MEMOIR

Presented to the Royal Academy of Sciences, October 2, 1820, which includes the summary of what was read at the same Academy on September 18 and 25, 1820, on the effects of electric currents.

BY M. AMPÈRE.

Sr. Del Mutual action of two electric currents.

1. Electromotive action manifests itself by two kinds of effects that I believe should first be distinguished by a precise definition.

I will call the first electric tension, the second electric current.

The first is observed when the two bodies between which this action takes place are separated from each other (1) by non-conducting bodies, at all points on their surface other than those where it is established; the second is where they are, on the contrary, part of a circuit of conducting bodies which makes them communicate by points on their surface different from those where the electromotive action occurs (2). In the first case, the effect of the electromotive action is to put the two bodies or the two systems of bodies between which it takes place, in two states of tension whose difference is constant when this action is constant, when, for example, it is produced by the contact of two substances of different nature; this difference would be variable, on the contrary, with the cause which produces it, if it were due to friction or pressure

This first case is the only one that can occur when the electromotive action develops between the various parts of the same non-conducting body; tourmaline offers an example when it changes temperature.

In the second case, there is no longer any electric tension, the light bodies are no longer noticeably attracted, and the ordinary electrometer can no longer be used to indicate what

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(1) When this separation takes place by the simple interruption of the conducting bodies, it is still by a non-conducting body, by air, that they are separated.

(2) This case includes where the two bodies or systems of bodies between which the electromotive action takes place would be in complete communication with the common reservoir which would then be part of the circuit.

takes place in the body; however, the electromotive action continues to act; for if water, for example, an acid, an alkali, or a saline solution forms part of the circuit, these bodies are decomposed, especially when the electromotive action is constant, as we have known for a long time ; and furthermore, as Mr. Oersted has just discovered, when the electromotive action is produced by the contact of metals, the magnetized needle is diverted from its direction when it is placed near any portion of the circuit; but these effects cease, the water no longer decomposes, and the needle returns to its ordinary position as soon as the circuit is interrupted, the tensions are re-established, and the light bodies are again attracted, which proves that these tensions are not the cause of the decomposition of the water, nor of the changes in direction of the magnetized needle discovered by Mr. OErsted. This second case is obviously the only one that could take place if the electromotive action developed between the various parts of the same conducting body. The consequences deduced, in this Memoir, from Mr. Oersted's experiments will lead us to recognize the existence of this circumstance in the only case where there is reason to admit it until now.

2. Let us now see what the difference between these two entirely distinct orders of phenomena lies in, one of which consists in the tension and the attractions or repulsions known for a long time, and the other in the decomposition of water and a large number of other substances, in the changes of direction of the needle, and in a sort of attractions and repulsions all different from ordinary electrical attractions and repulsions; which I believe I recognized first, and which I named voltaic attractions and repulsions, to distinguish them from the latter. When there is no continuity of conductors from one of the bodies or systems of bodies between which the electromotive action develops to the other, and when these bodies are themselves conductors, as in Volta's pile, one can only conceive of this action as constantly carrying positive electricity into one, and negative electricity into the other: in the first moment, when nothing opposes the effect it tends to produce, the two electricities each accumulate in the part of the total system towards which it is carried; but this effect stops as soon as the difference in electrical voltages (1) gives their mutual attraction, which tends to bring them together, a force sufficient to balance the electromotive action. Then everything remains in this state, except the loss of electricity which can take place little by little through the non-conducting body, air, for example, which interrupts the circuit; because it seems that there is no body which is absolutely insulating. As this loss takes place, the voltage decreases; but as soon as it is less the mutual attraction of the two electricities ceases to balance the electromotive action, this last force, in the

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(1) When the battery is isolated, this difference is the sum of the two voltages, one positive, the other negative: when one of its ends communicating with the common reservoir has a zero voltage, the same difference has an absolute value equal to that of the voltage at the other end. Thus

case where it is constant, it again carries positive electricity on one side and negative electricity on the other, and the tensions are reestablished. It is this state of a system of electromotive and conductive bodies that I call electric tension. We know that it subsists in the two halves of this system, either when they are separated, or in the case where they remain in contact after the electromotive action has ceased, provided that it then took place by pressure or by friction between bodies that are not both conductors. In these two cases, the tensions gradually decrease because of the loss of electricity we were talking about earlier.

But when the two bodies or two systems of bodies between which the electromotive action takes place are also in communication by conductive bodies between which there is no other electromotive action equal and opposite to the first, which would maintain the state of electrical equilibrium, and consequently the resulting tensions, these tensions disappear or at least become very small, and the phenomena indicated above occur as characterizing this second case. But since nothing is changed in the arrangement of the bodies between which the electromotive action developed, there can be no doubt that it continues to act, and since the mutual attraction of the two electricities, measured by the difference in electric tensions which has become zero, or has considerably diminished? can no longer balance this action, it is generally agreed that it continues to carry the two electricities in the two directions in which it previously carried them; so that a double current results, one of positive electricity, the other of negative electricity, leaving in opposite directions from the points where the electromotive action takes place, and going to meet in the part of the circuit opposite these points. The currents of which I speak continue to accelerate until the inertia of the electric fluids and the resistance they experience due to the imperfection of even the best conductors balance the electromotive force, after which they continue indefinitely with a constant speed as long as this force maintains the same intensity; but they always cease at the instant when the circuit is interrupted. It is this state of electricity in a series of electromotive and conductive bodies that I will call, for brevity, electric current; and as I shall continually have to speak of the two opposite directions in which the two electricities move, I shall imply whenever it is a question of them, to avoid a tedious repetition, after the words direction of the electric current, those of positive electricity; so that if it is a question, for example, of a voltaic pile, the expression direction of the electric current in the pile, will designate the direction which goes from the end where hydrogen is released in the decomposition of water, to that where oxygen is obtained; and this: direction of the electric current in the conductor which establishes the communication between the two ends of the pile, will designate the direction which goes, on the contrary, from the end where oxygen is produced to that where hydrogen is developed. To embrace these two cases in a single definition, we can say that what is called the direction of the electric current is that which follow the hydrogen and bases of the salts, when water or a saline substance is part of the circuit and is decomposed by the current, either, in the voltaic pile, these substances are part of the conductor, or they are interposed between the pairs of which the pile is composed

The learned research of Messrs. Gay-Lussac and Thénard on this apparatus, a fertile source of the greatest discoveries in almost all branches of the physical sciences, has demonstrated that the decomposition of water, salts, etc., is in no way produced by the difference in voltage between the two ends of the battery, but solely by what I call the electric current, since by immersing the two conducting wires in pure water, the decomposition is almost zero; whereas when, without changing anything in the arrangement of the rest of the apparatus, an acid or a saline solution is mixed with the water in which the wires are immersed, this decomposition becomes very rapid, because pure water is a poor conductor, and it conducts electricity well when it is mixed with a certain quantity of these substances

Now, it is quite obvious that the electrical tension of the ends of the wires immersed in the liquid cannot be increased in the second case; it can only be decreased as this liquid becomes a better conductor; what increases in this case is the electric current; it is therefore to this alone that the decomposition of the water and salts is due. It is easy to see that it is also this alone which acts on the magnetic needle inMr. Oersted's experiments. To do this, it is sufficient to place a magnetized needle on a horizontal battery whose direction is approximately in the magnetic meridian; as long as its ends do not communicate, the needle maintains its ordinary direction. But if a metal wire is attached to one of them, and the other end is placed in contact with that of the battery, the needle suddenly changes direction, and remains in its new position as long as the contact lasts and the battery conserves its energy; it is only as it loses it that the needle approaches its ordinary direction; whereas if the electric current is stopped, by interrupting the communication, it returns to it instantly. However, it is this communication itself which causes the electric tensions to cease or considerably diminish; it cannot therefore be these tensions, but only the current which influences the direction of the magnetized needle When pure water is part of the circuit, and the decomposition is barely noticeable, the magnetic needle placed above or below another portion of the circuit is also slightly deflected; the nitric acid mixed with this water, without changing anything else in the apparatus, increases this deflection at the same time as it makes the decomposition of the water faster.

3. The ordinary electrometer indicates when there is voltage and the intensity of this voltage; an instrument was missing which made known the presence of electric current in a battery or a conductor, which indicated its energy and direction. This instrument exists today; it is enough that the battery or any portion of the conductor are placed horizontally approximately in the direction of the magnetic meridian, and that an apparatus similar to a compass, and which differs only in the use made of it, is placed on the battery, or else below or above this portion of the conductor: as long as there is any interruption in the circuit, the magnetic needle remains in its ordinary position; but it deviates from this position, as soon as the current is established, all the more so as the energy is greater, and it would make known the direction according to this general fact, that if one places oneself by thought in the direction of the current, so that it is directed from the feet to the head of the observer, and that the latter has his face turned towards the needle; it is constantly to its left that the action of the current will move away from its ordinary position that of its extremities which is directed towards the north, and which I will always call the southern pole of the magnetic needle, because it is the pole homologous to the southern pole of the earth. This is what I will express more briefly by saying that the southern pole of the needle is carried to the left of the current which acts on the needle. I think that to distinguish this instrument from the ordinary electrometer, we must give it the name of galvanometer, and that it is appropriate to use it in all experiments on electric currents, as we usually adapt an electrometer to electrical machines, in order to see at any moment if the current is taking place and what its energy is.

The first use I made of this instrument was to use it to establish that the current existing in the voltaic pile, from the negative end to the positive end, had on the needle the same value influence as the current of the conductor which goes, on the contrary, from the positive end to the negative.

It is good to have for this purpose two magnetized needles, one placed on the battery and the other above or below the conductor; we see the southern pole of each needle being carried to the left of the current near which it is placed; so that when the second is above the conductor, it is carried to the side opposite to that towards which the needle placed on the battery tends, because the currents have opposite directions in these two portions of the circuit; the two needles are, on the contrary, carried to the same side, remaining almost parallel to each other, when one is above the battery and the other below the conductor (1). As soon as the circuit is interrupted, they immediately return, in both cases, to their ordinary position

4. Such are the differences recognized before me between the effects produced by electricity in the two states that I have just described, one of which consists, if not in rest, at least in a

slow movement produced only by the difficulty of completely isolating the bodies where the electric tension is manifested, the other in a double current of positive and negative electricity along a

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(1) So that this experiment leaves no doubt about the action of the current in the battery, it is appropriate to do it as I did with a trough battery whose zinc plates are welded to those of copper by the whole extent of one of their faces, and not simply by a branch of metal that one could rightly regard as a portion of conductor

continuous circuit of conducting bodies. We then understand, in the ordinary theory of electricity, that the two fluids of which it is considered to be composed are constantly separated from each other in one part of the circuit, and rapidly carried in opposite directions in another part of the same circuit where they continually reunite. Although the electric current thus defined can be produced with an ordinary machine, by arranging it in such a way as to develop the two electricities, and by joining by a conductor the two parts of the apparatus where they are produced, we cannot, unless using very large machines, obtain this current with a certain energy except with the aid of the voltaic pile, because the quantity of electricity produced by the friction machine remains the same in a given time, whatever the conductive capacity of the rest of the circuit, whereas that which the pile sets in motion for the same time increases indefinitely as the two ends are joined by a better conductor

But the differences I have just recalled are not the only ones that distinguish these two states of electricity. I discovered even more remarkable ones by arranging, in parallel directions, two rectilinear parts of two conducting wires joining the ends of two voltaic piles; one was fixed, and the other, suspended on points and made very mobile by a counterweight, could approach or move away from it while maintaining its parallelism with the first. I then observed that by passing an electric current through each of them at the same time, they attracted each other when the two currents were in the same direction; and that they repelled each other when they took place in opposite directions

Now, these attractions and repulsions of electric currents differ essentially from those that electricity produces in the state of rest; first, they cease, like chemical decompositions, at the instant when the circuit of the conducting bodies is interrupted. Secondly, in ordinary electrical attractions and repulsions, it is the electricities of opposite kinds that attract each other, and those of the same name repel each other; In the attractions and repulsions of electric currents, it is precisely the opposite, it is when the two conducting wires are placed parallel, so that the ends of the same name are on the same side and very close to each other, that there is Attraction, and there is repulsion when the two conductors being always parallel, the currents are in opposite directions, so that the ends of the same name are at the greatest possible distance. Thirdly, in the case where it is attraction which takes place, and that it is strong enough to bring the mobile conductor into contact with the fixed conductor, they remain attached to each other like two magnets, and do not separate immediately, as happens when two conducting bodies which attract each other because they are electrified, one positively, the other negatively, come to touch. Finally, and it appears that this last circumstance is due to the same cause as the previous one, two electric currents attract or repel each other in a vacuum as in air; which is again contrary to what is observed in the mutual action of two ordinarily electrified conductive bodies. It is not a question here of explaining these new phenomena; the attractions and repulsions which take place between two parallel currents, depending on whether they are directed in the same direction or in opposite directions, are facts given by an experiment which is easy to repeat. It is necessary, in order to prevent in this experiment the movements which would be given to the moving conductor by the small agitations of the air, to place the apparatus under a glass cage under which one passes, in the base which supports it, the portions of the conductors which must communicate with the two ends of the battery. The most convenient arrangement of these conductors is to place one on two supports in a horizontal situation where it is immobile, to suspend the other by two metal wires which are one with it, to a glass axis which is above the first conductor, and which rests, by very fine steel points, on two other metal supports; these points are welded to the two ends of the metal wires of which I have just spoken; so that communication is established by the supports with the help of these points. (See the figure of this apparatus, plate 1, fig. 1.)

The two conductors are thus parallel, and next to each other, in the same horizontal plane; one of them is mobile by the oscillations which it can make around the horizontal line passing through the ends of the two steel points, and, in this movement, it necessarily remains parallel to the fixed conductor

A counterweight is added above and in the middle of the glass axis to increase the mobility of the part of the device capable of wobbling, by raising its center of gravity

I had initially believed that it would be necessary to establish the electric current in the two conductors by means of two different batteries; but this is not necessary; it is sufficient that these conductors both form part of the same circuit; for the electric current exists everywhere with the same intensity. We must conclude from this observation that the electric tensions at the two ends of the battery have nothing to do with the phenomena with which we are concerned; for there is certainly no tension in the rest of the circuit. This is further confirmed by the possibility of moving the magnetized needle at a great distance from the battery, by means of a very long conductor whose middle curves in the direction of the magnetic meridian above or below the needle. This experiment was indicated to me by the illustrious scientist to whom the physico-mathematical sciences owe above all the great progress they have made in our day: it was entirely successful

Let us designate by A and B the two ends of the fixed conductor, by C that of the mobile conductor which is on the side of A, and by D that of the same conductor, which is on the side of B; it is clear that if one of the ends of the battery is placed in communication with A, B with C, and D with the other end of the battery, the electric current will be, in the same direction, in the two conductors; it is then that we will see them attract each other: if, on the contrary, A always communicating at one end of the battery, B communicates with D, and C with the other end of the battery; the current will be in opposite directions in the two conductors, and it is then that they will repel each other. It is understood, moreover, that the attractions and repulsions of electric currents taking place at all points of the circuit, one can, with a single fixed conductor, attract and repel as many conductors and vary the direction of as many magnetized needles as one wants: I propose to construct two mobile conductors under the same glass cage, so that by making them, as with a common fixed conductor, part of the same circuit, they are alternately both attracted, both repelled, or one attracted, the other repelled at the same time, depending on the manner in which the communications are established According to the success of the experiment that Mr. Marquis de La-place indicated to me, one could, by means of as many conducting wires and magnetized needles as there are letters, and by placing each letter on a different needle, establish with the aid of a battery placed far from these needles, and which one would make communicate alternately by its two ends with those of each conductor, form a sort of telegraph suitable for writing all the details that one would want to transmit, through whatever obstacles, to the person obliged to observe the letters placed on the needles. By establishing on the battery a keyboard whose keys would bear the same letters and would establish communication by their lowering, this means of correspondence could take place with sufficient ease, and would require only the time necessary to touch on one side and read on the other each letter (1).

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(1) Since writing this Memoir, I have learned from Mr. Arago that this telegraph had already been proposed by Mr. Semmering

If the moving conductor, instead of being subject to moving parallel to the fixed one, can only turn in a plane parallel to this fixed conductor, around a common perpendicular passing through their midpoints, it is clear that, according to the law we have just recognized for the attractions and repulsions of electric currents, each half of the two conductors will attract and repel each other at the same time, depending on whether the currents are in the same direction or in opposite directions; and consequently that the moving conductor will turn until it has become parallel to the fixed one, so that the currents are directed in the same direction. From this it follows that in the mutual action of two electric currents, the directing action and the attractive or repulsive action depend on the same principle, and are only different effects of one and the same action It is no longer necessary then to establish between these two effects the distinction that is so important to make, as we will see presently, when it comes to the mutual action of an electric current and a magnet considered as is ordinarily done in relation to its axis, because, in this action, the two bodies tend to place themselves in directions perpendicular to each other.

We will now move on to the examination of this last action and that of two magnets, one on the other

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except that instead of observing the change of direction of the magnetized needles, which was not known at the time, the author proposed to observe the decomposition of water in as many vases as there are letters.playstamp

, and we will see that they both fit into the law of the mutual action of two electric currents, by conceiving one of these currents established at each point of a line drawn on the surface of a magnet, from one pole to the other, in planes perpendicular to the axis of this magnet; so that it hardly seems possible to me, from the simple comparison of the facts, to doubt that there are really such currents around the axis of the magnets, or rather that the magnetization consists only in the operation by which one gives to the particles of the steel the property of producing, in the direction of the currents of which we have just spoken, the same electromotive action which is found in the voltaic pile, in the oxidized zinc of the mineralogists, in the heated tourmaline, and even in a pile formed of wet cardboard and discs of the same metal at two different temperatures. Only this electromotive action developing in the case of the magnet between the different particles of the same body, a body, a good conductor, it can never, as we have noted above, produce any electric tension, but only a continuous current similar to that which would take place in a voltaic pile returning on itself forming a closed curve: it is quite obvious, according to the preceding observations, that such a pile could not produce at any of its points either tensions or ordinary electric attractions or repulsions, nor chemical phenomena, since it is then impossible to interpose a liquid in the circuit; but that the current which would be established immediately in this pile would act to direct it, attract it or repel it, either on another electric current ,or on a magnet which, as we shall see, is only an assembly of electric currents.

This is how we arrive at this unexpected result: that the phenomena of the magnet are produced solely by electricity, and that there is no other difference between the two poles of a magnet than their position with respect to the currents of which the magnet is composed, so that the southern pole (1) is the one to the right of these currents, and the northern pole the one to the left.

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(1) The one which in the magnetic needle goes towards the north; it is to the right of the currents of which the magnet is composed, because it is to the left of a current placed outside the needle in the same direction, and which faces it