

# The Great Expectations of Michael Faraday

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Michael Faraday was perhaps the greatest experimental physicist of all time, but he faced profound obstacles during his rise to the top of the scientific heap. First, he was born into working-class English family and town that seemed to come straight out of a Charles Dickens novel. Consequently, he greatly relied on the charitable support of his “betters,” which was not reliable. Second, he worked during the birth of the Industrial Revolution, when many scientists were competing for the highest possible stakes.

This case study follows the biographical information in “The Electric Life of Michael Faraday” by Alan Hirshfeld, (Walker Publishing, New York, 2006). That work is based largely on a reading of Faraday’s letters, but it helps that Hirshfeld is also physicist. If you’re too busy to read the book, the Wikipedia page on Faraday’s life gives a nice biographical orientation to the specifics we discuss. As is often the case in history, there is plenty of leeway in interpreting the few recorded facts. Nobody alive today can really say, e.g., whether or not Faraday plagiarized the work Davy accused him of stealing. Different versions of the facts can be found elsewhere (such as the aforementioned Wikipedia page).

It also helps to understand the physics of magnetic fields. Chapter 19 of Serway and Faughn gives a reasonable description of the modern understanding of the relationship between magnetic fields and currents. Chapter 20 explains Faraday’s law.

## The Discovery of Faraday

Faraday was born in 1791 to a working-class family near present-day South London. At the age of 14, he became a bookbinder’s apprentice, which gave him access to books on a variety of subjects. Books he read during this period sparked an interest in physics and chemistry to such an extent that he attended a set of lectures given by John Tatum, founder of the City Philosophical Society of London. With his skill as a bookbinder, he transcribed his weekly lecture notes and added his own commentary and illustrations.

Faraday’s employer was impressed by these notes and showed them to an upper-class customer, William Dance. Similarly impressed, Dance gave Faraday tickets to see lectures by Humphry Davy at the Royal Institution. Davy was a brilliant and highly accomplished chemist, pioneering the field of electrochemistry. In particular, he used electrolysis to discover the elements sodium, potassium, magnesium, and calcium, among others. He also discovered the physiological effects of Nitrous Oxide – laughing gas – which became one of the first anesthetics ... and a source of entertainment for Davy and his friends.

Davy was also a celebrity, known for dynamic public lectures, spectacular demonstrations, and sex appeal. At that time, many scientists gave public lectures in order to generate interest in – and funding for – their work. It was considered highly fashionable for wealthy members of society to attend these lectures. Such lectures would have ordinarily been inaccessible to a

commoner like Faraday, but the gift of tickets gave him access to scientific learning and, eventually, real scientists. This was vital, because a person of Faraday's social status would not have had access to a University education.

Faraday saw Davy conduct electrical demonstrations using the new fangled invention called the battery. He again took extensive lecture notes and copied them in a more polished form; he even made a battery of his own. His bookbinder's apprenticeship was coming to an end, however, and a career in science was beyond his reach. In a mix of good and bad fortune, Davy injured himself working on an explosive compound and requested Faraday's help with demonstrations and lab work while he recovered. Davy may have received the recommendation from the same man who gave Faraday the lecture tickets.

After Davy recovered, he attempted to hire Faraday into the Royal Institution, but there were no positions open for assistants. Later, when an assistant was fired for "brawling", Faraday was hired. His tasks were menial at first: washing containers, setting up equipment, and housekeeping. But Faraday was highly skilled and tenacious, and eventually took on more direct role in laboratory experiments. He even injured himself with the same explosive as Davy.

When Davy, who was now *Sir* Humphry Davy, was preparing for a multiyear trip to Europe with his wife, Lady Davy, he chose Faraday to accompany him. Though Faraday would effectively be Davy's servant, this was an opportunity he could not pass up. He had never been more than a few miles outside London. Here was a chance to become a man of the world, while meeting some of the greatest European scientists.

Davy had come to accept Faraday as a junior colleague. He treated him with respect, and introduced him to many French scientists. They found Faraday impressive, and this built his confidence. However, Faraday had an awful time dealing with the arrogant and very class-conscious Lady Davy, who taunted him and treated him as a lowly servant. The trip was just long enough for Faraday, who had about had enough by the time the political climate forced them back to England.

Q1. How would someone like Faraday (poor but talented) get along today in trying to become an elite scientist?

Q2. Can science act as an equalizer today? In the time of Faraday?

Q3. Davy's trip was during the time of Napoleon's rule. Many regarded Sir Humphry Davy as unpatriotic for visiting France. How do you feel about this? Wayne State's physics department has, e.g., Pakistani and Iranian graduate students. Many of our faculty will attend a conference on Nuclear Physics in India (a rival of Pakistan) in February 2008. What are the pro's and con's of International Science?

## Faraday Invents the Electric Motor

Work and life resumed as Faraday and Davy returned home. Once a skeptic of love, Faraday changed his mind and married Sarah Barnard in 1821. At about the same time, news of

startling experiments connecting magnetism and electricity reached Davy's laboratory. In particular, Hans Christian Oersted was giving a demonstration on electricity, and noticed that the current in the wire affected a nearby compass needle. See fig. 1 below, and sec. 19.1 of Serway and Faughn for a modern explanation.

Traditional scientists at this time believed electricity and magnetism to be distinct phenomena. Moreover, all the forces that they knew (Newton's gravity, Coulomb's law) acted along straight lines. Oersted's experiment challenged everything they knew. Faraday, on the other hand, was not trained in these traditions. He came up with the notion that lines of magnetic flux circulated around the wire, and that the compass aligned with this flux; see Serway and Faughn. He visualized the flux lines by drawing pictures. He did not know calculus and essentially distrusted all of the sophisticated theorizing that his more learned colleagues were doing.

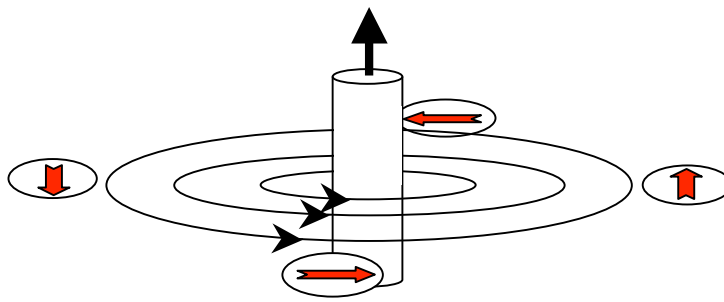


Figure 1. Oersted's experiment showed that a compass rotated as it was passed around a wire carrying electric current. The wire is shown standing "upright" in the center, with the compass in four positions around the wire. Faraday's interpretation – in modern terms – was that the compass aligned with lines of magnetic flux that circled the wire. Faraday's magnetic flux lines are shown as three lines circling the magnet.

While few scientists could make use of Oersted's results, Faraday's intuitive idea of flux led to many other experiments. Most importantly, Faraday created two electric motors: one in which the wire moves and one in which the magnet moves. The scientific community at the time could not ignore Faraday's experimental results and inventions. However, they regarded his notion of flux lines with condescension at best and ridicule at worst.

Q4. Was the scientific community justified in their denial of circular forces?

Q5. What aspects of today's science education today may hold back students, as the notion of linear forces held back Faraday's contemporaries?

## Accusations of Plagiarism

The idea of a relationship between electricity and magnetism had been in the air in Davy's laboratory. Faraday conducted his first experiments with wires and magnets somewhat after Davy and William Hyde Wollaston had attempted to conduct similar experiments. Davy and Wollaston had failed and dropped the problem, while Faraday succeeded. Importantly, when Faraday published his results, he did not acknowledge Davy or Wollaston. This enraged Davy, causing serious problems for Faraday as he strove to advance his career as an

independent scientist.

In brief, this is how the problem arose: To explain Oersted's experiment, it occurred to Wollaston that current might move in a helical fashion instead of straight through a wire (like a screw drilling into wood). Therefore, he thought the wire would spin in the presence of a strong magnetic field. Davy and Wollaston tried to observe this rotation, but could not get their experiment to work. This was not a well-known idea and Faraday did not record hearing about this work in his journals. However, the first experiments that Faraday performed on his way to the electric motor did resemble what Davy and Wollaston were trying to do. Furthermore, Faraday was working in a nearby lab when Wollaston and Davy were making their attempt, so its plausible that he overheard them.

Davy was outraged when Faraday published his work without citing him. When this came out in public, the idea of rotational motion of the wire around a magnet seemed so unique that people assumed Faraday took the idea without giving credit. After all, Davy was a great man and Faraday was his butler! This problem became critical when Faraday was later nominated to become a Fellow of the Royal Society. Many were hesitant to allow such a "plagiarist" into the Society. Interestingly, Wollaston, the real "victim" in the whole story saw no offense. Wollaston felt that Faraday's ideas were unique, and that he had succeeded where he himself had failed. He testified in support of Faraday.

Q6. How do the plagiarism standards for scientific publications compare to other disciplines, e.g., literature and journalism?

Q7. Was Faraday at fault? Why?

Q8. Wollaston never complained of plagiarism. Does this tell us anything? By the way, it was Wollaston who proved that static and current electricity are the same; he was no slouch.

Faraday was able to convince his opponents that he was not a plagiarist and did finally become a Fellow of the Royal Society. This freed him to pursue his own work.

He eventually arrived at what would be called "Faraday's Law of Induction," which states that electric current can be produced by a change in the magnetic flux through a closed circuit (he called it "cutting of magnetic curves"). Chapter 20 of Serway and Faughn is devoted to Faraday's Law and its consequences. These include electric generators (sec. 20.5). Much of the electric hardware of the industrial revolution was in-fact invented by Faraday.

Faraday attempted to generate electricity only from the magnetism and motion of the Earth. He never succeeded, but the effect was later observed in underwater telegraph cables. He waited to publish after making his initial announcement of the discovery, and was scooped by French and Italian scientists. Faraday played the plagiarism game once again, only this time he claimed he was the victim.

Q9. What external factors might have contributed to the fact that people like Faraday and Davy would have so concerned with priority over their discoveries?

Q10. Why do you think honesty is so important to scientists?

## “Math is Hard”

Faraday had little mathematical education. He knew very little algebra and trigonometry, and certainly no calculus. But it went further than that: at times he seemed to distrust mathematics.

André-Marie Ampère constructed a theory that described the behavior of the force around a current carrying wire; see fig. 1. His theory is described in modern terms in Serway and Faughn, ch. 19. The full description involves what we now call vector calculus, although Ampère’s formulation was highly complex because modern vector notation had not yet been introduced.

This was far beyond Faraday! To see how Faraday felt about that fact, we copy the following quote from Hirshfeld, pp 77-78. Faraday said, “I have really been ashamed sometimes of my difficulty in receiving evidence urged forward in support of opinions on electro magnetism but when I confess my want of mathematical knowledge and see mathematicians themselves differing about the validity of arguments used it will serve as my apology for wanting experiment.” In short, he felt that experiment trumps mathematics. Famously modest, Faraday nevertheless seems to feel that mathematics was somewhat irrelevant. Perhaps this is the pride of the master experimentalist. Maybe it is also a reaction to the feelings of his colleagues.

The problem is that scientists were slow to accept Faraday’s idea of magnetic flux lines precisely because there was no mathematical expression of this notion. He was sometimes regarded as an “idiot savant” who could construct beautiful experiments but understood little. Perhaps Faraday’s distrust was a reaction to this.

William Thompson, the Lord Kelvin, was initially irritated by Faraday’s disregard of mathematical theory, but slowly began to appreciate his notion of flux. He tried to find a mathematical expression for some of Faraday’s ideas in the 1845. But it was not until the 1860s when James Clerk Maxwell would formulate a consistent mathematical theory that included Faraday’s ideas.

Q11. Does experiment trump mathematics? Does that mean that mathematics is irrelevant? Can you think of a case study discussed in class in which a mathematical theory proved pivotal?

Q12. In the case study on the *Vis Viva* controversy, we imagined the mathematician Bernoulli valiantly battling philosophers like Voltaire over the definition of kinetic energy. His mathematically-illiterate opponents dismissed his arguments as mumbo jumbo from an effete elitist. Have the tables have turned in the case of Faraday? If you were a physicist of the day, would you trust the “flux” ideas of the outsider Faraday? What did Faraday have on his side that Voltaire and company did not?