

## Going deeper in electromagnetism

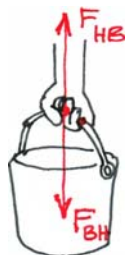
You might want to go beyond the textbook . . .

Science textbooks generally present the facts about electromagnetism as though the knowledge has always been there, if only you'd open a book or go on the internet. And science lessons often sound like that.

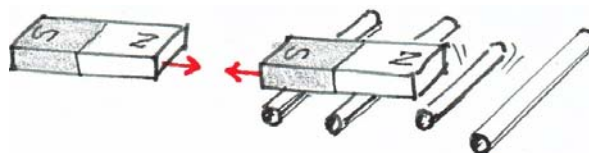
Real science is not like that. The science knowledge we now have has emerged over hundreds of years, from people struggling to make sense of puzzling observations, and looking for the words and mathematics to express their half-formed ideas.

The electromagnetic force that moves the non-magnetic aluminium foil, as you see in the video, is really strange and unlike other forces. Oersted and Ampere and other scientists of the time were puzzled by it, because it does not behave like forces that Newton had explained. To them, a fundamental principle of physics was that if two things interacted, the force between them acted along a line joining them. In the next diagrams you see what I'm trying to say about forces acting along the same line between the bodies.

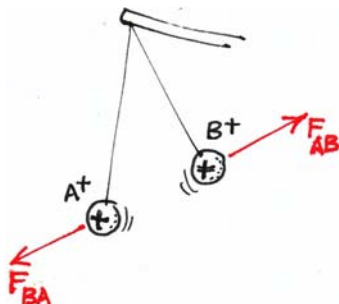
**Figure 1** The force of the bucket on the hand acts on the same line as the force of the hand on the bucket



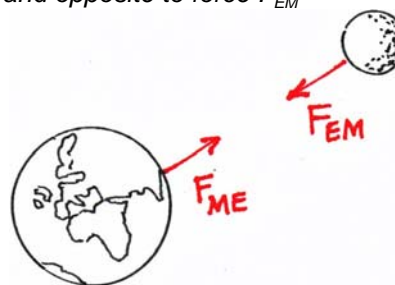
**Figure 2** The one magnet pulls the other magnet towards it, on a straight line.



**Figure 3** The two positive charges, A and B, repel each other, along the same straight line. The force of  $F_{BA}$  is equal but opposite to force  $F_{AB}$ .



**Figure 4** The Earth and the Moon attract each other, along the same straight line. Force  $F_{ME}$  is equal and opposite to force  $F_{EM}$



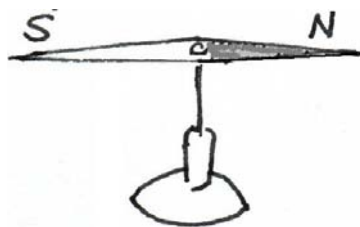
But now here was a force that acted **at right angles** to **both** the current direction **and** the magnetic field direction. Had Newton been wrong? If Newton had been wrong, what knowledge could they be sure about?

## Here's a story you can tell people in the workshop

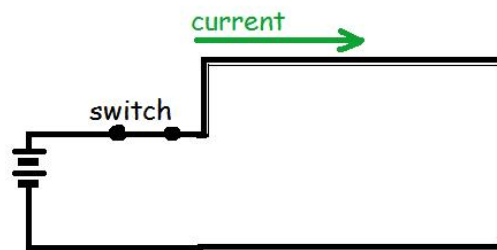
For many years during the early 1800s the Danish physicist Hans Christian Oersted tried to find a connection between the forces of electricity and magnetism. Oersted had a philosophical belief that all the forces of nature must somehow be related and that one day scientists would be able to discover the connections between them<sup>1</sup>.

In one of his experiments he would place a loop of copper wire around the magnetic needle of a compass, as you see in **Figure 7**. The compass needle naturally lay in the North-South direction due to the Earth's magnetic field. He imagined that when he closed the switch the current in the wire might somehow pull one of the poles of the compass needle toward it, but the needle did not move at all.<sup>2</sup>

**Figure 5** This is the kind of compass needle he used. It swings freely on a sharp pin.



**Figure 6** This is the kind of wire loop that he used.

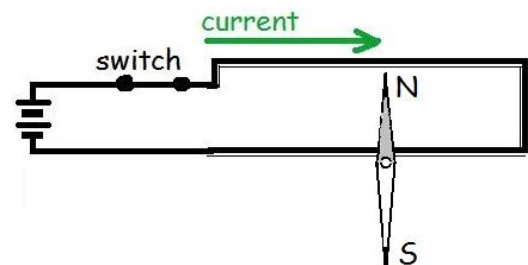


However, one evening in April of 1820, he gave one of his lectures on electricity, and showed the students that the compass needle did **not** respond to the current when it was placed as you see in **Figure 7**. The needle just stayed pointing North-and-South in the Earth's field. It seemed that there was no connection between electric current and the forces you get from magnets.

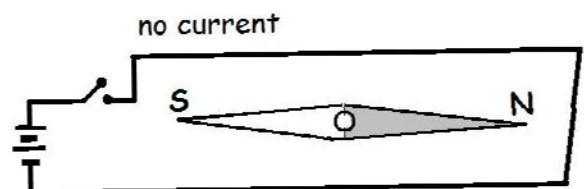
Most of the audience left but a few students stayed on to talk with Oersted. Perhaps one of them suggested it, but Oersted moved the coil so that it also lay North-and-South.

He didn't expect anything to happen, because scientists all thought that forces acted along the straight line between the inter-acting bodies, as you remember from the examples in **Figure 1** to **Figure 4**. After all, if both poles of the magnetic needle were already in the plane of the coil, how could the coil be expected to exert any deflecting force on the poles?

**Figure 7** The compass pointed North, due to the Earth's magnetic field, and the coil lay East-West. The compass did not move when he closed the switch.



**Figure 8** The compass still pointed North, but now the coil also lay North-South. You are seeing this apparatus from the top view, looking downwards.

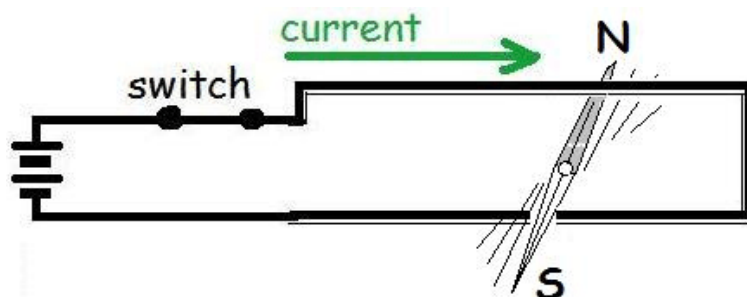


<sup>1</sup> In fact, scientists have now shown that there are just four fundamental forces: gravity, the electric force and two forces that act inside the nuclei of atoms. They have shown that the magnetic force is a result of the electric force on electrons, but thus far, nobody has been able to show how gravity could be connected to the other forces.

<sup>2</sup> You could ask the group to explain why the needle did not move. Of course the current was causing a magnetic field around the wire, but the compass needle was already aligned with the direction of the field and so the magnetic force did not move it in any new direction.

Nevertheless, he moved the coil to lie as you see in **Figure 8**, and closed the circuit. And made one of the most remarkable and important discoveries in the history of science. The magnetic needle suddenly turned to the East-West position, as in **Figure 9**.

**Figure 9** *The compass needle swung till it was at right angles to the plane of the coil. You are again seeing this from above.*



Oersted had discovered the link between electricity and magnetism, but it was of a completely unexpected character.

The current created something invisible but real that exerted a force on iron. The direction of the force was not in the direction of the current but at right angles to the current.

It took scientists many years to develop a theory that was good enough to calculate and predict the forces that an electric current generates.

Michael Faraday chose the word "field" to describe the space around the current, in which a piece of iron will feel a magnetic force.

In 1876 James Clerk Maxwell published a book that had four equations that describe the relationship between electric and magnetic fields. His four equations are the mathematical theory of electromagnetism.

#### **"Something deeply hidden"**

Einstein liked to tell this story about his childhood. He said he saw a "wonder" when he was four or five years old: a magnetic compass. No matter which way he turned, the needle always swung to point North, guided by an invisible force. This profoundly impressed the child. He later wrote that the compass convinced him that there had to be "something behind [the things we can see], something deeply hidden."

The electromagnetic force was unexpected and its explanation was "something deeply hidden". Nowadays we teach it as if it were easy to discover.

Perhaps we should let our students know how hard it was for those early scientists to understand what they were finding.