Chapter 11

Ørsted *Versus* Ampère

11.1 Ørsted's Interpretation of His Own Experiment

As was seen in Section 1.3, Ørsted presented on July 21, 1820, his fundamental discovery of the deflection of a magnetized needle due to a long and straight current-carrying conductor. His most important experiment is represented in figures 1.3 and 1.4. Figure 11.1 reproduces the first of these images.

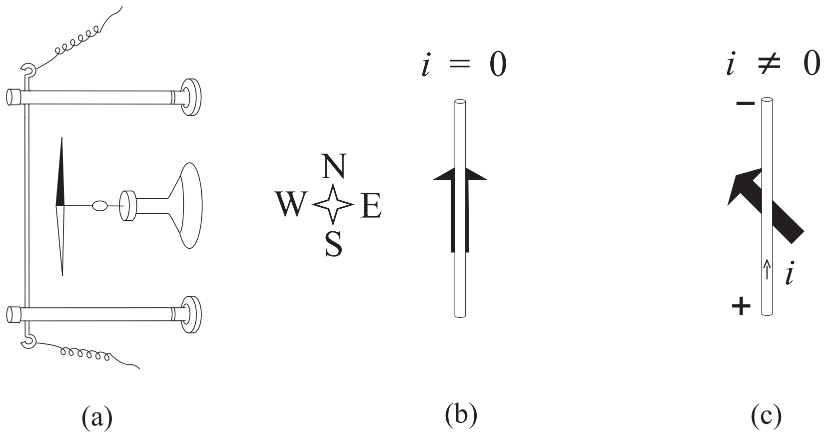

Figure 11.1: Representation of Ørsted's experiment with the horizontal wire above the magnetic needle. In (a) and (b) the needle points along the magnetic meridian while there is no electric current in the wire. In (c) there is a constant current flowing from the South towards the North. The needle is deviated from the magnetic meridian, with its North pole going westward.

Ørsted interpreted his crucial observation as follows:[1]

> We may now make a few observations towards explaining these phenomena.
>
> The electric conflict acts only on the magnetic particles of matter. All non-magnetic bodies appear penetrable by the electric conflict, while magnetic bodies, or rather their magnetic particles, resist the passage of this conflict. Hence they can be moved by the impetus of the contending powers.
>
> *It is sufficiently evident from the preceding facts that the electric conflict is not confined to the conductor, but dispersed pretty widely in the circumjacent space.*
>
> From the preceding facts we may likewise collect[2] that this conflict performs circles; for without this condition, it seems impossible that the one part of the uniting wire, when placed below the magnetic pole, should drive it towards the east, and when placed above it towards the west; for it is the nature of a circle that the motions in opposite parts should have an opposite direction. Besides, a motion in circles,

[1] [Oersted, 1820, p. 276], [Oersted, 1965, pp. 116-117] and [Ørsted, 1986, pp. 121-122], our emphasis in italics.

[2] In the original English translation of Oersted's paper we read, [Oersted, 1820, p. 276] and [Ørsted, 1998a, p. 419]: "From the preceding facts we may likewise collect..." In Tricker's book we read, [Oersted, 1965, p. 116]: "From the preceding facts we may likewise infer..."

joined with a progressive motion, according to the length of the conductor, ought to form a conchoidal or spiral line; but this, unless I am mistaken, contributes nothing to explain the phenomena hitherto observed.

All the effects on the north pole[3] *above-mentioned are easily understood by supposing that negative electricity moves in a spiral line bent towards the right, and propels the north pole, but does not act on the south pole.* The effects on the south pole are explained in a similar manner, if we ascribe to positive electricity a contrary motion and power of acting on the south pole, but not upon the north. The agreement of this law with nature will be better seen by a repetition of the experiment than by a long explanation. The mode of judging of the experiments will be much facilitated if the course of the electricities in the uniting wire be pointed out by marks or figures.

I shall merely add to the above that I have demonstrated in a book published five years ago that heat and light consist of the conflict of the electricities. From the observations now stated, we may conclude that a circular motion likewise occurs in these effects. This I think will contribute very much to illustrate the phenomena to which the appellation of polarization of light has been given.

Copenhagen, July 21, 1820. John Christian Oersted.

Ørsted did not present figures to illustrate his explanation. Figure 11.2 illustrates what he may have imagined according to his own description. In figure 11.2 (a) we have positive charges flowing along the magnetic meridian, from the South towards the North, inside the horizontal current-carrying wire, while the negative charges flow in the opposite sense. The North pole of the magnetized needle placed below the wire, which originally pointed along the NS direction when there was no current in the wire, is displaced westwards when a constant current flows in the wire. For instance, in this article he observed that:[4]

> If the distance of the uniting wire does not exceed three-quarters of an inch from the needle, the declination of the needle makes an angle of about 45°. If the distance is increased, the angle diminishes proportionally.

Figure 11.2 (b) presents the electric conflict flowing helically outside the wire, according to Ørsted's conception. According to his original interpretation, negative electricity would "propel the north pole" of the magnetized needle.

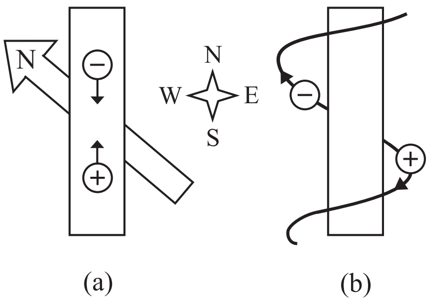

Figure 11.2: (a) Ørsted's experiment. (b) His interpretation of this observation in which he supposed positive and negative electricities describing helical paths around the wire and propelling the magnetic poles of the magnet. The arrows indicate the directions of motion of the supposed positive and negative charges moving (a) inside and (b) outside the wire.

It is curious to observe that the longitudinal component, parallel to the wire, of the motion of the supposed negative charges outside the wire point in the opposite sense of the motion of the negative charges inside the wire. The same behavior happens with the supposed motions of the positive charges inside and outside the wire.

Ørsted initially considered that the deflection of the needle was due only to the action of the current-carrying wire. Ampère, on the other hand, realized that this deflection was due to the joint action of the wire and the Earth acting on the needle. Ampère was the first to show, with his astatic needle, that, by

[3][*Note by R. A. R. Tricker, [Oersted, 1965, p. 117]:*] Oersted's expressions are "Omnes in polum septentrionalem" and "Effectus in polum meridionalem". If by "a spiral line bent towards the right" he means a right-handed screw, then he must be using septentrionalem in the same sense that boreal was used at the time, namely to indicate a south-seeking pole. The term north pole in the translation would therefore mean a south-seeking pole—i.e. one homologous with the earth's north pole.

[4][Oersted, 1820, p. 274], [Oersted, 1965, p. 114] and [Ørsted, 1986, p. 119].

eliminating the magnetic action of the Earth, the needle is orientated orthogonally to a current-carrying wire, as discussed in Section 3.2. Ampère presented this result at the Academy of Sciences of Paris in September 1820, publishing his results at the end of this year.

When Ørsted became aware of Ampère's experiments, he changed his interpretation of his own experiment. In an article of 1821, for instance, he said the following:[5]

> I shall here state, rather more in detail than I have done in my first publication, the rule by which I think all electro-magnetic effects are governed. It is this: *When opposite electrical powers*[6] *meet under circumstances which offer resistance, they are subjected to a new form of action, and in this state they act upon the magnetic needle in such a manner that positive electricity repels the south, and attracts the north pole of the compass: and negative electricity repels the north, and attracts the south pole;*[7] *but the direction followed by the electrical powers in this state is not a right line, but a spiral one, turning from left hand to the right.*

In his original paper of 1820, Ørsted mentioned the *negative electricity*. He now infers *negative electrical power*. These expressions would represent the analogous to our *negative electric charge*, or *negatively electrified particle*, the same being valid for the positive sign.

In his first interpretation of 1820, Ørsted believed that negative electricity *propelled* the North pole of a magnet, while the positive electricity *propelled* the South pole. He was certainly thinking of forces exerted by contact or collision. Similar examples are the orientation of a windsock by air currents in an airport or a flowing river propelling a water wheel or watermill. In the case of Ørsted's experiment, he imagined a material flow of charged particles pushing the poles of the magnet. These magnetic poles would not be penetrable by the electric charges, resisting their passage. As he said, the magnetic particles of matter would be moved by the impetus of the electric charges. In this paper of 1821, on the other hand, he mentioned the *attractions and repulsions* exerted by the electricities flowing helically outside the wire and acting on the poles of the magnetic needle. In 1820 he suggested actions transmitted through mechanical contact, charges propelling magnetic poles, while in 1821 he suggested actions at a distance (attractions and repulsions). In any event, it is not clear to us how these supposed attractions and repulsions acting between the charges of the electric conflict and the poles of the magnet might orientate the needle, as shown by his experiment.

We present here another quotation of Ørsted from 1821 in which he mentioned these attractions and repulsions acting between the electric charges and the poles of a magnet:[8]

> Given all this, the north pole of a magnetic needle is repelled by the negative electricity and attracted by the positive. Naturally, the south pole of the magnetic needle has the same relation with the positive electricity.

As can be seen from these quotations, from 1820 to 1821 he changed his conceptions of how the electricities flowing outside the current-carrying wire interacted with the magnetic poles of the needle. Moreover, later on he also began to talk about circles around a current-carrying wire, instead of considering helices or spirals around it. An example can be seen in a paper he published on 1830 related to thermoelectricity. What he called austral magnetism is the North pole of a magnetized needle, that is, the pole pointing approximately towards the terrestrial geographic North. His words:[9]

> If we now suppose that the electricity of the current enters the conductor at the right hand of the observer,[10] the austral magnetism (the same which predominates in the north-end of the needle,) will, upon the superior surface of the conductor go off from the observer; on the side most distant from the observer, the austral magnetism goes downwards; on the inferior surface it goes towards the observer; on the side nearest the observer it goes upwards. This is represented in figure 1 [figure 11.3], where BA is the conductor in which the direction of the current is AB, the circle *cedf* [sic][11] represents a plane perpendicular to the conductor, in which the magnetical circulation takes place. This plane is here and

[5] [Ørsted, 1998f, p. 432], italics in the original.

[6] [Note by Ørsted:] I here repeat what I have already stated in other works, that by *electrical forces*, I mean only the unknown cause of electrical phenomena, whether it belong to imperceptible matter or independent motion.

[7] [Note by Ørsted:] In my first memoir, I grounded all explanations upon the repulsions only which are exerted by electrical and magnetic forces; but I soon discovered, that from the fear of assuming more than the phenomenon required, I drew an unjust inference; for if magnetic forces are the same as electrical under another form of action, it follows, that opposite forces ought to attract each other reciprocally, and forces of the same kind to repel each other.

[8] [Ørsted, 1998e, p. 426].

[9] [Ørsted, 1998g, p. 549], our explanations in the footnotes.

[10] That is, for an observer looking at figure 11.3 at this instant.

[11] These letters are not indicated in Ørsted's figure.

in the other figures represented as if it were material and opaque. The little arrows show the direction of the austral magnetism.[12]

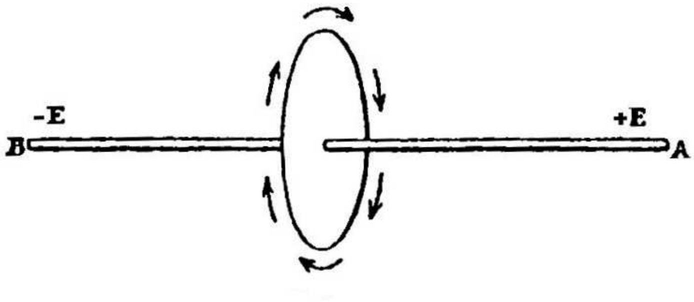

Figure 11.3: Ørsted's figure representing the magnetic action of a straight current-carrying conductor.

As can be seen from this quotation, after becoming aware of Ampère's experiment with his astatic needle, Ørsted was convinced that when a magnetic compass is only under the influence of a long, straight current-carrying conductor, without being influenced by terrestrial magnetism, the needle will become orientated in equilibrium orthogonally to the wire.

11.2 Ørsted Against Ampère

Ørsted never completely accepted Ampère's interpretations as regards the electromagnetic and electrodynamic phenomena. He considered his own theory correct as opposed to that of Ampère. He even performed an experiment, in 1830, with which he believed to have refuted Ampère's theory.[13] Ørsted mentioned several times that his theory was different from that of Ampère. For instance:[14]

> [...] and if I adopt a theory of magnetism differing from his [that is, differing from Ampère's theory], I shall never cease to acknowledge the great merit of his labours.

Some aspects which Ørsted criticized in Ampère's interpretations:

1. The mathematical complication of Ampère's theory.

2. The supposition of a direct interaction between two current-carrying conductors, without the intermediation of a flux of charges circulating around the wire.

3. The hypothesis of the existence of microscopic or molecular electric currents flowing inside a magnet. Ørsted, on the other hand, always considered magnetism as being due to a distribution of real magnetic particles distributed inside a magnet and inside the Earth.

We now present some of his quotations expressing these criticisms.

11.2.1 The Mathematical Complication of Ampère's Theory

We first quote a paper by Ørsted in which he expressed not only that his theory opposed that of Ampère, but also mentioned the mathematical difficulties found in Ampère's theory:[15]

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[12]That is, the direction of motion of the North pole of a magnet, due to the influence of the straight current-carrying conductor.
[13][Ørsted, 1998d].
[14][Ørsted, 1998f, p. 437].
[15][Ørsted, 1998d, p. 539], our emphasis in italics.

> Councillor of State[16] and Professor Ørsted has informed the Society of a new electromagnetic experiment which he believes to be inconsistent with Ampère's theory.[17] It is a familiar experience in the history of science that *opposing theories* about a natural phenomenon are able to persist for a long time even though there may be arguments which should decide the issue. In such a case an attempt must be made to devise an experiment which cannot possibly be explained in two ways. If one stopped at a crossroads where one did not know which direction to take, such an *experimentum crucis*, as Baco[18] called it, would show the right way. *The controversy between the explanation of the electromagnetic effects given by Ampère and the one given by the discoverer [that is, by Ørsted himself] may be said more or less to stand at such a point.* Admittedly, Ampère's theory has not retained many defenders outside France, and even there opinions are divided, but *the profusion of mathematical expositions which makes it difficult to assess this theory* has also prevented many physicists from deciding in favour of one view.

Another quotation showing that Ørsted considered Ampère's theory very complicated:[19]

> By these suppositions, and a considerable exertion of mathematical skill, he [Ampère] is enabled to make this view represent well enough the phenomena, *though his theory is very complicated.*

11.2.2 Direct Action between current-carrying conductors, Without being Mediated by a Flux of Electric Charges Circulating around the Wire

Ørsted's main criticism against Ampère was that Ampère did not accept the rotary action of the electric current, that is, Ampère did not accept Ørsted's conception according to which there were electric charges circulating externally around a current-carrying wire. This supposed circulation of electric charges around the wire was the basis of Ørsted's explanation of his own experiment of the deflection of a compass needle. Ampère, on the other hand, explained the torque exerted by the current-carrying wire in this experiment as being due to a direct interaction between the macroscopic current in the wire and the microscopic currents he supposed to exist inside the magnetic needle. Moreover, according to Ampère, this macroscopic torque was due to an integration of microscopic forces acting between a current element in the wire and a current element of a microscopic current inside the magnet, with these forces acting along the line connecting these two current elements and following the principle of action and reaction. Ørsted accepted the existence of real magnetic particles of austral and boreal magnetism. Ampère, on the other hand, explained the magnetic and electromagnetic interactions by supposing the existence of microscopic electric currents not only inside magnets, but also inside the Earth. Moreover, according to Ampère the so-called magnetic properties of magnets and the Earth were in fact due to electrodynamic interactions between these microscopic electric currents. Ampère's suppositions were contrary to those of Ørsted, who considered them unacceptable, as he expressed several times. Ørsted never abandoned the idea of the real existence of magnetic particles or poles. He also never abandoned his initial supposition of the existence of a helical or circular flow of electric charges moving externally around a current-carrying wire and being responsible for the magnetic properties of this wire. We quote here some statements by Ørsted related to these topics as expressed in 1830:[20]

> M. Ampère, to whom we are indebted for the discovery of the mutual attractions and repulsions of the electrical currents, considers the law of this action as a fundamental one, at least so far as our present knowledge extends. *He thus admits no rotative action in the electrical current, but he transports it to the magnet, in which he supposes electrical currents, revolving in planes perpendicular or nearly perpendicular to the axis of the magnet.*

Ampère wished that Ørsted would accept his theory. This never happened, although they met one another in Paris and had the opportunity to discuss magnetism. In a letter written to his wife on 25 April 1822, Ørsted described Ampère's discomfort when Ørsted maintained his own theory:[21]

> Ampère, *who has worked so much with my discovery and has founded a very elaborate theory on it, was greatly annoyed that I still keep to mine which is extremely simple. In order to have a conversation with me about this in the company of several scholars, he invited me to a dinner-party where* Fourier, Dulong, Chevreul, Friedrich Cuvier, Savary *and* Montferrand *were present too. The latter two are young disciples*

[16] [Between 1827 and 1840 Ørsted refers to himself in these reports as *Etatsraad*, an honorary title meaning Councillor of State.]
[17] [Summary in Oken's *Isis*, Vol. 22, Col. 260-62, Jena 1829.]
[18] [Bacon.]
[19] [Ørsted, 1998g, p. 568], our emphasis.
[20] [Ørsted, 1998g, p. 568], our emphasis.
[21] [Franksen, 1981, p. 32].

of Ampère. *After the meal the conversation began and lasted for nearly three hours. I quite succeeded in proving that my theory accounts for all the phenomena, and what was most remarkable, I had to prove to* Fourier *that my theory was older than* Ampère's *which was, however, easy, seeing that I have already given it in my first publication. Even* Ampère's *two disciples declared that my theory was able to explain all the phenomena. They declare that so will* Ampère's, *and as his theory is nothing but the reverse of mine, he having removed the circuits of forces, discovered by me, from the conductor to the magnet, it will no doubt be difficult to find any entirely decisive objection to his theory, but I do not care for that either.*