presence of the intermediate compound by the agency of which the catalytic action is effected, and which is formed, but disappears from the final result.

XXVII. "On the Relative Speed of the Electric Wave through Submarine Cables of different lengths, and a Unit of Speed for comparing Electric Cables by bisecting the Electric Wave." By Cromwell F. Varley, Esq. Communicated by Professor Stokes, Sec. R.S. Received June 19, 1862.

(Abstract.)

The present paper gives the results of some experiments which were undertaken to determine, first, the relative speed of the electric wave through cables of various lengths; secondly, the retarding effect of the iron covering of the cable; and thirdly, methods for the increase of the speed of the electric wave.

When a long submarine cable or subterranean wire is connected at one end through a galvanometer to the earth, and the other end is connected with a battery, a current flows through it, deflecting the galvanometer-needle.

If the needle be made very light and small, so as to have but a small amount of inertia, and the cable be long, the current will be seen to arrive after the lapse of a short but appreciable interval of time, and will gradually augment in intensity approaching to, but never attaining, the maximum.

Professor Thomson has investigated this subject mathematically, and arrived at the conclusion that in submarine cables of different lengths the speed is inversely as the square of the distance.

Through the Atlantic Cable, the conducting wire of which weighed 93 lbs. to the statute mile, and the length of which was rather more than 2300 statute miles, the electric current did not show itself on Thomson's sensitive reflecting galvanometer until more than one second after contact had been made with the battery at the other end.

In experiments made by the author in 1854 upon 1600 miles of wire between London and Manchester, connected up in one continuous circuit, the current was not visible upon the chemical recording instruments then in use until after the lapse of about three seconds.

These experiments were repeated by Professor Faraday; and he has made known the results.

From the imponderable nature of electricity (considered for a moment as a fluid), from its incompressibility, and other circumstances, the author infers that the electric current commences flowing out at the one end at the very instant that contact is made with the battery at the other end; but it is a considerable time before it reaches an appreciable strength; it then goes on augmenting in strength, approaching to, but never absolutely attaining, its maximum force.

As the first part of the wave commences to appear instantly, and as the top of the wave would require an indefinitely long period of time to be reached, it will be evident that the part of the wave best suited for investigation is half the maximum, as at that period the changes of its intensity in a given time are more rapid than at any other.

When attempting to measure by means of a galvanometer the arrival of the wave at half its maximum, the weight and momentum of the magnet of the galvanometer were found to interfere so much that, excepting through very long lengths of cable, nothing approaching to an accurate determination of the speed could be obtained. The use of electro-magnets was equally, if not more, objectionable, as they require a very appreciable but uncertain time to be magnetized.

The following method, however, of *bisecting the electric wave* has obviated these difficulties, and admits of the determination of the relative rates of transmission through cables of different lengths with very great accuracy.

The machine used consisted of an axle carrying two "commutators." This axle was driven by clockwork, governed, in one case, by a fly rotating in mercury, and in the second experiment by means of a fly in the air, together with a friction spring.

The commutator consists of two wheels, each wheel being in two halves. Upon the broad edge of the wheel rest two springs, one of which is connected with one pole of the battery, and the other with the other pole. The two halves of the wheel were constantly connected, by means of two other springs, the one with the cable wire, and the other with the earth, so that when the wheel was turned round, during one half of the revolution a positive current was flowing through the cable wire, and during the other a negative. The other commutator on the same axle was precisely similar in construction; but the two springs resting on the edge of the wheel

were connected with two wires of a galvanometer, and one half of the wheel was connected with the receiving end of the cable wire tested, and the other half of the commutator was connected with the earth.

The two commutators were so arranged that when, by the rotation of the wheel, the current of electricity from the battery was reversed, the connexions of the galvanometer were reversed also ; and therefore, if the speed of the electric wave through the cable were indefinitely great, the currents would flow through the galvanometer in one direction, no matter how fast the currents in the cable are reversed. As, however, a given amount of time elapses before these waves reach their maximum at the distant end of the circuit, and as also a given time elapses after the battery has been reversed at the one end before the current is reversed at the other or distant end, it is clear that by gradually augmenting the rate of rotation of the commutator until the wheel is a quarter of a revolution in advance of the wave, a point is arrived at when the galvanometer's connexions are reversed precisely at the moment that the wave reaches its maximum strength, and consequently the wave is bisected, one half of it flowing through the galvanometer in one direction, and the other half in the other. At this rate of rotation the galvanometer falls to zero; because, the wave being exactly bisected, the one half tends to deflect the needle to the right, and the other to the left, but, owing to the weight of the needle and the rapidity of the reversals, it (the needle) stands nearly steadily at zero. The galvanometer used consisted of a rather heavy astatic pair of needles suspended by a silk fibre. The wire acting upon the needles was about the twentieth part of an inch in thickness, in order that it should offer no serious resistance to the electric current. Its resistance was less than one Varley unit (1 mile copper wire $\frac{1}{16}$ inch in diameter).

The rate of rotation necessary to obtain the first zero is the point recommended for comparing the relative speeds of the electric waves through submarine cables of different dimensions.

By augmenting the speed beyond that necessary to produce the first zero, the needle becomes deflected in the opposite direction and gradually approaches a maximum ; that is to say, when the electric wave is half a revolution behind, the currents all flow through the galvanometer in one direction again. This is termed the second

maximum (the first maximum being that obtained when the wheel is not rotating at all); and by augmenting the speed still more, until the wave is three-quarters of a revolution behind, the wave is again bisected and a second zero is obtained, and so on.

The great variation of speed necessary to give these and other results was such that the means then at the author's disposal in the first experiments were not sufficiently regular to admit of very accurate readings.

The experiments now communicated were made upon two cables, one containing six conducting wires, a portion of which was laid in the Mediterranean. This cable had been lying exposed to sun and weather in the East India Docks for some years, and the gutta percha had become deteriorated to a considerable extent; its exact length was not known; and from these combined causes it could not be used for determining the rate at which the wave travels through given lengths, but it has served to demonstrate that Thomson's "law of the squares" is substantially correct in practice.

In the experiments made on this cable, the resistance of the galvanometer was equal to one mile of the cable. The battery power used averaged from 12 to 36 cells of Daniell's battery, each cell offering a resistance of one-sixth of a mile of the cable.

The first experiment was made upon two wires forming a loop of about 150 miles in length; and when the currents were reversed at the rate of 15·16 per second, the needle came to zero.

The second experiment was made through three wires, that is to say, 225 miles of cable. The speed then obtained was 6·57. Through four wires (*i. e.* double the length of first experiment) 3·78 reversals per second were obtained.

Through six wires, or three times the length of the first experiment, 1·75 per second were obtained, or inversely as the square of the length.

In the foregoing experiments the current was made to pass up one wire and down the second, up the third and down the fourth, and so on; but in experiment No. 5, the current was made to pass through all the six wires, one after the other, in the same direction, the object being to determine, if possible, what amount of retardation was attributable to the magnetization of the iron covering. On the current through the first wire ceasing, a magneto-electric current is produced in the opposite direction to the first magneto-electric

current; and consequently, when the wires were so connected that the current went up one wire and down the second, up the third and down the fourth, as in experiment No. 4, the magneto-electric action upon No. 2 wire is counterbalanced by the magneto-electric action upon No. 3, and so on; but in experiment No. 5 the magneto-electric current was in full force on all the wires. The result, however, did not show any appreciable difference in the speed of the wave, as the machine then used could not be governed with sufficient accuracy.

Experiments were made to determine the effect of applying resistance to one end of the cable. For instance, a telegraphic instrument, when applied to the cable, augments the resistance of the circuit; and when a resistance equal to half that of the cable was applied at one end, the rate of the electric wave through it was decreased to three-quarters. When a resistance equal to the whole of the cable was added at one end, so as to double the resistance of the whole circuit, the speed was reduced to about three-fifths; and when resistance double that of the cable was added, the speed was reduced rather more than one-half.

Variations in the electromotive force produced no sensible variation in the speed of the waves.

The second series of experiments were tried upon the Dunwich and Zandvoort cable, after it was submerged, and consequently in a straight line, and not, as in the previous experiment, in a coiled mass; it was therefore exposed to much less magneto-electric induction. The insulation of this cable was very high indeed.

The experiments on this cable, among other results, show that doubling the length of the circuit reduced the speed nearly four times. The experiments on the Mediterranean cable showed that, with three times the length, the speed was reduced nearly nine times. With twice the length the speed was reduced nearly four times, or inversely as the square of the distance nearly.

The mean of the experiments through 270 miles of cable are 4·76 revolutions of the wheel per second, or 9·52 reversals of the current per second.

In the experiments through 540 miles, or twice the length of cable, the speed was 1·326 revolution of the wheel, or 2·65 reversals per second. The reason why they do not follow the law of the squares exactly, is probably to be attributed to the resistance of the

battery used on this occasion, and also to the fact of the magneto-electric induction of the iron exterior.

Experiment 9 shows that, on the introduction midway in the circuit of an escape (circuit dérivé), the resistance of which is equal to half the circuit, the first zero is obtained at the rate of 2·78 revolutions per second, or 5·56 reversals per second; the introduction of this escape about doubles the speed of transmission; and thus, by the establishment of a series of escapes judiciously along the cable, the speed may be augmented to a very high degree without weakening the current too much for the purposes of telegraphy. Experiments were then tried with currents of various durations; and the results of these experiments are very important, the highest speed being obtained when the cable was connected to the battery for a very short interval of time and immediately afterwards put to earth. In this way, through the 540 miles, the speed of the wave was increased from 1·326 to 3·7.

In the experiments in which resistances of various amounts were added to one end of the cable, the consequent retardations agree very nearly with the results obtained upon the Mediterranean cable. It was found to be immaterial at which end of the circuit the resistance was added: this, however, can only hold good with highly insulated wires; for it is evident, upon a little consideration of the matter, that, where the line is imperfectly insulated, the resistance added at the sending end will produce more retardation than if applied to the receiving end.

In the experiments on the second zero and second maximum, it is shown that, if the speed required to produce the first zero be taken as unity, double that speed is necessary to produce the second maximum, and four times the speed to get the second zero.

Notwithstanding the difficulties under which these experiments were made (from the necessity of using a machine the rates of whose motion could not be very accurately governed), the results are still sufficiently accurate for all "*practical*" purposes of submarine telegraphy; but such nice points as the retarding influence of the iron covering cannot be inferred with any precision from these experiments. It is certain, however, that in long cables the retarding influence of the external iron covering is so small, compared with the retardation due to electrical induction, that it may be neglected in estimating the speed of the electric wave.