

Faraday: Father of Electromagnetism

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When, in 1805, George Riebau, the book binder on Blandford street, London, promoted the 14 year old errand boy Michael Faraday as an apprentice, little did he realise that this is no ordinary assistant he had got. For, Faraday not only bound the books but also devoured them! He found Jane Marcet's *Conversations on Chemistry* and the scientific entries in the *Encyclopaedia Britannica* (third edition, 1797) particularly interesting. He did not stop just at reading them either. He went on to perform whatever simple experiments he could, following the instructions. One such experiment was with an electrostatic machine he constructed and this started his long and fruitful tryst with electromagnetism which was to end with the conceptualization of electromagnetic fields some four decades later. The contributions of Michael Faraday during this period laid the foundations of electromagnetism and electro-technology. And this was only a part of the sum total of his scientific contributions, the other major contributions being to chemistry. Indeed it has been said that he would have got at least six Nobel prizes for his work if the prize were to have been instituted during that time. (See *Box 1*.) However, in this article, we shall describe only his contributions to electromagnetism, that too leaving out arguably the most important of his contributions to this field, the electromagnetic induction (covered in another article in this issue, p.35). His other contributions to electromagnetism include, electromagnetic rotation (1921), magneto-optical effect and diamagnetism (1845), and fundamentals of field theory. These discoveries and their applications have changed the world we live in, in an irreversible way.

Electromagnetic Rotation

The field of electricity can be thought to have started with the flying of a kite by Benjamin Franklin when he saw sparks jump

Keywords

Faraday effect, electromagnetic rotation, diamagnetism.



from a key tied to one end of the thread, the other end holding the kite in a stormy sky. Of course, magnetism was known to mankind from much earlier days, the ancient Greeks and the Chinese being familiar with the north-south pointing property of the loadstone. The first important step towards modern understanding of electromagnetism was taken in 1820 when the Danish natural philosopher Hans Christian Oersted observed that when an electric current passes through a wire it acts as if it was a magnet. It was soon clear to many scientists in Europe that this was a major discovery and efforts were started to understand and know more about the phenomenon.

Faraday, on his part, undertook a set of experiments on September 3, 1821, by exploring how magnetized needles behaved in the presence of strong currents. To study this, he built a new apparatus, consisting of a wire put through a cork floated in water. The wire made contact with globules of mercury at both ends. Thus, now he had a wire that could rotate. However, he found that the magnets thrust the wire from side to side: lateral motion instead of rotation. But when he bent the wire and applied the magnetic field repeatedly he found that it produced a circular motion. This account sounds simple and straightforward as discoveries always do after the fact! All the same, these experiments culminated in his discovery of electromagnetic rotation – the principle behind the electric motor.

Then Faraday built a new apparatus in which a magnet was stuck upright in wax in a cup of mercury and a piece of wire was allowed to circle around it when a current was applied. Faraday also shipped a model of this experiment with instructions on what to do to other scientists so that they could reproduce his results!

Faraday Effect

Around 1843, Faraday tried to address another question – whether space was a conductor of electricity or not. Initially his experiments indicated that space conducted electricity under some

Box 1.
**Michael Faraday's Six
Possible Nobels**

- Electrolysis (1833)
- Magnetic properties of matter
- Organics, C_6H_6 (1825)
- Electromagnetic induction (1831)
- Electromagnetic fields
- Faraday effect (1845)



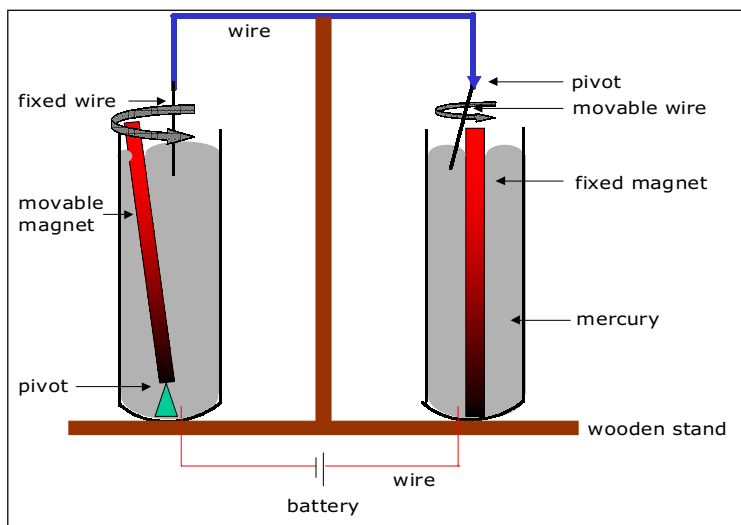


Figure 1. It is adapted from the book 'Michael Faraday and the Royal Institution' by John Meurig Thomas, reviewed in this issue by Vasant Natarajan.

nickel special, in that only they show magnetism? Do other materials also show magnetism?

At this stage, Faraday had a chance conversation with William Thomson (later Lord Kelvin), who was just twenty-one years old then, at the meeting of the British Association held at Cambridge in 1845. Thomson asked if the path of light changes while passing through an electrolyte. Faraday had tried out this experiment unsuccessfully earlier. He tried again, but still in vain. Then he thought he could try and see what would happen to light passing close to a powerful magnet. To check this out, he placed a piece of heavy glass (lead-containing glass) between the poles of a strong electromagnet and passed polarised light through the glass. When he turned the electromagnet on he found that the state of polarization of light has changed. This showed that light had been affected by magnetic force – the *magneto-optical effect*, which later came to be known as *Faraday effect*. (See Box 2.)

Diamagnetism

Another conclusion Faraday drew from the experiment mentioned above was that glass was also affected by the magnetic field. Can one demonstrate this directly, independent of the agency of light? Faraday hung a piece of heavy glass between the poles of

circumstances and in some others it behaved as a bad conductor. This was obviously an unsatisfactory situation which Faraday wanted to resolve. He started thinking about the nature of matter and proposed that instead of Daltonian atoms, atoms should be looked upon as centres of force where lines of force meet. But then, what is it that makes iron, cobalt and



Box 2. Faraday Effect

Faraday effect refers to the rotation of plane of the polarization (plane of vibration) of light beam by a magnetic field. Faraday discovered this effect in 1845 when studying the influence of a magnetic field on plane polarized light waves. (Light waves vibrate in two planes at right angles to one another, and passing ordinary light through certain substances eliminates the vibration in one plane). He discovered that the plane of vibration is rotated when the light path and the direction of the applied field are parallel. The Faraday effect occurs in many solids, liquids and gases. The magnitude of the rotation depends upon the strength of the magnetic field, the nature of the transmitting substance, and Verdet's constant, which is a property of the transmitting substance, its temperature, and the frequency of the light. The direction of rotation is the same as the direction of current flow in the wire of the electromagnet. If the same beam of light is reflected back and forth through the medium its rotation is increased each time.

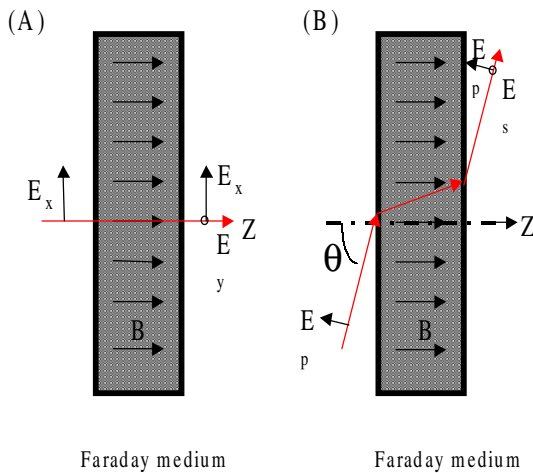


Figure 2. Faraday effect: (A) In going through a slab of magnetic material, a linearly-polarized beam with its E -field along the X -axis acquires a component of polarization along Y (the direction perpendicular to the plane of the paper). The lines of the B -field shown within the medium represent either an externally applied magnetic field or the intrinsic magnetization of the medium. (B) the effect is also observed at an oblique incidence. Shown here is a p -polarized incident beam, which acquires a s -component upon transmission through the magnetic medium.

an electromagnet and when the field was switched on, he observed that the glass moved. He tried the same experiment with many other substances and found that they too behaved similarly. Faraday concluded that this kind of magnetism was an inherent property of matter and called it *diamagnetism*.

Electromagnetic fields

One of the most important contributions of Michael Faraday to physics was his development of the concept of a field to describe magnetic and electric forces. This was conceived by him around 1845. In fact he proposed the widely used method for visualiz-



Suggested Reading

- [1] L Pearce Williams, *Michael Faraday*, Basic Books Reprinted in paperback by Da Capo Press, 1967.
- [2] DKC MacDonald, *Faraday, Maxwell and Kelvin*, Science Study Series, Anchor Books, 1964.

ing magnetic fields. Imagine a compass needle freely suspended near a magnet or an electrical current. We can trace in space the lines one obtains following the direction of the compass needle. Faraday called them *lines of force*, but the term *field lines* is now more commonly used. Faraday first suggested that current produces an electric ‘tension’ which produces an ‘electrotonic state’ or polarization of the molecules of matter and was responsible for transmitting the electric force. But after experimenting further, he preferred the concept of ‘lines of force’ to that of the electrotonic state. He also maintained that the lines of force could be made visible using iron filings.

Faraday’s experiments on electromagnetism and the concepts of lines of force led to Maxwell’s setting the theoretical foundations of the electromagnetic theory in 1873. Maxwell pays tribute to Faraday’s contribution in a unique way: “Before I began the study of electricity I resolved to read no mathematics on the subject until I had first read [Faraday]... I found that. Faraday’s methods ...begin with the whole and arrive at the parts by analysis while the ordinary mathematical methods were founded on the principle of beginning with the parts and building up the whole by synthesis.”

Faraday in fact more than made up for his lack of mathematical abilities by his powerful visual sense (both traits of people affected by dyslexia). He forged a finished image in his mind’s eye, and then broke that image down into parts that people could understand. Maxwell converted Faraday’s vision of force fields into mathematical language.

Faraday, to this day, remains a rare example of success achieved by patience, perseverance and genius over obstacles of birth and (lack of) education and fortune. From his experiments came devices which led directly to the modern electric motor, generator, and transformer. What is more, they led to a unified theoretical understanding of the phenomenon of electromagnetism. In Maxwell’s own words “*Faraday is, and must always remain, the father of that enlarged science of electromagnetism.*”

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