Memoir on Magnetization*

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Before presenting the phenomena that are the subject of this Memoir, I think I should recall the recent discoveries which I used as a starting point, and some of the experiments they have generated.

A few years ago we knew of other causes of magnetization that the influence of already magnetized body and the magnetic force of the earth. Could be attributed to the latter action, not only the effects of shock, but those of lightning, magnetism and accidental, but constant direction, observed by Franklin, Van Marum, Priestley and other physicists in the fragments of iron wires driven and broken by a strong electric discharge.

In 1820, after the discovery of Oersted, Mr. Arago observed that iron filings are attracted and supported by the wire joining the poles of an electromotor that detaches at the moment where communication is interrupted[1] as the current steel needles gives a magnetization permanently in a given direction, perpendicular to its own management, independent of the magnetic action exerted by the earth as two parallel needles with wire forming a right angle, placed at equal distances from both sides of this wire, acquire in the opposite direction the same degree of magnetism.

Mr. Ampere, which thenceforward was a magnet by a system of closed currents, perpendicular to the magnetic axis, proposed to drive the helical wire. The result was as he had announced, as to the strong action of the helices to magnetize their axis parallel to a needle wrapped in their turns.

Mr. Arago discovered that in the interior of a helix long compared to its diameter, very-short needles parallel to its axis, but distributed in any way

*from *Annales de Chimie et de Physique*, Vol. 34, 1827. Translated by Eric Hickok with the help of Google Translate. My apologies to all who speak both French and English.

[1]Mr. Arago has sometimes found that the filings still clung to a platinum wire, a few moments after the communication had been destroyed.

acquire magnetic intensity roughly equal. Outside, the same helix magnetized barely even less, it is longer and the turns are closer together. It is easy to represent these results using the analytical law proposed by Mr. Ampere for the mutual action of two elements of currents.

We had utilized, in these experiments, the voltaic currents. Mr. Arago soon experienced a similar kind of action, but different in several respects. He recognized that a current of electricity normally generated by friction machines has the property to make the steel magnetic, by interrupting from the conductor the flow is forced to be by a series of small sparks that a current, it flows into the ground by a long metal wire, produces no magnetization in the steel, does not pull on the iron filings.

Mr. Ridolfi has, long after, announced that by communicating, by means of a wire rolled into a helix, the cushions and conductor an excellent electrical machine, he managed to magnetize steel needles by the action of direct current (*tacita corrente*) running through the wire.

For electric discharges, like the pile, the direction in which the magnetism is developed is perpendicular to the direction of the wire.

A useful application of the important property that he discovered appeared to Mr. Arago now. The magnetization provides a way to very simply and very accurately compare the conductivity of different bodies to the electric force built up to high voltages and large areas. This method has not yet been published, he was kind enough to allow me to give the description here.

I suppose that a wire conductor starting from the outer coating of a battery and straight in a portion of its length, branches into a certain number of branches of the same metal, all equal in diameter, shape and length, and that meet all in a common point. Placed crosswise on the right side of each wire, before and after branching, steel needles, and a discharge is passed through the whole system. It will travel the entire first conductor and will be divided between the different branches into equal portions. The magnetization of the needles placed on the first wire will be the measure of the effect of total electricity: the magnetization of the needles placed on the branched wires, measure the effect of a certain fraction of that quantity; one third, if there are three branches; one tenth, if there are ten. This forms a magnetic intensity scale related to any portion of the given discharge. If then, replacing the different branches, all of the same metal, similar wires of different metals, we passed through this new system a second discharge equal to that of known action, it will be divided evenly between the different wires, and needles similar to the first, placed crosswise on each of them, indicate, the degree of their magnetization, if a metal sent one third, another one quarter, another one tenth of the total amount of electricity.

Since the research of Mr. Arago, Mr. Nobili has published some interesting experiments on magnetization. One of them is to send either an electric discharge or a current from a pile (Mr. Nobili has never separated these two means magnetization) through a flat spiral of copper wire. If between the windings is isolated from each other is fixed, perpendicular to their plane, steel needles, we find that the needles located toward the center and needles adjacent to the circumference are magnetized in opposite directions; and that consequently at a certain distance from the center the magnetization is zero. It was easy to predict this result, since, according to the manner of wire conductors known long before, the effect of the turns ranging from the center on a needle have an effect contrary to the effect of the outer turns.

I repeated the experience of Mr. Nobili for a few sets of accurate measurements, and I found that it was calculated quite accurately the distance from the center to which there is no magnetization produced, the least for a weak pile, by the formula

$$\int \frac{a\,\mathrm{d}\omega}{R} - \int\int \frac{\mathrm{d}\omega\,\mathrm{d}t}{r} = 0,$$

t is the radius vector, ω the central angle for any point of the spiral[2], r the distance from the ends of the needle to this point, a and R the same quantities related to the outer circumference, by which we can assume the spiral is completed. This formula is based on the analytical law proposed by Mr. Ampere.

Finally, as to the actions of magnetic bodies other than iron, until the brilliant discovery of Mr. Arago, we knew that the experiments of Coulomb, which he himself regarded the implications as questionable, and the traces of magnetism observed in Mr. Ampere's wire copper subjected to the action of a very powerful voltaic current, or by Mr. Becquerel in small needles of different materials, wrapped turns of a strong multiplier.

I turn now to the exhibition of research in which I delivered, on the means of magnetization that I have just covered, research in which I had the advantage, we will readily appreciate, to be constantly supported by kindness and guidance of Mr. Arago.

[2]Or rather the radius of a circumference of a circle passing through this point, with which the whole coil blend significantly, the limits are $\omega = 0$; $t = 0$ and $\omega = 2\pi$; $t = a$

I will deal first with the magnetizing action of electrical discharges transmitted, 1. by the straight wire conductors; 2. by wires rolled into a helix. I will then outline the influence that metals other than iron and steel experience in these phenomena. Finally I will discuss similar actions, produced by continuous currents of voltaic pile, and by magnets themselves.

On the action of electric discharges transmitted by the straight wire conductors.

The following experiments aimed to inform the general form of the phenomena produced by very energetic actions, I have used very fine needles. They are arranged in horizontal directions, at different heights, perpendicular to the wire stretched in a straight line and horizontal itself, their middle corresponding vertically to this wire. To do this, it is advantageous to fix them along the ridge of a plane very slightly inclined in such a way that, the first needle being in contact with the conductor, the others away from it almost imperceptibly, and are, however, widely separated to ensure that their mutual influence can have no appreciable action.

I'll transcribe the results of some experiments: each was repeated several times, and all agree in a satisfactory manner.

I took a platinum wire $\frac{1}{4}$ of a millimeter in thickness and of a length of 2 meters. It was stretched in a straight line to a distance of more than one centimeter from the ruler that served as support. The needles, rigidly tempered, had $\frac{1}{4}$ mm diameter, 15 mm in length. After being magnetized by the discharge of a battery of 22 square feet, which was still far from being charged to saturation[3], they were made to oscillate. I will indicate the direction of magnetization, developed in every needle, calling needles magnetized positively those of which the poles are positioned in the direction that the current

[3]We do not give here the indications of the electrometer, because they could only serve to make known whether the two discharges differed little from each other. I have since used as an accurate measure of voltages, the balance of Coulomb, with this change, the needle that has the movable disk, instead of being glass, is metallic, the stationary ball, instead of being insulated, is supported by a thin metal rod. Then, using the silver wire to which the movable needle is suspended, it establishes externally the communication between the movable disk and the stationary ball. If the whole system is communicating with the inner coating of a battery, the distances that the disc is pushed are indicative of the state of the electrified surface at that instant. This device, as so modified, has all the precision desirable.

from a battery through the horizontal wire would have headed, if they had a magnetization prior, and, hung over this wire, they could never have moved so along horizontal planes. This meaning is the same, regardless of the distance from the needle to the wire. We shall understand by the words *needles magnetized negatively* those whose poles are directed in opposite directions. That said, here are the times of the oscillations observed:

		Duration of 60 oscillations (seconds)	Direction of magnetization
1st needle in contact with the wire during the discharge[4]		52.4	positive
2nd during the discharge to	1.2 mm from the wire	63.8	id.
3rd	2.5	72.8	negative
4th	3.7	44.6	id.
5th	5.0	40.0	id.
6th	6.0	41.8	id.
7th	7.4	44.8	id.
8th	8.5	58.2	id.
9th	9.7	80.1	id.
10th	10.9	112.0	positive
11th	11.8	78.6	id.
12th	12.5	61.0	id.
13th	13.8	49.6	id.
14th	16.3	38.2	id.
15th	18.7	33.8	id.
16th	21.0	31.3	id.
17th	23.8	29.5	id.
18th	28.5	30.8	id.
19th	34.0	29.8	id.

[4]The needles were during the discharge approximately 2 cm from each other, and as the last would have been too close to the ends of the wire, if there was only one slightly-inclined support, they were arranged parallel to each other on many levels and consistently linked.

20th	46.0	35.9	id.
21st	70.0	55.6	id.
22nd	100.0	87.6	id.
23rd	130.0	108.0	id.

We see that the magnetism produced by the discharge has changed twice, first at approximately 2 mm from the wire, the second at nearly 10.4 mm. The *maximum* for a negative magnetic needle is found 5 mm from the wire. The *maximum* positive needles are the one in contact with the wire, the other about 3 cm higher. In the latter *maximum*, the needle made 60 oscillations in 29.7 seconds. Magnetized to saturation by strong magnets, it makes 60 oscillations in approximately 23 seconds. No discharge within the limits of those I have used does this state of saturation, the wire remains the same and the same length.

The needles, strongly magnetized in one direction or the other, do not offer consequent points, nor multiple centers. We ensure them easily by examining the curves that the iron filings form around them[5].

By submitting to the same discharge needles of the same temper and the same diameter but of very different lengths, 15 mm, 10 mm and 5 mm, one finds that the distances from the wire at which the sign changes occur do not differ by 2 or 3 tenths of a millimeter, that is to say, quantities which one can hardly address in the first experiments.

As a second example, I took only half a length (1 meter) of the same platinum wire. For a discharge like the previous one, the form of the set of magnetic intensity, as we see, is entirely changed[6].

[5]I searched, after reading this Memoir, to determine the position of the poles by sliding along the small needle suspended horizontally, a very fine copper wire, vertical and traversed by a voltaic current. It is known that to the very poles the action of the wire to rotate the needle is zero, that below and above these points it is exerted in opposite directions. Thus we find that, for very different intensities, it is always very near the ends and approach suddenly from the center, when the magnetization is about to change sign, as if the middle of needles preserved then some magnetization. It is understandable thereby how the direction in which the needles are magnetized by the discharge hardly depends on their length. I have yet to put them through a kind of final test in which I submitted the magnetic needles in the helices, that is to study the magnetism of their fragments after they have broken.

[6]The first needle has at its ends traces of multiple centers.

Needles of 15 mm length	Distance from the wire during the discharge (mm)	Duration of 60 oscillations (seconds)	Direction of magnetization
1st needle in contact with the wire	0.0	63.1	positive
2nd	1.1	149.0	negative
In another set to	1.4	108.3	id.
3rd	2.0	—	no significant magnetization
4th	3.0	85.6	positive
5th	4.3	65.6	id.
6th	5.5	63.0	id.
7th	6.7	73.6	id.
8th	8.0	92.2	positive
9th	8.6	188.0	very slightly negative
10th	9.6	94.8	negative
11th	10.5	77.2	id.
12th	12.3	61.2	id.
13th	13.5	56.4	id.
14th	14.6	56.0	id.
15th	15.7	59.4	id.
16th	16.9	63.0	id.
17th	18.2	65.0	id.
18th	19.1	76.8	id.
19th	20.0	94.2	id.
20th	20.9	149.0	id.
21st	21.4	—	near zero, slightly neg.
22nd	23.3	83.7	positive
23rd	32.7	41.4	id.
24th	44.0	34.0	id.
25th	70.0	43.2	id.
26th	100.0	62.2	id.
27th	130.0	88.2	id.

This set offers four changes in the magnetization direction. The first takes place in less than one millimeter from the wire, the second at 2 mm. The third at 8.4 mm. The last at 21.5 mm. We see that the negative needles in the first round, are positive here, and vice versa. The final *maximum*, which was located at 3 cm high, is 4 cm and a half. Its value is less: it is only 34 seconds.

Under the same circumstances, for needles 10 mm length, the same sign changes occurred at 0.5 mm, 2.5 mm, 9.5 mm and about 20.5 mm. Needles for 5 mm length 0.5 mm, 3.2 mm, 10.5 mm and about 20 mm. These distances are almost the same as obtained for needles of 15 mm.

I turn to a third example. For the same discharge, a platinum wire larger than the previous one, 0.37 mm in diameter and the same length (1 meter), gave sign changes four times, at the distances of nearly 3, 5, 9 and 12 mm from the wire. In addition up to 2 cm, we find only very weakly magnetized needles, among which for stronger discharges would manifest a third period, if not by the sign change, at least by variations in intensity, as well as I have observed in a set obtained with a brass wire of a roughly equal diameter. For the platinum wire which I have mentioned, the most magnetic needle was at a distance of about 6 cm from the wire. It took 56 seconds to make 60 oscillations. The most magnetic needle, for the thinnest wire of the same length mentioned earlier, did the same number of oscillations in 34 seconds, and was only at a distance of 4 cm and half from the wire[7].

To complete the comparison between different platinum wires, I selected one much thinner than the preceding. It was $\frac{1}{8}$ of a millimeter in thickness. A length of one meter of this wire, for a discharge equal to the previous, gave the following results:

[7] On the same platinum wire of 0.37 mm in diameter, but a length of only 0.65 m, and for a stronger discharge than the previous ones, small needles of 5 mm have changed five times in magnetization direction: the last change took place 28 mm from the wire. The needles in contact with the wire itself were negatively magnetized and the most of any magnets. We had to go away as far as 10 cm from the wire to find a slightly stronger magnetization.

Needles of 15 mm length	Distance from the wire during the discharge (mm)	Duration of 60 oscillations (seconds)	Direction of magnetization
1st needle in contact with the wire	0.0	34.4	positive
2nd	1.2	25.2	id.
3rd	2.6	24.1	id.
4th	5.0	24.3	id.
5th	7.4	24.0	id.
6th	9.7	23.3	id.
7th	12.0	23.5	id.
8th	15.1	24.9	id.
9th	18.5	27.0	id.
10th	22.5	25.8	id.
11th	28.0	27.0	id.
12th	34.0	30.9	id.
13th	45.0	37.6	id.
14th	70.0	61.8	id.
15th	100.0	97.2	id.
16th	130.0	120.5	id.

This set no longer provides changes of sign. Scarcely do we note, in the beginning, the variations in intensity. It is important in that, 1st. the *maximum* magnetic intensity is 11 mm height, about five times closer to the wire, as when employing a platinum wire three times larger. 2nd. This *maximum* is the state of saturation which is obtained with the magnets,and its value is almost six times greater than the value given by the wire with a diameter triple. At the same time that the *maximum* approaches the wire, the decrease of intensities beyond this *maximum* becomes more rapid.

If we pass through the wire $\frac{1}{8}$ of a millimeter thick and 1 meter in length, discharges less strong, we see the *maximum* decrease very slowly approaching the conductor, but we never get to sign changes in the magnetization, not at all a similar set to those already presented by other wires. Conversely, by gradually reducing the discharges, we never get with other thicker wires and of the same length as the set provided by the finest wire. The sign changes disappear well then and are no longer observed in their place as the variations in intensity, but at the same time the value of the *maxima* decreases as they are at lower heights.

If, however, stronger discharges than the one we previously described the effects of are passed through wires of a larger diameter, without changing their length, we see the *maximum* magnetization increase slightly in value, but move farther away, and the set change its shape, but without going into any other sets, at least within the limits of electric power from the battery used.

In previous experiments, the given discharge has always produced an increase in the strength of magnetization as the length of the wire was larger compared to its diameter. This increase of effect has a limit. Here are the sets given by, for the same discharge much weaker than the previous discharges, three lengths of the same platinum wire $\frac{1}{8}$ mm in diameter.

Length of wire: 0.50 m

Needles of 15 mm length	Distance from the wire during the discharge (mm)	Duration of 60 oscillations (seconds)	Direction of magnetization
1	0.4	60.0	positive
2	1.3	117.5	negative
3	2.5	54.0	id.
4	5.0	81.6	id.
5	6.1	88.8	positive
6	7.6	47.2	id.
7	9.0	37.9	id.
8	11.4	31.7	id.
9	13.8	29.4	id.
10	21.0	29.8	id.
11	33.0	34.2	id.
12	44.2	45.6	id.

A needle placed a long way from the third, and approximately the same distance from the wire conductor, was similarly negative and made 60 oscillations in 54.8 seconds.

Lengths of the same wire: 1.0 m and 4.30 m

15 mm Needles	Distance from the wire during the discharge (mm)	Duration of 60 oscillations (seconds) Length of wire 1 m	4.3 m	Direction of magnetization
1	0.0	66.4	39.8	positive
2	1.2	31.6	29.9	id.
3	5.0	25.5	26.1	id.
4	8.5	25.5	29.9	id.
5	11.4	24.6	36.7	id.
6	22.6	31.4	72.2	id.
7	34.0	44.0	118.5	id.
8	45.0	66.2	146.5	id.

We see, comparing the three previous sets, 1st. that the wire of one meter gave the highest absolute *maximum*; 2nd. the relative *maxima* on each set are particularly close to the wire, though this wire is longer, the diameters remain the same here.

In general, for the same battery, wires of the same type and similar needles, the shape of the set depends on three things, the intensity of the discharge, the diameter and the length of the wire. If the discharge and the length of the wire do not vary, there is a diameter at which the *maximum* magnetization has the greatest value, for diameters larger or smaller, this maximum is less. The discharge and the wire diameter remaining the same, there is a length at which the *maximum* is greater than for any other length greater or smaller.

The length or diameter that give it the largest magnetization are, one much smaller, the other increases as the wire is less conductive.

The *maximum* magnetization is particularly farther from the wire, the number of sign changes within the interval is even more significant than the length of the wire relative to its diameter is less.

This gives similar sets by means of equal discharge, by varying both the length and diameter of the wire after a certain relation[8]. When the

[8]This relationship differs significantly from the simple relationship which, according to research by Mr. Davy and Mr. Becquerel, wires must exist between two conductors of the

lengths and diameters of two wires do not satisfy this relationship, we can not generally, through equal or different discharges, get the two sets of wires exactly alike. The disparity is most evident when the wires and the discharge are under the necessary conditions for the magnetization sign change along with the distance.

I have not yet done so for complete set with wires whose thickness was more than one millimeter. But I made sure that a brass rod of 5 mm thickness still gives, according to the intensity of the discharge, needles magnetized in different directions.

As soon as part of the wire stretched in a straight line of sufficient length, the shape of the part that is not stretched has no effect on the magnetization, while great in length, as we have seen.

All points of the wire perform equal actions, at least in such very considerable lengths. Indeed at the same heights, needles far apart from each other, provided they are not too near the ends of the straight part, receive exactly the same amount of magnetism in the same direction. This is even true when some of the needles are wrapped in glass tubes sealed with shellac, while others are exposed to the action without an envelope of the current. This test is only a repetition of the first experiments of Mr. Arago. It does not assume that any part of the discharge, when the wire is very fine, either transmitted through the air and the surrounding bodies, or at least that such part can have a significant effect. Finally, to rule out the supposition that the rulers of dry wood placed below the wires can have some action, it suffices to to have the needles, one above, the other below the horizontal conductor, so that these latter are very close to the level which serves as support. There are, as might be expected, at distances equal to the wire on either side, the same magnetic intensity and opposite polarity.

To study the mutual influence of different parts of a circuit, I prepared three sets of needles on three wires of brass placed after each other and joined together at their ends. Each wire was one meter in length, the first, located between the other two, 0.125 mm, the second 0.375 mm, the third 0.75 mm in diameter. In all, the *most* positive needle had 60 oscillations in 36 seconds; for the thinnest wire alone, the *maximum* would have been approximately the same value, it would have been for the other two from about 57 seconds to 64 seconds. The sign changes were found on the three wires, the first between

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same nature, to pass on with equal intensity the same voltaic current. We known then the ratio of the lengths of their wires to their cross-sections should be constant.

3 and 4 mm high, the second between 13 and 14 mm. The negative magnetic needles were slightly less on the wire the largest. Tried separately, the last two wires gave a discharge equal to four times of changes of sign. The very fine wire produced only two, one to 4 mm, the other about 11 mm high.

The equality of action taking place in all parts of the same wire conductor exists therefore even in very nearly the whole extent of a circuit composed of several different diameters wires, at least at some distance from junction points. The shape of the periods is the same on all but minor displacements in the position changes of sign, and the same as on a wire equal in length to the sum of all lengths and a diameter midway between all diameters. If one of the wires is very thin, about its place in the circuit compared to the other, they shall provide very nearly its properties, where as its behavior has nothing but small changes. Things in passing, in relation to this wire, as if it stretched very little, compared to the other, as if we were to increase much extent. The conductors invariably attached to a battery must be large enough that their influence is negligible.

One should not expand what has been said about the equality of action observed in any one circuit, a system of wires of many different sizes, comparable to the distances where the sign changes occur, or in the event that during the discharge one of wires changes state, is completely gone.

In order to know if the magnetizing force of a discharge would be modified by a resistance which, in any setting, would tend to prevent the wire conductor to expand, or would oppose with small transverse movements, I filled with mercury one crystal tube with an outside diameter had very nearly 4 mm, and the inner diameter of 4 tenths of a millimeter. The ends was closed by two brass wires fixed with a little wax and in contact with mercury. In regard to the pressure exerted during the discharge, the effect was to separate the tube in half, exactly in the middle of its length, to break near its ends, and the crisscross symmetrically from the middle up to two quarters and a little beyond, through sloping cracks such as would be present in the nets of two helices rotating in opposite directions. The other two quarters of the tube were intact to the ends. The pressure was slightly higher in these quarters; for, in these two points, mercury was released in very fine droplets, although it had been expelled most abundantly towards both ends and in the middle. Small air bubbles or water interrupting the metal mesh must be avoided: it would suffice to determine the shared breaking points.

In regard to the magnetization, the set presents a significant irregularity. With regards to the breaking point in the middle the tube there is a needle very slightly magnetic between two needles that are heavily magnetic. This experiment was not repeated.

When a very fine wire of brass, platinum, has a length such that the magnetization produced by a strong discharge can present changes of sign and that this wire is broken by the current, the magnetic effects, except perhaps a very small distance from the breaking point, remain the same as if the wire had not ceased being taut.

After passing a very strong discharge through a wire conductor, we got considerably more for approximately equal amounts of electricity. This alteration may depend on very low sometimes a superficial oxidation, and should take in general to the state of annealing of the metal during the discharge increased to a high temperature[9].

So far I have assumed all the needles of the same diameter ($\frac{1}{4}$ mm) and the same temper (tempered rigid). These two circumstances, the caliber and diameter, have the greatest influence on the direction and intensity of magnetization that can produce a discharge and one given conductor, while, as we have seen, the length of the needles has nearly no point.

As an example of how the *maxima* and changes of sign in the magnetization travel with the caliber, I reproduce the following sets obtained on a brass wire of $\frac{1}{8}$ of a millimeter in diameter, and a single discharge. The needles were shearings 15 millimeters long and 0.30 mm in diameter. They were all cut from the same piece of steel.

1st Series. Rigidly tempered needles

	Distance from the wire during the discharge (mm)	Duration of 60 oscillations (seconds)	Direction of magnetization
1	0.6	82.8	positive
2	1.6	73.4	id.
3	2.6	80.0	id.
4	3.9	134.5	id.
5	4.9	102.0	negative

[9]I searched if, as Mr. de La Rive and Mr. Marianini have noted for wires that were used to establish communication between the poles of a pile, a platinum wire that comes to pass a strong discharge would when the ends immersed in a conductive liquid, traces of electrical current. I have not seen, but the device which I used was not sensitive enough, and this experiment is worth repeating.

6	6.5	73.6	id.
7	7.6	65.8	id.
8	9.8	65.6	id.
9	10.8	60.8	id.
10	12.4	95.4	id.
11	14.8	134.4	positive
12	45.0	42.4	id.
2nd Series. Untempered needles, flexible			
1	0.0	118.5	positive
2	1.2	230.0	id.
3	2.4	109.5	id.
4	3.8	78.0	id.
5	5.3	61.2	id.
6	6.3	56.4	id.
7	7.3	51.6	id.
8	9.4	50.2	id.
9	10.3	48.4	id.
10	12.8	46.8	id.
11	15.4	47.2	id.
12	42.0	70.6	id.

The rigidly tempered needles exhibit two changes of sign, the untempered needles only offer one *minimum* of intensity at a distance of the wire. The *maximum* of the rigidly tempered needles is farther the wire, and has a value higher than the flexible needles.

In general the magnetization, in state rigidly tempered, is a state of balance between forces and greater resistances. A small external cause changes it more difficult. In this state, the needles acquire one higher *maximum*, either in one direction or in the opposite direction, the reach for any discharge, begin to move away from it in a manner sensitive to stronger discharges and change more abruptly sign. The mechanism of magnetization due to Mr. Arago offers a way to accurately compare the different degrees of coercive force which increases much as the *maximum* magnetic intensity (saturation state) is growing itself, but can still vary considerably when the *maximum* changes very little.

The influence of the diameter of the needles on the magnetization they receive can not be disengaged from other causes, such as the tempering, creates variability in results. Since the inner layers of a thick needle can not be taken in the sudden cooling, the same layout as the outer layers. Nevertheless, I extract a set made with three different sizes of needles and of 15 mm length, a brass wire of 0.125 mm ($\frac{1}{8}$ mm), the following values of magnetic intensity at equal heights.

Distance from the axis of the needles over during the discharge (m)	Duration of 60 oscillations (seconds) 0.30 mm diameter needle	0.80 mm diameter needle	1.75 mm diameter needle
0.8	70 pos.	120 pos.	99 pos.
17.0	58 neg.	59 id.	106 id.
27.0	38 pos.	63 id.	117 id.
Maximum intensity of magnetic needles with magnets	25	31	44

Instead of changes of sign offered by thin needles, the medium needles have only minimal contact with the wire itself, and the big needles have one continuous decrease in intensity as they move away from the wire.

The sets presented by the medium needles and thicker, are those that would be obtained with small needles to discharge increasingly weak; discharges to increasingly stronger, thicker the needles offer themselves for changes sign.

The phenomenon of the reversal of poles produced in the compass needles by lightning could already be explained by the known facts, since the fluid, depending on whether it passes from one side or the other of the needles, everything equal, to magnetize them in opposite directions. But this phenomenon allows yet another explanation based on the foregoing facts. Because the fluid passing always on the same side of the needle, the direction of the magnetization still depends on the distance and intensity of the blow. Note, as well as compass needles are in the circumstances that facilitate the production of alternatives of magnetism opposites. They have a very small thickness, which makes them very nearly isolated nets in a very small diameter, and receive the rigid tempering.

On the action of discharges transmitted by wire conductors rolled into a helix.

The needles that I used in the following experiments were 15 mm length, $\frac{1}{4}$ mm in diameter, and were rigidly tempered.

I rolled into a helix on a hollow cylinder of dry wood, along 9 cm and about 6.5 mm diameter brass wire 0.180 mm in size. The gauge of the helix was about 3 mm high. For a length of wire is 0.80 m, and similar needles, successively placed in the middle of the cylinder in the direction of its axis, have been magnetized by discharges of increasing strength. Here is for each needle after the magnetization in the order of increasing intensity discharge, the duration of 60 oscillations: + 25.6 seconds; + 56.8 seconds; – 38.2 seconds; – 25.5 seconds; + 28.9 seconds; + 1.27 seconds; – 42.0 seconds; – 33.1 seconds; – 57.6 seconds; + 27.8 seconds; + 23.0 seconds; + 34.6 seconds; – 75 seconds; + 31.3 seconds. The + sign indicates that the needle was magnetized in the direction that one would direct the voltaic current, what I have called so far *positively magnetized*; the – sign indicates a direction of magnetization opposite.

This set presents six times the changes which sign. The second discharge (corresponding to the number + 56.8 seconds) was equivalent to the amount of electric fluid, to that of an ordinary Leyden jar. From the battery, you could see only one bright spot.

Perhaps be obtained with less wire length of more changes of direction in the magnetization. When, on the contrary, it extends the wire rolled helical portion remains the same, not only requires a greater force for the first inversions of poles, but instead of the succeeding changes of sign, we no longer find that variations of magnetic intensity: thus, for discharges equal to those of the previous set and a wire like that, but twice as long (1.6 m) numbers correspondents to 3rd, 5th, 7th, 9th, 11th , 12th and 13th observations this set + 25.0 seconds; – 31.9 seconds; + 31.0 seconds; + 25.6 seconds; + 51.6 seconds; + 54.6 seconds and + 46.0 seconds. Beyond, the magnetization continues to increase in the same direction.

The time formed by the fourth value is what becomes, by the effect of lengthening of the wire, to the period between the 6th and the 10th observation in the first round. One can see how it differs. Both periods, however, should be identical, if the effect of elongation of the wire could be offset by increased intensity of discharges. This compensation can not take place. One should not forget that in both cases, the part of the wire which acts immediately on the needle is exactly the same. A similar conclusion was already presented in the review of the action straight conductors.

I do not here report the different sets of magnetic intensity which are obtained by using the same wire lengths larger and larger. While with the wire throughout the first pole reversal took place in a quantity of fluid which has exceeded the charge of a single Leyden jar, it is only for a very strong discharge of the battery with 22 square feet you get the same effect with a wire with an equal diameter and 11 meters long, the part rolled into a helix is the same in both cases. But this wire provided needles magnetized to saturation (making 60 oscillations in just under 23 seconds) in one way or the other.

The gauge of the helix remains always the same, a brass wire of 0.09 mm diameter, 6.5 m long, has not given inversions of poles. I have not obtained more with a silver wire $\frac{1}{40}$ of a millimeter in diameter, 0.25 m throughout, from the lower charges till those that reduced completely in smoke. The maximum magnetic intensity was in the wires for the state of saturation.

I made contact with one of their ends the helix formed of the same silver wire made up like a helix and a copper wire much larger. A discharge, from one helix to the other, produced in the second the changes of magnetic direction, even when the wire very thin was completely vaporized, and although it magnetized constantly in the same direction the needles subjected to its direct action. Thus, if the diameters of the wires that make up a circuit are very different, where at least one of these sizes is of extreme thinness, rather, finally, when during the discharge one of the wires changes state, the action of different parts of the circuit may not be equal.

In general, for the same wire and on the same helix, the first *maximum* value increases when the wire gets longer, and decreases when its diameter increases. In the first case, we need a larger force, to get the first big reversal of poles or the period of variations of intensity that replaces it; whereas the second, a smaller force. A *maximum* any is even higher than the limits of the period, to which it belongs are more open.

I turn now to the case, leaving invariant the diameter and length of the wire, we successively change the length, diameter, the gauge of the helix.

The length of the helices, once it is equal to seven or eight times their diameter and two or three times larger than the length of the needles, has almost no appreciable influence on the intensity of magnetization.

The experiments of Mr. Arago have shown, as I have at the beginning of this Memoir, as needles similar, arranged in any manner in the interior of a large helix, at least at some distance from its ends, are all parallel to its axis the same degree of magnetization[10]; finally the degree of magnetization is essentially the same in two helices of different diameters, provided they are long enough, that they are not equal and short enough.

When the windings are a bit distant, 3 mm, for example, the helices have an action even greater than their diameter is smaller, but the increase of energy is extremely low. It is almost imperceptible and entirely negligible for half a step lower, 1.5 mm. The most accurate way to see these small differences is to place, one in the other, as did Mr. Arago, two helices that rotate in the same direction, and to connect by their ends the wires that cover them. The current then passes through in the opposite direction, they act in the opposite direction of the needles placed in the inner helix, and these needles, or have no magnetization or to acquire the largest discharge a very weak magnetism in the direction that the smaller diameter helix tends to give them. However, the magnetism is thought to gradually with the intensity of the discharge.

If the two helices, placed one inside the other and still not even, instead of turning in the same direction, rotate in opposite directions, one *clockwise*, the other *anticlockwise*, the current passes through them lengthwise in opposite direction, and transversely, their actions, always very nearly equal, added, rather than destroy, as they did in the previous case. We can thus measure the effects of forces double, triple, quadruple. It is sufficient to arrive on the first discharge to a single helix, of a system of two, three or four helices of not even contained in each other and turned alternately in opposite directions. The mutual action of helices that wrap however here, as discussed below, a source of error, but this error is very low, if the wire of which they are all formed is rather fine.

Here, for electric charges whose intensities can be roughly represented by the numbers 2, 3, 4, $4\frac{1}{2}$ and 5, the duration of oscillation, which measure the magnetism of magnetic needles, the some in single helix which I previously used, the others in the system of two helices not the same, I will call for short, *double helix*.

[10]This is even true, in whatever direction that the needles are magnetized.

Intensities of electric charges	Duration of 60 oscillations (seconds)	
	Single helix	Double helix
2	+ 23.5	+ 22.9
3	+ 22.9	+ 30.4
4	+ 27.2	+ 62.0
$4\frac{1}{2}$	+ 31.8	– 77.0
5	– 32.8	– 23.5

We can already see by these assessments, although they are still pretty rough, not only that the action of a double discharge is very different than double the share of a single discharge, but the ratio of these two forces is variable and depends on their absolute intensity.

A double helix acts much like a single helix half a step shorter the wire length is the same for both.

We can ensure that if it passes some portion of the discharge from one turn to another without following the contours, this portion is entirely negligible, at least for the heights of steps and the wires I have used. It is enough to completely isolate with shellac the turns of a helix a little long in one half of its length. This gives, by passing a discharge through the propeller, magnetic intensities exactly equal to one while the other half, regardless of the direction of the magnet, it reaches its maximum and it is almost zero.

Since in the interior of a helix, like needles are magnetized, all points of these needles are having equal shares. The differences of magnetization that present different parts of a needle could be attributed to the reaction of these parties on each other. In order to assess the influence of these reactions, I took the needles of the same caliber and same diameter, but three lengths, 15 mm, 10 mm and 5 mm. I placed in the same helix, with each discharge, three new needles, one of each length. After they have been magnetized, or been oscillating. We then broke into two averages the needles, those of 15 mm into three equal parts, and it made the oscillate equal to fragments smaller needles. This is what we see then: the fragments of the same needle, equal to one another, are always magnetized in the same direction, that of the entire needle, and also magnetic. At least the differences, usually very small, still carry from one end to another the same sign, which announced merely an inequality in the gradual tempering of the different points of the needle, inequality, almost inevitable that, since in general these points only in succession plunge into the cold liquid.

The numbers in the table below, express the periods of oscillation of the fragments of the same needle are the average of almost equal duration is obtained by making successive oscillate. The signs continue to indicate the direction of the magnet.

Electric charges	Duration of 60 oscillations (s)				
	15 mm needles	10 mm needles	5 mm needles	5 mm fragments of needles broken in half	5 mm fragments of larger needles
1	+ 29.4	+ 22.4	+ 16.7	+ 14.0	+ 11.5
2	– 40.0	– 30.6	– 22.3	– 16.6	– 16.0
4	– 85.4	– 66.8	zero	– 28.2	– 24.5
6	+ 30.3	+ 21.6	+ 14.2	+ 12.5	+ 11.7
	+ 28.5	+ 20.0	+ 14.2	+ 12.5	+ 11.4
	– 28.7	– 21.1	– 14.7		
	– 26.9	–19.8	– 14.8		
	+ 33.6	+24.0	+ 16.6		

We see that the needles of different lengths are always magnetized in the same direction. Perhaps the shorter the needles do they change the sign for a little less strength. We note that these needles 5 mm are less magnetized in one direction or the other, the fragments equals of the needles 10 mm; that they are themselves less than the fragments of the longest needles.

Undoubtedly, by breaking the needles distort the magnetism of their parts, but in a quantity that is not very large. One of the needles 15 mm, that made 60 oscillations in 28.5 seconds, was placed in a small glass tube of the same length, extremely lightweight, where it entered with friction. It made it do the same number of oscillations in 37.8 seconds. It was withdrawn, it was broken into three pieces, each of which separately made 60 oscillations in 11.8 seconds. The three pieces have been replaced after the other in a small glass tube, it took 41 seconds, instead of 37.8 seconds, to oscillate an equal number of times.

I shall cite, on the occasion of recent research, a similar experience. The magnet, there are for a long time, saturated with two strong magnets, an untempered steel needle about 1 mm in diameter and 13 centimeters in length, on which I had previously drawn, centimeter by centimeter, with a fine file, lines annular shallow but sufficient to determine the breaking of the needle when exerted on either side light pressure. I made sure that the entire needle had a magnetic center, then I broke it into 13 equal parts. The extreme fragments were much smaller than the distance between the poles at either end of the needle. Magnetic distribution changed almost instantaneously. For, after a few minutes and except for very low and erratic differences in intensity, all fragments had the same amount of magnetization and almost the *maximum* that they could achieve. The needle made complete 60 oscillations in 3 minutes and 16.3 seconds. The fragments, from the north pole to the center, made the same number of oscillations in 47.2 seconds; 49.2 seconds; 48.8 seconds; 47.2 seconds; 47.3 seconds; 50.2 seconds; 48.0 seconds, middle fragment; following fragment, 47.0 seconds. In the state of saturation, these fragments did 60 oscillations in 44 seconds and 46 seconds.

I return to the phenomena of magnetism produced by electricity. In the above, I assumed that all the discharges, the weakest as the the strongest, were drawn from the same battery that charges the same correspond equal voltages. By giving electrified surface very different and increasingly small expanses, as for charges equal the voltage is higher, I think, for some tests, the maxima intensity magnetic the helix and the wire remaining the same, have a lower value. This decrease was there a limit? How does the influence of voltage combine with the length of the wires, their diameter and the spacing of the turns? How are the phenomena modified by atmospheric conditions, by the temperature of the wires? Those elements of the question I have yet to study. Finally, I have spoken only effects produced by a single discharge. I must, as a basis for a possible explanation, indicate the effects you get in the helices, by means of successive discharges. If these discharges are very low, such as simple spark from the machine and very near, their action adds up to a limit of magnetization which depends on the nature of the needles. An arbitrary number does not raise the same sparks more beyond this magnetism limit already produced. The resistance that opposes its development increases therefore the magnetization is already developed. This resistance can be large enough in the needles even without magnetism, for a continuous set of sparks sufficiently low may never have any significant influence.

If, instead of adding, the sparks, traversing the wire in the opposite direction tend to produce opposite effects, the resistance, as we approach the first maximum of magnetization, is becoming more unequal in both directions, and the strength needed to destroy the magnetization produced only a very small part of the strength lost when trying to increase it.

As soon as the discharge exceeds the level of intensity capable of provide maximum of the first needle magnetism (which may be far from the state of saturation), the direction and degree of magnetization that provide them are with very nearly, and increasingly independent of the state where the magnetic needles were before the experiment.

On the action of the bodies other than iron and steel under the influence of electrical discharges, but isolated from the conductor they traverse.

One of the first observations of Mr. Arago, in his research on magnetization, was this influence that magnetized iron and steel, very different in that other electrical actions, is transmitted through wood, glass, insulating substances, without experiencing any appreciable change. Two needles[11] placed in one helix, one enclosed in a crystal tube, the other outside the tube, received exactly the same amount of magnetism. These tests, as Mr. Arago intended to vary and extend, were no longer followed up when he discovered the very remarkable action that all substances, especially metals in the state of movement, have on the magnetic needle. I expressed to him, shortly after, the desire to know what could be the influence of the latter class of bodies on the magnetization developed by electrical currents, and he was willing to commit to follow a kind of research that he himself had proposed to take.

I placed first in a helix two needles, one without a casing, the other wrapped in a thick copper cylinder, separated from the conductor. The effect of a discharge which strongly magnetized the former was imperceptible in the second. Nothing is passed through the copper. I substituted an already-magnetized needle for the needle without magnetization enclosed in the sheath metal. I placed it so that a new discharge had to change its poles or at least weaken its magnetism, if the casing had no cushioning effect. The duration of the oscillations, measured before and after the event,

[11] *Ann. de Chim. et de Phys.*, 1820

is exactly the same. It is useless to say that, to eliminate the influence due to terrestrial magnetism, we always put the needle during the discharge, in a direction perpendicular to the magnetic meridian.

I gradually decreased the thickness of the metal casing, the intensity of discharges remaining always the same, the wrapped needles began to experience action more and more sensitive. For a certain thickness, the needle enclosed in the metal and the exposed needle exposed, if I may say so, were equally magnetized. For smaller and smaller thicknesses still, the wrapped needle became the more strongly magnetic of the two, reached a maximum intensity, and finally approached again by successive decreases the degree of magnetization of the other needle.

As the intensity of discharge increases, the thickness of metal shell to which the wrapped needle and one that is not receiving the same degree of magnetization, is becoming increasingly large. At the same time the increase in magnetism of reduced thickness of envelopes is becoming greater. For very low discharges, the thickness, which has no action is very small.

These experiments were made with strips of tin wrapped around the needles. This arrangement allowed to gradually decrease the thickness of the envelope. I made sure the rest of a cylinder of rolled tin, equal to very nearly in size and weight, the greater density of the rolled tin provides, exerted about the same action.

The eighth part of a sheet of beaten silver, weighing 0.005 g, was rolled around a needle 2 cm long and fifteen times heavier. This very thin casing, subject to the discharge of an average Leyden jar, raised to a third the degree of magnetism that the same discharge imparted to a similar needle by its direct action.

When in a given helix, the first *maximum* reached by the needle-free envelope is very close to the saturation state for discharges increasingly strong and magnetize them less and less, the magnetism of needles like in a suitable container continues to rise well beyond the *maximum* of the first. It may even rise further when they are already magnetized in the opposite direction. This is further proof that even at high voltages the electric fluid does not pass, at least in appreciable quantities, from one turn to the other in the helices, without following the contours.

Thus two needles of 2 cm length magnetized, one without a casing, the other in a small cylinder of tin with a 2 mm radius, a single discharge, employed, the first 8 minutes and 30 seconds, the second 43 seconds just to make 60 oscillations.

Three needles of 15 mm in length and 0.4 mm in diameter, one in a copper cylinder of 5 mm radius, the second in a similar cylinder of tin, the third without a casing, received in the same helix amounts of magnetism having to measure the numbers + 2'35"; + 45"; – 1'52": duration of 60 oscillations for each needle. The – sign before the last value indicates that the needle not in a casing was magnetized in the opposite direction from others. The discharge was very strong, and the copper cylinder was almost completely destroyed the action, as tin was instead much higher.

Comparing two metal tubes of equal thicknesses and lengths, but different radii and therefore different masses, we find that the larger one whose mass is the largest, has the strongest action. If two tubes have the same diameter, same thickness and unequal lengths, the shortest is the one whose action has the most influence. Of the two helices, on the contrary, the longest is the most powerful. I suppose the lengths of the tubes quite large compared to needles.

Here's an example. I compared two cylinders of tin 3 mm thick, one of 65 mm and the other 100 mm in length. Their actions for a relatively low discharge, were in the ratio of about 3 to 1.

There must exist between the thickness and length of a metal cylinder, some relationship so that the influence of the cylinder is the highest possible, under the action of the given discharge.

If a metal tube is both very long and an inside diameter large enough, the needle parallel to its axis are given approximately equal amounts of magnetism in the whole space it envelops at least a little away from its ends.

One can change the nature of the insulating material that separates the helix from the metal casing, giving this casing into the interior of the helix any position, provided that their axes of face are always parallel without changing the action of the metal on the needle therein. Comparing these two experiments to experiments made entirely similar to Mr. Arago on the magnetization direct of needles without casings, we see that the electric motion works the same way on any metal, and the steel that only retains its magnetism.

When multiplying concentrically around the needle alternatives conducting layers and non-conductive, the first action does not appear significantly altered by the fact of their isolation. There is no doubt, however, that their action is very weakened by sections perpendicular to the axis of figure, or whose planes pass through this axis. Indeed, very thick casings of fine filings of copper or even iron, equal in weight to the metal cylinders that completely destroy the influence of the given discharge, just modify this influence. We see on the analogy of these results with the best experiences of Mr. Arago on the rotation of the plates.

If in a metal cylinder, for example in a glass tube filled with mercury, needles parallel to its axis are placed at different distances from the surface, from the circumference to the center, and compared to a needle subject without a casing in the same helix at the same discharge, we see first a gradual increase of intensity, a *maximum*, and a decrease extends to the center. If the discharge is quite low or casing thick enough, there are a range over which the sum of the actions of the metal is zero. It is even very probable that for much stronger electric discharges and metal thickness proportionately large, there are several concentric surfaces of no action.

Here are the measurements of the magnetic intensities obtained at different distances from the metal surface in a glass tube of 10 mm of inner radius filled with mercury:

Distance to the outer surface of the liquid (meters)	1.5	2.0	2.8	4.0	6.0	10.0
Duration of 40 oscillations (seconds)	28.9	28.8	29.1	30.8	49.2	82.7

A magnetized needle in same token, outside the influence of mercury, made the same number of oscillations in 1'49.3": the needles were 2 cm in length, 0.5 mm in diameter.

The only metal I've tried in cylinders very thick, iron, copper, tin and mercury, acting with an energy less and less. As for non-metallic conductors, such as nitric acid, sulfuric acid and water, if their action is not zero, the experiences I tried were not sensitive enough to make me acknowledge with any certainty.

We have seen how the metal under the influence of discharges inside the helices change the magnetization. It would be easy to conclude how the metal plates under the influence of discharges transmitted by a straight wire[12] act on steel needles arranged transversely to this wire. However, as this action has two distinct cases, I set them out separately. I suppose the needles in contact with metal surfaces, and discharges less than that which, by their

[12]It is almost indifferent here that the metal is or is not isolated from the conductor, that is to say that it is sufficiently isolated by the lack of full contact fails to establish that only through a pressure.

direct action, occurring in the steel, according to the distance of the line of opposite magnetic states.

1. A large plate placed between the conductor and needles discharges very small, much weakens the magnetization and increases for stronger discharges. Thus, even for the same discharge, a thin plate and thick plate can produce adverse effects, and there is a certain thickness at which the effect is zero.

2. Needles placed on the plate, between the plate and the wire: for very low discharges, it increases their magnetization, and especially as it is thicker. There is such a discharge for which a thick plate increases it and a thin plate decreases. For stronger discharges, the one and the other weaken, especially the last, and effect of giving the needle a magnetism that contrary to the current single developer.

In general, the two sides of the same plate exert opposite actions.

When the discharge is strong enough to magnetize the needles in opposite directions through its direct action depending on their distance to the wire, the magnetization under the influence of metals results from several causes, each of which is subject to laws different journals. The various parts of the metal plates pass as well as the needles, through a sequence of opposite states, and in each of these states, they act as a magnet to act endowed with a similar polarity.

In seeking to compare plates of different metals of similar shape and of equal thickness, one soon notices not only that the reports of their actions vary with the intensity of the discharges, but that the order of the set we would like to form is inverted. The copper acts in thin plates less than the brass plaque still much thinner, it ends up doing more. Here are some numerical values. The direction of magnetization is always referred to by the + and – signs. Three needles below the wire conductor: 1st magnetized on a glass slide, duration of 60 oscillations + 1'25.2"; 2nd on a slide of brass – 1'28"; 3rd on a similar copper strip – 1'56". For a greater discharge and two thinner strips, copper – 1'4"; brass – 1'34". The difference between the action of tin and that of brass is not greater than the difference between the actions of brass and copper. I find the following three values for three similar needles, on glass + 1'34 "; on tin – 1'6"; on brass – 1'36".

Silver acts almost like copper, gold much more.

The action of the metal casing is a means of studying what is happening in different parts of steel needles, which are themselves during the magnetization. It is indeed like the other metal casings that the outer layers of the needles act on the inner layers, and this influence may differ entirely from the magnetic action they perform later as permanently magnetized needles. The experiment I have reported on on the magnetization produced at different distances from the surface in a glass tube filled with mercury, is an example of this kind of research. It should have been, for it was full with needles distributed throughout the mass and to its ends. The reaction of the needles with the metal that contain may, at least in a first approximation, be neglected.

In proportion as for equal charges the voltage decreases, as happens when one increases the extent of the electrified surfaces, the influence of the metal during the discharge becomes weaker. This influence might be quite small under the action of a current of electricity flowing without interruption and without spark to those of the conductor pads, with friction in machines powerful enough to produce so, as was announced by Mr. Ridolfi the permanent magnetization of steel needles. However, this same current may offer, through its action on metals, the characteristics that already distinguished by the extent of larger conductors of a very small diameter that may fit, verified these conjectures.

On the magnetization by voltaic currents.

The phenomena that I have just explained are reproducible and are readily measured. This is not the case of those that remain for me to describe. The causes are many and vary from one moment to another. I also will not have to take more research is entirely fails to complete, a small number of general results.

All the points of a wire conductor equal and uniform, through which a current exert of equal actions[13]. If it is straight, it magnetizes equally along the whole length, at least for a length that is not very large and at some distance from its ends. But it magnetizes very little if the pile is not very strong. I prefer to run from point to point so as to form several small helices of a few turns, similar, separated by portions of the figure and range of any kind. Such needles are magnetized in each of these helices.

The magnetization by voltaic currents is fully developed in a very short time and is substantially instantaneous, at least for small needles. A weak pile can act for a long time, if its intensity does not increase, on a similar needle that is not tempered, without changing appreciably the degree of

[13]Mr. Becquerel had already noted this fact by another kind of observation.

magnetism that it gives when communication is established. This is true even if the degree is very far from the state of saturation.

In general, in any way that the intensity of the pile varies, if the current does not change direction while a needle is subject to its action, the magnetized needle will be as if the pile had always been the strongest of these different intensities. The magnetization produced by a pile can provide very different indications from those that are drawn from a finite deviations already magnetized needle.

Independently of the slow variations of direct current running through a pile, the voltage, at the moment when communication is established, like the moment when it is broken, produces a visible spark or at least a similar electricity transmission discharge from the machines by friction. The same effect can be repeated at intervals longer or shorter every time that communications are not properly established, for contact of the wires of copper and mercury, especially if the surfaces are slightly soiled.

We must therefore find, in the magnetization by the pile, the observed phenomena in the passage of an electric discharge, modified by the action of direct current and the smallness of the voltages.

As the voltage increases and the conductivity decreases, the part of the effect similar to the effects of discharges is greater, the action of the current has less influence. Thus, with a device 20 couples[14], and very little liquid conductor, I obtained in a manner non questionable, since many needles showed the same result, a magnetization direction contrary to that given the same stack more strongly excited. The needles that were beyond just the end of the small helices were then magnetized in the same direction and no more strongly than the needles placed in the center of these helices. The opposite took place when the pile was more energetic. However, I have observed this phenomenon not enough to indicate the cause, except as a possible cause. The dry batteries need to reproduce it easily.

It is particularly in the action of metals other than iron and steel that the influence of small voltages is sensitive. If two needles are placed in one helix, one without a casing, the other surrounded by a copper cylinder even very thick 5 mm radius for example, a powerful current to them loving very nearly the same, especially since the conductivity of the device is greater. a weak current Gives them levels of magnetism even more differentiated than by

[14]The wire conductor was soldered to the end plates, and needles, placed before the immersion of the plates, were removed only after they had removed the liquid.

repetition and that is interrupted successively more often the communication, the conductibility is imperfect and the voltage higher.

So with a small unit of ten couples weakly excited, I find that increased immersion of the wire in mercury, a very small needle without a casing was so magnetic it made 60 oscillations in 36 seconds, a needle similar, placed in a copper cylinder, the same number of oscillations in 62 seconds. The plates having been lowered into the liquid and then removed without it being touched or communication between the poles established in advance, or the needles placed to in advance equally, they have almost received the same magnetization; still there is in this case a sudden change in the electric motion, at the moment when the plates come out of the liquid.

If one leaves the plates of a device long time immersed the difference of magnetization of two needles, one with no metal casing, the other surrounded, becomes increasingly important as the action is less intense, but probably because the influence of the spark, although weakened, decreases relatively less than the current. And three pairs of needles with and without metal casing, have been magnetized, one at the beginning of the immersion of a pile, the second 8 minutes after, the third after 20 minutes, the differences of time employed by two needles of the same couple for 60 oscillations, were 15", 48" and 2', the time employed by the needle without casing being 2'52", 2'55" and 3'37". (In the state of saturation, 60 oscillations lasted 2'38".)

The influence of damping metal casings grows a little with thickness. I had to find though, if a thick casing weakens the magnetization, it. or if a thin casing would increase it. The casings were tested maybe too thin: their influence was imperceptible. The small difference of action of two unequally depleted casings is probably the part of the effect due to the current.

I am far from familiar with the circumstances in why this occur under the influence of voltaic currents actions I just mentioned. I found that thick metal casings increased the magnetization of an quantities greater than those possible deviations from these experiences, and when this happened, the needles were removed from the helices without changing the immersion of the plates nor the communications.

The wire conductor was soldered to the end elements, and each sheet of zinc soldered to the copper sheet following. In fact, here there is a circumstance in which the discoveries of Mr. Arago do not allow for neglecting the discussion, this is the displacement of the needles relative to the wire conductor and the copper cylinder.

Both needles enclosed, one in a case of copper, the other in a wooden case, and similarly placed between two magnets, low enough to not give them a degree of magnetism, far removed from the state of saturation, have always received magnetization substantially equal. Care must be taken to return the magnets, to destroy the effect due to the inclination of their magnetic axes.

I have exhibited the new developments, independent of any explanation. May I be now allowed to indicate rapidly the consequences.

An electrical discharge is a phenomenon of movement. Is this movement a material transport, continuous, in a particular direction? Then the alternations of opposing magnetisims is observed at various distances from a straight conductor, or a helix for gradually increasing discharges, would be due only to mutual reactions of the magnetic particles in the steel needles. The way the action of a wire varies with its length seems to me to exclude this assumption.

The movement during the electrical discharge is made, on the contrary, of a series of oscillations, transmitted from wire[15] to the surrounding environs, and soon damped by resistances that rise quickly with the absolute speed of particles agitated?

All events leading to this hypothesis, which depend not only the intensity but the direction of magnetism of laws under which small movements are damped in the wire, in the environment that surrounds it, the substance that receives and retains the magnetization.

The oscillations in the wire will have an absolute speed much less, they will die out more rapidly than this wire were longer, thinner, the resistance specific to its nature will be greater. This explains how it is for a straight conductor and a discharge, given a length of wire that produces the highest magnetization: if the length is less, small movements decreases too slowly; increased, their intensity is too weak.

For metallic substances can, as we have seen, sometimes enhance and sometimes weaken the magnetization, it is sufficient that they absorb, in both cases, small movements propagated by the wire, and that their action is not simply proportional to the absolute speed of these movements. It is therefore sufficient to accept for infinitesimal displacements, that the discovery due to

[15]The wire must be completely insulated from the ground of the battery, receiving and transmitting the discharge of two sparks without the magnetic effects that have been described cease to occur.

Mr. Arago demonstrates for oscillations of a finite amplitude.

Under the influence of the pile, the phenomena relative to the magnetization is direct, or to the action of metal casings, are similar to those that have regular electricity discharge. When the communication is destroyed while the needles are subjected to the action of the wire conductor, it is natural to think that the balance is restored in this wire by a series of small movements similar to those that discharge would excite. But when the needles are removed from the voltaic action, without a sudden interruption of the circuit, the influence of that a metal casing has repeatedly acted to increase the magnetization seems to indicate the existence of two counter currents animated by very different velocities in the closed circuit , or rather small movements whose duration and speed in opposite directions would be very uneven. A pendulum swinging in an environment having a density would decrease continuously from one end to the other of the arcs it traveled would be an example of this kind of movement. The contact of two metals offers such an environment, does it not? This assumption, which may give rise to some specific research to confirm or to destroy it, may not acquire any weight but by new facts.

By applying the experiences in this Memoir the considerations that I simply state here, I found nothing of which they make easily reason. But it would be too long and may have moved to enter, on a first job, in this theoretical discussion. New research, that I suggested, will provide me, hopefully, the opportunity to come back and the means to develop it.