# Chapter 16

# Ampère Against His Main Opponents

Ampère's main experimental and theoretical works on electrodynamics ranged from 1820 to 1827. In this period he developed his extremely original conception that magnetism is due to electric currents flowing in magnets and in the Earth. Moreover, he obtained his force between current elements and several extremely relevant results from the integration of this expression. At this phase he received the support of some colleagues and students like Arago, Gaspard and Auguste de la Rive, Fresnel, Savary, Liouville and Demonferrand. Despite this support, the main scientists working on electromagnetism at this time were totally against several aspects of his conceptions. Among his main opponents we can quote Ørsted, Biot, Savart, Faraday and Grassmann, although this last scientist published his criticisms after Ampère's death.

In this part of the book we discuss how Ampère answered the main criticisms to his work and what his main objections were against the theories of these scientists. Initially we list Ampère's arguments against his main opponents, presenting some specific arguments against some of them. We then discuss some generic arguments which can be applied to the conceptions of one or more of these authors.

Before discussing specific topics, it is worthwhile presenting one of the main points of controversy between Ampère and his opponents, in particular Ørsted, Biot, Savart and Faraday.[1] This aspect of the disagreement is reflected in the interpretation of Ørsted's original experiment of 1820. All of these authors, with the exception of Ampère, interpreted this experiment based on gyratory forces or rotatory actions exerted by the current-carrying wire on the supposed magnetic poles of the magnetized needle placed close to the wire. Let $i$ be the constant electric current flowing in a long and straight wire. The magnetic poles of the needle had a real existence according to all opponents of Ampère. The forces exerted by the wire on the poles of the magnet would act in planes orthogonal to the straight wire, being also orthogonal to the straight line connecting the midpoint of the magnet to the wire. These rotatory forces would act in opposite senses on the North and South poles of the magnet which were initially aligned with the wire, as indicated in figure 16.1 (a). Figure 16.1 (b) presents a cross section of figure 16.1 (a).

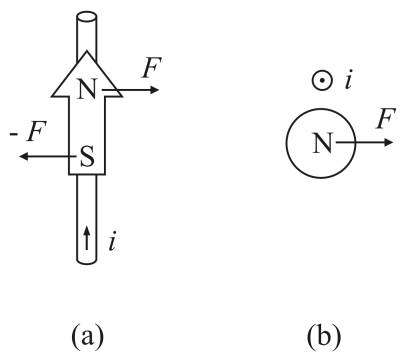


Figure 16.1: (a) Forces exerted by a long and straight current-carrying wire and acting on the supposed magnetic poles of a compass needle $NS$ aligned with the wire, according to the conceptions of Ørsted, Biot, Savart and Faraday. (b) A cross section of the previous situation. The current $i$ of the wire is leaving the paper in this representation and we see only the upper North pole of the magnet.

[1] [Heilbron, 1981].

A similar interpretation is obtained nowadays in terms of the magnetic field produced by the current-carrying wire, as represented in figure 16.2 (a). Figure 16.2 (b) represents the forces acting on the North and South poles of a compass needle aligned with the wire, according to equation (15.4). Figure 16.2 (c) represents a cross section of this configuration, indicating only the force acting on the North pole of the magnet.

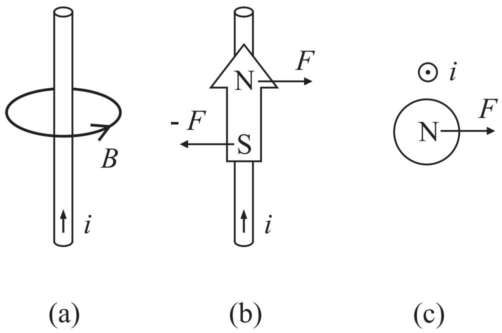


Figure 16.2: (a) Magnetic field produced by a long and straight current-carrying wire. (b) Forces exerted by the magnetic field on the North and South poles of a compass needle aligned with the magnet. (c) Cross section of this configuration showing only the force acting on the North pole of the magnet.

Ampère's interpretation of what happened in Ørsted's experiment was completely different. Instead of supposing the real existence of magnetic poles on the compass needle, Ampère, after Fresnel's suggestion, supposed there were microscopic currents flowing around the particles of the needle. The magnetic properties of magnets would be due to these molecular currents, as represented in figure 16.3 (a) and (b). The magnitude of each one of these molecular currents was represented by $i'$. These molecular currents would cancel one another inside the magnet, as they would be flowing in opposite directions in each internal point, there remaining only an effective electric current $i'$ on the surface of the magnet, figure 16.3 (c).

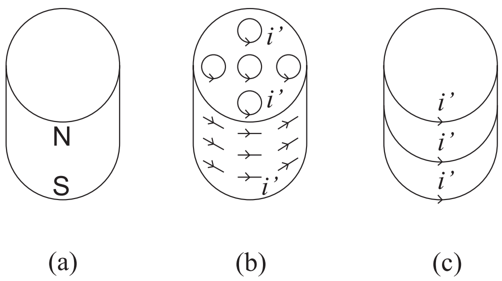


Figure 16.3: (a) Cylindrical magnet. (b) Ampère's molecular currents of intensity $i'$. (c) Effective electric currents flowing on the surface of the magnet due to the cancellation of the microscopic currents in any internal point of the magnet.

The torque exerted by a long straight wire carrying a constant current $i$ acting on the magnet would be due to forces acting between each current element $ids$ of the wire interacting with each current element $i'ds'$ of the microscopic currents of the magnet. Figure 16.4 presents a simplified view indicating the essence of Ampère's interpretation of Ørsted's experiment. In configuration (a) we have a long straight wire carrying a constant current $i$ and a cylindrical magnet $NS$ which is initially aligned with the wire. Figure 16.4 (b) presents a simplified view of Ampère's conception of a magnet, as indicated in figure 16.3. The cylindrical $NS$ magnet has been replaced by only three circular current loops flowing on the surface of the magnet, each one with the same intensity $i'$ of a microscopic current. Figure 16.4 (b) also indicates the net forces $F$ and $-F$ exerted by the straight wire and acting on the surface currents of the magnet. These forces are parallel to the straight wire carrying a current $i$. Figure 16.4 (c) presents a cross section of this situation indicating only the current $i$ of the wire leaving the plane of the paper and a single circular current loop $i'$ in the plane of the paper representing the upper current $i'$ flowing through the surface of the magnet. The force $F$ acting on the left side of the circular loop leaves the paper, while the force $-F$ acting on the right side of the circular loop penetrates the paper. These opposite forces exert a torque on the magnet.

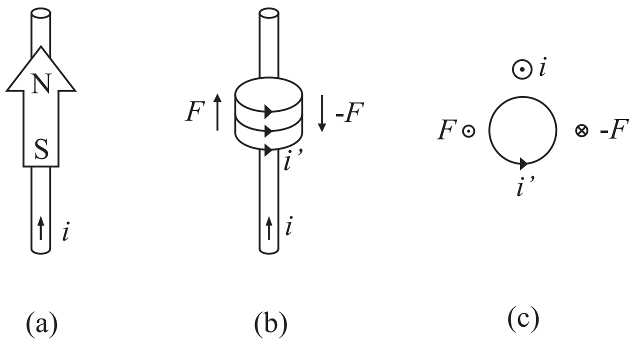


Figure 16.4: (a) Cylindrical magnet $NS$ which is initially parallel to a long straight wire carrying a constant current $i$. (b) According to Ampère, the magnet would be equivalent to a series of current loops of intensity $i'$ flowing through its surface. The forces $F$ and $-F$ exerted by the wire on the current loops of the magnet are parallel to the wire. (c) Cross section view of this configuration showing a single current loop flowing through the surface of the magnet and the opposite forces $F$ and $-F$ exerted on its left and right sides.

There are then two opposite interpretations of Ørsted's experiment. The one based on the existence of magnetic poles requires the existence of opposite gyratory forces acting tangentially like circles around the straight wire, as represented in figures 16.1 and 16.2. Ampère's explanation, on the other hand, is based only on the interaction between current elements and leads to opposite forces parallel to the wire, as represented in figure 16.4. In both cases the same torque is predicted acting on the compass needle, forcing it to point orthogonally to the wire. However, the mechanism responsible for these forces is completely different. These two opposing paradigms are discussed at length in this book.

## 16.1 Ampère Against Ørsted

As seen in Sections 1.3 and 3.1, Ampère's interpretation of Ørsted's experiment was totally different from Ørsted's own conception discussed in Section 11.1.

Ørsted was against Ampère's conception. Likewise, Ampère rejected Ørsted's interpretation. His main criticisms as regards Ørsted's theory were as follows:

1. Ampère did not believe in the existence of magnetic poles. He interpreted all magnetic and electromagnetic phenomena based on the interaction between electric currents, as will be discussed in Section 19.1.

2. Ampère was against Ørsted's idea of a vortex of electric charges flowing around a current-carrying wire, as discussed in Section 20.1.

3. Ampère pointed out that Ørsted's conception did not establish the identity between a magnetic fluid and a galvanic fluid, as discussed in Section 19.2.

4. Ampère identified two problems in Ørsted's idea about the existence of magnetic poles and in the supposed interaction of a magnetic pole with an electric charge. Ørsted had assumed this interaction in his own interpretation of his experiment, according to which electric charges flowing around the wire would propel the magnetic poles of the magnet. The two problems pointed out by Ampère were: (a) The interaction between distinct magnitudes, that is, the interaction of a magnetic pole with an electric charge. (b) Ørsted's conception did not lead to a real unification of the electromagnetic phenomena. In order to overcome these problems, Ampère proposed the interaction between current elements and the hypothesis of electric currents flowing in magnets and in the Earth, as discussed in Section 19.3.

5. According to Ampère's point of view, Ørsted never succeeded in explaining convincingly the interaction between two current-carrying wires, a phenomenon first observed and explained by Ampère. This topic is discussed in Subsection 21.1.2.

## 16.2 Ampère Against Biot and Savart

Biot and Savart criticized Ampère's suppositions. Ampère, likewise, attacked head on the hypotheses of these authors. In January 1821, Ampère even thought of an experiment in order to distinguish his theory from that of Biot, as discussed in Section 6.3. At this time Ampère utilized an incomplete form of his force law between current elements, believing that the constant $k$ appearing in his force law given by equations (2.1) and (2.2) should vanish, that is, believing at that time that $k = 0$. He performed this experiment with Despretz and obtained a result against his own theory in its incomplete form, with $k = 0$. The outcome of this experiment was favorable to Biot's theory. It was only in 1823 that Savary was able to show, utilizing Ampère's complete force with $k = -1/2$, that this theory led to the same result for this specific experiment as the result given by Biot's theory, as discussed in Sections 6.3 and 9.8. Ampère always remained totally against Biot and Savart's conceptions.

Ampère's main criticisms against Biot and Savart's theory were as follows:

1. Ampère was against Biot and Savart's hypothesis about the existence of magnetic fluids (called austral and boreal fluids, or North and South poles, respectively), as discussed in Section 19.1.

2. Ampère pointed out mistakes made by Biot and Savart when they "deduced" the supposed force exerted by a current element acting on a magnetic pole, as discussed in Chapter 17.

3. According to Ampère, the primitive fact yielding the main elements capable of explaining all known phenomena was the interaction between current-carrying elements (or the interaction between current-carrying wires). Biot and Savart, on the other hand, believed that the interaction of a current-carrying wire with a magnet was the basic or primitive fact. This topic will be discussed in Section 19.3.

4. According to Ampère, the explanation Biot and Savart gave to account for Ørsted's experiment, based on the hypothesis of the magnetization of the wire by the passage of a current though it, led to contradictions related to the observed phenomena, as discussed in Section 18.1.

5. According to Ampère, moreover, Biot and Savart's hypothesis of the magnetization of the wire did not explain quantitatively nor qualitatively the interaction between two current-carrying conductors, as discussed in Subsection 21.1.3.

6. Biot and Savart's magnetization hypothesis was also against the phenomena of continuous rotation observed in Faraday and Ampère's experiments, as discussed in Section 18.3.

7. Ampère discussed in the *Théorie* the wrong explanation given by Biot as regards the experiment of continuous revolution of a magnet around a current-carrying wire.[2]

8. Ampère was also against Biot's explanation of the experiment of the rotation of a magnet around its own axis, as discussed in Section 21.3.

9. According to Ampère, the force proposed by Biot and Savart acting between a current element and a magnetic pole led to a primitive couple which violated Newton's third law in its strong form. That is, Biot and Savart's force was not a central force. It satisfied the principle of action and reaction. However, the action and reaction were not directed along the same straight line, being directed along parallel straight lines. Biot and Savart's action and reaction pair would generate a primitive couple in the system composed of a current element and a magnetic pole. Ampère's force between current elements, on the other hand, was central and always complied with Newton's third law of motion in its strong form, as discussed in Section 20.2.

10. Ampère showed that Biot and Savart's fundamental assumption in order to explain Ørsted's experiment, based only on the interaction between magnetic poles, did not lead to the unification of magnetic, electromagnetic and electrodynamic phenomena, as discussed in Section 22.1.

[2] [Ampère, 1826f, pp. 166-167] and [Ampère, 1823c, Ampère, 1990, pp. 338-339].

## 16.3 Ampère Against Faraday

The main criticisms Ampère raised against Faraday's conceptions were as follows:

1. Ampère was against Faraday's belief in the real existence of magnetic poles, as discussed in Section 19.1.

2. Faraday had argued in favor of a law of revolution, as discussed in Section 13.2. Ampère always fought against this rotational, rotary, gyratory, or revolutive action, as discussed in Section 20.1.2.

3. Ampère always considered that a primitive, fundamental, or primordial action must take place between magnitudes of the same type. Faraday, on the other hand, considered as a simple action the force he supposed to be acting between a current-carrying wire and a magnetic pole. This topic will be discussed in Section 19.3.

4. Ampère never accepted Faraday's explanation for the attractions and repulsions between current-carrying wires, a phenomenon first observed and explained by Ampère. This topic is dicussed in Subsection 21.1.4.

5. Ampère showed experimentally that Faraday was wrong when he did not believe it would be possible to produce a rotation of a magnet around its own axis of symmetry utilizing only electric currents, as discussed in Subsection 7.2.3.

6. When Faraday heard of Ampère's experiment producing the rotation of a magnet around its own axis, he offered an explanation based on a supposed torque exerted by the magnetic pole of the magnet acting on electric currents flowing inside the magnet. Ampère rejected Faraday's explanation as it violated Newton's third law, as discussed in detail in Section 21.3.

## 16.4 "Ampère" Against Grassmann

Ampère died in 1836. Therefore, he did not know Grassmann's criticisms against his force law, published in 1845, and could not answer them. This is the reason for the quotation marks in the title of this Section. In any event, from all that we know from his works and correspondence, it is easy to imagine some arguments he might utilize to defend against Grassmann's criticisms presented in Section 14.2. Some of these arguments might be the following:

1. Grassmann said that Ampère's force between current elements was complicated. Ampère might answer saying that his force law was the simplest of all formulas which was in agreement with the experimental results.

2. Grassmann said that Ampère was obliged to utilize an arbitrary supposition, namely, that the force between two current elements had to act along the straight line connecting them. Ampère might have replied that is was possible to describe all experimental results related to the interaction between current-carrying wires utilizing this supposition. Therefore, it would be preferable to assume this hypothesis than any other one. After all, the other forces of nature also behave like that. Examples: gravitational, electrostatic and magnetic forces. It does not make sense to complicate a theory when this is not necessary.

3. As discussed in Section 14.2, Grassmann considered it improbable that a force between two parallel current elements should change from attraction to repulsion at a critical angle between the direction of the elements and the straight line connecting them. Ampère might had replied that no experiment had been shown contrary to this prediction.

It is also possible to imagine some arguments which he might utilize against Grassmann's force. These arguments arise from his personality, correspondence and papers. They can also be obtained from the criticisms he presented against the works of Ørsted, Biot, Savart and Faraday:

1. Grassmann never presented experimental results which were in disagreement with Ampère's force between current elements. All criticisms he presented against Ampère's force were subjective, like