



XLIV. First memoir on various phœnomena of induction

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Supposed existence of Mannite in the Roots of Triticum repens, or Couch-grass.

In a note on the article Mannite, in the eighth volume of the last German edition of Berzelius's *Lehrbuch*, it is stated that Professor Pfaff had succeeded in obtaining mannite from the roots of *Triticum repens*, or couch-grass. M. Pfaff says that he treated the extract of the couch-grass roots with boiling alcohol, which on cooling deposited a number of long needle-shaped crystals, which he believed to be a new species of sugar, but which Berzelius is rather disposed to regard as more probably mannite. I have twice repeated M. Pfaff's experiment on two different quantities of couch-grass roots, but with very opposite results. The alcoholic solution on standing deposited it is true a quantity of long slender crystalline needles. These, however, had not a sweet taste, and when thrown into hot sulphuric acid they dissolved with effervescence without blackening the solution. When heated on platinum foil they melted, and left a white fusible alkaline residue, which, when neutralized with muriatic acid, produced a yellow crystalline precipitate in an alcoholic solution of platinum. I have every reason to believe, therefore, that these acicular crystals were merely binoxalate of potash. The grass roots certainly contained a great deal of an uncrystallizable sugar which readily fermented.

XLIV. *First Memoir on various Phænomena of Induction.*
By M. ELIAS WARTMANN, Professor in the Academy of Lausanne*.

1. **T**HE phænomena of electric induction have been studied for some years past by a great number of physicists. Much however is still to be desired in the way of the determination of the laws which govern them and the establishment of a theory which binds all these laws together.

2. In this first memoir I propose to make known various new results which I have obtained. I shall hereafter endeavour to show what is their relation to other electric phæno-

* Translated from an article in the *Archives de l'Electricité*, itself extracted from vol. x. No. 10 of the *Bulletins de l'Acad. Roy. de Bruxelles*. The principal results of these researches, and some of those which will be found in the second memoir, the author states, were communicated to the Société de Physique et d'Hist. Natur. de Genève, at the meetings of the 7th of April and 6th of October 1842; as well as to the Société des Sciences Naturelles du Canton de Vaud (*Bulletins*, No. 3, pages 63, 65, 68; No. 5, p. 112).

mena, whether unpublished or already known, by endeavouring to sketch out this general theory which the science does not possess.

§ I. Description of the Apparatus.

3. I constructed a triple helix of large dimensions by rolling at one operation, on a great wooden bobbin, three copper wires covered with silk and perfectly annealed. Each of these wires is $23^m\cdot6$ long and $0^m\cdot003$ in diameter. They are so arranged that in all the circumvolutions the middle wire preserves its position with regard to the two others. It is this which, for brevity, I shall designate the *induced wire*, reserving the name of *inductor wires* for its two neighbours indifferently. Their diameter is sufficient to ensure that they are never heated by the currents to which they are subjected. An aperture is formed in the bobbin, destined in certain cases to receive a cylinder of soft iron of $0^m\cdot17$ long by $0^m\cdot05$ in diameter.

4. A small helix was also formed of three copper wires, not more than $0^m\cdot0008$ in diameter. Two amongst them are equal, and each of them makes 500 turns; the third, a little thicker, only makes 75 revolutions on the rectangular frame of wood which forms the interior of the apparatus: a parallelopiped of soft iron may be introduced into this frame. This helix differs from the first, in the circumstance that the wires in their superposed layers are always in the same direction and do not cross each other.

5. The measuring instruments which were used are the following:—

a. A multiplying rheometer of 3000 turns, to which an almost astatic system of very light needles gives extreme sensibility; I shall call it the *hydro-electric rheometer*.

b. A second rheometer, likewise very delicate, and which I shall call the *thermo-electric rheometer*, because its wire is thicker and only forms 75 revolutions.

c. A *metallic thermometer* of Bréguet, the helix of which, composed of silver, of gold, and of platinum, presents 46 free spiral turns. It is arranged so that it may be placed in a voltaic circuit. The instrument appreciates $0^\circ\cdot0714$ cent.*

d. A *needle* called *astatic*, the graduated circle of which is $0^m\cdot102$ in diameter: metallic wires of different dimensions might in this instrument be stretched in the plane of the magnetic meridian, and they would thus become parallel to the axis of the needle.

* For a complete description of this instrument, see *Memoires de la Société de Physique et d'Histoire Naturelle de Genève*, vol. ix. p. 123, or *Archives de l'Electricité*, vol. i. p. 77.

e. A small *helix* for magnetizing, formed of a wire of plated copper (*cuivre argenté*) of 0^m·00065 in diameter, making 94 revolutions around a tube of reed.

6. The pile employed is constructed of separate elements and has a constant force. The zincs are amalgamated solid cylinders, of 0^m·15 long and 0^m·045 in diameter; they are immersed in a solution of chloride of sodium, inclosed in membrane. The coppers are hollow cylinders of 0^m·06 in diameter, immersed in a saturated solution of sulphate of copper. The energy of this apparatus is sustained during more than five hours without very perceptible variations*.

7. The *additional wires* of which we shall treat were all carefully annealed; they are of the following dimensions. (See the annexed Table.)

Nature of the wires.	Lengths.	Diameters.
	metres.	metres.
Copper	9·510	0·00072
Platinum	0·435	0·00033
Brass, No. 1 ...	9·760	0·00230
Brass, No. 2 ...	15·640	0·00025
Iron, No. 1 ...	1·830	0·00034
Iron, No. 2 ...	6·743	0·00150
Iron, No. 3 ...	22·128	0·00020

8. In all the experiments related in this memoir we shall only treat of currents induced by the completion of the voltaic circuit, unless the contrary be expressly indicated.

9. The numbers stated in the tables are the mean of several readings according well with each other. To obtain this mean was essential, whether as a guarantee against the variations of intensity of the pile, or especially on account of the difficulty of the readings when the needles, yielding to an instantaneous deviating action, traverse an arc, the precise amplitude of which it is necessary to appreciate.

10. The needles of the rheometers generally coincided with the seventh degree to the right or left of the zero of graduation; when they were in equilibrium, having no compass with sines at my disposal, I strove to leave to the most intense currents an energy which would cause the index to deviate not more than from thirty to forty degrees, so that I might consider the angle described as sensibly proportional to the force which acted on the needle.

§ II. *Induction of a constant wire by a variable wire.*

11. The circuit of the induced wire of the great helix with

* *Archives de l'Electricité*, vol. ii. p. 597.

the thermo-electric rheometer was closed. That of one of the inductor wires was also closed by plunging its two extremities into a capsule full of mercury. Lastly, the other inductor wire was put into communication with a pile of two elements, either directly or by the intermediation of the brass wire No. 2, the length of which had been made variable.

12. Repeated experiments have shown, that for the additional lengths of wire increasing in geometrical progression, the intensities of the induced current, measured by the rheometer, diminish in arithmetical progression (α).

13. The same trials have been repeated by *opening* the circuit of the second inductor wire, all other circumstances remaining constant. Their results have been as follows:—

a. For the additional lengths of wire increasing in geometrical progression, the intensities of the induced current, measured by the rheometer, again diminish in arithmetical progression (β).

b. The intensity of the induced current measured by the rheometer is *greater* when the circuit of the second inductor is closed than when it is open (γ).

c. From the existence of the laws (α) and (β) it results that for the lengths of additional wire increasing in geometrical progression, the differences of intensity of the induced current, measured by the rheometer, when the circuit of the second inductor wire is closed and when it is open, decrease according to an arithmetical progression (δ).

14. Let M be the intensity of the induced current measured by the rheometer (general term of the arithmetical progression);

T the corresponding term of the geometrical progression;

a the first term of the arithmetical progression;

e the first term of the geometrical progression (unit of the additional length of wire);

r ratio of arithmetical progression;

q ratio of geometrical progression.

These quantities are connected by the relations

$$M = a - r \left(\frac{\log T - \log e}{\log q} \right),$$

$$T = e q \left(\frac{a - M}{r} \right).$$

15. The following Tables will serve as a proof of these enunciations. The ratio of arithmetical progression has been designated by r .

Lengths of additional wire. $q=2$.	Second inductor wire closed.			Second inductor wire open.		
	Deviations of the rheometer.		Differences. Mean error $=0^{\circ}75$.	Deviations of the rheometer.		Differences. Mean error $=0^{\circ}21$.
	Observed.	Calculated. $r=2^{\circ}33$.		Observed.	Calculated. $r=1^{\circ}50$.	
1	19°00	19°00	0°00	14°00	14°00	0°00
2	19°00	16°66	-2°34	15°00*	12°50	-2°50
4	16°50	14°33	-2°17	11°00	11°00	0°00
8	13°00	12°00	-1°00	9°00	9°50	+0°50
16	10°00	9°66	-0°34	7°00	8°00	+1°00
32	7°00	7°33	+0°67	7°00	6°50	-0°50
64	5°00	5°00	0°00	5°00	5°00	0°00

Calculated deviations of the rheometer.				
Additional lengths. $q=2$.	Second inductor wire.		Excess.	Constant differences.
	Closed.	Open.		
1	19°00	14°00	5°00	0°84
2	16°66	12°50	4°16	0°83
4	14°33	11°00	3°33	0°83
8	12°00	9°50	2°50	0°84
16	9°66	8°00	1°66	0°83
32	7°33	6°50	0°83	0°83
64	5°00	5°00	0°00	

16. From the preceding logarithms we should conclude, that when the conducting wire of a current is connected with another wire convolved in the form of a helix, its conductivity measured by the intensity of the current which it is capable of inducing, varies for different portions of its length according to a different law from that which it follows when it only completes the circuit, admitting proportionality to exist between the inducing and the induced current, as several physicists suppose (ϵ).

17. In order to verify this conjecture, the copper wire was placed parallel to the axis of the astatic needle, situated in the plane of the magnetic meridian, and the *maximum* amplitude of the arc traversed by this needle was observed, as well as the value of its stable deviation, in the following different alternatives (the additional copper wire being united with the first inductor wire to close the circuit of a pile of two elements):—

a. The circuit of the second inductor and that of the induced wire both being closed.

b. These two circuits being open.

c. The one being shut, the other open.

* This abnormal result is either an error of reading of the assistant, occasioned by the smallness of the interval between the divisions of the dial, or a heating of the wire under the influence of the current.

d. The circuit of the induced wire being closed by a pile of a single pair, and that of the second inductor being open.

e. Lastly, the same conditions existing as in the case *d*, but the circuit of the second inductor being closed by some mercury.

18. These experiments have led to the following results:—

a. The state of the simultaneous or separate closing or opening of the circuits of the induced wire and of the second inductor wire has no influence on the intensity of the inducing current (ξ).

b. This intensity diminishes in arithmetical progression, for the lengths of the inductor wire increase in geometrical progression (η).

c. The intensity of the inducing current is independent of the presence or the absence of a voltaic current in the induced wire; it does not vary with the state of closure or of opening of the circuit of the second inductor (θ).

19. The annexed Tables contain the confirmation of these laws.

Lengths of additional wire. $q=2$.	Readings of the astatic needle.			Differences. Mean error $=0^{\circ}.90$.
	Impulsions.	Deviations.		
		Observed.	Calculated. $r=2^{\circ}.90$.	
1	100.00	34.50	34.50	0.00
2	90.00	31.50	31.60	+0.10
4	80.00	31.00	28.70	-2.30
8	70.00	28.00	25.80	-2.20
16	60.00	24.00	22.90	-1.10
32	44.00	20.00	20.00	0.00

Intensities of the inductor wire measured by the astatic needle, amplitudes and deviations.									
Lengths of additional wire. $q=2$.	Second inductor wire, closed.			Second inductor wire, open.			Second inductor wire, closed or open.		
	Amplitudes.		Differ-ences. Mean error $=0^{\circ}.76$.	Amplitudes.		Differ-ences. Mean error $=2^{\circ}.57$.	Deviations.		Differ-ences. Mean error $=0^{\circ}.97$.
	Observed.	Calculated. $r=12^{\circ}.25$.		Observed.	Calculated. $r=11^{\circ}.50$.		Observed.	Calculated. $r=3^{\circ}.00$.	
1	117.50	117.50	0.00	113.00	113.00	0.00	38.00	38.00	0.00
2	105.00	105.25	+0.25	104.50	101.50	-3.00	35.30	35.00	-0.30
4	99.00	93.00	-6.00	99.50	90.00	-9.50	34.50	32.00	-2.50
8	79.50	80.75	+1.15	81.00	78.50	-2.50	30.00	29.00	-1.00
16	70.00	68.50	-1.50	70.00	67.00	-3.00	28.00	26.00	-2.00
32	55.50	56.25	+0.76	55.50	55.50	0.00	24.00	23.00	-1.00
64	44.00	44.00	0.00	44.00	44.00	0.00	20.00	20.00	0.00

20. In order to unite all the desirable demonstrations of the exactness of these results, I have repeated with the same wire and under similar circumstances, some experiments on its conductivity as a function of its length, the wire and the thermo-electric rheometer being alone in the circuit. I obtained, as it was easy to foresee, values which agree with the formula of M. Ohm*. Thus the remark (16.) is established.

§ III. *Induction of a constant wire by two wires, one of which is variable.*

21. Proceeding from the facts above related, similar results for the simultaneous induction of two inductor currents on a wire placed symmetrically between them, were to be expected. The subject divided itself naturally into six cases, which were examined. Calling the currents induced at the time of the closing of the circuit *direct currents*, those which are induced at the time of its rupture *inverse currents*, these six cases are characterized as follows:—

a. The two inductors are equal and traversed by direct currents in the same direction.

b. The two inductors are equal and traversed by direct currents in contrary directions.

c. The two inductors are unequal and traversed by direct currents in contrary directions.

d. The two inductors are unequal and traversed by direct currents in contrary directions.

e. The two inductors are equal and traversed, one by a direct current, the other simultaneously by an inverse current.

f. The two inductors are unequal and traversed, one by a direct current, the other by an inverse simultaneous current.

22. *First case.*—Different precautions are requisite in the arrangement of the apparatus, in order not to bring any perturbing force into play. I found that the current of ten pairs, in passing through the two wires of the small helix, heated them rapidly. On the other hand, the great conductivity of the wires of the great helix causing each of them, taken separately, to be sufficient even to discharge the current of twenty pairs, the deviations of the hydro-electric rheometer united to the induced wire remained the same, whether the two inducing wires or a single wire were employed. The arrangement which I found to succeed the best, consisted in mounting two piles of ten pairs, and making the current pass from the one into the first inductor wire, that of the other

* *Die Galvanische Kette Mathematisch bearbeitet*, p 36. "Des Travaux et des Opinions des Allemands sur la Pile Voltaïque," *Archives de l'Électricité*, vol. i. pages 36 and 46. [Ohm's investigation here referred to will be found in *SCIENTIFIC MEMOIRS*, vol. ii. p. 401.]

into the second, the direction of the two currents being the same. Thus we find, that if the two inductor currents are equal, the rheometric deviations which measure the intensities are double what they are with a single current; and if the currents are unequal, the deviations are the sum of the effects of each elementary current (v).

23. *Second case.*—I even employed the great helix and a pile of ten pairs. The two inductor wires were joined end to end, so that the direction of the current in the one was opposed to the direction of that in the other. The equality of their dimensions and of their conductivity involved the equality of the current which traversed each of them, a current the value of which amounted to half that of the pile. The induced currents also were perfectly equal, and as their directions were opposed, the needle of the rheometer remained quite motionless. The result was the same whether the circuit was broken or closed (x).

24. That the indications of the rheometer are indeed the measure of the currents simultaneously induced might be disputed. In order to reply to this objection, I substituted the metallic thermometer of Bréguet for this instrument. At the rupture as well as at the closing of the inductor currents, the needle of this very delicate apparatus remained stationary. This experiment repeated a great number of times invariably gave the same result*. I also substituted the small helix for the thermometer; small needles of tempered steel were not magnetized, in its interior, either at the closing, or at the rupture of the inductor currents.

25. *Third case.*—This was examined by help of the great helix, of two piles of ten pairs and of different wires. I was led to the following conclusions:—

a. When the length of one of the inductor wires remains invariable, and that of the other is gradually increased, for the lengths of the additional wire increasing in geometrical progression, the intensities of the induced current measured by the rheometer diminish according to an arithmetical progression, the first term of which corresponds to the sum of the effects of the inductor wires when the length of the additional wire is null, and the last term of which is equivalent to the action of the constant inductor wire taken by itself, whether

* This experiment is interesting by its connexion with the researches of Prof. Dove on the induced currents, which, equal in rheometrical measure, produce at the same time very different physiological actions. See *Berichte der Berliner Akademie der Wissenschaften*, 1839, p. 163. *Archives de l'Electricité*, vol. ii. p. 290.

at a length of additional wire, such that the lengthened circuit is an infinitely worse conductor than the invariable circuit (λ).

b. The value of the ratio of the arithmetical progression varies with the nature and the dimensions of the additional wire employed (μ).

26. *Fourth case.*—This was studied like the second, with the apparatus mentioned (23.). The laws which govern it are—

a. For the additional lengths of the inductor wire, increasing in geometrical progression, the deviations of the rheometer, which measure the difference of intensity of the two currents simultaneously induced, increase according to an arithmetical progression, the first term of which is zero, and the last term of which is equivalent to the action of the constant inducing wire, taken by itself, even at an infinite additional length (ν).

b. From whence it results, that for additional lengths, which increase in geometrical progression, the differences between the effects of induction, produced by the two wires simultaneously, and those which the variable wire produces by itself, diminish according to an arithmetical progression (ξ).

c. The value of the ratio of these arithmetical progressions varies with the nature and the dimensions of the additional wire employed (ϕ).

d. The presence or the absence of bars of soft iron in the helices only modifies the intensity of the induction (π).

27. The subjoined Tables are intended to prove the enunciations (ν) and (ϕ).

Lengths of additional wire. $q=2$.	Copper wire.			Platinum wire.		
	Deviations.		Differences. Mean error $=0^{\circ}45$.	Deviations.		Differences. Mean error $=0^{\circ}20$.
	Observed.	Calculated. $r=2^{\circ}00$.		Observed.	Calculated. $r=2^{\circ}00$.	
1	2.00	2.00	0.00	4.20	4.20	0.00
2	3.00	4.00	+1.00	6.50	6.20	—0.30
4	4.20	6.00	+1.80	8.00	8.20	+0.20
8	7.00	8.00	+1.00	11.00	10.20	—0.80
16	9.00	10.00	+1.00	13.00	12.20	—0.80
32	12.20	12.00	—0.20	14.00	14.20	+0.20
64	14.20	14.00	—0.20	—	—	—
128	16.80	16.00	—0.80	—	—	—
256	—	—	—	—	—	—

Lengths of additional wire. $q=2$.	Iron wire, No. 1.			Iron wire, No. 2.		
	Deviations.		Differences. Mean error $=0^{\circ}34$.	Deviations.		Differences. Mean error $=0^{\circ}70$.
	Observed.	Calculated. $r=1^{\circ}60$.		Observed.	Calculated. $r=3^{\circ}50$.	
1	5.50	5.50	0.00	3.00	3.00	0.00
2	7.00	7.10	+0.10	5.80	6.50	+0.70
4	9.00	8.70	-0.30	6.50	10.00	+3.50
8	12.00	10.30	-1.70	10.00	13.50	+3.50
16	13.00	11.90	-1.10	16.00	17.00	+1.00
32	14.00	13.50	-0.50	20.50	20.50	0.00
64	15.00	15.10	+0.10	25.00	24.00	-1.00
128	16.00	16.70	+0.70	29.00	27.50	-1.50
256	—	—	—	31.00	31.00	0.00

Lengths of additional wire. $q=3$.	Iron wire, No. 2.			Copper wire.		
	Deviations.		Differences. Mean error $=0^{\circ}40$.	Deviations.		Differences. Mean error $=0^{\circ}12$.
	Observed.	Calculated. $r=7^{\circ}00$.		Observed.	Calculated. $r=3^{\circ}00$.	
1	3.00	3.00	0.00	2.50	2.50	0.00
3	8.00	10.00	+2.00	4.50	5.50	+1.00
9	17.00	17.00	0.00	8.50	8.50	0.00
27	24.00	24.00	0.00	12.00	11.50	-0.50
81	31.00	31.00	0.00	—	—	—

28. The following Table will justify the assertions (ξ) and (σ).

Lengths of additional wire. $q=2$.	Copper wire.			Platinum wire.			Iron wire, No. 1.		
	Deviations.		Differences. Mean error $=0^{\circ}50$.	Deviations.		Differences. Mean error $=0^{\circ}30$.	Deviations.		Differences. Mean error $=0^{\circ}55$.
	Observed.	Calculated. $r=2^{\circ}00$.		Observed.	Calculated. $r=2^{\circ}00$.		Observed.	Calculated. $r=1^{\circ}60$.	
1	16.20	16.20	0.00	12.80	12.80	0.00	11.50	11.50	0.00
2	15.20	14.20	-1.00	10.50	10.80	+0.30	10.00	9.90	-0.10
4	14.00	12.20	-1.80	9.00	8.80	-0.20	7.50	8.30	+0.80
8	11.20	10.20	-1.00	6.00	6.80	+0.80	5.00	6.70	+1.70
16	9.20	8.20	-1.00	4.00	4.80	+0.80	4.00	5.10	+1.10
32	6.00	6.20	+0.20	—	—	—	3.00	3.50	+0.50
64	4.20	4.20	0.00	—	—	—	2.00	1.90	-0.10
128	1.50	2.20	+0.70	—	—	—	—	—	—

29. These laws were also verified by substituting the magnetizing helix for the rheometer. The magnetization took place as soon as an additional length modified the equality of conductivity of the two circuits.

30. Lastly, they were verified by means of the metallic thermometer. The result of this experiment may be given as follows:—

When an induced current is the effect of two simultaneous inductor currents and of opposed directions, the one constant, the other made variable by lengths of wire which increase (exteriorly to the helix) in geometrical progression, its thermal effects decrease in arithmetical progression (ρ).

It is worthy of remark that this logarithmic law is analogous to that which M. Biot has discovered for the propagation of heat in a solid bar*.

31. *Fifth case.*—This was examined by means of the great helix, the thermo-electric rheometer, and a single pair of Daniell's battery.

The magnetized needle was never deflected, although a sort of vibration or shake, attributable to the difficulty of working in an absolutely synchronous manner the opening of one of the circuits and the closing of the other, showed the existence of induction. We conclude from this experiment that the direct induced current is equal to the inverse current (σ).

32. *Sixth case.*—Studied as the preceding, it has led to the following law:—

On lengthening the wire intended to cause direct induction by the closing of its circuit, by quantities increasing in geometrical proportion, we find that the current equal to the difference of the two opposed inductive actions increases in intensity in arithmetical progression (τ).

33. The following are the results of an experiment which establishes the preceding law:—

Lengths of additional wire. $q=2$.	Copper wire.		
	Deviations.		Differences. Mean error $=0^{\circ}16$.
	Observed.	Calculated. $1=4^{\circ}00$.	
1	3 ⁰⁰	2 ⁰⁰	—1 ⁰⁰
2	6 ⁰⁰	6 ⁰⁰	0 ⁰⁰
4	10 ⁰⁰	10 ⁰⁰	0 ⁰⁰
8	14 ⁰⁰	14 ⁰⁰	0 ⁰⁰
16	18 ⁰⁰	18 ⁰⁰	0 ⁰⁰
32	22 ⁰⁰	22 ⁰⁰	0 ⁰⁰

34. Many precautions must be taken in order that the experiments, the details of which I have just related, may be

* Biot, *Traité de Physique Expérimentale et Mathématique*, vol. iv. p. 669. See also Poisson, *Théorie Mathématique de la Chaleur*, p. 250 (§ 123).

considered correct. Care must be taken to prevent the additional wires from being heated by the current; without this their conductivity with small lengths ceases to be comparable to their conductivity with great lengths. The current of induction which traverses the rheometer should, as much as possible, be moderated, so that it shall not alter the relation of the magnetization of the two needles. The rheometer itself should be removed from the inductric spiral, to a sufficient distance for the electro-magnetic induction of its inductor wires not to be felt.

35. In addition, the two extremities of the wires, the immersion of which must close the simple or double inductor circuit, is to be plunged at the same instant into the mercury. It is convenient to destroy the contact at the precise instant when the needle tends, by virtue of the acquired movement, to go beyond its primitive position of equilibrium; we thus avail ourselves of the second induced current to render it immoveable, which saves much time in long experiments of this nature, and destroys the influence of the variations of intensity of the current in piles continued in action during two or three hours.

§ IV. *Influence of the state of closing or opening of the circuit induced upon the action of the inductor current on itself.*

36. There is a very great correlation between the inductor circuit and the induced circuit. When the latter is open, we know that we obtain, at the breaking of the inductor current in the mercury, very brilliant sparks, the brightness of which increases if we place a hollow pencil of iron wires in the helix, and still more if this pencil is solid. These sparks, improperly so called, are, I think, produced by the combustion and the volatilization of the globule of mercury which adheres to the extremity of the wire, and which becomes thinner in proportion as this extremity is the more removed from the surface of the liquid in its reservoir. Now, when the induced circuit is very accurately closed, these sparks diminish considerably, and even disappear altogether*. Between the two limits of open circuit and circuit perfectly closed by the aid of very short massive and good conducting bodies, there is an infinity of intermediate degrees to which sparks more or less brilliant correspond.

* M. Abria has also shown, that a circuit placed near the inductor does not exert any reaction when it is open. See *Ann. de Ch. et de Phys.*, vol. iii. p. 10 (September 1841). [We believe that it is perfectly well known to British observers that the sparks here alluded to are produced solely by the combustion of the mercury.—EDIT.]

37. This explains why the closure of the circuit induced by the aid of a voltaic pile diminishes the brightness of the sparks, without the direction or the intensity of the current of this apparatus having the least influence; the pile evidently acts as an imperfect conductor.

38. When the inductor circuit is closed by a voltmeter in which some acidulated water for example is electrolysed, the quantity of gas obtained in the unit of time is independent of the presence or the absence of the metallic bundles [*faisceaux*] in the bobbin; it does not vary equally when we pass or arrest a continued current in any direction through the induced wire.

§ V. *Influence of the Atmospheric Pressure upon Induction.*

A. *Static Induction or Influence.*

39. Mr. Faraday, in his beautiful researches in electricity, has entered upon the question of the relation which exists between the atmospheric pressure and static induction*. I shall relate a few of my numerous experiments upon the same subject; experiments which are only new or varied forms of those of the learned English natural philosopher, and which lead to similar conclusions.

40. I have employed a large electrical machine, the plate of which is 0^m·85 in diameter, and the brass conductors of which are each 0^m·90 long and 0^m·108 in diameter. Under favourable circumstances it gives sparks 0^m·27 to 0^m·32; sparks are drawn from it easily at 0^m·11 to 0^m·16 distance.

41. On operating in the dark, every time a spark is drawn from the machine, there springs a purple glow (*purpurine*) between the two balls or the two charcoal points, which terminate at an inch distance, the stems of an electrical egg void of air; but this light disappears in proportion to the return of the fluid. With my machine this luminous appearance† scarcely takes place but at a *maximum* distance of a metre from the conductors, and appears the more brilliant in proportion to the proximity of the egg. For each distance it remains the same, whether the egg rests upon an insulating support, or whether it is connected with the ground by the mediation of the hand or a metallic chain.

42. It is not even necessary to draw a spark from the con-

* Experimental Researches, §§ 1613 to 1616; also §§ 1359, 1405, 1526 to 1543.

† It is what Mr. Faraday calls *glow*, and what the Germans designate by *das elektrische Glimmen*. It is distinct from the spark, properly so called, *spark*, *brush*, *funke*.

ductor in order to obtain the appearance of the electric glow (*lueur*); it is observable without interruption as soon as the plate is turned rather rapidly, on placing the egg at a proper distance.

43. Upon the glass plate of the air-pump I spread a leaf of the same nature, on which I insulated a brass button of $0^m\cdot048$ diameter. This ball was covered with a glass funnel reversed, in the neck of which I cemented a stem, also of brass, of $0^m\cdot004$ thickness, and terminated below by a ball $0^m\cdot024$ in diameter. Between the two balls there was about $0^m\cdot019$ interval. The funnel was itself placed under a glass bell, bearing a leather valve and a stem which descended to $0^m\cdot03$ from the preceding. After exhaustion of the air, the same phænomena appeared, the plate (secondary) employed being placed in communication with the ground or insulated on a glass plate.

44. Analogous results were obtained on replacing the bell furnished with the metallic stem, *projecting exteriorly*, by an attached glass bell; the balls were then in the most perfect state of insulation and in the most perfect vacuum. I employed a double-cylinder air-pump by Babinet.

45. I have thus proved, that on placing an electrical egg near a Leyden jar of mean dimensions and charged to saturation, there is no luminous spark between the charcoal points, when the electrical explosion between the two armatures takes place instantaneously, whilst a very brilliant one is visible during the entire duration of a prolonged discharge, such as is obtained by means of a point. I believe this observation is new.

B. *Dynamical Induction.*

46. The small helix was placed on the plate of the air-pump. By means of very fine copper wires covered with silk, a communication was made between the inductor wire and piles of four or six pairs, and between the induced wire and the hydro-electrical rheometer. These conducting wires, plunged in the grease with which the broad surface of contact of the bell-glass with the plate attached was covered, did not at all prevent a very good vacuum from being formed.

47. The deviation of the needle caused by the induced current was found to be *independent* of the quantity of gas re-admitted into the receiver. The observations were repeated at different times for differences of $0^m\cdot025$ height of the column of mercury measuring the elastic tension, from a vacuum up to the ordinary atmospheric pressure, $0^m\cdot725$.

§ VI. *Examination of two circumstances under which the electric currents and the magnets do not produce induction.*

48. Since the labours of Ampère and Mr. Faraday upon electro-magnetism and magneto-electricity, no attempts have been made, that I am aware, to ascertain whether the presence of a magnet or an electric current *always* induces electricity in the neighbouring conductors, and whether induction takes place *in the same manner in all directions*.

49. To obtain some datum upon those problems which are at the foundation of every solid theory of induction, it was necessary to examine whether a rectilinear current induces spherical electricity around every molecule of the conductor, supposed to be *electrically isotropic* (?) (that is to say, having an equal conductivity in all directions). The experiments of Mr. Faraday had shown us that induction takes place in a wire placed *parallel* to the inductor wire, whether the two wires were or were not twisted into a helix. My experiments have proved to me, that induction does not take place in a sensible manner in a wire which is at a right angle to the current.

50. I arrived at this conclusion by the two following methods:—I placed the brass wire No. 1 in the small hollow helix for magnetizing, and after having united the extremities of the latter with the thermo-electric rheometer, I closed with a wire the circuit of a strong voltaic element. At the breaking, as at the closing of the circuit, the needle remained perfectly immovable, when even a bright spark upon the mercury proved the intensity of the current and its induction upon itself.

51. I substituted for the preceding apparatus an electro-magnet, and I closed the circuit of the pile by the iron of the instrument. The needle of the rheometer, which communicated with its external helix by copper wire and by insulated spirals, one with another, in no degree deviated, even on placing in the circuit a large spiral plate (*coil*).

52. Thus a voltaic conductor induces currents in neighbouring conductors only parallel to its own direction. It is from the parallelism between the currents which surround the magnets (according to M. Ampère) and the coils of the exterior helix of the electro-magnet, that the approach of a magnetic body near soft iron determines induced currents in the helix, and that the passage of the current in the latter magnetizes the bar. The same fact also accounts for the action of the voltaic current on the magnetized needle,—an action discovered by M. Oersted, and which is the foundation of electro-magnetism.

53. It remained to examine whether the presence of a magnet or of a conductor traversed by a current always induces electricity in a neighbouring conductor, placed in a convenient manner? To this question the reply must be *negative*.

54. We know that if a natural or artificial magnet, or an electro-dynamic helix, is brought near to an electro-magnet of soft iron, the latter, on taking the magnetic power, produces an instantaneous current of induction in its helix. But when the approach is made slowly, the developed current loses its intensity, and by increasing or diminishing the distance of the soft iron from the magnet by very slow degrees, we succeed in completely destroying all sensible induction.

55. The first experiments were made with a horse-shoe iron magnet, capable of supporting eight kilogrammes; it was suspended by a metallic chain connected with the arbor of a lathe. An electro-magnet was fixed solidly on the table under the magnet, and its helix fastened to the thermo-electric rheometer. On turning the winch very slowly, I succeeded in bringing the magnet to within $0^{\text{m}}.004$ distance of the electro-magnet without any induction in the helix; but from that point the attraction of the magnets having brought them in contact from the extensibility of the chain, the needle was violently deflected.

56. I then used a magnet formed of seven horse-shoe iron plates, capable of raising nearly forty kilogrammes. The electro-magnet was no other than one of the keepers of the magneto-electric machine, of which the magnet formed part. On employing the same rheometer, I succeeded in bringing to the point of contact, and of separating to a distance of several millimetres, the two pieces *without any sensible induction resulting*. I operated by means of a screw which moved very slowly the slide upon which the magnet was solidly retained. The needle of the rheometer deviated several turns as soon as I rapidly caused a variation, although of a small arc, in the position of the keeper parallel to the polar surfaces of the magnet, at any of the distances at which the experiment had been made.

57. I arrived at the same result on employing the voltaic current as the cause of induction. I placed a cylindrical copper ring in some water containing $\frac{1}{10}$ th of sulphuric acid, so that its geometrical axis was vertical. This ring was connected with one of the extremities of the wire of the rheometer, and to the other extremity I soldered a very thin plate of amalgamated zinc, cut into the form of a very slender tongue. This plate, being immersed in the direction of the axis of the ring, produced an induced current very nearly null when the

immersion was made very slowly, whilst it occasioned one measured by 40° of sudden deviation when the immersion took place rapidly.

XLV. *Addition to a former communication on the Diffusion of Gases.* By THOMAS S. THOMSON, Esq.

To Richard Taylor, Esq.

DEAR SIR,

IN following up the ideas contained in my paper on the Diffusion of Gases, which you had the kindness to lay before the public (pres. vol. p. 51), a subsequent consideration has occurred to me which I now send you for publication. The chemical constitution of the atmosphere is twenty-one parts by measure of oxygen and seventy-nine parts by measure of nitrogen. Now supposing a tube twenty-one miles in length and another seventy-nine miles, separated from each other by a perfectly moveable diaphragm, the former filled with oxygen and the latter with nitrogen gas, sound would travel along this tube in a certain appreciable space of time which can be calculated as follows. The data I extract from Poisson's *Mécanique*.

a = velocity of sound

g = $9^m.80896$

h = $0^m.76$

$\frac{m}{\Delta}$ = 10.462

α = 0.00375

θ = $15^\circ.9$ (centigrade)

γ = 1.3748 .

The velocity of sound is expressed by the following formula :

$$a = \sqrt{\frac{g m h \gamma}{\Delta} (1 + \alpha \theta)}.$$

I mean now to assert that if, by the removal of the diaphragm, the gases be permitted to diffuse themselves through each other, sound would still travel in precisely the same time from one end of the tube to the other.

It is a necessary consequence of D'Alembert's principle, which I extract from Poisson,

$$A m P + A' m' P' + A'' m'' P'' + \&c. = 0.$$

The direction which molecular chemistry is taking at the present day renders it necessary to recall to the minds of some of your readers, that the repulsion of gaseous particles does not obey the law of the inverse of the square of the distance, but the inverse of the distance itself. It forms the subject of