RADIO MAGiC

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The Road to Radio—Part 4

The agreement of this law with nature will be better seen by repeating the experiments than by a long explanation.—H. C. Ørsted

Introduction

The year is 1813. Our quantum jump drive, stealth-cloaked Humvee has accumulated years of battlefield damage from shot and shrapnel because of the ongoing Napoleonic Wars, but we have arrived safely in Copenhagen, Denmark—finally.

Genesis

Hans Christian Ørsted (Figure 1, next page) recently published *Ansichten der chemischen Naturgesetze, durch die neuern Entdeckungen* gewonnen (View of the Chemical Laws of Nature, Derived from Recent Discoveries), but it is widely known and read because of Marcel de Serres' translation *Recherches sur l'identité des forces chimiques et électriques* (Research on the Identity of Chemical and Electrical Forces). The chapters of our interest explore static or common electricity—a surface charge phenomenon, dynamic electricity (galvanism) created by electrochemical reactions and magnetism. Ørsted notes that although static-charged objects affect both magnetic (steel, iron, nickel, etc.) and non-magnetic (copper, paper, hair, etc.) objects, their influence did not appear to stem from any inherent magnetic force of their own, which requires further investigation.

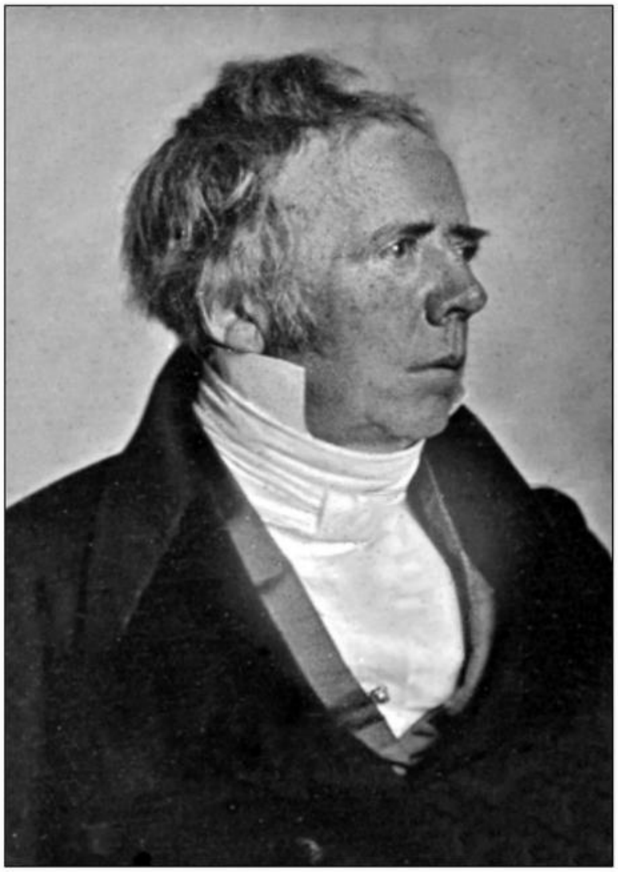


Figure 1: Hans Christian Ørsted Portrait
Daguerreotype of Ørsted, age 65. Credit: Johann Peter Dinesen, 1842.

Recherches introduced Ørsted's new “dynamic system”, a modification of philosopher Immanuel Kant's metaphysical theory of “dynamism”: that only two forces (attractive and repulsive) constitute all matter. Ørsted posits that Kant's forces, besides creating matter, interact with each other in various degrees of “conflict”, and this causes all observable phenomena. This conflict can manifest itself as attraction or repulsion, expansion or compression, and balance or imbalance. For example, system equilibrium occurs when the two forces are balanced, while various degrees of disequilibrium affect a material’s conductivity as it becomes more unbalanced.

Poorly balanced conductors restrict force movement, resulting in excess energy accumulation (friction) that creates heat, light and combustion. He points out the numerous similarities among the static electric, galvanic and magnetic forces, which suggests that some undefined relationship exists. While stopping short of explicitly stating their interconnectedness, Ørsted proposes that galvanism could be a mediator between static electricity and magnetism, implying a hierarchical force spectrum exists in nature. However, he excludes the magnetic and gravitational forces because, while both act at a distance, they differ significantly: magnetism has polarity with both attractive and repulsive properties, but various materials are impervious to its effects. In contrast, gravity has no polarity, is an attractive-only force and can easily pass through and affect all matter.

Much like his late mentor Johann Wilhelm Ritter, Ørsted prioritized analogies and abstract concepts over any empirical proof. This resulted in harsh criticism of *Recherches* as being overly speculative with obvious Naturphilosophie undertones. This criticism is openly expressed in an anonymous review published in the widely read *Allgemeine Literatur-Zeitung* (General Literature Journal):

> "The author's theory has significant flaws and lacks practical applications. Since the author derives matter in general, and associated effects from only Kant's two forces, it is quite striking that he says nothing about the attractive force of gravity and the consequences that would follow from his theory. One can only view the work as hastily thrown-together thoughts that require a more careful dissection to earn the approval it perhaps deserves."

Ørsted's past association with Ritter and Naturphilosophie has put the "mark of Cain" on him in Kantian-dominated academia. Whatever he did or said would always be taken with a considerable amount of sceptical salt.

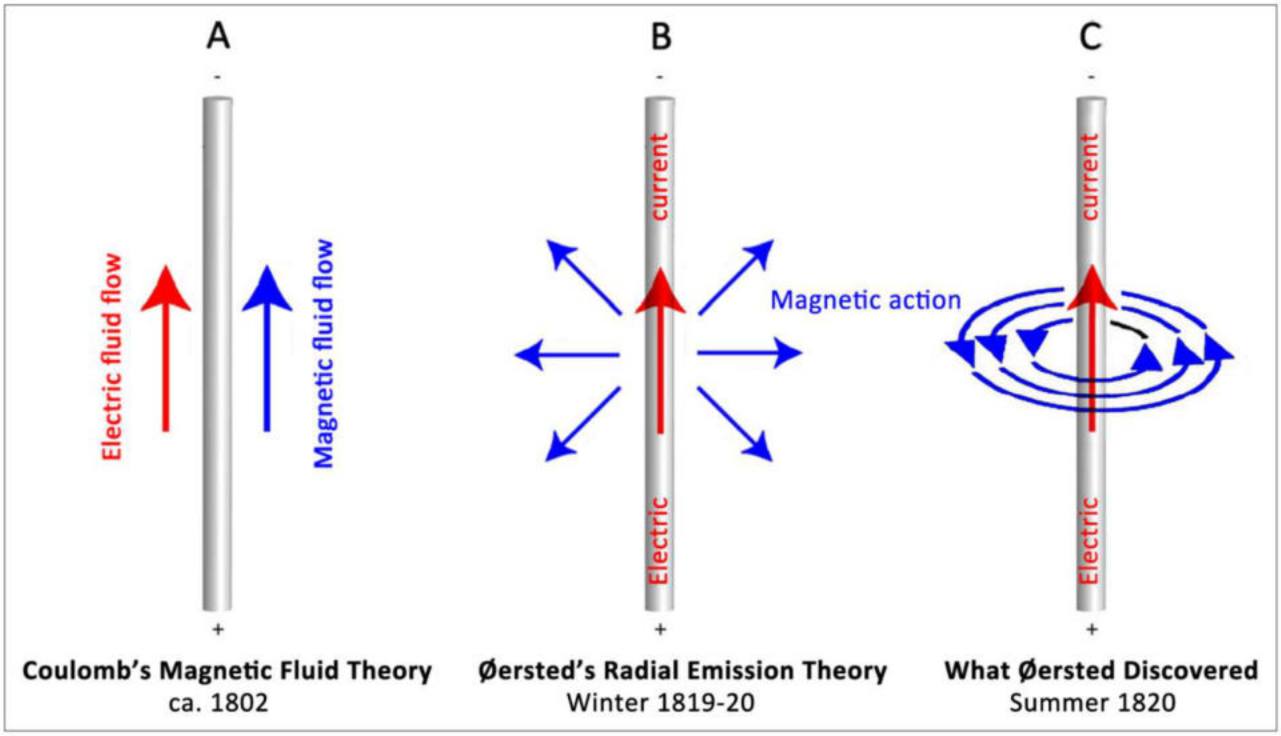
Note 1*: The geologist, naturalist and writer Pierre Toussaint Marcel de Serres de Mesplès' translations and writings helped bridge diverse scientific communities across Europe, fostering the faster exchange of ideas.*

Morphosis

Jumping ahead a few years, Ørsted has modified his dynamic system to include magnetism by introducing two new hypotheses (Figure 2, next page):

1. When an electric current is produced, the heat in a conductor is created by the electrical conflict between Kant's two dynamic forces, which also creates an internal magnetic action (heat hypothesis).
2. When a critical amount of the electrical conflict is exceeded, the magnetic action radiates outward from the conductor in all directions like heat and light (radial emission hypothesis).

Figure 2: The Forks in the Road to Electromagnetism
Conventional current flow (positive to negative, based on Benjamin Franklin's single-fluid theory) was used to determine the spatial orientation of magnetic fluid flowing through a conductor or by the magnetic action around it.



However, sometime over the winter of 1819-1820, Ørsted knew that something was wrong, but he will never reveal the when and how. The magnetic action radiated outward as he theorized, but not in a linear fashion (straight lines)—it was circular! It must be experimental error! However, over several months of carefully conducted experiments (60+), Ørsted learned more about the character and behaviour of this unknown phenomenon until he was—without any doubt—convinced that a serious force flaw existed in classical (Newtonian) physics. But when you strike at the king—the great Sir Isaac Newton—you had better not miss!

On July 21, 1820, at considerable expense and risk to his reputation, Ørsted distributed a nicely bound and printed four-page Latin treatise called *Experimenta circa effectum conflicts electrici in acum magneticam* (Experiments on the Effect of the Conflict of Electricity on a Magnetic Needle). This is a simplified translation of its major points:

“The experiments detailed here were conducted during the winter while lecturing on electricity, galvanism and magnetism. Initial experiments seemed to show that a magnetic needle could be deflected using a galvanic apparatus, specifically with a closed (not open) galvanic circuit (a point of contention among some prominent physicists of the time).

However, because the initial apparatus was inefficient and yielded indistinct results, I enlisted the help of my colleague Esmarch (a councillor of justice) to improve the setup and expand the experiments. We also had the assistance of several other notable scientists as witnesses and collaborators: Wleugel (a knight and governor), Hauch (renowned naturalist), Reinhardt (professor of natural history), Jacobsen (professor of medicine) and Zeisel (an experienced chemist and philosophy doctor).

The galvanic apparatus consisted of twenty rectangular copper containers, each measuring twelve inches in length and height, and just over two inches in width. Each container held two inclined copper plates and a zinc plate suspended in a solution of sulfuric and nitric acids. Smaller apparatus could be used provided they could heat a metallic wire. The opposite ends of the apparatus were connected by a metallic wire (henceforth referred to as the connecting wire or conductor). The observed effect is referred to as an electrical conflict. The connecting wire was positioned horizontally above the magnetic needle, parallel to it. The needle deflected towards the west under the part of the wire receiving the negative electricity from the galvanic apparatus. The deflection angle decreased with increasing distance between the wire and needle.

The experiment was repeated with the wire moved to the east and west of the needle, with other materials replacing the wire. The effects were unchanged except for intensity. The material (platinum, gold, silver, brass, iron, lead, tin, mercury) used in the conductor had little impact. The effect was observed even through materials such as glass, metal, wood, pottery and liquid. The key observation is that the needle's deflection was not due to simple attraction or repulsion, but is a complex interaction.

The pole above which negative electricity enters deflects westward; the pole below deflects eastward. Additional observations were made on needle behaviour under different orientations of the wire, finding patterns in how the needle would move and tilt when the wire was positioned perpendicular or at angles.

The electrical conflict only acts on the magnetic particles of matter. All non-magnetic bodies appear penetrable by the electrical conflict, while magnetic bodies resist its passage.

The electrical conflict is not contained within the conductor alone but extends into the surrounding space.

The electrical conflict moves in spirals that extend into the surrounding space."

Ørsted shrewdly sent copies to specific scientific academies and open-minded colleagues for peer review to overcome academic "inertia". Among these were:

- Det Kongelige Danske Akademi (Danish Royal Society)
- The Royal Society (of London)
- L'Académie royale des sciences (French Royal Academy of Sciences)
- Die Deutsche Akademie der Wissenschaften (German Academy of Sciences)
- **Jean-Baptiste Biot, Félix Savart and André-Marie Ampère**
  Physicists and mathematicians. Within three months, the Biot-Savart Law was derived. It describes the magnetic field generated by an electric current at a specific point in space surrounding the conductor. Working with Biot and Savart, Ampère took a different approach, presenting his initial findings in early September (the Circuital Law). Ampère also came up with the handy "Right-Hand Rule" (Figure 3, next page), along with the term "intensité", symbol 'I', describing the strength of electric current flow. But he disagreed with Ørsted's conflict of forces theory. Ampère believed electric current was created by moving electric charges, generating a circular magnetic action, influence or effect as they flowed in conductors.

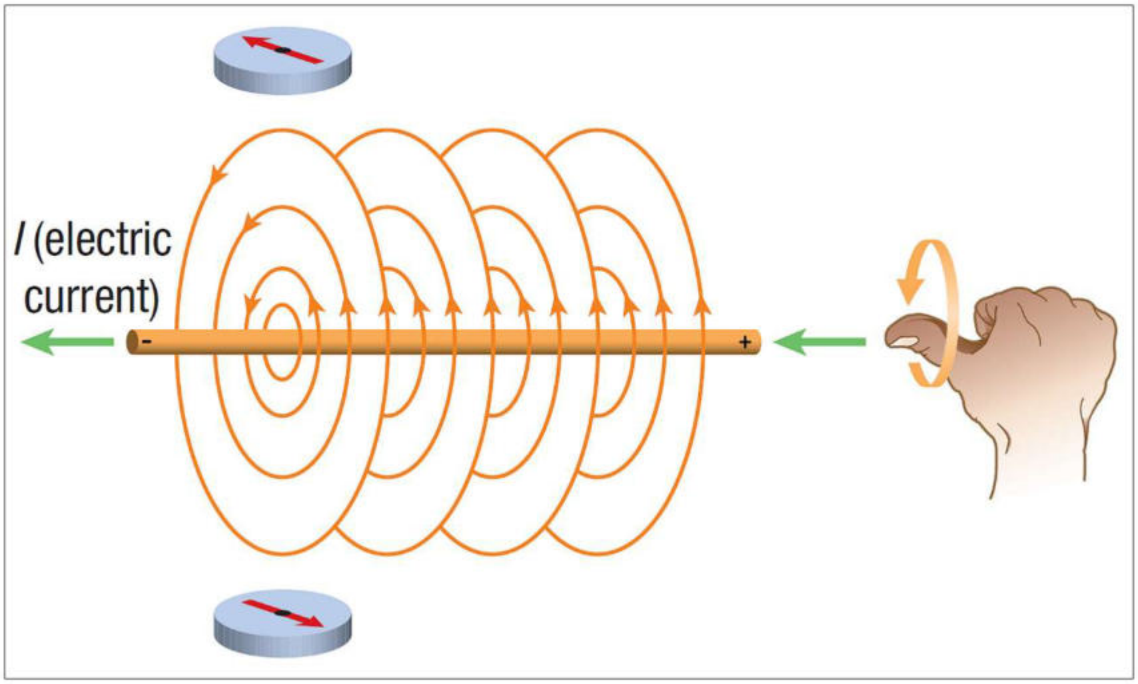


Figure 3: Ampère's Right-Hand Rule
This applies to conventional (positive to negative) current flow only. Credit: *Physics 12-8, Magnets and Electromagnets*, Nelson Education, 2012.

- **Johann Schweigger**
  Physicist and chemist who invented the first practical application of the discovery, which he called a "multiplicator". Ampère refined and it. Later renamed "galvanometer", in honour of Luigi Galvani (Figure 4, next page).
- **François Jean Arago**
  Physicist, mathematician and astronomer who demonstrated Ørsted's experiment to members of the Académie. So disbelieving of this "German reverie" (fantasy or delusion), Arago was called back to repeat them several more times (Figure 5, next page).
- **Humphry Davy (his assistant was Michael Faraday)**
  Both pioneering electrochemists. *Experimenta* had such a profound effect on Faraday that he taught himself physics and later became one of the greatest (self-taught) experimental physicists of 19th century.
- **Christopher Hansteen**
  Geophysicist and astronomer, best known for his work in early geophysics and geomagnetism. He is a former student and lab assistant of Ørsted's. More about him later.

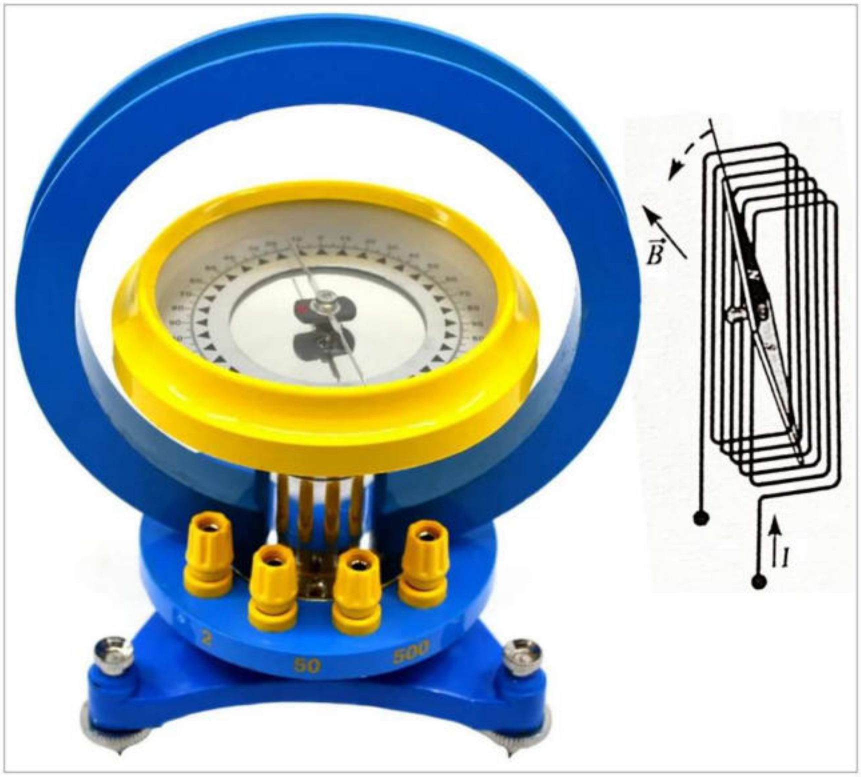


Figure 4: Galvanometer (Modern Version)
Properly called a “tangent galvanometer”, it is mainly used today for classroom demonstrations of the Tangent Law of Magnetism. It can detect and measure minute magnetic and geomagnetic fields, as well as steady electric currents.
Credit: Eisco Labs.

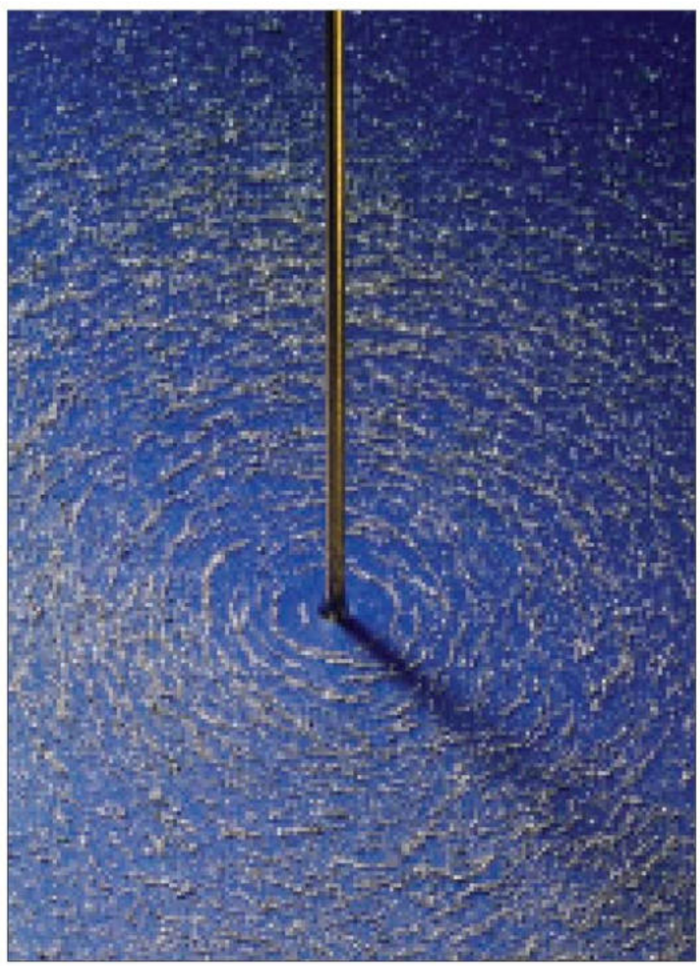


Figure 5: Arago Demonstrates Circular Magnetic Action
Frustrated by obstinate Académie members, Arago used a vertical metal rod with cardstock pushed down the center and sprinkled iron filings on the cardstock. When the ends of the rod were connected to a galvanic battery—"Messieurs, et voilà!”
Credit: *Physics 12-8, Magnets and Electromagnets*, Nelson Education, 2012.

Unfortunately, Ørsted wrote his treatise using complex and arcane Latin, perhaps trying to sound majestic or poetic. This caused difficulties with its proper translation into other languages as well as in reproducing and understandings his experiments. One recipient tersely wrote back to him, “Why have not you just written your report in plain German and French, languages you have mastery of, or in normal Latin?!”

Note 2: *He did not include diagrams, which would have really helped. Figure 6 is one (of many) drawn in his notebook. Also included are pictures of my two experiments (Figures 7A and 7B, next page).*

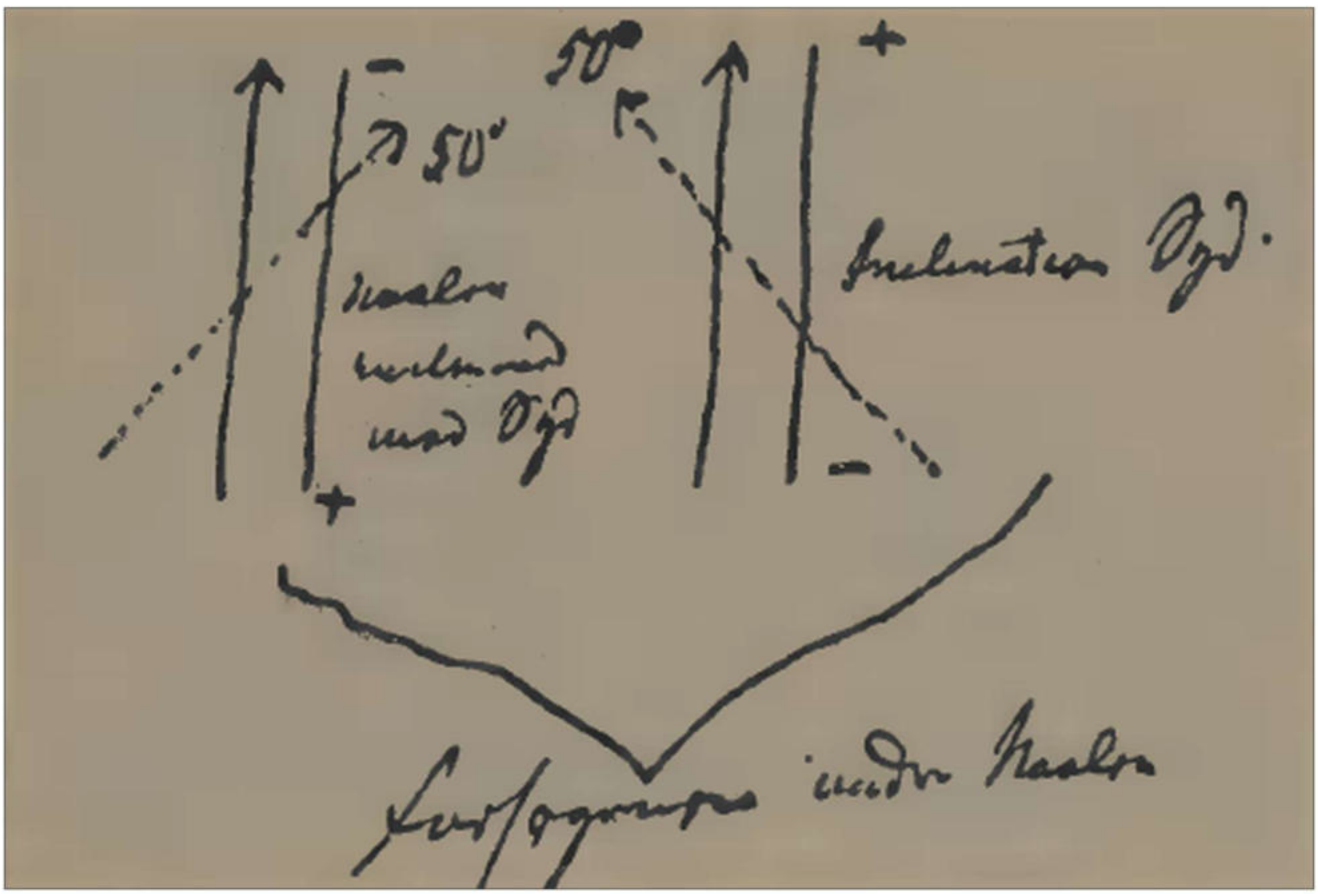
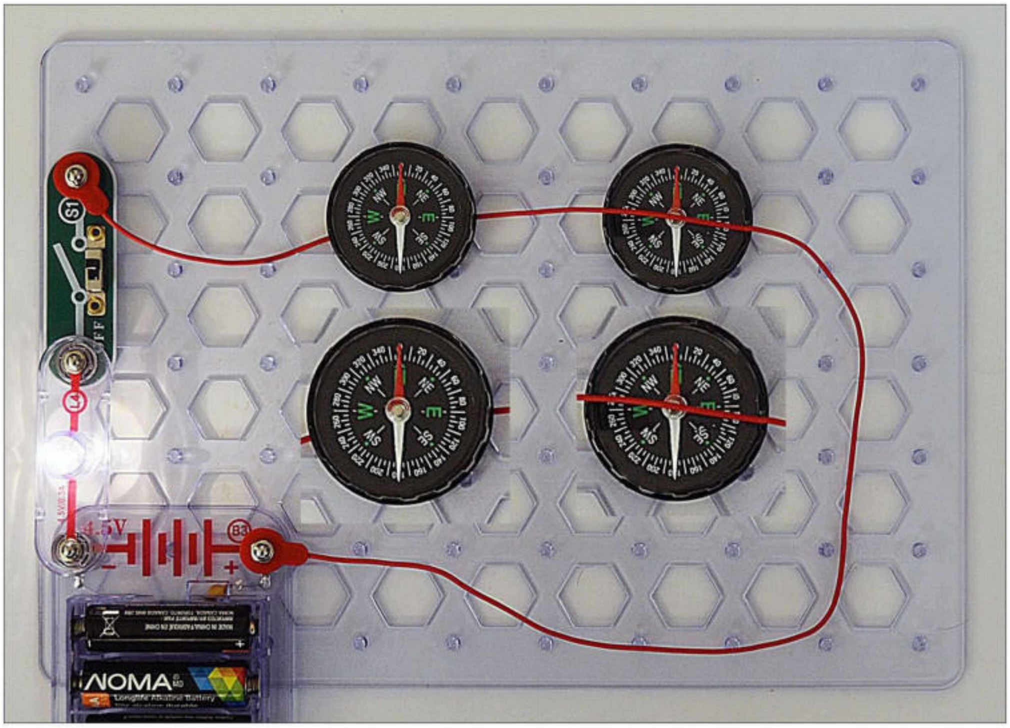


Figure 6: Compass Needle Deflection around a Wire Caused by Electric Current
Credit: H. C. Ørsted, 1820.



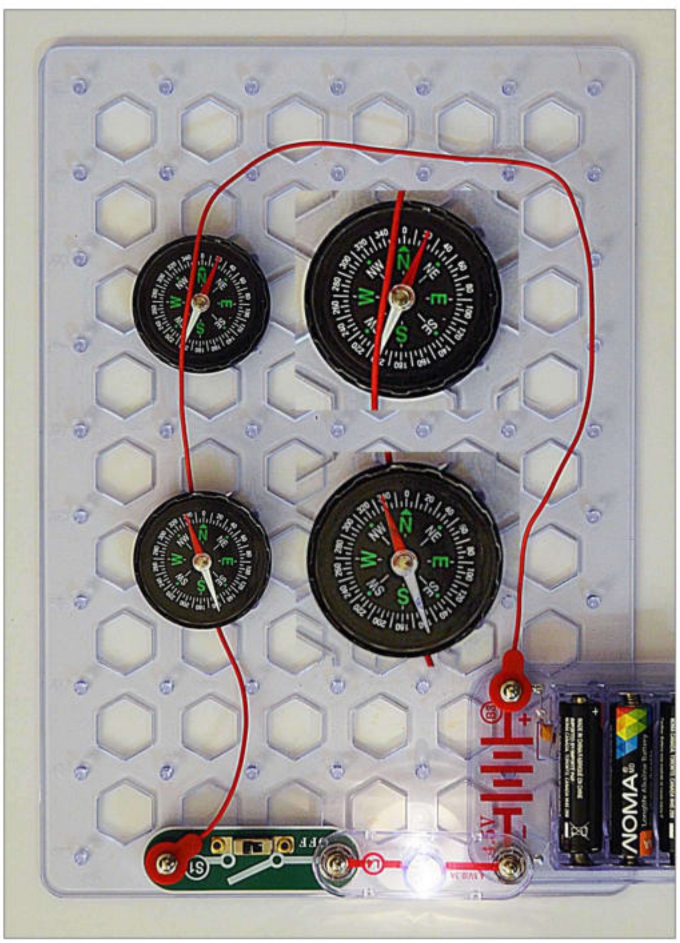


Figure 7A: Experiment I (Top)
There is no observable magnetic effect when a current-carrying conductor is placed perpendicular to magnetic compasses, aligned to magnetic north, using this over-and-under wire example (instead of changing battery polarity). Enlarge compass face inserts added for clarity.

Figure 7B: Experiment II (Left)
But when a current-carrying conductor is placed parallel to magnetic compasses, first aligned to magnetic north, a very noticeable deflection of the magnetic needles is observed using this over-and-under wire example (instead of changing battery polarity). Enlarged compass face inserts added for clarity.

Breaking (Electromagnetic) Bad

Early 19th-century scientists treated the common or static electric, galvanic and magnetic forces as well as the force of gravity, as linear reactions acting instantaneously (or nearly so) over a distance, so the mathematical and conceptual framework to satisfactorily explain Ørsted's discovery did not exist for a circular force acting at right angles (orthogonally)! The reaction of most physicists was of total disbelief and incredulity, even suspecting that some sort of trickery was involved! And so the sharpened "poison pen" or quill of Ludwig Wilhelm Gilbert, editor of *Annalen der Physik*, a harsh critic of any speculative science—especially Naturphilosophie—returned with a vengeance. Years earlier, he had led the vitriolic editorial attacks against Ritter that effectively ended his career (Part 2 refers). Was this another one of his "whimsicalities" resurrected by the protégé? Gilbert was also very sceptical of Ørsted's treatise and the dynamic theory it was based upon. Because of this, he called it a chance or accidental classroom discovery, more so because Ørsted's own theory did not predict a circular force acting at right angles (nor did anyone else). In this sense, he was quite correct that it was an accidental discovery and totally unexpected.

Experimenta sparked a far more controversial article by Pietro Configliachi, editor of the *Giornale di Fisica* (Journey of Physics). He revealed the earlier but largely ignored works of Jean-Baptiste Mojon and Gian Domenico de Romagnosi. He pointed out that their experiments had detected two distinct phenomena: Mojon showed that an electric current traversing steel needles magnetized them, while Romagnosi observed an effect on an external magnetic needle (magnetic compass) not traversed by an electric current. In the case of Romagnosi, Configliachi referred to the two Italian newspaper accounts announcing this discovery in 1802, including his application for a Prix du galvanisme as well as Giovanni Aldini's 1804 *Essai théorique et expérimental sur le galvanisme* (Theoretical and Experimental Essay on Galvanism), describing Mojon's experiment referencing a "Romanesi" (Romagnosi mistranslated), including the fact that Ørsted had several meetings with Aldini in Paris in 1803, and had also contributed material to *Essai*. Had he not read it in 1803 or in the intervening years?! Configliachi was inferring prior knowledge without proper credit being given—plagiarism without actually using the word—furiously fanning the flames of opposition against Ørsted.

In June 1821, the King of Denmark stepped in and ended the controversy by knighting Ørsted, immediately elevating his social status, making him a Danish national hero and a royal favourite. The former protégé of the German Ritter (the “knight”) was now a de facto Danish ridder (a knight). And according to the Rules of Chivalry, any further public attacks on Ridder Hans, whether personal or professional, were also viewed as attacks on the King himself. Because British and European royal families were interrelated by blood, and their benevolent patronage was the lifeblood of all royal academies, societies and prestigious universities from where most academics obtained their employment and/or research grants, it was now very wise and prudent to “let it go”.

Ørsted had already been awarded the Royal Society's prestigious Copley Medal and foreign membership because of Davy and Faraday’s support in late 1820. Napoleon’s Prix du galvanisme no longer existed after the Bourbon monarchy restoration in 1815, but the Institut de France awarded the now Ridder Hans 3,000 gold francs (the old secondary prix for lesser achievements, a sly slight). He was very quickly showered with many other foreign awards, honours, memberships in academies, along with all expenses paid invitations to come visit and lecture at academies and universities across Europe and Britain. However, most members of the Académie royale des sciences felt humiliated by this “obscure German chemist” (an obvious insult) who had bested the greatest minds of France—and singlehandedly at that! They dragged their heels before granting him membership in 1824.

Note 3: *The argument was (and has always been for over 200 years) whether Romagnosi’s noted actions of his magnetic compass needle were the result of static electricity or dynamic electricity (galvanism) or even a defective compass. The agreed-upon ruling was “static electricity”. But I believe that it was dynamic electricity because of my Part 3 article experiments plus this new one using an actual galvanic battery of the period albeit a scaled down version (Figure 8, next page).*

Figure 8: The "Romagnosi Effect"

This Eisco (10-cell, 10-volt) voltaic/galvanic electrochemical battery is operating in the open-circuit mode (not connected to an external circuit); therefore, no external electric current can flow. Yet "something" is affecting the compass needle—first aligned to magnetic north—and pulling it to the north-north-east. This battery uses pure copper and zinc discs (both non-magnetic) and felt washer insulators mounted on a plastic spindle and base. More importantly, there was no compass needle deviation until after the felt washers were dry-soaked in acetic acid (5% vinegar solution) began a strong electrochemical (redox) reaction. This is definitely not static electricity! Romagnosi noted that even when his much, much larger galvanic battery was in the open-circuit condition, there was a very strong electrochemical reaction eating away the zinc plates. This is an indication of an internal electric current flowing, and whenever is an electric current, there is also electromagnetism. Therefore, I believe this is empirical proof that electromagnetism was first discovered in 1802 by Romagnosi and not in 1820 by Ørsted. To my surprise, I cannot find any record of anyone actually repeating Romagnosi's experiment. It seems that "everyone" just assumed that the original ruling made two centuries ago was correct and required no further investigation!

Aftermath

Despite numerous attempts—positioning magnets near, above and below wires—even coiling wires around bar magnets—generating an electric current using static magnetism was impossible. No one, including Ørsted, understood the crucial role of relative motion because another concept was lacking in 1820 physics—force symmetry—as it applied to electromagnetism. That the electric and magnetic forces are actually two aspects of the same fundamental force; that changes in one can produce changes in the other will hide in plain sight for another decade. Consequently, research focused on studying and quantifying the magnetic forces between electric currents, along with heated debates about the fundamental nature of electromagnetism: Was it Ørsted's conflict of forces or Ampère's mechanistic mathematics?

By 1825, the overwhelming fame, constant expectations, lack of privacy and endless demands of correspondence and public appearances along with still lingering silent suspicions of plagiarism (from Romagnosi), all weighed heavily on Ørsted. Realizing his conflict theory was taking him down a dark, deserted, lonely cul-de-sac, he abandoned experimental physics altogether and returned to his first love—chemistry. He also channelled his efforts into improving the Danish science and technology educational system, founding the Københavns Polytekniske Læreanstalt (Polytechnical Institute of Copenhagen) in 1829, serving as its first rector until 1851 (his death). It is now part of Danmarks Tekniske Universitet or DTU (Technical University of Denmark). He was also a talented amateur poet and published several of his Naturphilosophie-inspired works (e.g. *The Soul in Nature*, *The Airship*, *Visions of Spirits*). And, in 1830, Ørsted belatedly and finally acknowledged Romagnosi's priority in the fifth and final English-language version of *Experimenta*, published in the British *Encyclopædia Metropolitana*:

> "Neither the French Institute, nor the other learned societies, nor the numerous natural philosophers took any notice of Romanesi's work, which would have accelerated the discovery of electromagnetism by sixteen years."

Tellingly, the "sixteen years" was referenced from the year 1804 when Aldini's *Essai* was published, and he also used the misspelt name "Romanesi". So he had read *Essai*!

Postscript
Decades later, Christopher Hansteen sent a letter, dated December 30, 1857, to Michael Faraday, which, for some inexplicable reason, contained a detailed, seemingly first-person narrative but did not provide any specific date(s) for the supposedly witnessed event—a definite red flag:

> “Professor Oersted was a man of genius, but he was a very unhappy experimentator; he could not manipulate instruments. He must always have an assistant or one of his auditors, who had easy hands to arrange the experiment; I have often in this way assisted him as his auditor. Already in the former century there was a general thought, that there was a great conformity and perhaps identity between the electrical and magnetical force; it was only the question how to demonstrate it by experiments. Oersted had tried to place the wire of his galvanic battery perpendicular (at right angles) over the magnetical needle, but remarked no sensible motion.
>
> Once, after the end of his lecture, as he had used a strong galvanic battery in other experiments, he said, ‘Let us now once, as the battery is in activity, try to place the wire parallel with the needle.’ As this was made he was quite struck with perplexity by seeing the needle making a great oscillation (almost at right angles with the magnetic meridian). Then he said: ‘let us now invert the direction of the current’, and the needle deviated in the contrary direction.
>
> Thus the great detection was made; and it has been said, not without reason, that ‘he tumbled over it by accident’. He had not before any more idea than any other person, that the force should be transversal. But as Lagrange has said of Newton in a similar occasion: ‘Such accidents only meet persons, who deserve them.’”

We do know from 1816 to 1825, Hansteen lived in Christiania (now Oslo), Norway, and was very busy in his own right. He sent only a handful of letters from 1810 to 1820 about his work (but no planned visits) to Ørsted, who never replied, until:

> “Copenhagen, July 22nd, 1820
>
> I am extremely pleased to be able to send you, my highly esteemed friend, the enclosed report on the magnetic effects of galvanism. It seems to me that the consequences of my discovery could be very far-reaching. I would soon like to hear your opinion on this.
>
> Yours truly,
> H. C. Ørsted”

Note 4: *Modern scholars dismiss this letter as either being apocryphal or “retrospective mythmaking”. But Cui bono?—Who benefits? Faraday was highly suspicious and never replied. No bona fide first-person witness published accounts of Ørsted's discovery, written by any of his students in 1820 (predating Experimenta) or even years later, are known to exist. There are no known personal journal or diary entries. There are no claims of, “I was there the day Professor Ørsted discovery electromagnetism!”*

My Final

Whether Ørsted's revolutionary discovery resulted from having prior knowledge, a serendipitous accident, or “a prepared mind” combined with meticulous experimentation does not really matter. What does matter is that he had the courage of his convictions to cast the die and cross the Rubicon of physics. The end justifies the means.—73

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