# Chapter 13

# Faraday *Versus* Ampère

## 13.1 Faraday's Interpretation of Ørsted's Experiment

The main electromagnetic researches of Faraday began after Ørsted's announcement of his discovery in July 1820. Starting in 1813 Faraday had been an assistant of Humphry Davy (1778-1829) at the Royal Institution in London.[1] Faraday initially reproduced some of the main experiments performed by Ørsted, Ampère, and a few other scientists and then began his own researches. Between 1821 and 1822 he published a paper, in three parts, presenting a historical sketch of electromagnetism.[2] Although published anonymously, he later on assumed its authorship.[3]

In 1821 Faraday performed some experiments analyzing the torque acting on a horizontal magnetic needle close to a vertical wire carrying a constant current. He interpreted his observations in terms of the forces exerted by the current-carrying wire and acting on the magnetic poles of the needle. From these experiments he concluded that these poles were not located exactly at the extremities of the needle. Moreover, the forces exerted by the wire on the magnetic pole did not point towards the wire. They were orthogonal to the wire and to the straight line connecting the pole to the wire. These forces should cause the rotation or revolution of the pole around the wire. These rotational, rotary, or revolutive forces were not attractive nor repulsive. Although in these experiments Faraday did not observe the motion of the current-carrying wire due to the forces exerted by the magnet, he believed these opposite forces should be present. Probably he was thinking in terms of Newton's action and reaction law. Faraday described his experiments, somewhat analogous to those of Ørsted, as follows:[4]

> It is evident from this that the centre of the active portion of either limb of the needle, or the true pole, as it may be called, is not at the extremity of the needle, but may be represented by a point generally in the axis of the needle, at some little distance from the end. It was evident, also, that this point had a tendency to revolve round the wire, and necessarily, therefore, the wire round this point; and as the same effects in the opposite direction took place with the other pole, it was evident that each pole had the power of acting on the wire by itself, and not as any part of the needle, or as connected with the opposite pole.
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> [...]
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> Several important conclusions flow from these facts; such as that there is no attraction between the wire and either pole of a magnet; that the wire ought to revolve round a magnetic pole, and a magnetic pole round the wire; that both attraction and repulsion of connecting wires, and probably magnets, are compound actions; [...]
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> The revolution of the wire and the pole round each other being the first important thing required to prove the nature of the force mutually exerted by them, various means were tried to succeed in producing it. [...]

In September 1821, Faraday succeeded with these experiments of continuous rotation of the extremity of a current-carrying wire around a magnet, and also with the experiments of continuous rotation of the extremity of a magnet around a current-carrying wire, as discussed in Section 7.1. Once more he interpreted

[1] [Davy, 1821, p. 18].
[2] [Faraday, 1821a], [Faraday, 1821b] and [Faraday, 1822b].
[3] [Williams, 1989b, p. 85, n. 14].
[4] [Faraday, 1822e, p. 76] and [Faraday, 1952d, p. 797].

these experiments based on the existence of magnetic poles, together with the forces between these poles and the current-carrying wire. According to Faraday, these forces followed the principle of action and reaction. However, they were not directed along the shortest distance connecting each pole with the long straight wire. According to Faraday, these forces were orthogonal to this shortest line, being also orthogonal to the wire. They caused the rotation of the pole around the wire, together with the opposite rotation of the wire around the pole. These opposite forces causing a mutual rotation are represented in figure 13.1. Each one of these forces might be reversed by reversing the direction of the current or the type of magnetic pole. By reversing simultaneously the direction of the current and the type of magnetic pole, the forces would remain pointing as indicated in this figure.

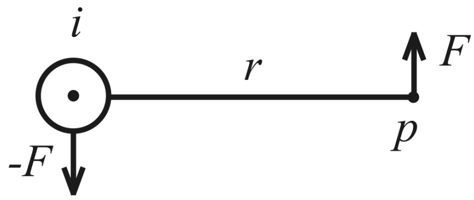


Figure 13.1: A long straight wire normal to the plane of the paper, with a current $i$ coming out of the paper. The arrows indicate the forces exerted between a North pole $p$ of the magnetized needle and the current-carrying wire, according to Faraday's conceptions.

## 13.2 Faraday Against Ampère

As discussed in Section 7.1, Ampère abandoned most of his electrodynamic researches between January and September 1821. Faraday's discovery of continuous rotation made Ampère resume his researches. Ampère recognized the importance of Faraday's discovery as regards his own motivation. However, he emphasized that Faraday's conceptions used to explain these phenomena were contrary to his own interpretations. In a letter addressed to C. J. Bredin, dated December 3, 1821, Ampère mentioned this controversy:[5]

> When arriving here [in Paris,] metaphysics occupied my thoughts; however, after Faraday's work, I think only of electric currents. This memoir contains very singular electromagnetic facts, which perfectly confirm my theory, although the author tries to fight against it by replacing it with a [theory] of his creation.

We list here some objections Faraday presented against Ampère's conceptions and explanations:

1. Faraday was always skeptical about the idea that an electric current is due to the motion of electric charges.

2. Faraday doubted Ampère's magnetic conception, according to which the magnetic properties of the Earth and magnets were due to electric currents flowing in the Earth and in magnets.

3. According to Faraday the simplest or basic cases to be considered were the circular motion of a magnetic pole around a current-carrying wire and the opposite circular motion of a current-carrying wire around a magnetic pole. He believed that the attraction and repulsion between two current-carrying wires should be considered a complex phenomenon, which might be explained in terms of simpler configurations not involving the direct interaction between current-carrying conductors.

In his historical sketch of electromagnetism, published between 1821 and 1822, Faraday expressed his skepticism relative to the usual conception of an electric current as being due to the flow of electric charges:[6]

> Those who consider electricity as a fluid, or as two fluids, conceive that a current or currents of electricity are passing through the wire during the whole time it forms the connection between the poles of an active [voltaic] apparatus. There are many arguments in favour of the materiality of electricity, and but few

[5] [Launay (ed.), 1936a, pp. 576-577] and [Blondel, 1982, pp. 109-110].
[6] [Faraday, 1821a, p. 196] and [Blondel, 1982, p. 52].

> against it; but still it is only a supposition; and it will be as well to remember, while pursuing the subject of electro-magnetism, that we have no proof of the materiality of electricity, or of the existence of any current through the wire.

Faraday's doubts mentioned in item 2 were expressed as follows in a letter to De la Rive of 12 September 1821:[7]

> But yet I am by no means decided that there are currents of electricity in the common magnet. I have no doubt that electricity puts the circles of the helix into the same state as those circles are in that may be conceived in the bar magnet, but I am not certain that this state is directly dependent on the electricity, or that it cannot be produced by other agencies; and therefore, until the presence of electrical currents be proved in the magnet by other than magnetical effects, I shall remain in doubt about Ampère's theory.

Only after his own discovery of electromagnetic induction in 1831 did Faraday begin to have a more positive attitude towards Ampère's magnetic theory. He mentioned the following in a letter to Phillips, dated 29 November 1831:[8]

> Then I found that magnets would induce just like voltaic currents, and by bringing helices and wires and jackets up to the poles of magnets, electrical currents were produced in them; these currents being able to deflect the galvanometer, or to make, by means of the helix, magnetic needles, or in one case even to give a spark. Hence the evolution of *electricity from magnetism*. The currents were not permanent. They ceased the moment the wires ceased to approach the magnet, because the new and apparently quiescent state was assumed, just as in the case of the induction of currents. But when the magnet was removed, and its induction therefore ceased, the return currents appeared as before. These two kinds of induction I have distinguished by the terms *volta-electric* and *magneto-electric* induction. Their identity of action and results is, I think, a very powerful proof of M. Ampère's theory of magnetism.

In his fundamental article of 1831 describing his discovery of the induction of electric currents, Faraday expressed himself as follows:[9]

> The similarity of action, almost amounting to identity, between common magnets and either electro-magnets or volta-electric currents, is strikingly in accordance with and confirmatory of M. Ampère's theory, and furnishes powerful reasons for believing that the action is the same in both cases; but, as a distinction in language is still necessary, I propose to call the agency thus exerted by ordinary magnets, *magneto-electric* or *magnelectric* induction.

We now present the criticism of item 3 made by Faraday against Ampère's ideas. In his paper of 1821 describing the discovery of continuous rotation, Faraday mentioned the following:[10]

> A simple case which may be taken of magnetic motion, is the circle described by the wire or the pole round each other.

On the other hand, as regards the phenomenon Ampère discovered of the attraction and repulsion between parallel current-carrying wires, Faraday made the following evaluation:[11]

> [...] the attractions and repulsions of M. Ampère's wires are not simple, but complicated results.

Faraday believed that it would be possible to explain the interactions between current-carrying conductors supposing only the interactions between a current-carrying wire and the supposed magnetic poles existing in the other current-carrying wire.

In his letter to De la Rive, dated 12 September 1821, Faraday emphasized this point of view as follows:[12]

> I find all the usual attractions and repulsions of the magnetic needle by the conjunctive wire are deceptions, the motions being not attractions or repulsions, nor the result of any attractive or repulsive forces, but the result of a force in the wire, which, instead of bringing the pole of the needle nearer to or further from the wire, endeavours to make it move round it in a never-ending circle and motion whilst the battery remains in action. I have succeeded not only in showing the existence of this motion theoretically, but experimentally, and have been able to make the wire revolve round a magnetic pole, or a magnetic pole round the wire, at pleasure. The law of revolution, and to which all the other motions of the needle and wire are reducible, is simple and beautiful.

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7 [Jones, 1870a, p. 317].
8 [Jones, 1870b, p. 8].
9 [Faraday, 1952c, §58, p. 273].
10 [Faraday, 1822e, p. 79] and [Faraday, 1952d, p. 799].
11 [Faraday, 1822e, p. 79] and [Faraday, 1952d, p. 799].
12 [Jones, 1870a, p. 316] and [Gross, 2009].