Ørsted and the Discovery of Electromagnetism: Research Highlights

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Summary

In July of 1820, Hans Christian Ørsted announced that a wire carrying electricity could deflect a magnetic compass needle, a finding that is now considered the discovery of electromagnetism. Ørsted's finding is among the most important breakthroughs in the history of science. It was critical to a long list of subsequent advances that are responsible for the technological advances that enable modern life. Its importance is difficult to overstate.

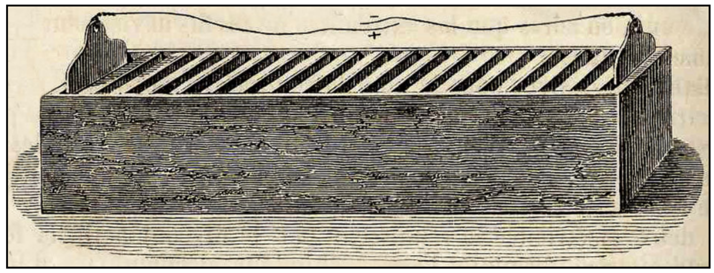

Figure 1. Image of a horizontal voltaic pile.[1]

The case study, Ørsted and the Discovery of Electromagnetism, investigates the history of this discovery. The paper draws three primary conclusions:

(1) Electromagnetism could have been easily discovered eighteen years earlier had natural philosophers looked for magnetism in the current-carrying wire.

(2) The theory that led Ørsted to test the current-carrying wire for magnetism was substantively built on contemporary metaphysics.

(3) Mathematical and experimentalist approaches failed to make the discovery.

Below are the highlights from the case study organized around these three findings. Each highlight includes a set of page number references to the case study itself for a more detailed discussion of the relevant topics. The external references to which the case study is indebted are available in the bibliography on pages 55–65 of the case study.

[1] "File:Trough battery.jpg," *Wikimedia Commons*, last modified February 19, 2021, https://commons.wikimedia.org/wiki/File:Trough_battery.jpg.

(1) Electromagnetism could have been easily discovered eighteen years earlier had natural philosophers looked for magnetism in the current-carrying wire.

Overview

Sections 1 and 2 of the case study demonstrate when the discovery of electromagnetism was technologically possible and whether there were any significant impediments to the discovery. To determine when the discovery was possible, I work out how much current would be required to produce a magnetic field equivalent to Earth's, and then I use contemporaneous experimental descriptions to determine how much current experimenters could have produced. The result is that by 1802, experimenters were capable of producing many more times the current required to create a detectable magnetic field. Next, I consider two elements that might have impeded the discovery: the unusual geometry of the magnetic effect and the lack of any known interaction between electricity and magnetism. I show that the geometry would have posed a substantial impediment in only two very specific experimental configurations, although other configurations would have made the effect more difficult to detect. I then discuss the history of searches for electromagnetism, showing that both speculation and experiment regarding the effect were relatively common. I ultimately conclude that there were no significant impediments to the discovery after 1802 and thus the discovery could have been made eighteen years earlier.

A) Speculation that electricity and magnetism shared some connection was relatively common historically.

Explanation

Electricity and magnetism have much in common, and it was an antecedently plausible hypothesis that there might be some connection between them. In particular, they share characteristics like attraction and repulsion at a distance, effects that diminish by the inverse of distance squared, and polarity, among other striking similarities. Given these similarities, several natural philosophers attempted to discover a connection between electricity and magnetism—including experimental attempts to demonstrate the connection between 1800 and 1820. The failure to discover electromagnetism sooner was not for lack of trying.

References

— On why it was an antecedently plausible hypothesis that there might be some connection between electricity and magnetism, see 21.
— On the history of attempts to discover a connection between electricity and magnetism, see section 2 (21–23) or the appendix (66–69).

B) Ørsted's experiment would have been easy to perform anytime after 1802.

Explanation

The strength of the magnetic field (measured in microteslas, µT) produced by a current-carrying wire is proportional to the current (measured in amps, A) and inversely proportional to the distance from the wire. Producing a magnetic field equivalent to Earth's (30 µT at the equator) requires between 0.75 A and 7.5 A, depending on the distance between a wire and the instrument. In an 1802 report , Pepys describes melting an iron wire 0.1 in. thick, which calculations show would require nearly 100 A. Thus, sufficient current to produce magnetic effects was available by 1802.

Additionally, it was possible to detect magnetic fields much weaker than 30 µT. For example, in 1792, Bennet proposed a device that, based on experimental descriptions, would have been capable of detecting a magnetic field as weak as 1.3 µT. Thus, the magnetic effects that natural philosophers could have produced after 1802 would have been easy to detect. The discovery would have been made somewhat more difficult by the unexpected fact that magnetism moves in a circle around the wire and thus tends to pull a magnetic needle up or down instead of causing it to rotate in some configurations of the experiment. However, with a strong pile and a wire placed close to the needle, only two very specific experimental arrangements would have made detection impossible. Thus, the experiment required to discover electromagnetism would have been easy to perform anytime after 1802.

References

— On what Ørsted's discovered, see 4–6.
— On the current strength required to produce a detectable magnetic field, see 9–10.
— On the current available in Pepys's experiment, see 12.
— On the sensitivity of Bennet's instrument as a detector of magnetism, see 13–15.
— On whether the discovery would have been made more difficult by the unusual geometry of the magnetic effect, see 16–19.

C) No one thought to check the current-carrying wire for magnetism until Ørsted.

Explanation

The technological requirements for Ørsted's discovery were met by 1802, and the experiment would have been quite straightforward to perform. Why, then, was the discovery not made until 1820? The answer suggested by Ampère and Hachette, two of Ørsted's contemporaries, is that no one checked the current-carrying wire for magnetism until Ørsted. Indeed, it appears that a number of natural philosophers thought the pile might reveal electromagnetism, and they conducted a wide variety of unsuccessful experiments to search for it. These experiments include attempts to use the open pile to produce magnetism, attempts to produce a pile out of magnets, and attempts to investigate the effects of static electric attraction on magnetic objects.

References

— On Hachette's commentary on the discovery, see 8.
— On Ampère's commentary on the discovery, see 8–9.
— On experiments aimed at causing the pile to demonstrate magnetic effects, see the introduction (2–4), 22–23, and 67–69.

(2) The theory that led Ørsted to test the current-carrying wire for magnetism was substantively built on contemporary metaphysics.

Overview

Section 3 is concerned with why it was Ørsted and not others who ultimately discovered electromagnetism. From his extensive writings, it is clear that Ørsted's approach to natural philosophy was deeply influenced by contemporary metaphysics and philosophy of science, especially the work of Immanuel Kant (1724–1804) and Friedrich Wilhelm Joseph von Schelling (1775–1854). Yet, the precise connection between these views and the discovery of electromagnetism is less clear.

Additionally, while Ørsted offered a theory to explain the discovery, known as the "conflict of electricity" theory, he failed to sufficiently explain the details of this theory or its connection to his past work. I review Ørsted's 1806 account of electrical conduction and note how this theory is a precursor to his later account of the electromagnetic effect. As a result, this account, or something like it, probably represents how Ørsted viewed the current-carrying wire. I then point out the Kant- and Schelling-influenced metaphysical views that the account requires to identify the precise role of philosophy in the discovery of electromagnetism.

A) Ørsted's research program was defined by three metaphysical principles that he acquired from Kant and Schelling.

Explanation

In very broad terms, a few distinct aspects of Ørsted's approach to natural philosophy are both sufficiently central to his philosophical system and sufficiently distinct from the approach taken by his contemporaries that they can be thought of as central to the discovery of electromagnetism. These key elements are (1) Ørsted's belief in the importance of establishing natural laws a priori, (2) Ørsted's dynamical theory of matter, and (3) Ørsted's belief in the ultimate unification of natural philosophy into a single, unified whole.

Taken together, these views allowed Ørsted to interpret the empirical evidence differently than his contemporaries and to guess correctly that a current of electricity might produce forces beyond heat and light. Ørsted's writings indicate that he acquired the first two ideas from his reading of Kant, especially the Kant of *Metaphysical Foundations of Natural Science*, and the third from Schelling and the intellectual tradition of *Naturphilosophie*.

References
— On Ørsted's background, including his early exposure to the ideas of Kant and Schelling, see section 3.1 (24–28).
— On the distinctive properties of Ørsted's approach to natural philosophy, see section 3.2 (29–32).
— On Ørsted's belief in the importance of establishing natural laws a priori, see 29–30.
— On Ørsted's dynamical theory of matter, see 30–31.
— On Ørsted's belief in nature as an integrated whole, see 31–32.
— On Ørsted's use of these beliefs in the discovery of electromagnetism, see section 3.3 (32–38).

B) Ørsted used these metaphysical principles to develop a theory of electrical conduction that later led him to check the current-carrying wire for magnetism.

Explanation
In 1806, Ørsted developed a theory of how electricity moves through a conductor that might be called the "undulatory theory" of electrical conduction. Rather than seeing conduction as the transmission of a subtle fluid (electricity) between two points, Ørsted saw it as the result of a complex struggle between more fundamental forces. He argued that the undulatory theory could even explain phenomena beyond electrical conduction, including patterns in how wires melt when subjected to a sufficiently strong current, the propagation of sound, and the color patterns displayed by electric sparks. This theory suggested to Ørsted that just as a current-carrying wire produces heat and light, it might also produce magnetism and thus explains why he conducted the critical experiment in 1820.

References
— For a description of Ørsted's undulatory theory, see 32–35.
— On the relationship between Ørsted's metaphysical principles and the undulatory theory, see 36–37.
— On how the undulatory theory led to Ørsted's discovery, see 35–37.

(3) Mathematical and experimentalist approaches failed to lead to the discovery.

Overview
In section 4 of the case study, I examine why the discovery did not occur elsewhere. To explain this, it is useful to divide the approaches to natural philosophy that operated between 1800 and 1820 into three categories: the mathematical approach, the experimentalist approach, and Ørsted's philosophical or metaphysical approach. Why didn't the mathematical and experimentalist approaches lead to the discovery of electromagnetism? I show that both of these failed to recognize the important differences between the closed pile and the open pile; they either failed to seriously study the closed pile (in the case of the mathematical approach) or overlooked the possibility that the closed pile might reveal a magnetic effect (in the case of the experimentalist approach).

Additionally, I show that a decline in exploratory experimentation between the middle of the eighteenth century and the beginning of the nineteenth century likely prevented natural philosophers from discovering electromagnetism in the absence of a correct hypothesis about where to look.

A) The French mathematical approach did not discover electromagnetism because it focused only on the pile's static electric properties and overlooked the distinct and important properties of the electric current.

Explanation
Between Napoleon's assumption of power in 1799 and his final defeat in 1815, two French natural philosophers, Pierre-Simon Laplace (1749–1827) and Claude Louis Berthollet (1748–1822), used their special closeness to Napoleon and skill in coordinating a research program to focus French natural philosophy on the goal of mathematizing fields like electricity, magnetism, and heat in much the same way Newton had transformed celestial mechanics. While this approach achieved success in many areas, it was largely unsuccessful in the study of the voltaic pile because the instruments and mathematical techniques they brought to bear on the problem applied only to the study of the pile in the "open" configuration and did not generalize to the "closed" configuration.

As a result, otherwise capable French natural philosophers like Jean-Baptiste Biot (1774–1862) made claims about the functioning of the pile that were true only for the open configuration—and demonstrably false for the closed configuration. Little work was done on the closed pile, and thus French natural philosophers had little chance of discovering electromagnetism.

References
— For a description of the French mathematical approach, see 39–40.
— On French research of the pile, see 40–41.
— On Biot's research of the pile and subsequent erroneous claims, see 40–41.

B) The experimentalist approach that was dominant in England and the German states was misled by the association between the pile and the galvanic research tradition. The misunderstanding led them to experiment with the open pile—where no electric current is present—instead of the closed pile in their search for electromagnetism.

Explanation
Several natural philosophers had the idea that the pile might show some deeper connection between electricity and magnetism, and they conducted several experiments in an attempt to demonstrate this. Yet, these experiments focused on the open configuration of the pile instead of the closed configuration and thus failed to discover electromagnetism.

I show that this was because the open pile demonstrated effects that made it the more plausible place to look. In particular, the open pile demonstrated effects that were more consistent with so-called common (i.e., static) electricity, including signs of electrical attraction and repulsion, a stronger initial shock, and visible sparks. The closed pile, on the other hand, was associated with the galvanic research tradition and demonstrated much weaker shocks, no visible shocks or signs of electrical attraction and repulsion, and the ability to make wires glow and give off heat. For those who thought electricity and magnetism might be connected, the open pile demonstrated stronger electrical effects that pointed to common electricity, making it the more plausible place to search for electromagnetism. Thus, the experimentalists failed to discover electromagnetism because they didn't look in the right place.

References
— On experiments aimed at discovering a connection between electricity and magnetism, see section 2 (21–23) and the appendix (66–69).
— On how the research tradition that led to the invention of the pile affected the device's reception, see section 4.3 (46–52), particularly 46–48.
— On the difference in the phenomena demonstrated by the open and closed configurations of the pile, see 49–50.
— On why the open pile would have seemed the more plausible place to search for electromagnetism, see 50–52.

C) While the discovery could have been made accidentally, it became less likely due to a decline in exploratory experimentation.

Explanation

There are a few ways that electromagnetism could have been discovered experimentally in the absence of anything like Ørsted's metaphysical approach. The discovery could have been made by accident provided that one happened to bring a detector of magnetism close to a current-carrying wire. It also could have been made by experimenting with the voltaic pile to test for a wide range of potentially interesting effects, including magnetism, without a strong theoretical reason to suspect they would be found.

These kinds of experiments did not happen because a change in the nature of scientific investigation occurred between the discovery of the Leyden jar in the mid-eighteenth century and the discovery of the voltaic pile in the early nineteenth century. During that period, broad exploratory experimentation designed to find interesting unpredicted effects became less common and was replaced by more controlled experiments designed to respond to the existing literature on the topic. Thus, no one until Ørsted thought the current-carrying wire might produce magnetism, and no one decided to bring the two together just in case something interesting happened.

References

— For an explanation of the distinction between theory-driven and exploratory experimentation, see 43.

— On the nature of scientific investigation during the mid-eighteenth century, see Leverage's case study on the Leyden Jar.

— On the nature of scientific investigation in the early nineteenth century, see 44–46.