equal, and in opposite directions, will mutually destroy each other, and a similar equilibrium will be equally obtained, in this kind of pressure, for all the other couples of points M, M′. which correspond on the two sides of the plane of x, y.

581. A similar process of reasoning will prove that the forces $K \frac{y}{r} \omega E^2$ will destroy each other two

and two, upon corresponding points, taken on two sides of the plane of x, z, and of which the co-ordinates will be $+ x$, $+ y$, $+ z$ for the one, and $+ x$, $- y + z$ for the other.

582. It remains, then, to consider the components of the pressures, taken parallel to the co-ordinates x; that is, parallel to the straight line which joins the centres Cc, of the two spheres; and, indeed, from the symmetrical disposition of electricity round the straight line, it is evident that it cannot have any motion but in this single direction; and, consequently, these components alone must produce the tendency of the two spheres towards each other.

583. To obtain, in the simplest manner, the sum of all these components, it must be remarked, that their general expression $K \frac{x}{r} \omega E^2$ contains no variable but x; for cos. u, which enters into the value of E^2 is equal to $\frac{x}{r}$; it hence follows that their intensities are equal in the points relatively to which the co-ordinate x is the same, and which are consequently situated upon one small circle, parallel to the plane of the co-ordinates y, z. Besides, as all these points are equally distant from the line of the centres, it is clear that the total result of the equal forces which are applied to them will be in the direction of this line; consequently, this will also be the direction of the general result of all the efforts of this kind exerted upon the whole surface of the sphere A.

584. To obtain now, easily, the sum of all these forces, parallel to the line of the centres, which is here that of the co-ordinates x, let us begin by joining together the values of x which are equal and contrary; for the thicknesses E, of the electric stratum on the two hemispheres of A being almost equal, from the supposition that the two spheres are very distant, the pressures corresponding to opposite values $+ x$ and $- x$, must be almost equal also; and, as the components which they give parallel to the co-ordinates x are in a contrary direction, their sum must be reduced to a very small quantity. To introduce this circumstance, call E, what E becomes when we change $+ x$ into $- x$; then the expressions of the corresponding components parallel to the co-ordinates x will be,

On the side of the positive co-ordinates x, $\left.\right\}$ $+ K \frac{x}{r} \omega E^2$ Tending to move the air in the direction A B

On the side of the negative co-ordinates $-x$, $\left.\right\}$ $- K \frac{x}{r} \omega E^2$ Tending to move the air in the direction B A

585. We preserve the superficial element ω always of the same value, as it is exactly alike in the two cases, on account of the symmetrical form of the sphere on the two sides of the plane of the co-ordinates y, z; adding these two components to each other, with their actual sign, their sum will express the element of the total resulting force, which tends to carry the air in the direction A B. This, then, will be

$K \frac{x}{r} \omega (E^2 - E^2)$, or, what is the same thing,

$$K \frac{x}{r} \omega (E + E) (E - E).$$

586. But, from the preceding formula, we have generally

$$E = e + \frac{e' r'^2}{ar} - \frac{e' r'^2 (a^2 - r^2)}{r (a^2 - 2ar \cos. u + r^2)^{\frac{3}{2}}}$$

To change $+x$ into $-x$, $+$ cos. u must become $-$ cos. u, because $\cos. u = \frac{x}{r}$; for this second case, then, we shall have

$$E = e + \frac{e' r'^2}{ar} - \frac{e' r'^2 (a^2 - r^2)}{r (a^2 + 2ar \cos. u + r^2)^{\frac{3}{2}}}$$

consequently, by subtracting these equations from each other, we have

$$E - E = \frac{e' r'^2 (a^2 - r^2)}{r} \left\{ \frac{1}{(a^2 + 2ar \cos. u + r^2)^{\frac{3}{2}}} - \frac{1}{(a^2 - 2ar \cos. u + r^2)^{\frac{3}{2}}} \right\}$$

or, what is the same thing, and is better adapted for approximations,

$$E - E = \frac{e' r'^2 \left(1 - \frac{r^2}{a^2}\right)}{ar} \left\{ \frac{1}{\left(1 + \frac{2r}{a} \cos. u + \frac{r^2}{a^2}\right)^{\frac{3}{2}}} - \frac{1}{\left(1 - \frac{2r}{a} \cos. u + \frac{r^2}{a^2}\right)^{\frac{3}{2}}} \right\}$$

587. Since we suppose the two spheres very distant from each other, compared with the magnitude of their radii, $\frac{r}{a}$ will be a very small fraction; hence we may develope this expression for E—E into a converging series of the ascending powers of $\frac{r}{a}$, this will be effected by the binomial theorem; and taking only the first power of $\frac{r}{a}$, which, in the case we are considering, will contain an infinitely great proportion of the total result, compared with the other powers, it will become

$$E - E = \frac{e' r'^2}{ar} \left\{ 1 - \frac{3r}{a} \cos. u - 1 - \frac{3r}{a} \cos. u \right\}$$

or by reduction $E - E = \frac{-6r'^2 e' \cos. u}{a^2}$.

This value of E—E must now be multiplied by E + E, to form the factor $E^2 - E^2$ which enters into the expression of the total resulting force; but since E—E is already of the order $\frac{r'^2}{a^2}$, it is evident that, in E + E we must confine ourselves to the terms which are not divided by a; this limitation reduces the value of E + E to $2e$, and employing this to multiply E—E, there results

$$E^2 - E^2 = \frac{-12ee'r'^2}{a^2} \cos. u.$$

588. It only remains to substitute this value in the expression of the resulting force parallel to the co-ordinates x, which we have found equal to $\frac{K x \omega}{r} (E^2 - E^2)$ for the superficial element ω; and by putting for $\frac{x}{r}$ its value cos. u, the expression will become

$$\frac{-12Kee'r'^2}{a^2} \omega \cos.^2 u.$$

589. Each of these partial results is proportional to the superficial element ω, and to the square of the cosine of the angle, which these elements form with the axis of the co-ordinates x. But, if we compare them together upon different spheres, this angle will always be expressed by the same values; for the equal values of u, however, the superficial element ω will vary in magnitude proportionally to the square of the radius r of the sphere. Consequently, the sum of all the values of the factor $\omega \cos.^2 u$, extended to every sphere, will only vary from each other in the ratio of the square r^2; it may be represented then by $K'r^2$, K' being a constant and numerical co-efficient which may be found, and which, in reality, is found by the processes of the integral calculus. Supposing it known then, the total result of the pressures parallel to the co-ordinates x will be $\frac{-12KK'ee'r^2r'^2}{a^2}$ (1)

It will be directly proportional then to the quantities $4\pi^2r^2e$, $4\pi r'^2e'$ of external electricity which they possess, and inversely proportional to the square of the distance of the two centres. When the quantities of electricity given to the two spheres are of the same nature, whether vitreous or resinous, the values of e and of e' must be considered as having the same sign. In that case the expression (1) is negative; that is to say, according to what has been previously admitted, that, in this case, the air which surrounds the sphere A, is more pressed in the direction B A, than in the direction A B. It will not then press equally the sphere A, as it did before it was electrified; it will press it less on the side which is most distant from the other sphere, since it is in that direction that the electric reaction is the strongest. Consequently, if the sphere A is at liberty to move, and deprived of its weight, or if its weight be sustained by a thread of suspension, it will put itself in motion from the side where the atmospheric pressure has become the weakest, that is to say, that it will recede from the other sphere B.

590. The contrary would happen, according to our formula, if the quantities e, e', of electricity introduced into the two spheres were of a different nature, for then it would be necessary in the calculation to give to them different signs. The formula (1), which represents the total result of the pressures exerted against the air parallel to the line of the centres, will then become positive; that is to say, according to what has been already agreed on, the external air will be more pressed in the direction A B, than in that of B A; the sphere A will move then in the direction in which the external pressure will have become the weakest, that is towards the sphere B, agreeably to observation.

591. We have hitherto only considered the effect of the pressures round the sphere A, but the same reasonings and calculations will apply to the other sphere; only we must then employ, instead of E and E, the expressions of the electric strata which correspond to them, and which we have seen to be

$$E' = e' - \frac{3er^2}{a^2}\cos. u' + \frac{5er^2r'}{2a^3}(1 - 3\cos.^2 u').$$

It might be shown for this case, as well as for the other, that there cannot be any inequality of pressure but in the direction of the co-ordinates x; then comparing the points of the surface, which correspond to the two sides of the plane of the co-ordinates y, z, we shall find that the element of the resulting force of the pressures parallel to the co-ordinates x, is in general expressed by $\frac{K r\omega'}{r'}(E'^2 - E'^2)$ in representing by E' what E' becomes when we change $+x$ into $-x$, that is to say, $+\cos. u$ into $-\cos. u'$, the angle u' being here reckoned from the point a, situated on the side of A upon the line of the centres. By next considering the spheres as very distant, we shall obtain in the same manner the value of E'—E'. Approximating no farther than the first power of $\frac{r'}{a}$, this will give E'—E' $= \frac{-6er^2}{a^2}\cos. u'$. We have then only to take $E + E' = 2e'$, and putting these values in the expressions of the partial resulting force, it will become $\frac{-12Kee'r^2\omega' \cos.^2 u'}{a^2}$. It may be demonstrated as above, that the sum of the factors $\omega' \cos.^2 u'$ will be proportional to the square of the radius of the sphere B, and may besides be represented by $K'r'^2$; K' being the same numerical co-efficient we have already employed. For the total resulting force then, the expression will finally become $\frac{-12KK'ee'r^2r'^2}{a^2}$, that is, exactly the same which we have obtained for the other sphere, which ought to be the case, since in these sort of phenomena action and re-action are always equal. Here, as in the example immediately above, the positive sign of the expression will signify that the resulting force of the pressures exerted against the air round the sphere B, is directed towards the other sphere, and the negative sign will signify that this resulting force is directed the opposite way. The first case will take place when the electric charges $e\,e'$ are of a contrary nature; in that case, the sphere B will advance from the side where the atmospheric pressure is weakest, that is towards A; the other case will happen when the electric charges $e\,e'$ are of the same nature, then B will recede from A.

592. The common expression for the result of the pressures vanishes for both the spheres, when e or e' is nothing, that is, when one of them is in the natural state. This seems to indicate that they would then neither approach nor recede from each other, while, in reality, we know that in this case they always approach. This apparent contradiction is owing to the degree of approximation at which we stopped our development of the above expression. We have supposed our two spheres very distant from each other, compared with the radii of their surfaces; the result of this is, that whatever be the quantity $4\pi r^2e$, $4\pi r'^2e'$ of external electricity which we have introduced into each of them, it will distribute itself almost uniformly over the two hemispheres, anterior and posterior; so that the

difference of the pressures exerted against the air by these two hemispheres, which is the only cause of motion, will be very small; and it is to this degree of minuteness that we have confined our approximations in developing $E^2 - E'^2$.

593. If, however, the one of the two spheres, B for example, is only electrified by the influence of the other, which we always suppose very distant, the development of its natural electricities will be still very feeble, and of the same order of minuteness with that to which we have confined our approximations; but this weak electricity still dividing itself between the two hemispheres of B, in a manner nearly equal, as in the example immediately above, the difference of pressures round the two hemispheres will become very minute in a still lower degree—will become a quantity of the second order of minuteness, and, consequently, cannot be found in our developments, such as we have limited them. To obtain it complete, we must not, in the calculation of $E' + E'$ confine ourselves to quantities, independent of $\frac{r'}{a}$, but take its whole value. We shall then have, first of all,

$$E' = e' - \frac{3er^2}{a^2} \cos. u' + \frac{5er^2r'}{2a^3} (1 - 3 \cos.^2 u')$$

then changing $+ x$ into $- x$, or $+ \cos. u'$ into $- \cos. u'$, we shall have,

$$E'_{,} = e' + \frac{3er^2 \cos. u'}{a^2} + \frac{5er^2r'}{2a^3} (1 - 3 \cos.^2 u')$$

then adding these two expressions,

$$E' + E'_{,} = 2e' + \frac{5er^2r'}{a^3}(1 - 3 \cos.^2 u').$$

594. This complete value of $E' + E'_{,}$ will now no more vanish when e' is nothing; but it will be seen that the terms which remain are of the order of those which we have neglected in our first approximation. Making, then, here e' equal to nothing, it remains,

$$E' + E'_{,} = \frac{5er^2r'}{a^3} (1 - 3 \cos.^2 u')$$

we also find, as before,

$$E' - E'_{,} = - \frac{6er^2}{a^2} \cos. u'$$

with these values, the expression of the partial resulting force

$$\frac{K x \omega'}{r'}(E'^2 - E'^2_{,}), \text{ or } K \omega' (E'^2 - E'^2_{,}) \cos. u'$$

becomes $\frac{-30 K e^2 r^4 r'}{a^5} . \omega' \cos.^2 u' (1 - 3 \cos.^2 u')$.

595. It only remains to take the sum of it over all the extent of the surface of the sphere B; but, in this operation, the variable factor, $\omega' \cos.^2 u'$ $(1 - 3 \cos.^2 u')$, will give a result proportional to the square of the radius r' of the sphere B, and which we may consequently represent by $K'' r'^2$, K'' being a constant numerical co-efficient different from K'; thus, the total resulting force will at last be $\frac{-30 K K'' e^2 r^4 r'^3}{a^5}$.

596. This force, then, will be an order of minuteness, much inferior to that which we obtained at first, when e' was not supposed to be nothing, since the radii there are divided by the fifth power of the distance of the centres of the two spheres, instead of the simple square which we had in the other approximation. It is obvious, that experiments of this kind, made with the electric balance, by charging only one of the balls, might produce an error as to the true law of the phenomena, if the theory did not throw light upon them; for one might be led to conclude from them, that the apparent attraction determined in this case is not reciprocally as the square of the distance of the centres of the two spheres, which nevertheless would be contrary to the truth: consequently, when it is meant to put this simple law of the square to the test, the balls must not be allowed to approach so near to each other, that the electricity developed by their reciprocal influence, may bear any sensible proportion to the quantities of external electricity introduced into them; and this is the reason that, in these experiments, it is always more certain to employ, instead of balls, small circular discs of gilt paper; for, on account of the thinness of these discs, the quantities of vitreous or resinous electricity developed at their surfaces, having scarcely any room to separate from each other, their actions on the exterior bodies must be always nearly alike, and cannot, therefore, alter the results any more than if their development had not taken place.

597. The theory, which we have thus explained in regard to spheres, applies equally well to bodies of any form whatever; but here the difficulty of the analysis prevents us from anticipating any thing but the general effects which the different pressures produce, without our being able to reduce them to numbers. Here it will suffice to have established the general mode of reasoning applicable to all the, questions of this kind, and to have followed out the whole development for the single case, which analysis has been able as yet completely to surmount.—We shall add, that before the theory had acquired its actual precision, it could not be clearly conceived how the attractions and repulsions, which in reality only take place between the electrical principles themselves, were communicated to the material particles of the electrified bodies; and philosophers were reduced to the necessity of denoting this effect by the vague word *tension*, which represented the electricity like a kind of spring placed between the bodies and tending to make them approach or recede. A few miscellaneous illustrations, including the latest and most important discoveries, must conclude our article.

New Galvanic Battery for Medical Purposes.

598. The object of this battery is to increase the galvanic power, ad libitum, and to continue it for a great length of time, without any fresh excitation. These most desirable results are effected by a metallic and a semi-metallic substance, combined with another less oxidable metal, the surfaces of which are acted on by one or two mineral acids diluted with pure water. The power and duration obtained by these means are very great, though contrary to the hitherto acknowledged laws of galvanism, which require

two dissimilar metals and one interposed fluid to develope the galvanic influence. This apparatus is designed for philosophical experiments on animals, and for the use of an operator in full practice. It is not only capable of increased power, but, by a simple contrivance, it perpetuates its action to almost any length of time for a succession of operations; these advantages are obtained by the shape and position of the plates; for, instead of being square and stationary, as in the common battery, they are circular and made to revolve on an axis at the will of the operator. As only one segment of the circle is used at one time, several different operations may be effected in each revolution of the entire circle, without the trouble of wiping any part of the circle. A constant stream of galvanic fluid may thus be exhibited almost ad infinitum, and the unpleasant effluvia arising from the frequent addition of acid, as in the common mode, is prevented. The apparatus being concealed from view, in a handsome covered box, cannot give alarm to the most timid patient. The greatest facility is afforded in removing the oxide from the surfaces of the plates by a few revolutions round its axis, and the virtue of the acid solution in the cells remains in full strength for a very long time.

599. M. La Beaume's portable galvanic battery consists of a box containing four series of plates, and four divisions made with pieces of glass and baked wood, which are interposed to divide the box for the plates; the ends of each series are connected by a hole in the plates, so that a connecting wire is not required. There is also a space for a bottle of acid. The inside of the box cover contains the apparatus necessary for the galvanic operation. By a few simple directions the battery may be preserved in good order for some months, or even years. The cover, after the apparatus is taken out of it, is placed on the box, and, sliding into a groove, is fastened by a pin.

600. Another portable galvanic battery for suspended animation. This apparatus possesses a very great galvanic power in a small compass, and its action can be perpetuated for as long a time as may be necessary, which is accomplished by the combination of different metals. It consists of 300 or 400 plates in a box about three feet long, three inches deep, and three inches wide; the circular plates are about the size of half a crown, and when the apparatus is taken out, the box is filled with diluted nitric acid, and the row of stringed plates is placed horizontally on the two supports of the battery.

601. A third portable galvanic battery intended to be used in suspended animation from drowning, &c., is contained in a walking-stick, for the convenience of town or country practitioners, when no conveyance can be immediately obtained for a larger battery. This galvanic apparatus is contained in a hollow stick, with three divisions; the first division contains a bottle of acid, salt, and linen rag, covered by a metal cap affixed to the handle of the stick, and which is to be used as a cup to mix the acid with water. The second division is composed of two parts, one sliding on the other by means of a groove; when opened, it forms a pair of galvanic batteries of 300 or 400 plates of combined metal, which are connected together by an arched wire. The third division, which is the smaller end of the stick, contains a small lancet, the conducting wires, &c., and is also held by the hand during the operation. This stick contains all that is necessary for the galvanic process except water, which can be obtained on the spot. The power of this battery is rendered equal to the following, by the combination of the plates, the strength of the acid, and the horizontal position of the plates, which prevents the circuit of communication being formed by the expressed moisture of the interposed cloths, which must result from a perpendicular position of the pensile pile, as invented by professor Aldini, and improved by Dr. de Sanctis.

602. The most portable battery consists of a series of plates of the form and size of a shilling or a sixpence; each pair being intersected by a piece of cloth, on the principle of professor Aldini; and this battery is more powerful than his, because the semi-metal is combined with one of the other metals. This battery consists of 200 or 300 plates, and may be conveyed with perfect ease in the pocket.

Electricity developed in Capillary Attraction.

603. M. Becquerel is said to have demonstrated, that there is a sensible development of electricity during the ascent of liquids in capillary tubes. He first obtained this result by increasing the sensibility of Schweigger's galvanometer. He placed three of these instruments together, so that the magnetic needle of the middle one deviates from its ordinary direction, by the lateral effects produced upon each of its poles by the contrary poles of the two other needles. From this arrangement it follows, that, when an electric current passes into the apparatus, tending to bring the needle into the plane of the magnetic meridian, the middle needle will be as much less retarded in its process as the poles, opposite to its own, of the other two needles are more remote from it, consequently, the oscillations will have a wider extent than if there were only one galvanometer.

604. In order to observe the electricity of capillary action, M. Bacquerel could not employ glass, as it is not a conductor of electricity; but he employed sponge of platinum, aud small pieces of charcoal. Pure hydrochloric acid, much diluted with water, is poured out into the platinum dish, which communicates with one of the ends of the wire of the galvanometer; and into the dish is plunged sponge of platinum, which is fixed at the other end of the wire. At this contact there is produced an electric current, which goes from the sponge to the acid, and the direction of which is contrary to that of the current which would have been obtained if the acid had been attacked by the metal. As the interstices of the sponge are filled with the fluid, the current diminishes, and it ceases when the sponge has absorbed all the liquid which it can contain. Sometimes the current takes another direction, but the cause of that is not known.

The same effect is produced with nitric acid, but it is less marked. The same result was obtained with a small piece of charcoal, prevented from touching the platinum by a band of papier Joseph.

Electricity developed in Solutions and Mixtures.

605. By means of the same apparatus, M. Becquerel has discovered that an electrical current goes from the acid to the water, when sponge of platinum, that has imbibed distilled water, is plunged into the dish of platinum, containing hydrochloric acid.

606. In order to observe the electricity of solutions of alkalies in water, he fixed in the platina pincers a fragment of hydrate of potassa or soda, enveloped in papier Joseph, and then plunged it into distilled water in the platina cup. A current was thus produced from the water to the alkali.

607. M. Becquerel also found that electricity was developed during the mixture of sulphuric and nitric acids.

Electrical Effect.

608. The following effect is attributed by Mr. Fox, who observed it, to electricity. A piece of iron pyrites was fastened with a piece of brass wire in a moss-house, the moss being damp. On the following day, the wire was found broken and excessively brittle, and, in those parts in contact with the pyrites, much corroded. On one occasion, after the brass wire had been fastened once or twice round a piece of iron pyrites, and had remained for some days enveloped in damp linen, the constituents of the brass wire were separated, and it was converted into copper wire coated with zinc.

Conduction of Electricity by Amadou.

609. It is remarked, in a late number of the Journal de Physique, that the effect of a piece of amadou, in drawing off electricity from charged surfaces, is equal to that of a metallic point. For this purpose, it requires to be dry; and, it may be observed, that at the time a number of fibres rise up and point towards the electrified surface. For the rapid abstraction of electricity, it requires, however, that besides offering points, the body should possess a high conducting power, which was not previously known to belong to this substance.

Effect of Voltaic Electricity upon Alcohol.

610. M. Lindersdorff produced an ethereal fluid by the action of the Voltaic pile upon alcohol; and, by continued electrisation, a mixture of equal parts of alcohol and liquid ammonia lost its inflammability, and acquired a bitter flavor, yellow color, and nauseous odor.

Improvement upon the dry Pile of Zamboni.

611. In constructing the dry galvanic pile of Zamboni with tinned paper and black oxide of manganese, M. Zamboni recommends the use of tinned paper, which, when disposed alone in the pile, has the same polarity as when it is employed along with oxide of manganese. The reason of this is, that a pile of tinned paper has electrical poles. But, whatever be the kind of paper which is used, the pile always increases in energy, and its polarity always coincides with that of a pile of tinned paper and oxide of manganese, when the paper has been impregnated with a solution of sulphate of zinc, and afterwards dried. In preparing the paper, M. Zamboni avails himself of a dry season. He spreads the solution of sulphate of zinc over the face of the paper which is not covered with tin, and having dried it, but without taking away from the paper its own natural humidity, he covers this face with very dry oxide of manganese. The pile being thus constructed, it is carefully defended from the air. If the paper is not fine and unsized, a little alcohol should be added to the solution of sulphate of zinc. The best manner of preserving the pile, as Zamboni has ascertained by long experience, is to enclose it in a glass tube, whose diameter is somewhat greater than that of the discs, and to run into the intermediate space a moderately warm cement of wax and turpentine. A pile of 2000 discs, constructed in this manner, gives a spark visible in day-light. M. Zamboni recommends the perfect insulation of all the parts of the pile that require to be insulated.

Thermo-Electricity.

612. It was proved, by professor Sebeck, that antimony, brought into contact with another metal, and unequally heated, would cause the magnetic needle to deviate from its meridian. With a view to ascertain this fact, and to investigate whether this property was restricted to antimony, or extended to other metals, the following experiments were made.

613. (1.) A parallopiped of antimony was procured, about fifteen inches long, and one inch square. This bar was prepared by treating crude antimony with sulphate of potassa and tartrate of potassa. A slip of copper was attached to both ends of the antimony. It was kept in close contact with the antimony by means of copper rings. This bar was laid in the direction of the magnetic meridian. A needle was placed on the antimony, and the ends of the bar were successively heated by a spirit-lamp. When the heat was thus applied to the south end, the magnetic needle immediately, and strongly, deviated to the east. The extent of this deviation depends on the length, mobility, and strength of the needle. It has been seen as much as 68°. When the heat spreads more uniformly through the metal, the deviation decreases, and the needle gradually returns to the magnetic meridian.

614. Supposing the deviation to the east at its maximum, the lamp burning under the end facing the south, if it then be removed, and placed under the end facing the north, the deviation to the east will decrease, and it will change into a deviation to the west.

615. In general, if the heat is applied under the north end of the bar, the needle will deviate to the west.

Professor Cumming's Table of Thermo-Electrics.

616. In the following table of thermo-electrics, by professor Cumming, each substance is positive to all below, and negative to all above it, two being used together.

Bismuth,	Cobalt,	Brass,	Charcoal,
Mercury,	Silver,	Copper,	Plumbago,
Nickel,	Tin,	Gold,	Iron,
Platina,	Lead,	Zinc,	Arsenic,
Palladium,	Rhodium,		Antimony.

Analogy between the Phenomena of Galvanism and those of Fermentation.

617. M. Schweigger has observed this analogy in the following points:—

618. (1.) Galvanic piles, like fermentable mixtures, exhibit their effects only by the reciprocal action of three different bodies.

619. (2.) The products of galvanic action are two, an oxidated body, and a hydrogenated body. The same happens with the products of fermentation, which are alcohol and carbonic acid.

620. (3.) The presence of electro-negative bodies favors the decomposition of water, whilst, according to Dobino, a similar effect goes on in fermentation.

Experiments on the Ignition of Wire.

621. The following experiments on the ignition of wires are very interesting. Being connected with the phenomena of caloric developed in the action of the galvanic battery, they may be acceptable as a contribution towards that mass of facts which will at some future period assume a more scientific form.

622. In these experiments, Mr. Murray used four porcelain troughs, each containing ten cells, and each cell supplied with one and a half fluid ounce of the strongest nitrous acid, being filled up with water to the depth of two-thirds, and properly mixed with a glass rod. Nitrous acid, in this proportion, he has ever found best calculated for the development of galvanic action. Fifteen to eighteen inches of fine platinum wire may be readily ignited. He of course used the triad (four inches square), for which we are indebted to the sagacity of that ingenious and profound philosopher, Dr Wollaston.

623. When sulphuric acid is employed, as is done most injudiciously by some, in mixture with the nitrous acid, the vapor is perfectly intolerable, and much of the action is no doubt lost and expended in vapor, and in the great temperature developed at the same time.

624. In connexion with the subsequent detail, it may be proper to mention, that a riband of a platinum foil, was suspended from one of the conductors, and brought in contact with the mercurial surface (that metal being contained in a shallow glass-basin), while the other one is plunged into the mercury, deflagrates with great brilliancy, and oscillates like a pendulum.

625. We may now state generally, that steel and platinum wires may be intensely ignited, in alcohol, ether, and its vapor, oil of olives, naphtha, and sulphuret of carbon. Mr. Murray has not succeeded in igniting these in water, and concludes that it is owing to the superior conducting property of that fluid. The degree of ignition, all circumstances being the same, will correspond with the .elations in which the medium containing the wire stands to conduction.

626. Platinum and steel wires may be ignited in carbonic acid gas, hydrogene, cyanogene, and olefiant gas.

627. Gold wire was wrapped round platinum in all its extent; and this double wire placed as the uniting wire between the conducting rods. It was ignited throughout, and the fusion of the gold wire supervened, the gold being collected into little spheres of a prolate form, at equal distances, and appearing like a row of beads.

628. Steel wire was, in like manner, entwined with gold wire. It also was ignited in its whole extent; the gold wire was fused, and exhibited the bead-like form.

629. Platinum was woven with copper wire. The platinum wire was ignited throughout; the copper wire not undergoing fusion nor even ignition.

630. It may here be remarked, that, in the ignition and combustion of steel wire, for instance, the fusion is primarily confined to the surface, and the fused scale or film may, perhaps, not penetrate more than one-third the diameter of the wire, while the remaining part may not have undergone the least physical change. The fused matter formed itself into spherules, with regular intervals. This appears to be a curious phenomenon; and it will also be observed that, when the calorific heat is short of ignition, the steel wire will be blued in patches.

631. Steel wire was doubled for one-half its extent; the single and denuded part was alone ignited.

632. Platinum wire was doubled for one-half its extent; and that part only which was single could be ignited.

633. Steel wire was partly enveloped in gold wire; only that portion of the steel wire which was void of the gold wire could be ignited; the part encased in the folds of the gold wire was partially blued, and was rendered magnetic.

634. Copper wire was twisted round platinum wire, for half the length of the latter. The uncovered platinum was alone ignited. Copper wire was twisted around steel wire in the manner of the preceding; the naked steel wire was ignited alone. Steel wire was twisted round platinum wire, for one-half its length; only that portion of the platinum wire excepted from the steel could be ignited.

635. Peculiar phenomena are connected with these exhibitions. When the second wire is carried through the whole extent of the uniting wire, ignition is superinduced throughout; but when only partial, the ignition is confined to the denuded portion.

636. Copper, platinum, and copper wires, were linked together, and made the communicating chain. The platinum placed between the copper wires was ignited alone.

637. Platinum, copper, and platinum wires, exhibited, on the tract of either platinum wire, ignition, while the intermediate copper wire remained dark and unignited.

638. In the case of steel, copper, and steel wires (so linked together), the steel wire on each side was ignited, while the copper wire remained unaltered.

639. In the chain of platinum, steel, and platinum wires, the platinum wires were exclusively ignited, and the steel unignited.

640. In that of steel, platinum, and steel, the intermediate link of platinum was ignited, and the steel wire on each end remained without ignition.

641. In a chain of gold, steel, and gold, the gold wires on each end were ignited and fused, and the intermediate steel was not ignited.

642. In one formed of steel, gold, and steel wires, the central one of gold was exclusively ignited.

643. Mr. Murray next tried spiral coils of platinum and steel, of various diameters, and found that they were ignited, though curvilinear, in the same manner as if the wires were not curved.

644. The preceding experiments seem to prove, that the caloric developed in galvanic action, has no relation with the medium in which the ignition takes place; and that it is evolved in some inverse ratio of the conducting properties of the uniting wire.

645. The phenomena of ignition in links of various metals united into a chain, seem connected with the passage of a material agent through them, displaying its powers in greater or less ignition, according as the passage is interrupted, or its fire more or less retarded, and, of course, as the amount of the resistance. The agent or agents, therefore, developed in transitu from pole to pole, will swell into ignition, if the conducting power of the medium traversed is low, or even burst its metalline confine, and expend its impetus in all the brilliancy of an intense combustion. The gold, platinum, and copper wires, were $\frac{1}{100}$th of an inch in diameter; and the steel the finest harpsichord wire.

Description and Use of a very Sensible Electrometer, for indicating the Kind of Electricity which is applied to it.

646. Some years back, M. Behrens published the Description of an Electrometer, which indicates the kind of electricity that is presented to it; but it appears to have been forgotten, with the dry electrical columns, which formed an essential part of the apparatus. The electrical perpetual motion of Zamboni is similar to this electrometer, and M. Butzengeiger was employed to execute one of them, which we may proceed to describe.

647. A cylindrical vessel of glass about two inches and a half in diameter, and three and a half high, has fitted to it a brass cap, from which two small dry electrical columns descend into the vessel, and are attached to the cap by screws, so that the one has its positive and the other its negative pole, making a slight projection above the cap. Each column is composed of 400 discs of gold and silver paper, glued together, and three lines in diameter, so as to fill two tubes of varnished glass. Each of these tubes is terminated below by a ring of brass, projecting a little, and rounded, which is in electrical communication with the discs. When the brass cap is in its place, the columns descend vertically, and the lower ring is one-fourth of an inch distant from the bottom of the glass. The axes of the columns are one inch and seven lines distant, but may be brought nearer one another. From the centre of the cap rises a tube of glass, varnished within and without, and within the tube is a brass wire kept in the axis by a cork, but touching the tube no where else. At the lower end of the brass wire is suspended a piece of gold leaf, two inches and a half long and three lines wide, exactly in the middle of the interval between the two columns, and parallel to their axis, if they are accurately vertical. At the upper end of the brass wire is a small brass ball, upon which may be screwed one of the discs of a condenser, as in the electrometer of Volta. By this arrangement, the electrical columns which Behrens had placed without the glass, which defends the gold leaf from the agitations of the air, are placed within the glass, so that their position is not only better preserved, but they are defended so completely from moisture, dust, &c., that they retain the same electrical intensity.

648. This electrometer is used in the following manner:—The cap of metal is put in communication with the ground by means of a metallic wire, and by touching the brass ball, any accidental electricity is discharged, which may belong to this part of the apparatus. If the skin is dry, the touch of the finger is not sufficient. As the gold leaf is suspended between the columns, at the level of the rings of metal which terminate them, the one positively and the other negatively, the gold leaf is attracted equally on both sides, and remains quietly in the middle in its ordinary state; but if, by means of the metallic wire, we communicate to it the weakest degree of electricity, the lower extremity of the gold leaf is attracted by the ring which possesses an electricity opposite to that which is communicated. Having come in contact with this ring, it is successively repelled and attracted by the opposite ring. This oscillatory motion continues till the gold leaf attaches itself to one of the columns, from which it may be easily detached by touching the brass wire, so as to dissipate its electricity, and by shaking the instrument. In order to determine the nature of the electricity, the upper poles of the two columns which project above the brass cap have the signs + and — upon them, and the electricity required is that which is indicated by the sign of the column towards which the gold leaf first moves, or which it first touches, when the electricity is stronger.

649. By this electrometer, strong and weak degrees of electricity may be equally well examined. In the first case, the electrified body is made to approach slowly and at a distance the ball of the electrometer, till the gold leaf is put in motion towards one of the columns. If, for example, we bring an excited stick of sealing-wax to the distance of about three feet from the ball, we shall observe a motion of the gold leaf towards the column marked —. If we bring it to a less distance, it will strike the column, from which it may be easily detached,

by bringing the wax still nearer. In the second case, the electrified body must be moved much nearer the ball, and brought into contact with it, if necessary, till the gold leaf is put in action. This degree of electricity is so weak, that it would be absolutely insensible in the ordinary electrometer of Bennet.

650. When the electricity is still feebler, we may advantageously employ a condenser adapted to the instrument. The circular plate, on the margin of which is screwed the ball of the electrometer, replaces the cover of the condenser, and a plate of disc furnished with a glass handle, and which is placed above the first, represents the base. These plates are covered with a thin coating of amber varnish on the faces which are brought into contact. If we wish to try a very weak electricity, we first touch, in order to deprive it of its electricity, the inferior plate, or the wire which carries the ball; we then place above it the other plate, and afterwards touch the lower plate or its wire, with the body whose electricity we wish to examine, touching, at the same time, the upper plate, in order to deprive it of its electricity. The upper disc is then removed by its glass handle, and we observe towards which of the two small columns the gold leaf is carried, and the sign marked upon this column will indicate the kind of electricity. If, for example, we put in contact with the lower surface of the lower plate of the condenser a small disc of zinc, about three-fourths of an inch in diameter, and press it against this plate, without touching the plate with the finger, and if we touch at the same time the upper disc of the condenser, to deprive it of its electricity, and if we afterwards remove the disc of zinc on one side, and on the other side the upper plate, we shall observe the gold leaf approach the column marked *minus*. A similar effect will be observed, if we put in contact with the disc of the apparatus the metallic side of a piece of silvered paper.

651. It will often be more convenient to put the body we wish to examine in contact with the upper and moveable plate, and touching the inferior plate, to deprive it of its electricity, proceeding in other respects as we have already described. The electricity, however, which the instrument now indicates, will be opposite to that which is communicated to the upper plate, because, by this method, the plate united to the instrument forms the base of the condenser.

652. If the body which we examine cannot be conveniently put in immediate contact with the lower plate of the condenser, a communication with it may be formed, by means of a metallic wire, with an insulating handle, the rest of the operation being the same as before.

Electro-magnetic Effects of Alkalies, Acids, and Salts, by M. Yelin.

653. The magnetic needle used by M. Yelin was nearly 1·5 inch long, and ·008 of an inch in diameter. It weighed little more than half a grain, and was delicately suspended by a spider's web, from a rod passing through the top of a glass cylinder, so that it could be raised or lowered at pleasure. The bottom of the instrument is a piece of card-board, on which circles are marked and divided, indicating the number of degrees through which the needle may have moved.

654. The conductor, whose state was to be indicated by this needle, was sometimes a band of tin 0·4 of an inch broad, and 24 inches long; sometimes a brass-wire helix, which, being brought up close beneath the needle, formed a kind of condenser, and rendered the action more sensible.

655. (1.) The tin band was placed under the needle, both being parallel to the magnetic meridian; a small glass was filled with muriatic acid; the end of the band, towards the austral pole of the needle, was plunged into the acid, and, in a few moments after, the other extremity was immersed; immediately the austral pole went to the east. The experiment being repeated, except that the end of the band, corresponding to the boreal of the needle, was first immersed; the austral pole went to the west. When, in place of muriatic acid, a solution of ammonia, mineral alkali (soda), or sal-ammonia, was used, the results were exactly the same; but if a solution of vegetable alkali (potassa) was used, the deviations were all in the opposite directions. Pure water produced no effect, but $\frac{1}{200}$ of acid made it active. All solutions of salts, or acid, thus applied, produced an effect upon the needle. It appears in these cases that, according as the first contact is made to the right or left, an arrangement of molecules is established in the fluid, proper to form a species of pile of which the two poles are very distinct, and that the whole of this little pile is reconstructed in the opposite direction, when the contact is made in the opposite way.

656. Place the needle over the condenser, the wires of the latter and the needle being parallel to the magnetic meridian; hold a cylinder of zinc in perfect contact with each end of the wire of the condenser, the arrangement will then be zinc, brass, zinc; plunge the cylinder corresponding with the austral pole of the needle into muriatic acid, and then plunge the other into the same acid, the austral pole of the needle will go towards the east. Repeat the experiment with nitric acid and fresh cylinders of zinc; now the austral pole of the needle will go towards the west. These and other results are the same, whether the conductors are put in contact with the metals before or after their immersion in the fluid.

657. The needle condenser and metal bars (zinc), being as before, let the glass be filled with a solution of potassa, then immerse the end of the bar corresponding to the austral pole of the needle, and afterwards the other bar; the austral pole will deviate to the east. Take the bars out of the solution, but without changing their position in the hands, and, as soon as the needle is at rest, introduce them again, beginning with the bar corresponding to the boreal pole of the needle; the needle (the austral pole) will now deviate to the west. Take the bars out of the fluid, and, without changing them from hand to hand, turn them so that the ends which were before immersed in the liquid, shall now be in contact

with the extremities of the condenser wire, then repeat the above experiments, and the same results will be obtained. Finally, if the bars, being well cleaned, are changed from hand to hand, and the experiments again repeated, the same results will be produced.

658. But now, preserving the apparatus as it was, change the solution of potassa for very pure muriatic acid. The zinc bar, corresponding to the boreal pole, being first immersed in the acid, the austral pole will go eastward. Remove that bar from the acid which was last plunged in, and a little while after, the other bar, and without changing them at all in the hand, wait till the needle is quiet; commence by the bar corresponding to the boreal pole; at the moment when that which agrees with the austral pole shall touch the acid, the needle (the austral pole) will deviate towards the west, and it will go in the same direction as often as the experiment is repeated, whether the operation be begun on the right or on the left hand.

659. If the bars be then well washed and dried, and restored to the ends of the condenser wire they were in contact with before, but with that part which was before immersed, now in contact with the wire, and the immersions and experiment be repeated, one of these two things will happen: either the needle will constantly move to the east, whichever bar is first immersed, or the action will be very doubtful or null.

660. If, instead of turning the bars, they are changed one for the other, the needle will go constantly to the west, whichever bar is first immersed; but the previous results may be at any time restored by re-changing the bars, and then the needle will go to the east.

661. The faculty thus acquired by the bars of zinc, of becoming positive or negative, according as they are plunged either first or last in the acid, they preserve some time. They may be washed, dried, and held in the hand, without losing their state, and hence particular precautions are required in making delicate experiments with the metals.

662. This faculty is not communicated either to the fluid or to the extremities of the condenser wire. All the metals which become magnetometers by muriatic acid, as well as all the acids which produce an electro-magnetic action with homogeneous metals, produce the same phenomena.

663. These experiments may be compared, with interest, with the observations of M. Volta, that a band of wet paper, making part of the conductor of his pile, becomes charged with electricities, which it preserves some time; with that of M. Gautheret, who thought he remarked something similar in the conducting wires of the pile; and with that of M. Ritter on his secondary piles, the phenomena of which M. Volta attributed to the electro-motive action of the alkalies and salts interposed. 'A very decided electric charge may be remarked in the metals interposed between the conductor and the fluid; they are both unipolar, i. e. charged each with a single electricity, which they retain for some time, and this electricity is constantly positive in one, and negative in the other. They form, therefore, the elements of a species of pile, of which the extremities may be detached without losing their electricity; and, in consequence of this property, I call it a secondary pile, with mobile unipolar extremities.

664. 'I have sometimes succeeded, with bars of some length, in obtaining distinct poles at each extremity, so that when the bars were turned, opposite results were presented by the needle; but I have not been able to discover the condition of this phenomenon, so as to be able to produce it at pleasure.'

665. M. Yelin remarks, however, that he has never yet been able to ascertain the existence of free magnetism, or electricity, in any of these bars. Many other experiments are given in tables, which we have not room to notice, though they are of great interest. The bars M. Yelin used were ·275 of an inch in diameter, and 2·75 inches long.—*Bib. Univ.* xxiii. 38.

Terrestrial Magnetism.

666. The following curious electro-magnetic experiment was exhibited by Dr. Birkbeck, at the London Institution. A hollow globe of wood, fifteen inches in diameter, was first accurately turned, and, from the equator towards each extremity of its axis, grooves were cut parallel to the equator, at the distance of 4¼° from each other, like parallels of latitude, and another, rather deeper, groove from one pole to the other, along a meridian half-round.

667. Beginning now at the equator with the middle of a wire, about ninety feet in length, and one-tenth of an inch in diameter, which just fitted the grooves, it was carried round in the successive circles towards each pole, making an abrupt turn from one circle to another along the meridian groove above-mentioned. From the point where the wire arrived at the poles, it was carefully bound with silk, and returned back again to the equator along the same meridian. The two ends of the wire being thus brought together, they proceeded to a little distance from the globe, where they terminated. By this means the effect of the short abrupt turnings of the wire along the meridian towards the poles, is counteracted by wire returning back again from the poles to the equator, leaving thereby only the parallel wires active when the two extremities are connected with the battery.

668. The globe being thus far formed, it is covered with zones, in the usual way, so as to exhibit to appearance a common fifteen-inch terrestrial globe, the wire being completely hidden. But this covering is so laid on that, instead of the terrestrial pole coinciding with the poles formed by the wire, the latter is brought into lat. 75° N., and long. 76° 40′ W., which is the situation which Mr. Barlow conceives will best agree with the observed bearings of the needle in most parts of the world. Things being thus adjusted, the globe is placed on a large cup near the battery, so as to admit of its being placed in any position, or so as to bring any part to the zenith, without the encumbrance of the usual brazen meridian and horizon. A needle is now suspended over the globe, leaving it free to take any dip; while, by means of a silk suspension, it is

also free to take any direction; lastly, the needle is insulated from the action of terrestrial magnetism, by opposing to it the north end of a small bar magnet in the line of the dip. By this means the needle retains its magnetic power, but is under no magnetic influence.

669. The extremities of the curves being now connected with the poles of the battery, the globe immediately becomes strongly active upon the needle, causing it to assume the same dip, and the same direction, with respect to the artificial globe, as the actual needle does in the corresponding part of the earth itself, at least to a very considerable extent. Thus, if we bring the Island of Ascension to the zenith, the needle is found perfectly horizontal, with a slight westerly variation. If we bring London to the zenith, we find the dip about 70°, and 24° or 25° of westerly variation; if the globe is again shifted in position, so as to bring Cape Horn in the zenith, the dip is about 60° the contrary way, that is, with the south end below; and the variation about 30° easterly, and so on with various other places.

670. The purpose of this experiment is to show, that what we have hitherto considered as the magnetism of the earth, may be only modified electricity, and to illustrate, experimentally, the theory advanced by M. Ampère, who attributes all magnetic phenomena to electrical results.

Rousseau's Apparatus.

671. M. Rousseau, who has been occupied several years in the construction of dry Voltaic piles, has conceived the idea of employing those instruments to appreciate the different degrees of conducting power of the substances arranged in the class of bad conductors of electricity. For this purpose he has contrived the apparatus we are about to describe. The dry pile, which forms the principal part of it, is made of discs of zinc and tin-foil, separated by pieces of parchment, soaked in a mixture of equal parts of oil of poppies and essence of turpentine; the whole is covered laterally with resin, to prevent the contact of the air. The base of the pile communicates with the ground. Its upper extremity may be connected by a metallic wire with an insulated vertical pivot, carrying a weakly magnetic needle, balanced horizontally. On a level with the needle, and distant from the pivot, about half the length of the latter, is a metallic ball, also insulated, but communicating with the pile. It is evident that, by this arrangement, the electricity accumulated at the upper pole of the pile is communicated to the needle and the ball; and consequently repulsion ensues, tending to separate the needle, which is moveable, from the ball which is stationary. If we place the pivot and the ball in the magnetic meridian, the needle touches it, and remains at rest as long as the apparatus is not connected with the pile; but the instant the communication is established between them, the needle is repelled; and, after some oscillations, takes its position of equilibrium, depending on its magnetic power and the energy of the pile. These two quantities remain constant for a considerable time, with the same apparatus, as may be ascertained by determining the angle which the needle makes with the magnetic meridian, after it has assumed a fixed position, by means of a divided circle adapted to the cage which covers it. A simple conducting needle, suspended by a metallic wire of proper diameter and length, might be substituted for the magnetic one; but M. Rousseau's apparatus is much more convenient, and sufficiently sensible for the kind of effect which it is his object to measure.

672. To use it for ascertaining different degrees of conducting power, it is sufficient to place the substance submitted to experiment in the electrical current, taking care that the thickness which the electricity has to pass through be always equal. If the flow of the quantity of electricity necessary to produce the greatest deviation be not instantaneous, the time required by the needle to assume its fixed position may be taken as the measure of the degree of the conducting power of the substance employed.

673. To submit liquids to this kind of examination, M. Rousseau places them in small metallic cups, communicating by their foot with the needle and the ball: he then places in the liquid one of the extremities of the metallic wire, covered with gum lac, that the same surface of metal may always be in contact with the fluid, and measures the duration of the needle's motion from the moment when the communication is established with the pile by the other extremity of the wire.

674. By submitting the fixed vegetable oils employed in the arts and in domestic economy to this kind of proof, M. Rousseau has established a very singular fact, which may be useful in commerce; it is, that olive oil possesses a very inferior degree of conducting power to that of all other vegetable or animal oils, which nevertheless present, in all their physical properties, the strongest analogies to that substance. For instance, every thing being equal in both cases, olive oil required forty minutes to produce a certain deviation, while poppy oil, or the oil of the beech-mast, required only twenty-seven seconds to produce the same deviation. One-hundreth part of any other oil added to oil of olives reduces the time to ten minutes. It would, therefore, be easy to discover, by means of this instrument, the smallest traces of any oil fraudulently mixed with oil of olives.

675. If the proportion of the foreign substance be considerable, the difference of time necessary to produce the maximum of effect would no longer be sufficiently great, and could not be measured with sufficient precision to indicate the proportion of the elements, but the apparatus might easily be modified so as to adapt it to this kind of determination.

676. The solid fats are worse conductors than the animal oils, arising, no doubt, from the large proportion of stearine contained in the former; for M. Rousseau is satisfied, by comparative trials with stearine and elaine, prepared by M. Chevreul, that the conducting power of the latter much exceeds that of the former. The fat of an animal becomes a worse conductor in proportion to the age of the individual which affords it.

677. By means of the same apparatus, we

may also observe a considerable difference between resin, gum-lac, and sulphur, the most insulating of all known substances, and silk, crystal, and common glass.

678. M. Rousseau has not found any difference in the conducting power of liquids, whether spirituous or aqueous, acid, alkaline, or neuter, the time required by the needle to arrive at the maximum of deviation being too short, in every case, to ascertain the inequality of its duration. But a modification of the apparatus, similar to that for determining the proportions in an oleaginous mixture, would easily point out that difference.

679. It would be equally possible, and very curious, to try the effect of the two kinds of electricity on different substances; all that would be necessary would be to place the two poles alternately in connexion with the ground. According to Ermann's results, it is probable that a difference would be found between most substances.

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