ART. XIV.—*On the Laws of Electro-Magnetic Action, as depending on the Length and Dimensions of the conducting Wire, and on the question, Whether Electrical Phenomena are due to the transmission of a single or of a compound fluid?* By PETER BARLOW, F. R. S.

THE question or controversy relative to the two hypotheses on which electrical phenomena are explained, is well understood; but still there are such decided proofs advanced by the advocates on either side, in support of their particular doctrines, that it can hardly be said, although the balance seems to incline on the side of those who maintain for two distinct fluids, that the followers of Dr Franklin, who admit only one fluid, are decidedly in error.

The following experiments, although directed to another inquiry, may perhaps be found to throw some light on this subject, and therefore it will not be amiss, before entering upon a detail of them, to point out the views which led me to undertake them. In a very early stage of electro-magnetic experiments, it had been suggested, that an instantaneous telegraph might be established by means of conducting wires and compasses. The details of this contrivance are so obvious, and the principles on which it is founded so well understood, that there was only one question which could render the result doubtful, and this was, Is there any diminution of effect by lengthening the conducting wire? It had been said that the electric fluid, from a common electrical battery, had been transmitted through a wire four miles in length, without any sensible diminution of effect, and to every appearance instantaneously; and if this should be found to be the case with the galvanic circuit, then no question could be entertained of the practicability and utility of the suggestion above adverted to. I was, therefore, induced to make the trial, but I found such a sensible diminution with only 200 feet of wire, as at once to convince me of the impracticability of the scheme. It led me, however, to an inquiry as to the cause of this diminution, and the laws by which it is governed. This, again, drew my attention to the two hypotheses of electrical action adverted to above. For example, if the electric action were due to a current of a single fluid passing through the wire, and if none of it were dissipated in its course, then one could see no reason for any diminution at all, whatever might be the length of the wire; and, on the other hand, if the diminished action were due to such dissipation, then, at that part of the wire nearest to the positive pole of the battery, the action ought to be much stronger than at the other extremity, where a less quantity of the fluid would be returned to the battery than was issued at the positive pole. This has reference to the hypothesis of a single fluid, agreeably to Franklin's theory; but if we admit the two fluids issuing from both the extremities of the battery, and still attribute the diminished action to their dissipation, then at least the power exhibited by the centre of the wire ought to be much less than that shewn by those parts adjacent to the two poles of the battery. My object, therefore, thus became to examine, by means of compass needles, distributed at different distances along the wire, and with different lengths of the latter, the power thus exhibited, and to endeavour to determine the mathematical laws of its action, as depending on the length of the conducting circuit.

With this view, I procured about 840 feet of copper-wire, a little stouter than that used for bell-wire, and arranged it as shewn in Fig. 5. Plate III., where *abcd*, *a′b′c′d′* represent four upright props, framed in a square, and their ends driven into the ground, the circumference of each frame being exactly 10 feet. The wire was then brought from P, turned round an upright prop at G, whence it passed to the frame E, about which it was revolved in thirty-seven spiral volutions, from the bottom upwards, and then passed from *b* to *a′*, whence it was made to run from the top downwards, in 37 volutions about the frame F: it then proceeded from *d* to H, where it was turned round, as at G, to the other extremity N. The whole length of the wire was thus

PG	=	$15\frac{1}{2}$ feet.
Gc	=	$14\frac{1}{2}$
$37\frac{1}{2}$ volutions, frame E,		375
ba	=	28
$37\frac{1}{2}$ volutions, frame F,		375
*d*H	=	$14\frac{1}{2}$
NH	=	$15\frac{1}{2}$
	Total	838 feet.

The line *ab*, *a′b′*, as also GP, NH, were placed very exactly in the magnetic meridian, and G*c* and H*d* perpendicular to the same, or east and west. The three compasses on which the observations were made, were situated as shewn at B, C, D. At P and N were placed two cups of mercury, and from the battery K proceeded two stout conducting wires, which were immersed in the cups at P and N; and, by immersing also the extremities of the wires at P and N in the same cups, the circuit was carried through the whole wire. We thus began our observations on the whole length of 838 feet; then unwound two circumferences from each frame, thereby shortening the circuit 40 feet, or reducing it to 798 feet; we then unwound 40 feet more, and so on to the end, as detailed in the following tabulated results.

There still, however, remained to guard against the variable power of the battery while the experiments were in progress, which occupied several hours. This was as follows: Between N and P was situated another compass A, over which could be placed a short conducting wire, which, prior to each experiment, was made to unite the two cups N and P, and its effect on the compass was registered; immediately after which, the wires P and N were immersed, and the short conductor removed; by which means the relative power of the battery became known at each observation; for it is shewn in "Essay on Magnetic Attractions," &c. (art. 247.), that, all other things being the same, while the wire is placed in the magnetic meridian the power is directly as the tangent of the needle's deviation, or rather the latter is as the former. It is thus easy to compute what the several deviations would have been, had the power of the battery remained constant, as is done in Table II. It may be proper to state, that the apparatus employed was Dr Hare's calorimeter, and that it was raised out of the acid after each set of experiments: that is, as soon as the battery was immersed, the short conductor was placed in the cups, and the deviation on the compass A registered. This was now removed, the wires P and N inserted, and the deviations on the three compasses B, C, D, were registered by three observers, one at each. The distance of the conducting wire from the needle was only half an inch. These wires P, N were now removed, the battery remaining down, and the short wire again inserted, the compass A registered, and the observation on the other three compasses taken as before; thus obtaining two sets of observations at each immersion, corresponding to the distance of half an inch. Then, in the latter part of the series, the battery being still down, the wire at each compass was raised to 1½ inches above the needle, and a double set of observations obtained with this distance, precisely in the same manner, after which the battery was raised out of the fluid, while the wire was shortened and readjusted. This being premised, the following Table of results will be readily understood.

TABLE of Experimental Results, shewing the Deviation of Compass-Needles at different Distances, and with different Lengths of Conducting Wire.

Length of conducting Wire.	Deflection of Standard Compass A.	Deflection of the other Compasses.—Distance ½ Inch.			Deflection of Standard Compass A.	Deflection of the other Compasses.—Distance 1½ Inch.		
		Deflection Compass B.	Deflection Compass C.	Deflection Compass D.		Deflection Compass B.	Deflection Compass C.	Deflection Compass D.
Feet.								
838	21°	5°	5°	4½°				
	21	5	5	5				
798	25	6	6½	...				
	23	6½	6	6½				
758	25	8	9	7½				
	25	8	9	7¾				
718	25	9	10	8				
	25	8	10	8				
678	27	8	10½	9				
	25	8	10½	9				
638	25	10¼	11	11				
	26	10	10½	10½				
598	26	10½	10½	10				
	26	10	11	10				
558	26	10½	11½	10				
	26	10½	11½	9				
518	29	11½	13	11½				
	29	11½	13	12½				
478	30	13	14	12½				
	30	12½	14½	11½				
438	30	14	15½	13½				
	30	14	15	13				
398	31	14	15½	13½	31°	3½°	3½°	3°
	30½	14½	15½	13½	31	3½	3½	3
358	31	15	16	14½	31½	3	4	3½
	32	15	16	14½	31½	3¼	5	4
318	34	16	17	18	35	3	4½	4
	34	16	17	18	35	4	4½	4½
278	34	17	17½	17½	36	4	4	4½
	34	16½	17½	17½	36	4	5	5
238	35	18	18½	18	34	5½	5	5½
	35	19	18½	18	34	5	6	5
198	34	19	20	18½	34	5½	5½	6
	33½	19	19½	17½	34	5	5	5½
158	34½	22	21½	20½	36	6	6½	7
	34½	22	22	20½	34	6	7	7
118	34	24	23	22½	34	7	8	7½
	33	24	22	23	34	7½	8	7½
98	32½	24	25½	25	32	8	9	8½
	32	23	25	25½	32	8	9¼	8½

On examining these results, the first obvious inference is, that the diminution of effect due to a greater length of wire is not owing to an accidental dissipation of the fluid; the compass, which was more than 400 feet from either extremity of the wire, being equally affected by the galvanic action, as those which were only 7 feet distant. Indeed, the central compass appears, in many cases, to have been more deflected than the others; but this, I have little doubt, is due to errors in observation, or perhaps to the adjustment of the wire. It has been stated, that, in the greater series of experiments, the wire was only half an inch from the needle; and, consequently, any little error in adjusting it, or any slight inflection of the wire just above the needle, would make a difference fully equal to any of the differences exhibited in the tabulated results. Moreover, although the four compasses employed were all as nearly alike as it was possible to get them, yet there might be slight differences in their action, which would still farther contribute to increase the other sources of error. I shall therefore assume, that each of the three compasses employed in obtaining the results at B, C, D, were equally affected, and shall take the mean of the six observations made with each distinct length of wire for a mean result, and the mean of the two deflections shewn by the standard compass in each case, for the mean standard measure, as in the following Table; and then, assuming that the tangent of the mean angle of deflection is proportional to the tangent of the deflection shewn by the standard compass, I shall compute what the several mean deflections would have been, had the power of the battery remained constant as at first, using 21° as the standard in the larger series of experiments, and 31° in the smaller.

That is, let Δ and Δ' be two deflections shewn by the standard compass under different powers of the battery, and δ the mean deflection corresponding to the power Δ. Then, as

$$\tan\Delta : \tan\delta :: \tan\Delta' : \frac{\tan\Delta' \tan\delta}{\tan\Delta'} = \tan\delta',$$

the mean deflection that would be due to the power Δ'.

In this way the angles in the fourth and seventh columns have been computed; the former being all reduced to the power $= 21°$, and the latter $\Delta = 31°$.

Mean Deflection in the preceding Table, reduced to one Standard Power of the Battery, viz. $\Delta = 32°$.

Length of Wire.	Distance of Wire ½ Inch. Observed Standard Power.	Mean observed Deflection.	Reduced to Standard $\Delta = 21°$.	Distance of Wire 1½ Inch. Observed Standard Power.	Mean observed Deflection.	Reduced to Standard $\Delta = 31°$.
838	21°	4° 55′	4° 55′			
798	24	6 18	5 26			
758	25	8 12	6 46			
718	25	8 50	7 17			
678	26	9 10	7 4			
638	25½	10 32	8 31			
598	26	10 20	8 10			
558	26	10 30	8 17			
518	29	12 10	8 30			
478	30	13 0	8 44			
438	30	14 10	9 31			
398	30¾	14 25	9 25	31°	3° 20′	3° 20′
358	31½	15 10	9 38	31½	3 47	3 43
318	34	17 0	9 52	35	4 5	3 31
278	34	17 15	10 1	36	4 25	3 39
238	35	18 20	10 18	34	5 20	4 45
198	33¾	18 55	11 8	34	5 25	4 49
158	34½	21 25	12 21	35	6 35	4 30
118	33½	23 5	13 53	34	7 35	6 46
98	32¼	24 40	15 37	32	8 32	8 13

Although in these reduced results there are a few discrepancies, some of the numbers being less where they ought to be greater than the preceding; yet these, which may be attributed to errors and irregularities in the experiments, are not such as to leave any doubt, that, upon a general view of the question, there is a certain increase of effect as the wire shortens; and it only remains to ascertain according to what function of the length this increase takes place.

As the tangent of the angle of deflection is the measure of the electro-magnetic effect, it is natural to refer to this in preference to any other trigonometrical line; and, comparing these tangents with the lengths, the square root of the latter is the most simple function of it which seems to approach towards the required ratio, although perhaps the discrepancies are rather too great to enable us to say, with confidence, that such is the law in question. At the same time, the difficulty in reducing such observations to numerical results, arising from the variable power of the battery, and other circumstances, renders it necessary for us to admit errors which would not be admissible in other cases.

If the law we have supposed were the exact law in this case, then the tangent of each mean angle of deflection, multiplied by the square root of the length of the wire, would be a constant quantity; and therefore, conversely, this product or constant quantity in any one case, divided respectively by the square roots of the several lengths, ought to give the tangents of the angles of deflections due to these lengths; and in this way we are enabled to submit our law to the test of observation, as in the following Table; in which we have taken tan 15° 37′ × $\sqrt{98}$ = 2·7659, for the constant quantity in the first series, and tan 8° 13′ × $\sqrt{98}$ = 1·4283 in the second series.

Comparison of Computed and Observed Deflections.

Length of Wire.	Distance ½ Inch. Δ = 21°.			Distance 1½ Inch. Δ = 31°.		
	Deflection deduced from Observation.	Computed Deflection = $\frac{\tan 15° 37' \sqrt{98}}{\sqrt{L}}$	Errors.	Deflection deduced from Observation.	Computed Deflection = $\frac{\tan 8° 13' \sqrt{98}}{\sqrt{L}}$	Errors.
838	4° 55′	5° 28′	+0° 33′			
798	5 26	5 35	+0 7			
758	6 46	5 44	—1 2			
718	7 17	5 54	—1 23			
678	7 4	6 4	—1 0			
638	8 31	6 15	—2 16			
598	8 10	6 27	—1 43			
558	8 17	6 41	—1 36			
518	8 30	6 56	—1 34			
478	8 44	7 13	—1 31			
438	9 81	7 32	—1 59			
398	9 25	8 1	—1 24	3° 20′	4° 6′	+0° 46′
358	9 38	8 19	—1 19	3 43	4 25	+0 42
318	9 52	8 49	—1 3	3 31	4 35	+1 4
278	10 1	9 25	—0 36	3 39	4 33	+1 14
238	10 18	10 10	—0 8	4 45	5 17	+0 32
198	11 8	11 7	—0 1	4 49	5 48	+0 59
158	12 21	12 25	+0 4	4 30	6 39	+1 59
118	13 53	14 17	+0 24	6 46	7 29	+0 43
98	15 37	15 37	0 0	8 13	8 13	0 0

The errors in the fourth and seventh columns are, as has been already observed, rather too considerable to enable us to decide with certainty respecting the accuracy of the law assumed; at the same time, they are too small to allow us to suppose that the approximation is altogether accidental. Indeed, there can be no doubt, that the exhibited effect is governed by some law very nearly the same as that proposed; and it will remain for those who insist upon electric phenomena being due to the actual transmission of material or imponderable fluids, to prove that their hypothesis is consistent with this law of action, or with one but slightly different from it.

Experiments to ascertain the Conducting Power of different Wires, as depending upon their Thicknesses or Diameters.

I here procured a number of copper and brass wires, each two feet long, and weighing from 40 grains to near 4000 grains. An inch at each end was bent at right angles, which inch, after being well cleaned, and rubbed with nitrate of silver, was immersed in the cups filled with mercury, at N and P, as explained in the preceding article, and the deflection produced on the compass was carefully registered; but in this case, as in the last, it was necessary to guard against the variable power of the battery. This was done by employing one fixed wire to ascertain the relative power before and after each experiment. The weight of this standard wire was 470 grains for the two feet in length. Being thus provided, the experiments commenced by immersing this standard in the cups above mentioned. The result being registered, the smallest specimen was immersed, and the standard removed; then the specimen was removed, and the standard again immersed,—the mean of the first and third experiment being assumed as the mean standard power of the battery due to the period when the specimen was in the cups; and, in this way, we proceeded from the smallest to the largest copper-wire, and then from the smallest to the largest brass-wire. The following are the results, in which the first and the second observations on the standard wire are placed in adjacent columns, for the convenience of having their mean value also in an adjacent column to the results of the different specimens; but it will be understood, that the specimen was always submitted to trial between the observations on the standard, which latter was brass, and weighed 470 grains to the two feet in length.

Experiments on the relative Electro-Magnetic Effect of different sized Copper-Wires.

Weight of the Specimen in Grains.	Deflection produced by Standard Wire 1st Trial.	Deflection produced by Standard Wire 2d Trial.	Mean Deflection by Standard.	Deflection produced by the Specimen.
17	39°	37°	38°	25°
49	35	33	34	31
59	33	31	32	28
70	31	28½	29¾	28
95	28½	27½	28	26
140	27½	26½	27	26
180	26½	24	25¼	25½
250	22½	23	22¾	23
290	23	21	22	22
580	20	21	20½	21
1350	21	20	20½	20
1590	20	19½	19¾	19½

Experiments on the relative Electro-Magnetic Effect of different sized Brass-Wires.

Weight of the Specimen in Grains.	Deflection produced by Standard Wire 1st Trial.	Deflection produced by Standard Wire 2d Trial.	Mean Deflection by Standard.	Deflection produced by the Specimen.
38	33°	30°	31½°	26½°
44	30	29	29½	24
80	29	28	28½	26
100	28	27	27½	23½
150	27	26	26½	25
250	26	25½	25¾	25½
470	25½	24	24¾	24
680	24	23½	23¾	23½
1330	23	22	22½	22
1580	22	21	21½	22
1890	21	21	21	22
3770	21	21	21	21½

On a comparison of these several results, it will be seen, that, while the conducting wire weighed less than about 180 grains to the two feet in length, its effect on the needle was in defect, in comparison with that of the standard, which weighed 470 grains; but that no power was either gained or lost after this, although wire was employed weighing nearly 4000 grains, which appears to be consistent with the deductions made by Professor Cumming, published in the Transactions of the Cambridge Philosophical Society for 1821.

ART. XV.—*Notice regarding the different Character of the Waves of the Western Ocean, and of the British Seas.*

According to the observations of a gentleman conversant in marine affairs, there is a remarkable difference in the appearance, and also in the destructive effects, of the waves of the British Seas, compared with those of the Western Ocean. We doubt not that many will be surprised to be told, that the waves of the Bay of Biscay do not seem to be so destructive, in proportion to their great extent and weight, as those of our own seas. This appears to be owing to the slow pace at which these oceanic billows roll along in majestic style; while the surges of the British seas are quick in their motion, and impinge upon an obstacle with violent impulse.

In evidence of the fact, it may be remarked, that the great platform of the Tour de Corduan, situate in the Bay of Biscay, at the entrance of the Garonne, is only about 18 feet above the level of the sunken rock on which this magnificent structure is erected; and that the top of the parapet, or wall of circumvallation, which includes the store-rooms and other offices of the lighthouse, does not exceed 12 feet above the platform. Now, although the Corduan Rock is of much greater extent than the Edystone or the Bell Rock, yet, judging from the appearance of things, as represented in the vignette to Mr Smeaton's Narrative of the Edystone Lighthouse, and the frontispiece to Mr Stevenson's Account of the Bell Rock Lighthouse, in both of which the seas are represented as running up the building to the height of near 100 feet, we are led to apprehend, that, under like circumstances, the platform at Corduan would often be completely deluged with water, and that the offices erected upon it would be rendered wholly untenantable. And such would certainly be the case, but for the less velocity of the waves of the Bay of Biscay: Occasional seas and sprays do pass over the parapet-wall in very stormy weather, but not with such violence as to occasion material inconvenience to the inhabitants of the Tour de Corduan.