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*Memoir on Magnetism.** *By* M. F. Savary.

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Previous to the exposition of the phenomena which form the subject of this memoir, I believe it is my duty to recall the recent discoveries that have served me as a starting point, and some of the experiments to which they have given birth.

It is only a few years ago when no other cause of magnetization was known than the influence of bodies already magnetized, and the magnetic force of the terrestrial globe. To this latter action was attributed by many, not only the effects of the shock, but of the thunderbolt, and the accidental magnetism without constant direction observed by Franklin, Van Marum, Priestley, and other philosophers, in the fragments of iron wire traversed and broken by a strong electrical discharge.

In 1820, a short time after the discovery of Œrsted, M. Arago observed that iron filings are attracted and sustained by the wire which joins the poles of an electro-moving apparatus; that they are detached the instant that the communication is interrupted;† that the current gives to steel needles a permanent magnetism, in a determined direction, perpendicular to its own proper direction, independent of the magnetic action exercised by the earth; and that two needles, parallel to each other, forming with the conducting wire a right angle, placed at equal distances on each side of this wire, acquire the same degree of magnetism, but in opposite directions.

M. Ampere, who since that time represented a magnet by a system of closed currents, perpendicular to the magnetic axis, proposed to

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† M. Arago has sometimes found that the filings became attached even to a platinum wire, some instants after the communication had been broken.

roll the wire of the conductor as a helix. The result was such as he had expected, as to the energetic action of these helices to magnetize parallel to their axis a needle enveloped in their spirals.

M. Arago recognized that in the interior of a helix, sufficiently long in relation to its diameter, and of a very short interior diameter, needles parallel to its axis, but distributed in any manner whatever, acquired magnetic intensities sensibly equal. At the exterior the same helix has very little magnetizing power, still less when it is longer and the spirals are nearer to each other. It is easy to represent these results by means of the analytic law proposed by M. Ampere for the mutual action of two elements of the currents.

In these experiments, voltaic currents only were employed. M. Arago soon made known a species of analogous action, but differing in many respects. He found that currents of ordinary electricity, produced by friction-machines, possess the property of rendering steel magnetic, as soon as on interrupting the conductor the fluid was forced to flow off in a series of small sparks; that a continuous current, when it flows off into the earth by a long metallic wire, produces no magnetism in steel and exercises no attraction on iron filings.

M. Rodolfi, a long time after, announced that on making a communication between the cushions and the conductor of an excellent electrical machine by means of a helical wire, he succeeded in magnetizing steel needles by the action of the continuous current *(tacita corrente)* that traversed the wire.

By electrical discharges, as also by the pile, the direction in which magnetism is developed is perpendicular to the direction of the conducting wire.

A useful application of this important property, which he had discovered afterwards, presented itself to M. Arago. Magnetism furnished him with a very simple and exact means of comparing the conductibility of different bodies, for the electric fluid accumulated up to high tensions and on large surfaces. This method not having yet been published, he has readily permitted me to give a description of it here.

Let us suppose a conducting wire setting out from the exterior armature of a battery, that it be rectilinear in one portion of its extent, that it then becomes ramified in a certain number of branches of the same metal, all of equal diameter, form, and length, and that they re-unite in one common point. We then place transversely on the straight part of each wire, before and after the ramification, some steel needles, and then pass a discharge through the whole system. It will traverse the first conductor entirely, and become divided amongst the different branches in equal portions. The magnetism of the needles placed on the first wire will then be the measure of the effect produced by the total quantity of electricity: the magnetism of the needles placed on the ramifying wires, the measure of the effect by a certain fraction of that quantity; the third, if there are three branches; the tenth, if there are ten. We shall thus form a scale of magnetic intensities, in relation to any fraction whatever of a given discharge. If afterwards, substituting at the different branches, all of the same metal, similar wires of different metals, we pass a discharge through this new system, a second discharge equal to that the action of which is known, it will become unequally divided among the different wires, and similar needles placed transversely on each of them will indicate by the degree of their magnetism, whether one metal has transmitted the third, another the fourth, or another the tenth of the total quantity of electricity.

Since the researches of M. Arago, M. Nobili has published some interesting experiments on magnetism. One of them consists in making either an electrical discharge or a current from a pile (M. Nobili has never separated the two methods of magnetizing) traverse a spiral plane of copper wire. If between any of the isolated spirals we fit perpendicularly to their plane some steel needles, we find that the needles situated near the centre, and the needles near the circumference, are magnetized in a contrary direction; and that consequently at a certain distance from the centre the magnetism is neutral. It was easy to foresee this result, since after the long and well known action of connecting wires, the spirals comprised between the centre and a needle exercise on it a contrary action to the exterior spirals.

I have repeated the experiment of M. Nobili in order to obtain some series of exact measures, and I have found that the distance from the centre at which there is no magnetism produced, at least by a feeble pile, may be calculated with sufficient precision by the formula

$$\int \frac{a\, d\,\omega}{R} - \iint \frac{d\,\omega\, dt}{r} = o\,,$$

t represents the vector ray, ω the angle from the centre for any point whotever of the spiral,* r, the distance of the extremities of the needle at this point, a and R the same quantities relative to the exterior circumference, by which we may suppose the spiral to be terminated. This formula is founded on the analytic law proposed by M. Ampere.

And then, as to the magnetic actions of other bodies besides iron, until the brilliant discovery of M. Arago, we only knew of the experiments of Coulomb, who himself regarded the consequences as doubtful; and the traces of magnetism observed by M. Ampere in copper wires submitted to the action of a very powerful voltaic current, or by M. Becquerel in small needles of different substances, enveloped in the spirals of an energetic multiplier. I pass now to the exposition of the researches to which I have devoted myself, on the different means of magnetizing already

* Or rather the ray from a circumference of the circle passing by this point with which the entire spiral is sensibly confounded, the limits are

$$\omega = o\ ;\quad t = o$$
$$\omega = \pi \quad t = a$$

referred to, in which researches I have had the advantage, which will be easily perceived, of being sustained by the kindness and the counsel of M. Arago.

I shall occupy myself at first on the magetizing action of electrical discharges transmitted, first by rectilinear conducting wires, second by helical wires; I shall afterwards explain the influence which the other metals besides iron and steel undergo and exercise in this phenomena; and lastly, I shall speak of analogous actions, produced by the continuous currents of the pile of Volta, and by magnets themselves.

On the Action of Electrical Discharges Transmitted by Rectilinear Conducting Wires.

The following experiments having for their object the making known of the general phenomena produced by very energetic actions, I was obliged to employ very fine needles. They were disposed in horizontal directions at different heights perpendicularly to the wire, which was extended in a right and horizontal line, their middle corresponding vertically to this wire. For this end it is advantageous to fix them along the edge of a plane very slightly inclined, in such a manner that the first being in contact with the conductor the others are a little removed from it but almost insensibly, and are still found to be sufficiently spread to prevent their mutual influence having any appreciable power.

I now proceed to transcribe the result of some experiments; each of which was repeated several times, and all agreed in a satisfying manner.

I took a platinum wire of $\frac{1}{4}$ of a millimetre in thickness, and about two inches long. It was extended in a right line at a distance of more than a centimetre from the ruler which served to support it. The needles, tempered hard, were $\frac{1}{4}$ of a millimetre in diameter, and 15 millimetres in length. After having magnetized them by the discharge of a battery of twenty-two feet surface, which was still far from being charged to saturation,* they were made to oscillate. I shall indicate the direction of the magnetism developed in each needle by calling those needles positively magnetized whose poles are placed in the direction in which the current of a pile traversing the conducting wire would have deflected them

* The indications of the electrometer are not given here because they could not be made use of to show whether two discharges slightly differed from each other. I have since employed, as an exact measure of tension, the balance of Coulomb, with this alteration, that the needle carrying the *moveable* disc, instead of being glass, is metallic; the fixed ball, instead of being insulated, is supported by a thin stem of metal: then, by means of the silver wire to which the moveable needle is suspended, we establish an exterior communication between the moveable disc and the fixed ball. If afterwards we make the whole system communicate with the interior armature of a battery, the distances to which the disc is repulsed indicate at each instant the state of the electrized surface. This apparatus thus modified possesses all the desirable precision.

if they had had a previous magnetism, and which if suspended above this wire, would have no power to move except in horizontal planes. This direction is the same whatever be the distance of the needle from the wire. We must understand by the words, ***needles negatively magnetized,*** those whose poles will be deflected in a contrary direction. This admitted, I now give the times of the observed oscillations :

			Duration of 60 oscillations.			Direction of the magnetism.
	Mill.		m.	s.		
1st needle in contact with the wire during the discharge ..*			0	52	4	Positive.
2 during the discharge had ..	1	2 of wire	1	3	8	id.
3	2	5	1	12	8	Negative.
4	3	7	0	44	6	id.
5	5	0	0	40	0	id.
6	6	0	0	41	8	id.
7	7	4	0	44	8	id.
8	8	5	0	58	2	id.
9	9	7	1	20	1	id.
10	10	9	1	52	0	Positive.
11	11	8	1	18	6	id.
12	12	5	1	1	0	id.
13	13	8	0	49	6	id.
14	16	3	0	38	2	id.
15	18	7	0	33	8	id.
16	21	0	0	31	3	id.
17	23	8	0	29	5	id.
18	28	5	0	30	8	id.
19	34	0	0	29	8	id.
20	46	0	0	35	9	id.
21	70	0	0	55	6	id.
22	100	0	1	27	6	id.
23	130	0	1	48	0	id.

We see that the direction of the magnetism produced by the discharge has changed twice; the first at about two millimetres of wire; the second at nearly 10 mill. 4. The *maximum* for the needles negatively magnetized, is found at 5 mill. of wire. The *maximum* of the positive needles are, the one in contact with the wire, the other at about 3 cents. in height. At this latter *maximum* the needle made 60 oscillations in 29″, 7. On being magnetized to saturation by strong magnets, it made sixty oscillations in about 23″. No dis-

* The needles during the discharge, were about 2 cent. from each other; and as the latter ones would have been too near the extremities of the wire if they had only a single support slightly inclined, they were disposed on several parallel planes between them, and invariably connected.

charge within the limits I had in my power of employing, produced this state of saturation, the conducting wire remaining the same and of the same length.

The needles as strongly magnetized in one direction as in the other did not present either consequent points nor multiple centres. This may easily be proved by examining the curves formed around them by iron filings.*

By submitting to the same discharge needles of the same degree of hardness and of the same diameter, but of very different lengths, $15^{\text{mill.}}$, $10^{\text{mill.}}$, and of $5^{\text{mill.}}$, we find that the distances from the wire at which the changes in the sign takes place, do not differ from two or three-tenths of a millimetre; that is to say, quantities for which we can scarcely answer in the first experiments.

As a second example I took a wire of half the length (1 metre), of the same platinum wire. For a similar discharge to the preceding one the form of the series of magnetic intensities is thus, as we shall see, entirely changed.

Needles of 15 mill. in length.	Distance of wire during the discharge. Mill.			Duration of 60 oscillations. m.	s.			Direction of the magnetism.
†1st needle in contact with the wire	0	0	....	0	3	1	....	Positive.
2	1	1	....	2	29	0	....	Negative.
In another series at	1	4	....	1	48	3	....	id.
3	2	0	....	Without appreciable magnetism.				
4	3	0	....	1	25	6	....	Positive.
5	4	3	....	1	5	6	....	id.
6	5	5	....	1	3	0	....	id.
7	6	7	....	1	13	6	....	id.
8	8	0	....	1	32	2	....	id.
9	8	6	....	3	8	0	....	Very slightly negative.
10	9	6	....	1	34	8	....	Negative.
11	10	5	....	1	17	2	....	id.
12	12	3	....	1	1	2	....	id.
13	13	5	....	0	56	4	....	id.
14	14	6	....	0	56	0	....	id.

* I have endeavoured since the reading of this memoir to determine the position of the poles by sliding small needles, suspended horizontally, along a very fine copper wire, vertical, and traversed by a voltaic current. We know that at the poles themselves the action of the wire for making the needles turn is null, and that on both sides of these points it is exercised in a contrary direction. We find also that for very different intensities they are always strong near the extremities, and suddenly approach the centre, when the magnetism is on the point of changing its sign, as if the middle needles alone preserved, at that time, any magnetism. We may conceive by that how the direction in which these needles are magnetized by the discharge hardly depends on their length. It yet remains for me to submit them to a later species of proof to which I have submitted the needles magnetized in helices, that is to study the magnetism of their fragments after having broken them.

† This needle presented at its extremities traces of multiple centres.

Needles of 15 mill. in length.	Distance of wire during the discharge.			Duration of 60 oscillations.				Direction of the magnetism.
	Mill.			m.	s.			
15th needle in contact with the wire	15	7	....	0	59	4	....	Negative.
16	16	9	....	1	3	0	....	id.
17	18	2	....	1	5	0	....	id.
18	19	1	....	1	16	8	....	id.
19	20	0	....	1	34	2	....	id.
20	20	9	....	2	29	0	....	id.
21	21	4	....	Almost null			....	Slightly negative.
22	23	3	....	1	23	7	....	Positive.
23	32	7	....	0	41	4	....	id.
24	44	0	....	0	34	0	....	id.
25	70	0	....	0	43	2	....	id.
26	100	0	....	1	2	2	....	id.
27	130	0	....	1	28	2	....	id.

This series presents four changes in the direction of the magnetism. The first takes place at less than a millimetre from the wire; the second at 2 mill.; the third at 8 mill., 4; the last at 21 mill., 5. We see that needles which were negative in the first series are positive in this, and *vice versa*. The latter *maximum*, which is found at the height of 3 cent., is 4½ cent.. Its value is less; it being only 34″.

In the same circumstances, for needles ten millimetres long, the same changes of signs take place at 0 mill., 5; 2 mill., 5; 9 mill., 5; and about 20 mill., 5. For needles of five millimetres in length, at 0 mill., 5; about 3 mill., 2; 10 mill., 5; and about twenty millimetres. These distances are almost the same as were obtained with needles of fifteen millimetres.

I now proceed to a third example. For the same distance charge a platinum wire, rather thicker than the preceding one, of 0 mill., 37 diameter, and of the same length (one metre), gave changes in the sign four times, nearly at the distances of three, five, nine, and twelve millimetres from the wire. From thence up to 2 cent. we only find the needles very feebly magnetised; between which, with stronger discharges, a third period was manifested, except at the changes of the signs, at least by the variations of the intensity, just as I have observed it in a series obtained with a brass wire of an equal sensible diameter. For the platinum wire of which I have just spoken, the needle the most magnetized was that found at a distance of about 6 cent. from the wire. It took 56″ to make sixty oscillations. The needle possessing the most magnetism for a finer wire, and of the same length as before specified, made the same number of oscillations in 34″, and was at a distance of 4½ cent. from the wire.*

* On the same platinum wire of 0 mill., 57 diameter, but 0 met., 65 lengths only, and for a discharge stronger than the preceding ones, small needles of five millimetres have changed the direction of their magnetism five times;

In order to finish the comparison between different platinum wires I chose one much finer than the preceding ones. It was $\frac{1}{8}$ of a millimeter in thickness. A meter in length of this wire, with a discharge equal to the preceding one, gave the following results :—

Needles of 15 mill. in length.	Distance from the wire during the discharge.			Duration of 60 oscillations.				Direction of the magnetism.
	Mill.			m.	s.			
1st in contact with the wire......	0	0	....	0	34	4	....	Positive.
2	1	2	....	0	25	2	....	id.
3	2	6	....	0	24	1	....	id.
4	5	0	....	0	24	3	....	id.
5	7	4	....	0	24	0	....	id.
6	9	7	....	0	23	3	....	id.
7	12	0	....	0	23	5	....	id.
8	15	1	....	0	24	9	....	id.
9	18	5	....	0	27	0	....	id.
10	22	5	....	0	25	8	....	id.
11	28	0	....	0	27	0	....	id.
12	34	0	....	0	30	9	....	id.
13	45	0	....	0	37	6	....	id.
14	70	0	....	1	1	8	....	id.
15	100	0	....	1	37	2	....	id.
16	130	0	....	2	0	5	....	id.

This series presents no changes in the sign. At the commencement the variations of intensity are scarcely observable. It is important in this respect: 1st, the *maximum* of magnetic intensity is found at the height of 11 $^{\text{mill.}}$ about five times nearer the wire than when we employed a platinum wire three times as thick; 2ndly, this *maximum* is the state of saturation which we obtain by the magnets, and its value is nearly six times greater than the value given by a wire of triple its diameter. At the same time that the *maximum* approaches the wire the decrease of the intensities of this *maximum* from thence becomes more rapid.

If we pass through a wire $\frac{1}{8}$ of a millimetre in thickness and one metre in length, a series of discharges, diminishing their strength by degrees, we should see the *maximum* very slowly diminish as it approached the conductor; but we never obtain changes in the sign of the magnetism, and never any analogous series to those presented by the other wires. On the other hand, by gradually diminishing the discharges, we never obtain with the other thicker wires, and of the same length, the series just presented to us by the finest wire. The changes of sign quite disappear then, and we only observe variation of intensity in their place, but at the same time the value of *máxima* diminish in proportion as they are found at less heights.

the last change took place at twenty-eight millimetres from the wire. The needles in contact with the wire were even magnetized negatively, and the most magnetized of all. It was necessary to remove to a distance of 10 $^{\text{cent.}}$ from the wire to obtain a slight degree of magnetism.

If, on the contrary, we cause to traverse these wires of a still greater diameter, without changing their lengths, discharges of a stronger character than those whose effects have been described in the preceding paragraph, we shall see the *maximum* of magnetism augment a little in value; but this is by increasing the distance more and more, and the series changes in form, but without coming into any of the other series, at least in the limits of the electric force of the battery employed.

In the preceding experiments a given discharge has always produced a magnetism as much stronger as the length of the wire was greater in proportion to its diameter. This increase has a limit to its effect. The following series gives for a similar discharge, but much more feeble than the preceding ones, their lengths of the same platinum wire of $\frac{1}{8}$ of millimetre in diameter.

Length of the wire 0 met. 50.

Needles of 16 mill. in length.	Distance from the wire during the discharge. Mill.		Duration of 60 oscillations. m.	s.		Direction of the magnetism.
1	0	4	1	0	0	Positive.
2	1	3	1	57	5	Negative.
3	2	5	0	54	0	id.
4	5	0	1	21	6	id.
5	6	1	1	28	8	Positive.
6	7	6	0	47	2	id.
7	9	0	0	37	9	id.
8	11	4	0	31	7	id.
9	13	8	0	29	4	id.
10	21	0	0	29	8	id.
11	33	0	0	34	2	id.
12	44	0	0	45	6	id.

A needle placed at a considerable distance from the third, and apparently at the same distance from the conducting wire, was equally negative, and made 60 oscillations in 54″ 8.

Length of the same wire 1 met. 0, and 4 met. 30.

Needles 15 mill. long.	Distance from the wire during the discharge. Mill.		Duration of 60 oscillations. Length of wire. 1 met. m.	s.		4 met. 30. m.	s.		Direction of the magnetism.
1	0	0	1	6	4	0	39	8	Positive.
2	1	2	0	31	6	0	29	8	do.
3	5	0	0	25	5	0	26	1	do.
4	8	5	0	25	5	0	29	9	do.
5	11	4	0	24	6	0	36	7	do.
6	22	6	0	31	4	1	12	2	do.
7	34	0	0	44	0	1	58	5	do.
8	45	0	1	6	2	2	26	5	do.

We see in comparing the three preceding series, 1st, that the wire of a metre in length gave absolutely the most elevated *maximum*; 2ndly, that the relative *maxima* in each series were found nearer the wire in proportion as this wire was increased in length, the diameter still remaining the same.

In general, with the same battery, and with wires of the same nature, and with similar needles, the form of the series depends on three things: the intensity of the discharge, the diameter, and length of the wire. The discharge and the length of the wire being made constant, there is a diameter at which the *maximum* of magnetism has the highest value; for diameters greater or smaller than this the *maximum* is less. The discharge and the diameter being kept the same, we find a length at which the *maximum* is greater than for any other length either greater or smaller.

The length and the diameter which thus give the greatest degree of magnetism, is the one which is the smallest, and the other that which is the greatest, in proportion as the wire has less conducting properties.

The *maximum* of magnetism is further from the wire, the number of changes in the sign in the interval much more considerable, as the length of the wire is less in proportion to its diameter.

We obtain similar series by means of equal discharges, by varying at once the length and the diameter of the wire in a certain proportion.* When the length and the diameter of two wires are not satisfactory on this point, we can not in general, by means of discharges, either equal or different, obtain from the two wires exactly parallel series. The disparity is especially manifested when the wires and the discharge are in the necessary conditions for producing change in the sign of the magnetism with a change of distance.

I have not yet made a complete series with wires whose thickness was less than a millimetre. But I am convinced that a brass stem of five millimetres in thickness, will give needles magnetized in different directions according to the intensity of the discharge.

Hence that part of the conducting wire extended in a right line to a sufficient length, and the form of that part which is not so extended, exerts no influence on the magnetism, whilst its length does so to a considerable extent, as we have just seen.

All the points of the wire exercise equal actions, at least in these inconsiderable lengths. In fact, at the same height, those needles which were at a great distance from each other, providing that they were not too near the extremities of the rectilinear part, received exactly the same quantity of magnetism, and in the same direction. This is true again when amongst the needles, some of them are

* This proportion differs sensibly from the simple proportion which, according to the researches of M. Davy and M. Becquerel, ought to exist between two conducting wires of the same nature, because they transmit with an equal intensity a voltaic current of equal strength. We know then that the relation of these wires to their transverse sections ought to be constant.

enveloped in glass tubes, sealed with gum lac, and the others exposed without envelope to the action of the current. This latter proof is only a repetition of one of the first experiments of M. Arago. It does not permit me to suppose that a part of the discharge, when the wire is very fine, is transmitted by the air and the neighbouring bodies, or at least that such a part could have any sensible influence. In fine, in order to discard the supposition that the strips of dry wood placed under the wires could exert any influence, it will suffice to dispose the needles some above and some below the horizontal conductor, in such a manner that the latter are very near the plane which serves for a support. We find, as we might easily foresee, at equal distances from all parts of the wires that there is the same magnetic intensity and contrary polarities.

In order to study the mutual influence of the different parts of a circuit, I disposed three series of needles of three brass wires, placed one after the other, and joined together at their extremities. Each wire was a metre in length: the first, situated between the two others, $0^{mil.}$, 125, the second $0^{mil.}$, 375, the third $0^{mil.}$, 75, in diameter. The first needle had a *maximum* of positive intensity, which gave 60 oscillations in 36″; for the finest and farthest insulated wire, the maximum would have sensibly the same value; it would have been for the other two about 57″, and 1′4″. The changes in the signs were found in the three wires, the first between 3 and 4 millemetres in height, the second between 13 and 14 millimetres. The negatively magnetized needles were affected a little less on the thickest wire. On being acted upon singly, the two latter needles gave, with an equal discharge, changes in the signs of the magnetism four times. The very fine wire only exhibited them twice, one at $4^{mil.}$, the other at about $11^{mil.}$ in height.

The equality of the action which took place at all points of a similar wire conductor, still subsists then almost wholly throughout the extent of a circle composed of several wires of different diameter, at least at some distance from the points of junction. The form of the periods is the same on all, saving the slight displacements in the position of the changes of the sign, and the same as on a wire equal in length to the sum of all the lengths, and of a diameter that is intermediate between all the diameters. If one of the wires be very fine, whatever place it occupies in relation to the others, it communicates to them nearly its own properties, whilst its manner of acting only undergoes feeble modifications. Circumstances transpire with regard to this wire, as if it was lengthened a very little, but with regard to the others as if their extent was much augmented. The invariable conductors of a battery, then, ought to be sufficiently large to permit of their influence being neglected.

It is not necessary to understand what has just been said of the equality of action observed in a complete circuit, relating to a system of wires of very different diameters, comparable to the distances where the changes of sign take place; neither to a case where *during* the discharge one of the wires changes its state and becomes entirely volatilized.

With a view of examining whether the force of the magnetism of a discharge would be modified by a resistance which, in the middle of each wire would tend to hinder the conducting wire from dilating itself, or is opposed to small transverse movements, I filled a crystal tube, whose exterior diameter was nearly four millimetres, and the interior diameter four-tenths of a millimetre, with mercury. The ends were closed by two brass wires, fixed by a little wax, and in contact with the mercury. With regard to the pressure exercised during the discharge, the effect has been to separate the tube into two, precisely in the middle of its length, to break it very near the extremities, and to furrow it symmetrically from that part of the middle to the quarters and a little beyond, by oblique fissures, such as are presented by the fillets of two helices turning in contrary directions. The other two quarters of the tube up to the extremities were whole. The pressure had even been a little stronger at the quarters, for at these two points, the mercury had escaped in very fine drops, showing that it had been driven out more abundantly at the two ends and in the middle. It is necessary to avoid the small bubbles of air or water interrupting the metallic fillet: this will suffice to determine the rupture at the two points of separation.

Under the relation of magnetism, the series presents a notable irregularity. Opposite the point of rupture at the middle of the tube a needle was found very feebly magnetized between two needles that were strongly magnetized. This experiment was not repeated.

When a very fine brass or platinum wire, of such a length that the magnetism produced by a strong discharge will present changes in the sign, and the wire is broken by the current, the magnetic effects, except perhaps at a very small distance from the point of rupture, remain the same as if the wire still remained extended.

After having passed a very strong discharge through a wire conductor, we no longer obtained on this wire precisely the same series of magnetic intensities for quantities of electricity that are sensibly equal. This alteration, which is very feeble, depends perhaps sometimes on a superficial oxidation, and ought to agree in general with the degree of annealing which the metal undergoes during a discharge at a high temperature.

Hitherto I have supposed all the needles of the same diameter, $\frac{1}{4}$ of a millimetre, and of the same degree of temper, the rolled temper. These two circumstances, temper and the diameter, have the greatest influence on the direction and the intensity of the magnetism which a discharge may produce and a conductor give, whilst as we have seen, the length of the needles has scarcely any influence.

As an example of the manner in which these *maxima* and the changes of sign in the magnetism are displaced by the degree of temper, I transcribe the following series, obtained on on a brass wire of $\frac{1}{5}$ of a millimetre in diameter, and by a single discharge, the needles were all 15 millimetres long and 0 mil. 30 in diameter. They had all been cut from the same piece of steel.*

First Series. Needles tempered hard.

	Distance from the wire during the discharge. Mill.			Duration of 60 oscillations. m.	s.			Direction of the magnetism.
1	0	6	....	1	22	8	....	Positive.
2	1	6	....	1	13	4	....	do.
3	2	6	....	1	20	0	....	do.
4	3	9	....	2	14	5	....	do.
5	4	9	....	1	42	0	....	Negative.
6	6	3	....	1	13	6	....	do.
7	7	6	....	1	5	8	....	do.
8	9	8	....	1	5	6	....	do.
9	10	8	....	1	0	8	....	do.
10	12	4	....	1	35	4	....	do.
11	14	8	....	2	14	4	....	Positive.
12	45	0	....	0	42	2	....	do.

Second Series. Needles untempered: flexible.

1	0m.	0	....	1′	58″	5	....	Positive.
2	1	2	....	3	50	0	....	do.
3	2	4	....	1	49	5	....	do.
4	3	8	....	1	18	0	....	do.
5	5	3	....	1	1	2	....	do.
6	6	3	....	0	56	4	....	do.
7	7	3	....	0	51	6	....	do.
8	9	4	....	0	50	2	....	do.
9	10	3	....	0	48	4	....	do.
10	12	8	....	0	46	8	....	do.
11	15	4	....	0	47	2	....	do.
12	42	0	....	1	10	6	....	do.

The needles tempered hard presented two changes in the sign; the untempered needles only presented at some distance from the wire a *maximum* of intensity. The *maximum* of the hard tempered needles is very much further from the wire, and at a higher value than that of the flexible needles.

In general the magnetism in the hard tempered state is a state of equilibrium between the greatest forces and resistances: a feeble exterior cause alters it with greater difficulty. In this state the needles acquire a more elevated *maximum* either in one direction or the contrary one, attaining it by a less discharge, and only commence

* I have sought to find whether, as M. De la Rive and M. Marianini have remarked on wires which have served to establish the communication between the poles of a pile, a platinum wire which has transmitted a strong discharge would give, when its extremities are plunged into a liquid conductor, any traces of an electric current. I could not observe any: but the apparatus I made use of was not sufficiently sensible, and this experiment merits a repetition.

losing it in a sensible manner with stronger discharges, and suddenly changing the sign. The mode of magnetizing due to M. Arago, thus offers the means of comparing, with exactness, the different degrees of the coercive force, which augments nearly in proportion as the *maximum* of magnetic intensity, the state of saturation, is itself increased, but which may still vary considerably when this *maximum* is very little changed.

The influence of the diameter of the needles on the magnetism which they receive cannot be disengaged from other causes, which, such as the degree of temper, make the results vary; for the interior particles of a thick needle cannot have taken in the sudden cooling the same disposition as the exterior ones. Be it as it may, I extract from a series made with needles of three different thicknesses, and of 15 mill. in length, on a brass wire of 0 mill. 125 ($\frac{1}{8}$ mill.), the following values of magnetic intensities at equal heights :—

Distance of the axis of the needles from the wire during the discharge.	Duration of 60 oscillations. Needle of 0m. 30 in diam.	Needle of 0m. 80 in diam.	Needle of 1m. 75 in diam.
Mill.	m. s.	m. s.	m. s.
1 8	1 10 pos.	2 0 pos.	1 39 pos.
17 0	58 neg.	59 id.	1 46 id.
27 0	58 pos.	1 5 id.	57 id.
Maximum of intensity of needles magnetised by magnets	25	31	44

In place of the changes of sign presented by the thin needles, the mean needles only presented a *minimum* in contact with the wire even, and the largest needles a continued decrease of intensity in proportion as they were further removed from this wire.

The series presented by the mean needles and the thickest ones, are those which were obtained with the small needles with discharges more and more weak; with discharges more and more strong the thick needles themselves exhibited changes in the sign.

The phenomenon of the reversement of the poles produced in the needles of the compass by thunder may already be explained by known facts; since the fluid, according as it passed on one side or the other of these needles, all things beside being equal, ought to magnetise them in opposite directions. But this phenomenon still admits another explanation, founded on the preceding facts; for the fluid always passing on the same side of the needle, the direction of the magnetism still depends on the distance and the intensity of the discharge. We may even remark that compass needles are found in circumstances which facilitate the production of alternations of the contrary magnetisms. They are of very small substance, which places them almost in the state of isolated wires of a small diameter, and receiving the hard temper.

On the Action of Discharges Transmitted by Wire Conductors Wound as Helices.

The needles I have employed in the following experiments were fifteen millimetres long and quarter of a millimetre in diameter: they were tempered hard.

I rolled into a helix, on a hollow cylinder of dry wood of nine cent. long, and of about 0^{m}, 5 in diameter, a brass wire of $0^{mil.}$, 180 in thickness. The step or pitch of the helix was about 3 mil. in height. With a length of wire of $0^{met.}$, 80, the same needles, placed successively in the middle of the cylinder, in the direction of its axis, were magnetized by discharges, gradually increased. I here give for each needle after being magnetized, and in the order of the increasing intensity of the discharges, the duration of sixty oscillations: + 25″,6; + 56″,8; — 38″,2; — 25″,5; + 28″,9; + 27″,1; — 42″,0; — 33″,1; — 57″,6; + 27″,8; + 23″,0; + 34″,6; — 1″,15; + 31″,3. The sign + indicates that the needle was magnetized in the direction in which the voltaic current was transmitted, and which I have hitherto called *positively magnetized;* the sign — indicates a contrary direction of magnetism.

This series presents to us six changes in the sign. The second discharge, which corresponds to the number + 56″,8, was equivalent for the quantity of electric fluid to that of an ordinary Leyden jar. I could with difficulty perceive the luminous point drawn from the battery.

We should perhaps obtain with a less length of wire a greater number of changes in the direction in the magnetism. When on the contrary the wire is lengthened, the helically wound part remaining the same, not only does it require a greater force to obtain the first reversing of the poles, but in place of the changes of sign following, we only find some variations of magnetic intensity: thus for discharges equal to those of the preceding series, and a similar wire, but of double the length ($1^{m.}$, 6), the corresponding numbers to the 3rd, 5th, 7th, 9th, 11th, 12th, and 13th observations of that series are +25″,0; —31″,9; +31″,0; +25″,6; +51″,6; +54″,6; + 46″,0. Beyond that the magnetism continues to augment in the same direction.

The period which is formed by the four latter values is that which becomes by the effect produced by lengthening the wire, the period comprised between the sixth and tenth observations in the first series. We see how it differs from it. However, these two periods would become identical, if the effects due to the lengthening of the wire could be compensated for by an increase in the intensity of the discharges. This compensation, therefore, cannot take place. We must not forget that in the two cases that part of the wire which acts immediately on the needles is exactly the same. A similar conclusion has already been presented in the examination of the action of rectilinear conductors.

I shall not here report the different series of magnetic intensities obtained by employing lengths of the same wire, gradually increased, whilst with the wire 0$^{met.}$, 80 long, the first reversing of the poles takes place with a quantity of fluid which does not much surpass the charge of a simple Leyden jar. It is only with a very strong discharge of a battery of twenty-two feet surface that we obtain the same effect with a wire of equal diameter, and of eleven metres in length, the helically wound part being the same in both cases. But this wire has given needles magnetized to saturation, making sixty oscillations in a little less than 23″, as well in one direction as the other.

The pitch of a helix always remaining the same, a brass wire of 0$^{mil.}$, 09 in diameter, and 6$^{mil.}$, 5 long, no longer gave a reversion of the poles. Nor could I obtain it with a silver wire of $\frac{1}{40}$ of a millimetre in diameter, and 0, 25 millimetres long, from the most feeble discharges up to those which reduced it completely into smoke. The *maximum* of magnetic intensity was with wires in a state of saturation.

I brought into communication by one of their extremities the helix of this same silver wire and a similar helix formed of a copper wire considerably larger. A discharge passing from one helix to the other produced changes in the direction of the magnetism in the second, when even the very fine wire was completely vapourized, and had so much power that it constantly magnetized in the same direction the wires submitted to its direct action. Also in the case where the diameters of the wires composing a circuit are very different, where at least one of these diameters is of extreme tenuity and rather fine, when during the discharge one of these wires changes its state the action of different parts of the circuit cannot be equal.

In general, for the same wire on a similar helix, the first *maximum* augments in value when the wire is made longer, and diminishes when its diameter is increased. In the first case, it requires a greater force to obtain the first reversion of the poles or the period of variations of intensity which replace it; in the second it requires a less force. Any *maximum* whatever is as much more elevated as the limits of the period to which it belongs are more scattered.

I pass, however, now to the case where leaving the diameter and the length of the wire invariable, we successively change the length of the diameter and the pitch of the helix.

The length of the helices, when it is equal to seven or eight times their diameter, and two or three times greater than the length of the needles, has scarcely any appreciable influence on the length, or the intensity of the magnetism.

The experiments of M. Arago have shown, as I have already said at the commencement of this memoir, that similar needles disposed in any manner whatever in the interior of a large helix, at least at some distance from its extremities, all receive parallel to its axis the same degree of magnetization;* and likewise

* This is also true, is whatever way the needles are magnetized.

this degree of magnetization is sensibly the same in two helices of different diametres, provided that they be sufficiently long and their pitch be equal and sufficiently short. When the spirals are a little removed from each other, to 3 millimetres for example, the helices have much greater action than when their diameter is smaller, but this increase of energy is extremely feeble. It is almost insensible, and may be altogether neglected with a pitch a moiety less, 1·5 millimetres. The most exact means of proving these small differences is by placing one in the other, two helices which turn in the same direction, as was done by M. Arago, and to bring into communication by their extremities the wires which they cover. The current then traverses them in contrary directions; they act in contrary directions on the needles placed in the interior helix, and these needles, either remaining unmagnetized or only acquiring, with very strong discharges, a feeble magnetism in the direction which the helix of the smallest diameter gives them. However, this magnetism increases little by little with the intensity of the discharge.

If the two helices, placed one in the other, and always of the same pitch, in place of turning in the same direction, turned in contrary directions, the one *dextrosum*, the other *sinistrosum*, the current traverses them longitudinally in oppositedirections and transversely; their actions, always pretty nearly equal, are added together, instead of being destroyed as in the preceding case. We may thus measure double, triple, or quadruple forces. It is sufficient if we make the discharge arrive at first at a simple helix, from that to a system of two, three, or four helices of the same pitch, one enclosed in the other, and alternately turning in contrary directions. The mutual action of helices which envelope each other is here, however, as we shall hereafter see, a cause of error, but this error is very small, if the wire of which they are formed is sufficiently fine.

Here I give, for electric charges of which the intensity may be represented in the gross by the numbers 2, 3, 4, 4½, and 5, the durations of oscillations measured by the magnetism of magnetized needles; the one in the simple helix, of which I before made use of, the others in the system of two helices of the same pitch, which I shall call, for the sake of brevity, the *double helix*.

Intensities of electrical charges.	During 60 oscillations.						
	Simple helix.			Double helix.			
		s.			m.	s.	
2	+	23	5	+	0	22	9
3	+	22	9	+	0	30	4
4	+	27	2	+	1	2	0
4½	+	31	8	—	1	17	0
5	—	32	8	—	0	23	5

We see already by these estimates, inasmuch as they are still very large, not only that the action of a double discharge is very different to double the action of a simple discharge; but further, that the relation of these two forces is variable, and depends on their absolute intensity.

A double helix acts sensibly as a simple helix of a pitch a moiety shorter, the length of wire being the same for them both.

We may be assured that if a portion of a discharge is passed from one spiral to another, without following the contrary, this portion may be altogether neglected, at least for the heights of pitch that I have employed. It will suffice if we isolate with gum lac the spirals of an helix for a short extent, in any part of its length, we obtain on passing a discharge through this helix, exactly equal magnetic intensities in both of the moieties, whatever be the direction of the magnetism; whether it attains its *maximum*, or whether it be almost null.

Since in the whole interior of a helix similar needles are equally magnetized, every point of these needles are submitted to equal actions. The differences of magnetization which the different parts of the same needle present must only be attributed to the reaction of these parts upon each other. In order to appreciate the influence of these reactions, I took needles of the same temper and of the same diameter, but of three lengths: $15^{mill.}$, $10^{mill.}$, and $5^{mill.}$. I place in one and the same helix three new needles, one of each length. After having magnetized them they were made to oscillate. The mean needles were afterwards broken in two; those of fifteen millimetres into three equal parts, and these fragments, equal to small needles, were made to oscillate. These are the effects then remarked: the fragments of the same needle, equal to each other, are always magnetized in the same direction, that of the entire needle, and are equally magnetized; at least the differences, which are in general very small, always preserve the same sign from one extremity to the other, which solely announces a gradual inequality in the temper of the different points of the needle; an inequality almost inevitable, since in general these points are only successively plunged into the cold liquid.

The numbers which in the following table express the durations of the oscillations of the fragments of the same needle, are the means of durations almost equal, obtained by making them oscillate successively. The signs always indicate the direction of the magnetism.

Duration of 60 oscillations.

Electric charges.	Needles of 15 mill.	Needles of 10 mill.	Needles of 5 mill.	Fragments of 5 mill. of mean needles	Fragments of 5 mill. of large needles.
1........	+0′ 29″ 4	+0′ 22″ 4	+16″ 7	+14″ 0	+11″ 5
2........	—0 40 0	—0 30 6	—22 3	—16 6	—16 0
4........	—1 25 4	—1 6 8	null	—28 2	—24 5
6........	+0 30 3	+0 21 6	+14″ 2	+12 5	+11 7
....	+0 28 5	+0 20 0	+14 1	+12 5	+11 4
....	—0 28 7	—0 21 1	—14 7		
....	—0 26 9	—0 19 8	—14 8		
....	+0 33 6	+0 24 0	+16 6		

We see that the needles of different lengths are always magnetized in the same direction. Perhaps the shorter needles change the sign with forces a little less. It will be remarked that these needles of five millimetres are less magnetized in one direction as well as in the other, than the equal fragments of needles of ten millimetres; and that the latter are themselves less magnetized than the fragments of longer needles.

There can be no doubt but that in breaking the needles we alter the magnetism of their parts, but in a quantity which is not very considerable. One of the needles of fifteen millimetres, that made sixty oscillations in 28″, 5, was placed in a small glass tube of the same length as itself, extremely light, into which it entered with friction. This caused it to make the same number of oscillations in 37″, 8. It was then withdrawn; it was broken in three pieces, of which each separately made sixty oscillations in 11″, 8. The three pieces having been replaced, one after the other, in the small tube of glass, it then took 41″, in place of 37″, 8, to oscillate the same number of times.

I will cite, while noticing these latter researches, an analogous experiment. I magnetized, it is now a long time ago, to saturation, with two strong magnets, an untempered steel needle of about one millimetre in diameter, and thirteen centimetres long, on which I had previously traced, at the end of each centimetre, with a fine line, annular marks of but slight depth, but sufficient to determine the rupture of the needle when a slight pressure was exercised on any part of it. I convinced myself that the entire needle had only one magnetic centre. I then broke it into thirteen equal parts. The extreme fragments were then smaller than the distance of the poles from the two ends of the needle. Their magnetic distribution changed in a manner almost instantaneously. For after some minutes, and excepting some very feeble and irregular differences of intensity, all the fragments possessed the same quantity of magnetism, and almost the *maximum* to which it was possible they could obtain. The entire needle made sixty oscillations in 3″, 16′, 3. The fragments of that part from the north pole to the centre, made the same number of oscillations in 47″, 2; 49″, 2; 48″, 8; 47″, 2; 47″, 3; 50″, 2; 48″, 0, fragment from the middle; the following fragment 47″, 0. In a state of saturation, these fragments made sixty oscillations in 44″, and 46″.

I now return to the phenomena of magnetism produced by electricity. In what has been already said, I have supposed that all discharges, the feeblest as well as the strongest, being drawn from the same battery, that equal charges corresponded to the same tensions: In giving to electrized surfaces of very different extents, and gradually decreasing in proportion, that with equal charges the tension is more elevated. I found, by some trials, that the *maximum* of magnetic intensity, the helix and wire being the same, have a less value. Now has decrease any limit? How does the influence of tension combine with the influence of the length of the wires: with their diameter, and the distance between the spirals? These elements of the question I have yet to study. In fact I have only spoken of the effects produced by an unique discharge. I ought as the basis of a possible explication, point out the effects obtained in helices by means of successive discharges. If these discharges are very feeble, such as simple sparks drawn from a machine, and very near, their action is added to each other, with certain limits of magnetization, which depends on the nature of the needles. Any number whatever of the same sparks will not raise it beyond the limit of magnetism already produced. The resistance which is opposed to its development increases then with the magnetism already developed. This resistance which is, perhaps, great enough in needles still unmagnetized to prevent a continuous series of sparks sufficiently feeble from ever exerting any sensible influence.

If instead of increasing, the sparks traversing the wire in a contrary direction tend to produce opposite effects, the resistance, in proportion as we approach the first *maximum* of magnetization, becomes more and more unequal in the two directions, and the force necessary to destroy the magnetism produced is only a very feeble portion of the force lost when we seek to augment it.

And again: as soon as the discharges pass beyond the degree of intensity capable of giving the needles this first *maximum* of magnetism, which may be very far from the state of saturation, the direction and the degree of magnetism which they give them are very near, and more and more independent of the magnetic state in which those needles were found before the experiment.

On the action of other bodies, as Steel and Iron, submitted to the action of electric discharges, but isolated from the conductor which they traverse.

One of the first observations of M. Arago, at the time of his researches on magnetism, was, that the influence which magnetises iron and steel, very different from that of other electric actions, is transmitted through wood, glass, and other insulating substances, without undergoing any appreciable change. Two needles (*Ann. de Chem. et de Phys.*, 1820), placed in the same helix, the one enclosed in a crystal tube, the other out of this tube, received exactly the same quantity of magnetism. These trials, which M. Arago had intended to have varied and extended, were pursued no farther until the time when he discovered the very remarkable action that all the substances, and especially the metals in a state of movement, exercised on the needle. I expressed to him, a short time after, the desire I had to know what might be the influenc eof this latter class of bodies on the magnetism developed by the electric currents, and he was very desirous to engage me to follow out a class o fresearches which he himself had intended to repeat.

I at first placed two needles in a helix, the one without envelope, the other enveloped in a thick cylinder of red copper, isolated from the conductor. The effect of a discharge which strongly magnetized the first was insensible on the second. There was nothing transmitted through the copper. I substituted a needle already magnetized for the needle without magnetism enclosed in the metallic tube. I then placed it in such a manner that a new discharge ought to change its poles, or at least to enfeeble its magnetism, if the envelope did not destroy all its effects. The duration of the oscillations, measured before and after this trial, were found to be exactly the same. It is useless to say, that in order to eliminate the influence due to terrestial magnetism, the needles were always placed, during the discharge, in a direction perpendicular to the magnetic meridian.

I gradually diminished the thickness of this metallic envelope; the intensity of the discharges always remaining the same, the envelope needles commenced exhibiting an action more and more sensible. For a certain thickness the enclosed needle and that entirely naked, if I may be so allowed to express myself, were equally magnetized. For thickness gradually decreasing, the enveloped needle became the most strongly magnetized of the two, attaining a *maximum* of intensity, and then it afterwards approached anew, by successive diminutions, to the degree of magnetization of the other needle.

In proportion as the intensity of the discharges augment, the thickness of the metallic envelope with which the needle was covered, and the one that was not, received the same degree of magnetism, and may be gradually increased. At the same time the increase of magnetism due to a diminution of the thickness of the envelopes is more and more considerable. With very feeble discharges the thickness which has no action is very small.

These experiments were made with plates of pewter, rolled round the needles. This disposition permitted the thickness of the envelope to be gradually diminished. I assured myself besides, that a cylinder of cast pewter and a cylinder formed of leaves of rolled pewter, as nearly equal in volume and in weight as the greater density of the plate pewter would permit, exercised sensibly the same action.

The eighth part of leaf of beaten silver, weighing 0^{g}, 005, was rolled round a needle of two centimetres in length, and five times heavier. This very thin envelope, when submitted to a discharge from a Leyden jar, raised by one-third the degree of magnetism which the same discharge communicated to a similar needle by its direct action.

When in a given helix, the first *maximum* attained by the needles without envelope is very far from the state of saturation; with discharges increasing in strength, and which magnetize them in decreasing ratios, the maximum of similar needles in a convenient envelope continues considerably to raise itself beyond the *maximum* of the first ones. It will even become raised when these are magnetized in a contrary direction. This is a new proof that even at high tensions the electric fluid does not pass, at least in appreciable quantity, from one spiral to another of the helices, without following the turnings therein.

Thus, two needles of two centimetres in length, magnetized, the one without envelope, the other in a small cylinder of pewter of two millimetres radius, by a single discharge, employed for the first 8′, 30″, the second 43″ only made sixty oscillations.

Three needles, of fifteen millimetres in length, and $0^{mil.}$, 4 in diameter, the one in a cylinder of copper of five millimetres radius, the second in a similar cylinder of brass, the third without envelope, received in the same helix, quantities of magnetism having for their measure the numbers + 2′, 35″; + 45″; — 1′ 52″, durations of sixty oscillation for each needle. The sign —, which precedes the latter value, indicates that the needle without envelope was magnetized in a contrary direction to the others. The discharge was very strong, and the cylinder of copper had almost destroyed the action which the pewter on the contrary had considerably raised.

By comparing two metallic tubes of equal thickness and length, but of different radius, and consequently of different masses, we find that the largest, that whose mass is the most considerable, exercises the greatest action. If two tubes have the same diameter, the same thicknesses, and unequal lengths, the shortest is that whose action has the most influence. Of two helices, on the contrary, the longer is the most powerful. I suppose the length of the tubes sufficiently large in relation to that of the needles.

Here is an example. I compound two cylinders of pewter of three millimetres in thickness, one of sixty-five millimetres in length, the other 100 millimetres. Their action, with a rather weak discharge, were in the proportion of about three to one.

There must exist then between the thickness and the length of a metallic cylinder a certain relation, with which the influence of this cylinder is the greatest possible, under the action of a given discharge.

If a metallic tube is at the same time very long, and of an interior sufficiently great, the needles parallel at its axis receive quantities of magnetism sensibly equal in all the space enveloped by it, at least a short distance from its extremities.

We may change the nature of the isolating substance which separates the helix from the metallic envelope, and give to this envelope in the interior of the helix any position whatever, provided that the axis of their figure is always parallel, without changing the action of the metal on the needle which it encloses. On comparing these two experiments with experiments quite similar to those of M. Arago, on the direct magnetization of needles without envelopes we see that the electric movement acts in the same manner on any metal whatever, and on steel, which alone preserves its magnetism.

When we multiply concentrically around the needle alternating layers of conducting and non-conducting materials, the first actions do not appear sensibly modified by the fact of their insulation. There is no doubt, on the contrary, that their action is not very much enfeebled by the sections perpendicular to the axis of the figure, or in which these planes pass by this axis. In fact, envelopes of great thickness, of fine copper filings, or even of iron, equal in weight to the cylinders of those metals which completely destroy the influence of a given discharge, scarcely at all modify this influence. We see then the analogy which exists between these results with the beautiful experiments of M. Arago, on the rotation of plates.

If in a metallic cylinder, for example, in a tube of glass, filled with mercury, needles parallel to its axis are placed at different distances from the surface, from the circumference to the centre, and we then compare them to a needle submitted without envelope in the same helix to the same discharge, we at first remark a gradual increase of intensity, a *maximum*, and then a diminution, which extends to the centre. If the discharge is weak enough, or the envelope sufficiently thick, there is a certain radius on which the sum of the actions of the metal is null. It is even very probable that, with electric discharges much stronger and metallic thicknesses proportionally greater, we should find several concentric surfaces where the action is null.

I here give some measures of magnetic intensities, obtained at different distances from the metallic surface, in a tube of glass of 10 $^{\text{mill.}}$ interior radius, filled with mercury :—

Distance of the exterior surface of the liquid...	$1^{\text{m.}}$ 5;	$2^{\text{m.}}$ 0;	$2^{\text{m.}}$ 8;	$4^{\text{m.}}$ 0;	$6^{\text{m.}}$ 0;	$12^{\text{m.}}$ 0.
Duration of 40 oscillations..................	28″ 9;	28″ 8;	29″ 1;	30″ 8;	49″ 2;	1′ 22″ 7.

A needle magnetized with the same discharge, out of the influence of the mercury, made the same number of oscillations in 1′ 49″ 3: the needles were $2^{\text{cent.}}$ long, $0^{\text{m.}}$ 5 diameter.

The only metals that I have tried in very thick cylinders, iron, copper, pewter, and mercury, act with a decreasing energy. As to non-metallic conductors, such as nitric acid, sulphuric acid, and water, if their energy is not null, the experiments I have attempted were not sufficiently delicate to enable me to recognize it in a certain manner.

We have just seen how the metals, submitted to the influence of discharges in the interior of helices, modify the magnetism. It will be easy to conclude from that the manner in which these metallic plates, under the influence of discharges transmitted by a rectilinear wire conductor,* act on the steel needles disposed transversely to this wire; however, as this action presents two distinct cases, I now proceed to expose them separately. I suppose the needles to be in contact with the metallic surfaces, and the discharges inferior to those which, by their direct action, produce in steel, following the distance of the wire, opposite magnetic states.

1st. A large plate interposed between the conductor and the needles for very feeble discharges, considerably enfeebles the

* It is almost indifferent whether the needle be or be not isolated from the conductor; that is to say, if it is sufficiently isolated by the defect of absolute contact, which can only be established by means of a strong pressure.

magnetism, and augments it with stronger discharges. Thus, for a similar discharge, a thin plate and a thick one may produce contrary effects, and there is a certain thickness where the effect is null.

2nd. The needles put on the plate, between this place the wire; with very feeble discharges it augments their magnetism, and more so as its thickness is increased. There is a certain discharge with which a thick plate augments it and a thin plate diminishes it. With stronger discharges they are both enfeebled, the latter especially, and it finishes by giving to the needles a contrary magnetism to that which the current itself developes.

In general the two faces of the same plate exercise contrary actions.

When the discharge is strong enough to magnetize the needles by its direct action, in contrary directions following their distance from the wire, the magnetism, under the influence of the metals, results from several causes, each of which is submitted to these laws periodically different. The different parts of the metallic plates also pass, as well as the needles, through a series of opposite states, and in each of these states they act as a magnet possessed of an analogous polarity.

In searching to compare the different plates of different metals, of similar form and equal thickness, it was remarked that soon not only that the relations of their actions varied, but that the order of the series that was wished to be formed by it was found to be reversed. The red copper in thin plates acted less than the brass; in still thinner plates it finished by acting more. I here give some numerical values. The direction of the magnetism is always designated by the signs + and —. Three needles at two millimetres beneath the conductor, first, magnetised on a plate of glass, the duration of sixty oscillations: + 1′, 25″; second, on a plate of pewter, —1′, 28″; third, on a similar plate of copper, — 1′ 56″. With a stronger discharge and two thinner plates of copper —1′, 4″; pewter —1′, 34″. The difference between the action of tin and that of pewter is not greater than the difference between the actions of pewter and copper. I find the three following values with three similar needles; on the glass + 1′, 34″; on the tin, — 1′ 6″; on the pewter, 1′, 36″.

Silver acts almost like copper, gold has a much greater action.

The action of metallic envelopes is a means of studying what takes place in the different parts of the steel needles themselves during magnetization. It is, in fact, in the same manner as other metallic envelopes, that the exterior laminæ of the needles act in the interior parts, and this influence may differ materially from the magnetic action which they exercise at a later period, as particles magnetised in a permanent manner. The experiment I have reported on magnetism, produced at different distances from the surface, in a tube of glass filled with mercury, is an example of this class of researches. It would be necessary, to render it complete, to distribute the needles throughout the whole mass and up to its extremities. The reaction of these needles on the metal which envelopes them, at least in a first approximation, may be neglected.

In proportion as with equal charges the tension diminishes, as is the case when we augment the extent of the electrized surfaces, the influence of metals during the discharge becomes more feeble. This influence will doubtless be sufficiently small under the action of a current of electricity, circulating without interruption and without sparks from the conductor to the cushions, in the frictional machines powerful enough to produce them, as M. Rodolfi has announced permanent magnetism in steel needles. This same current however may offer, by its action on the metals, characters which distinguish it from voltaic currents, as it is already distinguished by the greater extent of conductors of a very small diameter which it may traverse. I have not yet, for want of a convenient apparatus, verified these conjectures.

On Magnetism produced by Voltaic Currents.

The phenomena I have just exposed are reproduced and measured with facility. This is not the case with those I am about to describe. A great number of causes make them vary every moment. And again I have only been able to draw from researches still very incomplete, a small number of general results.

All the points of a conducting wire, equal and homogenous, traversed by a voltaic current, exercise equal actions.* If it is rectilinear, it magnetizes equally in all its lengths, at least for a length which is not very great and at some distance from its extremities, but it magnetizes very little if the pile is not very strong. I prefer rolling it from space to space in such a manner as to form several small helices of some turns each of it, similar and separated by any portions of figure and extent whatever. Similar needles are equally magnetized in each of these helices.

The magnetization by voltaic currents, is entirely developed in a very short time; it is sensible instantaneously, at least with very small needles. A feeble pile may act during a long time, if its intensity is not augmented, even on a needle not tempered, without changing in an appreciable manner the degree of magnetism which it gives to the needle at the moment of establishing the communication. This is true, even when the degree is very far from a state of saturation.

In general, in whatever manner the pile is varied, if the current does not change its direction during the time a needle is submitted to its action, the needle will be magnetized as if the pile had always had the strongest of these different intensities. The magnetism produced by a pile, then, may furnish very different indications from those which we draw from the finished deviations of an already magnetized needle.

* M. Becquerel has already proved this fact from another class of observations.

Independently of the slow variations of the continuous current which traverses a pile, the tension at the instant the communication is established, as at the moment at which it is broken, produces a visible spark, or at least a transmission of electricity analogous to the discharges procured from the frictional machines. The same effect may be repeated, at intervals more or less apart, every time that the communications are only imperfectly established, as by the contact of wires of copper and mercury, especially if the surfaces are moistened with a saline mixture.

We ought, then, to observe again, in the magnetization by the pile, the phenomena observed in the passage of an electric discharge, modified by the action of the continuous current and the smallness of the tension.

In proportion as the tension is augmented, and the conductibility diminished, that part of the effect of discharge is greater, the action of the current continues with less influence. Thus, with an apparatus of 20 pairs,* and a very bad conducting liquid, I have obtained in a most certain manner, since the needles several times presented the same results, a direction of magnetism contrary to that which gave the same pile the most lively excitement. Some needles, which passed a little beyond the extremity of the small helices were then magnetized in the same direction, and more strongly than the needles placed at the centre of the same helices. The contrary took place when the pile was more energetic. I have not however sufficiently observed this phenomenon to point out the cause of it, if this is not the possible cause. The dry piles ought to produce it easily.

It is especially in the action of other metals besides steel and iron, that the influence of small tensions is sensible. If two needles are placed in the same helix, the one without any envelope, the other encircled by a thick cylinder of copper of five millimetres radius, for example, an energetic current magnetizes them almost equally, and more so as the conductibility is greater. A feeble current gives them degrees of magnetism still more different; the communication of which we may renew and interrupt successively a great number of times, as the conductibility is more imperfect, and the tension stronger.

Thus with an apparatus of ten pairs, feebly excited, I find that by multiplying the immersions of wire in mercury, a very small needle may be magnetized in such a manner as to make sixty oscillations in 36″; a similar needle placed in a cylinder of copper, the same number of oscillations in 1′, 2″. The plates having been lowered into the liquid, and afterwards withdrawn, without having touched either the communication between the poles established

* The conducting wire was soldered to the extreme plates, and the needles placed before the immersion of the plates were not removed until it was withdrawn from the liquid.

previously, or the needles placed equally in advance, these nearly received the same degree of magnetism. Still there is in this case a sudden change in the electric movement, at the instant the plates are withdrawn from the liquid.

If we leave the plates of an apparatus a long time immersed, the difference of the magnetism of the two needles, the one without metallic envelope, the other enveloped, becomes greater and greater in proportion as the action is less active; doubtless because the influence of the small spark, though it does become enfeebled, diminishes relatively less than that of the continuous current. Thus three pairs of needles, with and without metallic envelopes, having been magnetized, the one at the commencement of the immersion of the pile, the second 8′ after, the third at the end of 20′, the differences of the times employed by the two needles of the same pair to make sixty oscillations were 15″, 48″, and 2′; the time employed by the needle without envelope being 2′, 52″; 2′, 55″; and 3′, 37″. In the state of saturation the duration of sixty oscillations is 2′, 38″.

The redeeming influence of the metallic envelopes increases a little with their thickness. I ought to search out, if in the case where a thick envelope enfeebles the magnetism, a thin envelope would augment it. The envelopes tried were perhaps too thin, their influence being insensible. The small difference of action of the two envelopes of unequal thickness is without doubt, the part of the effect due to the continuous current.

I am far from well recognizing the circumstances in which are produced, under the influence of voltaic currents, the actions I have just been speaking of. I have sometimes found that the thick metallic envelopes augmented the magnetism in a superior quantity to a quarter of these experiments. When that happened the needles were withdrawn from the helices, without at all changing the immersions of the plates or the communications. The conducting wire was soldered to the extreme elements, and each plate of zinc soldered to the plate of copper following. In truth there is here a circumstance which the discoveries M. Arago will not permit me to neglect: the displacement of the needles in relation to the wire conductor and to the copper cylinder.

Two needles enclosed, the one in a copper tube, the other in one of wood, and similarly placed between two magnets sufficiently feeble only to give a degree of magnetism far removed from the state of saturation, have always received degrees of magnetism sensibly equal. We ought in all cases to take care to provide against the effect due to the inclination of their magnetic axis.

I have been obliged to expose new facts independently of any explanation; I may now, however, be permitted to point out rapidly the consequences.

An electric discharge is a phenomenon of movement. This movement, is it a continuous transport of matter in a determined direction?

Then the alternative opposed magnetisms which we observe at different distances from a rectilinear conductor, or in a helix with gradually increasing discharges, would be due uniquely to mutual reactions of magnetic particles in the steel needles. The manner in which the action of a wire changes with its length appears to me to exclude this supposition.

The electric movement during the discharge, is it composed, on the contrary, of a series of oscillations transmitted from the wire* to the surrounding media, and soon recovered by the resistances which rapidly are borne away with the absolute quickness of the agitated particles?

All the phenomena conduce to this hypothesis, which makes to depend, not only the intensity but the direction of the magnetism, on laws following which the small movements were weakened in the wire, in the medium which surrounds it, and in the substance which receives the magnetism.

The oscillations in the wire will have quickness absolutely as much less as they spread themselves more and more rapidly as this wire is increased in length, thinner, and as the resistance proper to its nature becomes more considerable. We thus explain how it is that, with a rectilinear conductor and a given discharge, a length of wire which produces the strongest magnetism, if the length is less, the small movements diminish too slowly; if greater, their intensity is too much enfeebled.

Inasmuch as powerful metallic substances, as we have seen, sometimes increase and sometimes enfeeble the magnetism, it is sufficient that they weaken, in the two cases, the small movements propagated by the wire, and that their section be not simply proportional to the absolute quickness of these movements. It suffices then to admit, with these infinitely small displacements, what the discovery of M. Arago puts in evidence with oscillations of a limited amplitude.

Under the influence of the pile, the relative phenomena, whether of direct magnetism or of the action of metallic envelopes, are analogous to those presented by the discharges of ordinary electricity. When we destroy the communication whilst the needles are submitted to the action of a wire conductor, it is natural to think that the equilibrium is re-established in this wire by a series of small movements analogous to those excited by the discharge. But when the needles are taken away from the voltaic action, without there being a sudden interruption of the circuit, the influence which a metallic envelope several times exercised to augment the magnetism, seemed to indicate in the closed circuit the existence of two contrary currents, animated by very different speeds, or rather by small movements, the duration and quickness of which were in the two opposite direc-

* The wire, which may be entirely insulated from the ground and from the battery, receives and transmits the discharge by two sparks without the magnetic effects already described taking place.

tions. A pendulum oscillating in the medium, whose density decreases continually from one extremity to the other of the axis it travels over, will be an example of this kind of movement. Does not the contact of the two metals present such a medium? This hypothesis, which may give birth to some researches, proper either to confirm or destroy it, can only acquire additional weight by new facts.

In applying to the experiments contained in this memoir the considerations which I limit myself only to indicate here, I have not found anything for which they do not easily render a reason. But it would be too long, and perhaps misplaced, to enter on the subject in a first work in this theoretical discussion. New researches, which it has suggested to me, will, I hope, furnish me with an occasion of returning to it and the means of developing it.

On the Chemical Statics of Organized Beings. Extract from the concluding Lecture, in L'Ecole de Médicine in Paris. By M. Dumas.

Life, whose painful mysteries you are called upon to fathom, exhibits among its phenomena some which are manifestly connected with the forces that inanimate nature herself brings into action, others which emanate from a more elevated source, less within the reach of our boldest stretch of thought.

I. Plants, animals, man, contain matter. Whence comes it? What does it effect in their tissues and in the fluids which bathe them? What becomes of it when death breaks the bonds by which its different parts were so closely united?

These are the questions which we touched upon together, at first with hesitation, for the problem might be far above the powers of modern chemistry; we afterwards considered them with somewhat more confidence, as we felt from the silent and inward assent of our understandings that the path was sure, and that we could descry the goal gradually standing out, clear of all that obstructed our vision. If from these labours which you have witnessed, or, I should rather say, in which you have taken part; if from this scientific effort there have arisen some general views, some simple formulæ, it is my duty to become their historian; but allow me the pleasure of adding, that they belong to you, that they belong to our school, the intelligence of which has been exercised on this new ground. It is the ardour with which you have followed me in this career that has given me strength to pursue it; it is your interest which has sustained me; your curiosity which has awakened mine: your confidence which has made me see, and which proves to me at this moment that we are still in the path of truth.

These remarks will remind you of the wonder with which we found that, of the numerous elements of modern chemistry, organic