Lessons in Electricity

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§ 29. *Physiological Effects of the Electric Discharge.*

The physiological effect of the electric shock has been studied in various ways. Graham caused a number of persons to lay hold of the same metal plate, which was connected with the outer coating of a charged Leyden jar, and also to lay hold of a rod by which the jar was discharged. The shock divided itself equally among them.

The Abbé Nollet formed a line of one hundred and eighty guardsmen, and sent the discharge through them all. He also killed sparrows and fishes by the shock. The analogy of these effects with those produced by thunder and lightning could not escape attention, nor fail to stimulate enquiry.

Indeed, as experimental knowledge increased, men's thoughts became more definite and exact as regards the relation of electrical effects to thunder and lightning. The Abbé Nollet thus quaintly expresses himself: 'If 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, and that the wonders which we now exhibit at our pleasure are little imitations of those

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great effects which frighten us; I avow that this idea, if it was well supported, would give me a great deal of pleasure.' He then points out the analogies between both, and continues thus: 'All those points of analogy, which I have been some time meditating, begin to make me believe that one might, by taking electricity as the model, form to one's self, in relation to thunder and lightning, more perfect and more probable ideas than what have been offered hitherto.'[1]

These views were prevalent at the time now referred to, and out of them grew the experimental proof by the great physical philosopher, Franklin, of the substantial identity of the lightning flash and the electric spark.

Franklin was twice struck senseless by the electric shock. He afterwards sent the discharge of two large jars through six robust men; they fell to the ground and got up again without knowing what had happened; they neither heard nor felt the discharge. Priestley, who made many valuable contributions to electricity, received the charge of two jars, but did not find it painful.

This experience agrees with mine. Some time ago I stood in this room with a charged battery of fifteen large Leyden jars beside me. Through some awkwardness on my part I touched the wire leading from the battery, and the discharge went through me. For a sensible interval life was absolutely blotted out, but there was no trace of pain. After a little time consciousness returned; I saw confusedly both the audience and the apparatus, and concluded from this, and from my own condition, that I had received the discharge. To prevent the audience from being alarmed, I made the remark that it had often been my desire to receive such a shock accidentally, and that my wish had at length been fulfilled. But though the *intellectual* consciousness of my position returned with exceeding rapidity, it was not so with the *optical* consciousness. For, while making

[1] Priestley's 'History of Electricity,' pp. 151–52.

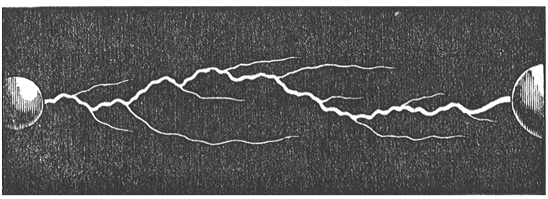
the foregoing remark, my body presented to my eyes the appearance of a number of separate pieces. The arms, for example, were detached from the trunk and suspended in the air. In fact, memory, and the power of reasoning, appeared to be complete, long before the restoration of the optic nerve to healthy action.

This may be regarded as an experimental proof that people killed by lightning suffer no pain.

§ 30. *Atmospheric Electricity.*

The air at all times can be proved to be a reservoir of electricity, which undergoes periodic variation. We have seen that ingenious men began soon to suspect a common origin for the crackling and light of the electric spark, and thunder and lightning. The greatest investigator in this field is the celebrated Dr. Franklin. He made an exhaustive comparison of the effects of electricity and those of lightning. The lightning flash he saw was of the same shape as the elongated electric spark; like electricity, lightning strikes pointed objects in preference to others; lightning pursues the path of least resistance; it burns, dissolves metals, rends bodies asunder, and strikes men blind. Franklin imitated all these effects, striking a pigeon blind, and killing a hen and turkey by the electrical discharge. I place before you in fig. 54, with a view to its comparison with a discharge of forked lightning, the long spark obtained from

Fig. 54.



an effective ebonite machine, furnished with a conductor of a special construction, which favours length of spark.

Having completely satisfied his mind by this comparison of the identity of both agents, Franklin proposed to draw electricity from the clouds by a pointed rod erected on a high tower. But before the tower could be built he succeeded in his object by means of a kite with a pointed wire attached to it. The electricity descended by the hempen string which held the kite, to a key at the end of it, the key being separated from the observer by a silken string held in the hand. Franklin thus obtained sparks, and charged a Leyden phial with atmospheric electricity.

But, spurred by Franklin's researches, an observer in France had previously proved the electrical character of lightning. A translation of Franklin's writings on the subject fell into the hands of the naturalist Buffon, who requested his friend D'Alibard to revise the translation. D'Alibard was thus induced to erect an iron rod 40 feet long, supported by silk strings, and ending in a sentry-box. It was watched by an old dragoon named Coiffier, who on the 10th of May, 1752, heard a clap of thunder, and immediately afterwards drew sparks from the end of the iron rod.

The danger of experiments with metal rods was soon illustrated. Professor Richmann of St. Petersburg had a rod raised three or four feet above the tiles of his house. It was connected by a chain with another rod in his room; the latter rod resting in a glass vessel, and being therefore insulated from the earth. On the 6th of August, 1753, a thunder cloud discharged itself against the external rod; the electricity passed downwards along the chain; on reaching the rod below, it was stopped by the glass vessel, darted to Richmann's head, which was about a foot distant, and killed him on the spot. Had a perfect communication existed between the lower rod and the earth, the lightning in this case would have expended itself harmlessly.

In 1749 Franklin proposed lightning conductors. He repeated his recommendation in 1753. He was opposed on two grounds. The

Abbé Nollet, and those who thought with him, considered it as impious to ward off heaven's lightnings, as for a child to ward off the chastening rod of its father. Others thought that the conductors would 'invite' the lightning to break upon them. A long discussion was also carried on as to whether the conductors should be blunt or pointed. Wilson advocated blunt conductors against Franklin, Cavendish, and Watson. He so influenced George III., hinting that the points were a republican device to injure his Majesty, that the pointed conductors on Buckingham House were changed for others ending in balls. Experience of the most varied kind has justified the employment of pointed conductors. In 1769 St. Paul's Cathedral was first protected.

The most decisive evidence in favour of conductors was obtained from ships; and such evidence was needed, to overcome the obstinate prejudice of seamen. Case after case occurred in which ships unprotected by conductors were singled out from protected ships, and shattered or destroyed by lightning. The conductors were at first made movable, being hoisted on the approach of a thunderstorm; but these were finally abandoned for the fixed lightning conductors devised by the late Sir Snow Harris. The saving of property and life by this obvious outgrowth of electrical research is incalculable.

§ 31. *The Returning Stroke.*

In the year 1779 Charles, Viscount Mahon, afterwards Earl Stanhope, published his 'Principles of Electricity.' On the title-page of the book stands the following remark:— 'This treatise comprehends an explanation of an electrical *returning stroke,* by which fatal effects may be produced even at a vast distance from the place where the lightning falls.'

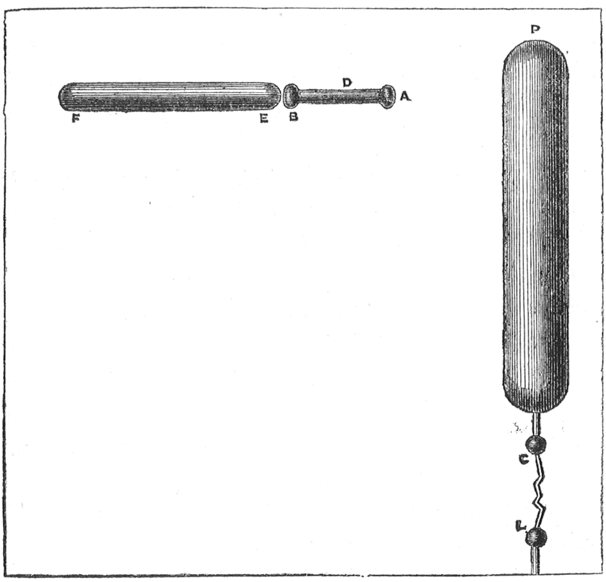
Lord Mahon's experiments, which are models of scientific clearness and precision, will be readily understood by reference to the principles of electric induction, with which you are now so familiar.

It need only be noted here that whenever he speaks of a body being plunged in an 'electrical atmosphere,' he means that the body is exposed to the inductive action of a second electrified body, which latter he supposed to be surrounded by such an atmosphere.

A few extracts from his work will give a clear notion of the nature of his discovery:—

'I placed an insulated metallic cylinder, A B, fig. 55, within the electrical atmosphere of the prime conductor [P C] when charged,

Fig. 55.



but beyond the striking distance. The distance between the near end A of the insulated metallic body and the side of the prime conductor was 20 inches. The body A B was of brass, of a cylindrical form, 18 inches long by 2 inches in diameter. I then placed another insulated brass body E F, 40 inches long by about $3\frac{3}{4}$ inches in diameter, with its end E at the distance of about one-tenth of an inch from the end B of the other metallic body A B. I electrified the prime conductor. All the time that it was receiving its *plus* charge of electricity there passed a great number of weak (red or purple) sparks from the end B of the near body A B into the end E of the remote body E F.'

Make clear to your mind the origin of this stream of weak red or purple sparks. It is obviously due to the inductive action of the prime conductor P C upon the body A B. The positive electricity of A B being repelled by the prime conductor, passed as a stream of sparks to E F.

'When the prime conductor, having received its full charge, came suddenly to discharge, with an explosion, its superabundant electricity on a large brass ball L, which was made to communicate with the earth, it always happened that the electrical fluid, which had been gradually expelled from the body A B and driven into the body E F, did suddenly return from the body E F into the body A B, in a strong and bright spark, at the very instant that the explosion took place upon the ball L.

'This I call the electrical *returning stroke.*'

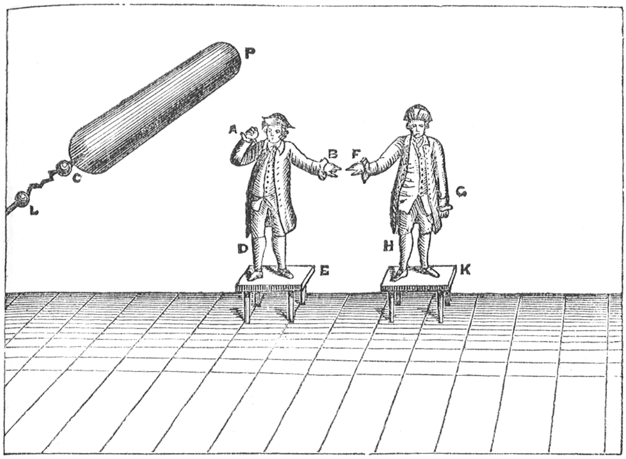
For the two conductors Lord Mahon then substituted his own body and that of another person, both of them standing upon insulating stools. He continues thus:—

'I placed myself upon an insulating stool E (fig. 56), so as to have my right arm A at the distance of about 20 inches from a large prime conductor; another person, standing upon another insulating stool K, brought his right hand F within one-quarter of an inch of my left hand B.

'When the prime conductor began to receive its plus charge of electricity, we felt the electrical fluid running out of my hand B into his hand F.

'When we separated our hands B and F a little, the electricity passed between us in small sparks, which sparks increased in sharpness the farther we removed our hands B and F asunder, until we had brought them quite out of a striking distance. The intervals

Fig. 56.



of time between these *departing sparks* increased also the more the distance between our hands B and F was increased, as must necessarily be the case.

'As soon as the prime conductor came suddenly to discharge its electricity upon the ball L, the superabundant electricity which the other person had received from my body did then return from him to me in a sharp spark, which issued from his hand F at the very instant that the explosion of the prime conductor took place upon the ball L.

'I still continued upon the insulating stool E, and I desired the other person to stand upon the floor. The returning stroke between us was *still stronger* than it had yet been. The reason of it was this:—the other person being no longer insulated, transmitted his superabundant electricity freely into the earth. I consequently became still more negative than before.

'Now, when the returning stroke came to take place, not only the electricity which had passed from my body into the body of the other person, but also the electricity which had passed from my body into the earth (through the other person), did suddenly return upon me from his hand F to my hand B, at the same instant that the discharge of the prime conductor took place upon the ball L. This caused the returning stroke to be stronger than before.'

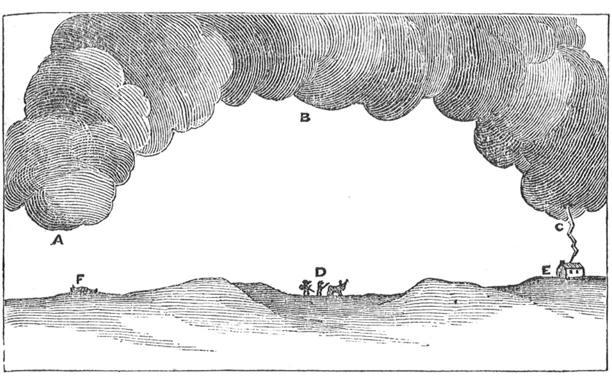
Lord Mahon fused metals, and produced strong physiological effects by the return stroke.

In nature disastrous effects may be produced by the return stroke. The earth's surface, and animals or men upon it, may be powerfully influenced by one end of an electrified cloud. Discharge may occur at the other end, possibly miles away. The restoration of the electric equilibrium by the return shock may be so violent as to cause death.

This was clearly seen and illustrated by Lord Mahon. Fig. 57 is a reduced copy of his illustration. A B C is the electrified cloud, the two ends of which, A and C, come near the earth. The discharge occurs at C. A man at F is killed by the returning stroke, while the people at D, nearer to the place of discharge, but farther from the cloud, are uninjured.

With the view of still further testing your knowledge of induction, I have here copied a portion of this admirable essay; but the

Fig. 57.



entire memoir of Lord Mahon would constitute a most useful and interesting lesson in electricity.

For our own instruction we can illustrate the return shock thus:—Connect one arm of your universal discharger, fig. 49, with a conductor like C, fig. 20, and the other arm with the earth. Bring C within a few inches of your prime conductor, but not within striking distance; on working the machine a stream of feeble sparks will pass from point to point of the discharger. Let the prime conductor be discharged from time to time by an assistant; at every discharge the returning stroke is announced by a flash between the points of the discharger at *s*. If gun-cotton with a little fulminating powder scattered on it, or a fine silver wire, be introduced between the points of the discharger, the one is exploded and the other deflagrated.

The stream of repelled sparks first seen may be entirely abolished by establishing an *imperfect* connexion between the conductor C and the earth: a chain resting upon the dry table on which the conductor stands will do. The chain permits the feebler sparks to pass through it in preference to crossing the space *s;* but the returning stroke is too strong and sudden to find a sufficiently open channel through the table and chain, and on the discharge of the prime conductor the spark is seen.

It was the action of the return shock upon a dead frog's limbs, observed in the laboratory of Professor Galvani, that led to Galvani's experiments on animal electricity; and led further to the discovery, by Volta, of the electricity which bears his name.

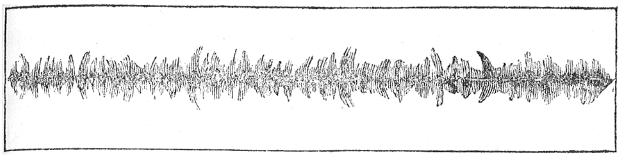
§ 32. *The Leyden Battery, its Currents, and some of their Effects.*

In the ordinary Leyden battery described in § 19 all the inner coatings are connected together, and all the outer coatings are also connected together. Such a battery acts as a single large jar of extraordinary dimensions.

Wires are warmed by a moderate electric discharge; by augmenting the charge they are caused to glow; with a strengthened charge the metal is torn to pieces; fusion follows; and by still stronger charges the wires are reduced to metallic dust and vapour.

For such experiments the wire must be thin. Without resistance we can have no heat, and when the wire is thick we have little resistance. The mechanism of the discharge, as shown by the figures produced, is different in different wires. The figure produced by the dust of a deflagrated silver wire on white paper is shown in fig. 58.

FIG. 58.



When the discharge of a powerful battery is sent through a long steel chain with the ends of its links unsoldered, the sparks between the unsoldered links carry the incandescent particles of the steel along with them. These are consumed in the air, a momentary blaze occurring along the entire chain. Chain cables have been fused by being made the channels of a flash of lightning.

Retaining our conception of an electric fluid, at this point we naturally add to it the conception of *a current*. It is the electric current which produces the effects just described. In many of our former experiments we had electricity at rest (static electricity), here we have electricity in motion (dynamic electricity).

Sending the current from a battery through a flat spiral (the primary) formed of fifty or sixty feet of copper wire, and placing within a little distance of it a second similar spiral (the secondary) with its ends connected; the passage of the current in the first spiral excites in the second a current, which is competent to deflagrate wires, and to produce all the other effects of the electrical discharge. Even when the spirals are some feet asunder, the shock produced by the secondary current is still manifest.

The current from the secondary spiral may be carried round a third; and this third spiral may be allowed to act upon a fourth, exactly as the primary did upon the secondary. A tertiary current is thus evoked by the secondary in the fourth spiral.

Carrying this tertiary current round a fifth spiral, and causing it to act inductively upon a sixth, we obtain in the latter a current of the fourth order. In this way we generate a long progeny of currents, all of them having the current sent from the battery through the first spiral, for a common progenitor. To Prof. Henry of the United States, and to Prof. Riess of Berlin, we are indebted for the investigation of the laws of these currents. These researches, however, were subsequent to, and were indeed suggested by, experiments of a similar character previously made by Faraday with Voltaic electricity.

Besides the electricity of friction and induction we have the following sources and forms of this power.

The contact of dissimilar metals produces electricity.

The contact of metals with liquids produces electricity.

A mere variation of the character of the contact of two bodies produces electricity.

Chemical action produces a continuous flow of electricity (Voltaic electricity).

Heat, suitably applied to dissimilar metals, produces a continuous flow of electricity (thermo-electricity).

The heating and cooling of certain crystals produce electricity (pyro-electricity).

The motion of magnets, and of bodies carrying electric currents, produces electricity (magneto-electricity).

The friction of sand against a metal plate produces electricity.

The friction of condensed water-particles against a safety valve, or better still against a box-wood nozzle through which steam is driven, produces electricity (Armstrong's hydro-electric machine).

These are different manifestations of one and the same power; and they are all evoked by an equivalent expenditure of some other power.