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Historical Article

Michael Faraday: a virtuous life dedicated to science

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Abstract. We review the main aspects of the life of Michael Faraday and some of his main scientific discoveries. Although these aspects are well known and covered in many extensive treatises, we try to illustrate in a concise way the two main "wonders" of Faraday's life: that the son of a poor blacksmith in the Victorian age was able to become the director the Royal Institution and member of the Royal Society, still keeping a honest and "virtuous" moral conduct, and that Faraday's approach to many topics, but mainly to electrochemistry and electrodynamics, has paved the way to the modern (atomistic and field-based) view of physics, only relying on experiments and intuition. We included many excerpts from Faraday's letters and laboratory notes in order to let the readers have a direct contact with this scientist.

Keywords. Faraday, history of science, biography.

I have far more confidence in the one man who works mentally and bodily at a matter than in the six who merely talk about it [1]

LIFE

Michael Faraday was born in 1791 in the village of Newington, now part of the urban area of London. His father worked as a blacksmiths and his family was able to allow him but the most basic education. At the age of 14 he had to find a job to ease the burden on his family.

He was hired in a London bookshop, run by Mr. George Riebau (Figure 1). Here he had to carry out the activities of an apprentice bookbinder and seller of books and newspapers for a period of seven years.

This work enabled Michael Faraday to read many books, that passed through the bookshop of Mr. Riebau. In particular, as he wrote remembering his early experiences, he was greatly impressed by reading the book "Conversations in Chemistry" by Prof. Marcet and the treatise on electricity that appeared in the *Encyclopaedia Britannica* [3].

These readings inspired him the idea of simple electrochemical experiments, building elementary electric generators (batteries). These simple

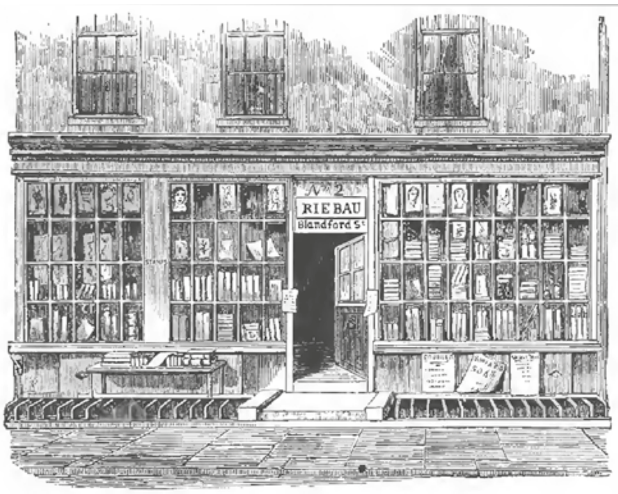

Figure 1. The bookshop of Mr. Riebau in London [2].

Figure 2. Sir Humphry Davy [4].

experiments were carried out by Faraday almost simultaneously with those conducted in Italy by Alessandro Volta and Luigi Galvani, who are recognized as the first discoverers of the electrodynamic effects (the Voltaic pile and experiments on animal electricity, respectively). In particular Faraday, at the age of 21, managed to discover the principles of electrolysis, which will be the basis of the great electrochemical developments in the nineteenth century.

Among the visitors of the library of Mr. Riebau there was one of the greatest British scientists of that time, Sir. Humphry Davy, the director of the Royal Institution of Great Britain (Figure 2).

This British scientific institution was founded in 1799 after the initiative of Lord Rumford (Benjamin Thomson, industrial, scientist and adventurer) with the aim of improving the technical skills of English scientists, still too much limited by the traditional academic-oriented training provided by the main British universities such as Cambridge and Oxford. Lord Rumford was deeply concerned by the gap accumulated by the English science with respect to the French one, in the decades between the Revolution and the rise to power of Napoleon. The French scientific institutions experienced a deep cultural revolution, no less impetuous than the political revolution, leading to a synthesis of modern science and technology. In order to find a comparable event in the western history, one has to go back to the Hellenistic period, when a huge number of scholars, among which one can mention Archimedes, Anaximander and Ptolemy, built the foundations of our scientific knowledge.

The institutional and the social importance attributed to the science in the post-revolutionary French society is definitely a factor of absolute modernity, that influenced, through the spirit of admiration and imitation, the entire European continent and also the Great Britain, mainly for a justified fear of its principal political and military competitor.

The defeat of Napoleon and the subsequent restoration contributed to lowering the tension. The directorship of the Royal Institution passed to H. Davy, who modified the ambitious program of that institution, which since the very beginning had been devoted to the training of high quality technicians (corresponding to nowadays engineers). One of his goals was to present science as an object of amusement for the educated public, which he amazed with spectacular experiments prepared in his laboratory.

This notwithstanding, Davy remained a great scientist and, once paid the fee of being a brilliant disseminator appreciated in all the cultural clubs of the capital, he devoted his time with rigor and continuity to the activities of a true researcher and teacher. Faraday, during his apprenticeship, was admitted to attend the lessons by Davy. Actually Mr. Riebau recommended him to the great British chemist, who was impressed by Faraday's ability as a student, not only in preparing the notes of his lectures, but also in decorating them with useful illustrations and comments.

Obviously Faraday, who was a skillful bookbinder, bound the notes in a very elegant fashion, and offered them as a present to Davy. All these facts convinced

Figure 3. Michael Faraday in his thirties [5].

Figure 4. Alessandro Volta presents his battery (Voltaic pile) to Napoleon [6].

Davy that Faraday was such a brilliant young man so fond of science that he hired him, at the end of his apprenticeship with Mr. Riebau, in the Royal Institution. One of the members of the Advisory Board suggested Davy to propose Faraday being hired as a cleaner of the laboratory glassware. Faraday accepted the offer, and this was the beginning of his scientific career in the Royal Institution, in 1813. There he spent the remaining 45 years of his scientific life, first as a chemical assistant of Davy, then as his first collaborator and finally as his successor at the head of this institution.

We want to point out that only the extraordinary scientific achievements in his career enabled Faraday to reach career milestones and a social position otherwise unattainable for the son of a poor blacksmith, moreover member of the Sandemanian religious confraternity, which did not recognize the religious authority of the Anglican church (Sandemanians considered themselves as a part of the Reformed Church of Scotland). Just to understand the uniqueness of Faraday's life, it should be noted that only Anglicans were allowed access to the great British universities, such as Oxford and Cambridge, and any academic member of these universities was necessarily required to be also a member of the Anglican Church.[1]

The first scientific experience of Faraday outside England came soon in his life. In 1814, he went along with H. Davy and his wife in a trip on the Continent, first in France and then in Switzerland, Italy and finally in Belgium. The entire journey lasted almost one year and a half.

In these years the war between France and England was raging. Nevertheless, Napoleon invited Davy to Paris and honoured him, for his researches on electricity and magnetism, with the scientific prize previously attributed to Alessandro Volta (Figure 4). Napoleon's decision should be understood not only for its political significance, i.e., demonstrating to the world that France acknowledged and honoured the scientific genius even from an enemy, but also for the genuine interest that the French emperor had for scientific discoveries, that would have shaken the future world. Already in 1804, deeply convinced of the social impact of the new scientific discoveries, Napoleon reformed the system of *Grandes Ecoles*, bringing them under the strict control of the state and reorganizing them as military schools.

Napoleon provided Davy and his companions with a special safe-conduct to reach Paris and then move freely throughout Europe, in the areas under the French control. As an illustration of the social rigidity of those times, Faraday had to carry out the role of valet of Davy's spouse, because of his humble origins, despite his mentor was persuaded of the outstanding scientific quality of his young assistant. But Lady Davy could not tolerate that a young son of a blacksmith could participate in their social life, other than with a well-defined subordinate role.

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[1] Isaac Newton was against trinitarianism and therefore a sort of heretic. Being a fellow in Cambridge, he was asked to take a vow of celibacy and become a member of the Church of England. While the first requirement was not a burden to him, he considered stopping his studies in order to avoid the ordination. He was finally dispensed with this duty.

Figure 5. Michael Faraday and Sarah Barnard [7].

Figure 6. André-Marie Ampère [8].

The impossibility of finding a valet in France, imposed Faraday to play this role for the entire duration of their journey, although he had previously agreed with Davy to accept it only for the period necessary to reach Paris from London.

This situation contributed to making the relationship between Davy and his protégé very tense. At some moment, during their stay in Paris, Faraday was at the point of going back home. We can conjecture that two main factors made Faraday change his mind. On one hand this European tour with Davy represented an exceptional opportunity for him to come into direct contact with the scientific world of the continent. On the other hand, we should consider that Faraday's strong religious education and his deep respect for the precepts of humility and human solidarity, that animated his confraternity, allowed him to endure the psychological pressure of such a conflictual situation.

This is a side of Faraday's character, which played a key role not only in his private life, but also in his professional activity. In fact, one of the foundations of his beliefs was the tolerance towards his fellows, regardless of their religious confession (many of his closest friends, in fact, did not share his own religious beliefs) and their social status. Moreover, his scientific work was pervaded by his strong conviction that trying to understand the laws of nature was a direct way to approach the knowledge of God's work in creation [9].

His life was marked by a personal commitment in support of poor people, not only through the actions promoted by his confraternity. For Faraday, this was the most natural behaviour, but also an aspect of his life that made no sense to brag about: his privacy, to that effect, was total. Faraday married in 1821 Sarah Barnard, a member of his own confraternity (Figure 5). He expressly recognized that his wife was a crucial support throughout all of his personal and professional life.

Faraday's scientific fame grew over the years, not only at home, due to his amazing discoveries in the field of electromagnetism, that we shall discuss later. Faraday maintained contacts with many of his contemporary scientists. His exchange of letters with the French scientist André-Marie Ampère (Figure 6) on the nature of electromagnetic forces (see the debate between action at

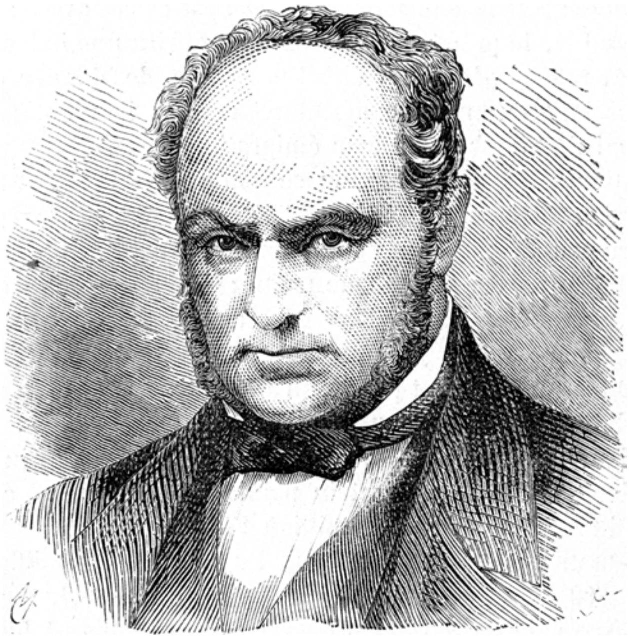

Figure 7. Carlo Matteucci [10].

Figure 8. Ottaviano Fabrizio Mossotti [11].

distance and force fields) was very popular and strongly inspired the forthcoming scientific debate.

Faraday was also in contact with some Italian physicists. As a matter of fact Faraday learnt some Italian to exchange letters with Carlo Matteucci (Figure 7), a physiologist of international fame, well known in the scientific community for his research on electrophysiology. Faraday personally met also Ottaviano Fabrizio Mossotti (Figure 8). In fact, Mossotti had been living for some time in London and developed a theory of dielectrics. His scientific work deeply attracted the attention of Faraday and significantly influenced the work of James Clerk Maxwell, mainly in relation to the discovery of the so-called "displacement current".

Mossotti and Matteucci, after several personal misfortunes also linked to their political and military involvement in the Italian *Risorgimento*, met again at the *Scuola Normale* in Pisa, where they managed to organize one of the first experimental physics laboratories in Italy.

Faraday was a tireless worker and a great science disseminator (Figure 10), with an uncommon skill for physical phenomena. He succeeded, as we shall see, in giving birth to original and almost revolutionary ideas, without any specific training in Mathematics, that would have presumably led him to translate his intuitions and numerous experimental findings in a complete general theory of electromagnetic phenomena.

Fortunately for him and all of us, a young Scottish scientist, James Clerk Maxwell (Figure 9), succeeded in such a task. It should be pointed out that Maxwell explicitly recognized that his fundamental work, on the theory of electromagnetic phenomena, was an almost direct deduction from the titanic experimental framework achieved by Faraday.

It is worth to be noticed that Maxwell, brilliant mathematician and theoretical physicist, was a rather poor lecturer, while the self-made-experimenter Faraday was a worthy heir of Sir Davy (Figure 10).

Because of his tireless activity, in 1839 Faraday had a nervous breakdown, from which he recovered with difficulties, and thanks to his wife's care. He managed to return to his studies on electromagnetism, but he had to refrain from the exhausting working periods he was used to, and slowed down his personal involvement as director of the Royal Institution (Figure 11).

The achievements already attained and those that followed in the second period of his scientific life granted him such a scientific reputation that he was worldwide renown in the middle of the XIX centuty. As a matter of fact Faraday was elected as a member of the most prestigious scientific academies of that time, but he always remained faithful to the principle of avoiding awards and honours at home.

When, during the Crimean War (1853-1856), the British government asked him to contribute to the production of chemical weapons, Faraday strongly opposed his ethical principles. With equal firmness he refused the social and economic benefits of becoming a knight,

Figure 9. James Clerk Maxwell [12].

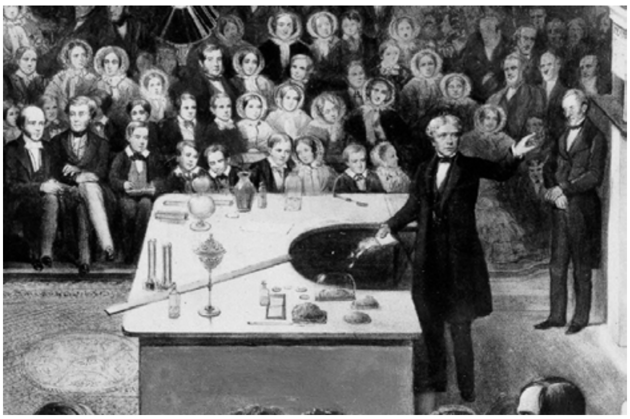

Figure 10. M. Faraday while holding a lecture at the Royal Institution in London [13].

and, twice, the appointment as president of the Royal Society. Only in 1848 he accepted the house at Hampton Court from the British Royal Family, in recognition of his scientific achievements.

In 1858 he moved there, where he died in 1867, at the age of 75. The great English scientist was buried in the Highgate Cemetery in London, because he had also refused the privilege of being buried in the English pantheon, the Westminster Abbey in London. As a Sandemanian, he decided that even after death he would have never entered an Anglican church, least of all lay there until the day of judgement. In Westminster Abbey

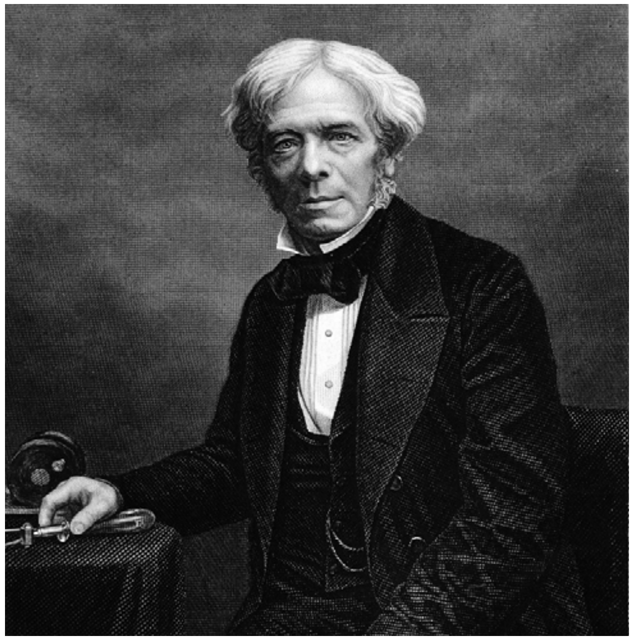

Figure 11. Michael Faraday in his sixties [14].

only a simple plaque nearby the tomb of Isaac Newton remembers the greatest British experimental scientist of all times.

SCIENTIFIC DISCOVERIES

History of Faraday's scientific discoveries

- 1810-1820 First Electrochemical Experiments
- 1820-1830 Electrical conduction experiments
- 1831 Law of electromagnetic induction
- 1832-1833 Laws of electrolysis
- 1837-39 Dielectric materials
- 1845-1846 Diamagnetism and Faraday effect
- 1855 Studies on paramagnetism

At the age of twenty, one year before the end of his apprenticeship at Mr. Riebau's bookshop, Faraday performed the first of the many important experiments of his scientific career.

As he stated in a letter to his friend Benjamin Abbott, Faraday set up an electric battery (Figure 12), using zinc and copper disks with the size of a half penny, separated by pieces of paper soaked in "Muriate of Soda".

Faraday discovered that the electrical power of this rudimentary stack was capable of separating the components of a magnesium sulphate solution. He submerged in the solution the copper wires connected to the poles

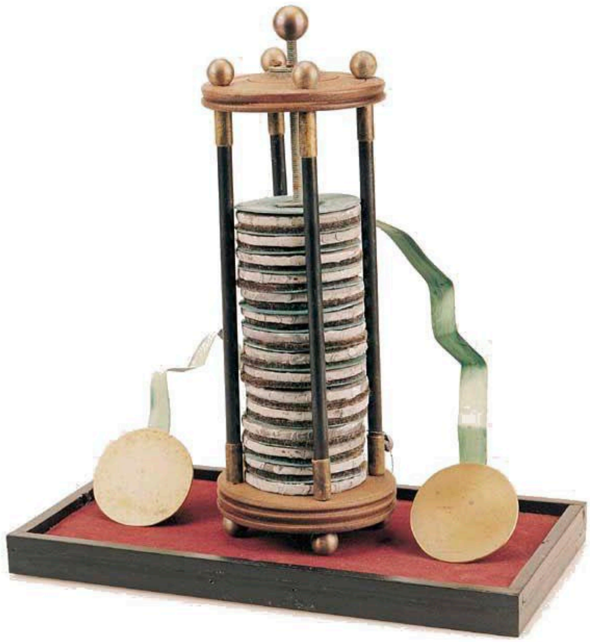

Figure 12. Alessandro Volta's pile (modern reconstruction) [15].

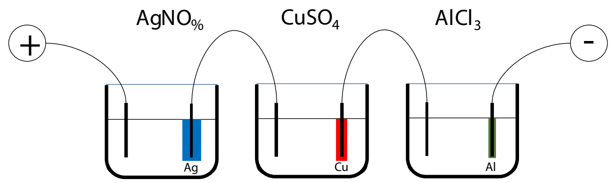

Figure 13. Demonstration of the experimental laws of Faraday on electrolysis (1834). Solutions of silver nitrate, copper sulphate and aluminium chloride. The electric current flowing through the cells is the same and the metal ions are deposited on the negative electrode in an amount proportional to the current flowing through the electrolytic cells (first Faraday's Law). Furthermore, if the amount of silver deposited is 108 g (atomic weight of Ag) that of copper is equal to 31.7 g (about half the atomic weight of Cu) and that of aluminium is 9 g (one third of the atomic weight of aluminium): this indicates that the Cu and Al ions, respectively, carry a double and triple charge with respect to that of the Ag ion (second Faraday's Law) [16].

of the pile. In a few hours the solution became muddy, because of the formation of a suspension of magnesia. In this way Faraday discovered the phenomenon of electrolysis. This was the beginning of an intense line of systematic and experimental research studies in the years to come. During his stay at the Royal Institution, Faraday managed to obtain the two fundamental laws of electrolysis (Figure 13).

First LAW: For a given solution, the quantity of matter that is deposited on the electrodes is proportional to the amount of charge which passes through the solution.

This implies that the ions carrying the charge through the solution have a well-defined electric charge.

Second LAW: The monovalent ions of different substances carry an equal quantity of electric charge, while the bi- or tri-valent ones carry a correspondingly higher charge.

This law implies the existence of an elementary charge unit that at the Faraday's times was attributed to individual atoms, but we now know to be that of the electron.

The results of this research were published by Faraday in 1834, almost at same time as Carlo Matteucci, who formulated the same laws of electrolysis but using completely independent methods.

Faraday was the author of numerous publications in scientific journals, but we can say with no doubt that his main contributions are collected in his Laboratory Journal, which he hold regularly from 1820 until 1862. This diary was published in 1932 by the Royal Institution in seven large volumes, totalling 3,236 pages accompanied by nearly a thousand illustrations of instruments and experimental setups. In these pages Faraday also describes his first experiments on electrical conduction (1820-1830) in which he confirmed his talent as experimenter, sensing and describing crucial phenomena, such as the fact that a conductor wire carrying an electric current exerts a force on the poles of a bar needle, showing that this force is the same along a circle concentric to the wire (Figure 14).

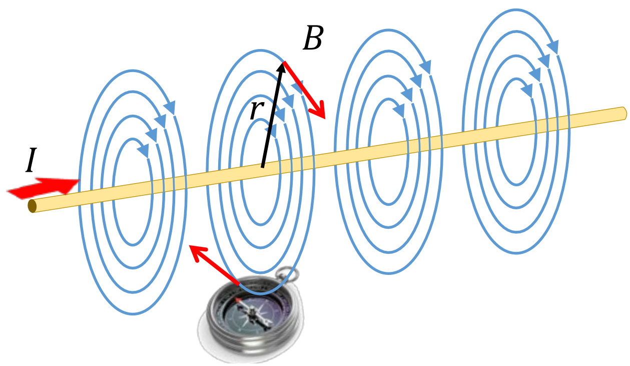

Figure 14. Magnetic field force lines generated by a rectilinear conductor carrying a constant electric current [16].

Similarly, a current-carrying wire can be put in rotation around a magnetic bar (Figure 15). The observation of this phenomenon can be considered as the first step of Faraday towards the design of an electric motor. This setup, far more refined than the ones used in the preliminary experiments carried out by the Danish physicist

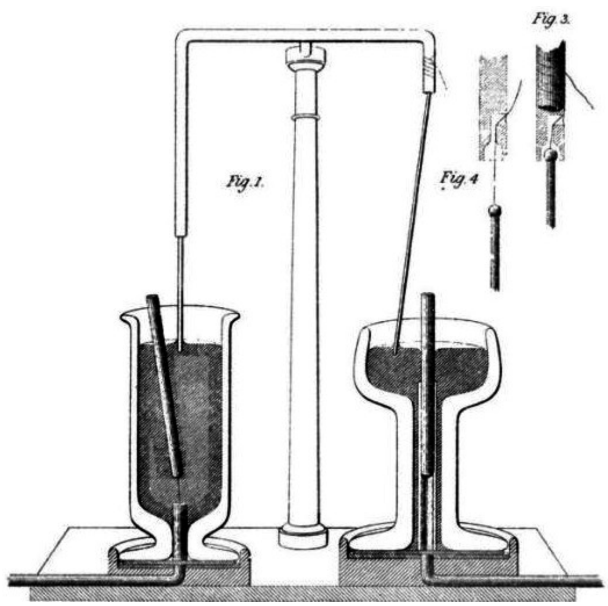

Figure 15. Left: ampoule filled with mercury which is anchored to a movable magnetic rod which rotates to the passage of an electric current along the conductor. Right: ampoule filled with mercury, which contains a fixed magnetic bar around which a conductive wire is crossed by an electric current [17].

H.C. Orsted, was built by Faraday after discussing the idea with H. Davy and W.H. Wollastone.

Faraday published the results of his research without mentioning Davy's and Wollastone's contributions (who, despite their efforts, were never able to build any device functioning as an electric motor) and this opened such a hard dispute, that at the end Faraday was forced to officially give up with his studies on electromagnetism. It is interesting to read from Faraday's words how he justified his act to the managers of the Royal Institution:

> *I hear every day more and more those sounds which though only whispers to me are I suspect spoken aloud amongst scientific men and which as they in part affect my honour and honesty I am anxious to do away with or at least to prove erroneous in those parts which are dishonourable to me. You know perfectly well what distress the very unexpected reception of my paper on Magnetism in public has caused me and you will not therefore be surprised at my anxiety to get out of it though I give trouble to you and others of my friends in doing so.*
> *I understand I am charged 1. with not acknowledging the information I received in assisting Sir H. Davy in his experiments on this subject; 2. with concealing the theory and views of Dr Wollaston; 3. with taking the subject whilst Dr Wollaston was at work on it; and 4. with dishonourably taking Dr Wollaston's thoughts and pursuing them without acknowledging the results I have brought out [18].*

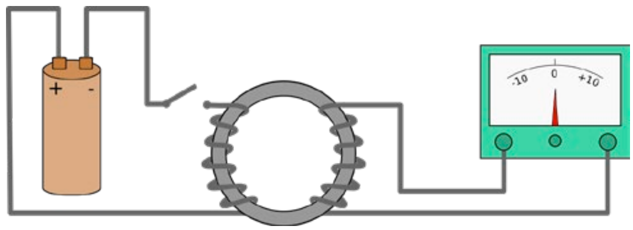

Figure 16. Scheme of the experiment on electromagnetic induction by Faraday, August 29, 1831. When the circuit on the left is closed, the presence of an induced current in the circuit on the right is observed, as long as the first does not reach the steady state value when the current in the second circuit disappears. In fact, the magnetic field flux inside the soft iron ring around which the two filaments are wrapped changes over time after closing the first circuit. The same phenomenon is observed after opening again the left circuit, in which case the flux of the magnetic field decreases. Therefore, induction, differently from the electrostatic interaction, is a dynamic phenomenon [19].

It is no exaggeration to affirm that the ability of Faraday had too much shaded that of his mentor, who decided to significantly limit the scientific autonomy of his assistant. Officially, Faraday was allowed only to continue his studies on electrochemistry, and was eventually able to come back formally on those about electromagnetism immediately after the death of Davy (1829), when he took over the direction of the Royal Institution. In two years of intense experimentation, he managed to understand the phenomenon of the magnetic induction (already highlighted by the abbot Francesco Zantedeschi).

Faraday's laboratory notebook reports his fundamental discovery of the electromagnetic induction on 29th August 1831. The page is entitled: "Experiments on the production of electricity from magnetism". In his notebook Faraday provided a detailed description of his experimental apparatus (Figure 16).

Note that also the French physicist André-Marie Ampere in 1822 had conjectured the possibility of such a phenomenon, based on the analogy with electrostatics. More precisely, Ampere believed that if a circuit had been traversed by a current, in a second circuit in its vicinity a current should be observed.

Actually Ampere did notice that something happened in the second circuit for a very short time, when the first circuit was moved with respect to the first, but he did not attribute any importance to this transient phenomenon. Faraday instead highlighted this effect in the experiment of 29th of August 1831 and only two months later, on the 17th of October, he was able to obtain the confirmation of the dynamic nature of the electromagnetic induction phenomenon, performing the experiment depicted in Figure 17.

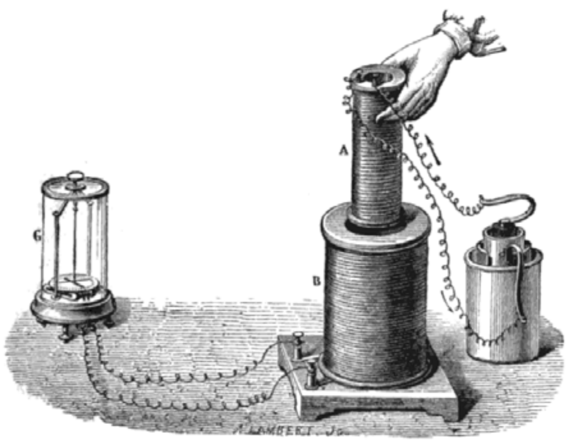

Figure 17. Scheme of the experiment of electromagnetic induction by Faraday, October 17th, 1831. By vertically moving the smallest coil within the larger one the magnetic field flux concatenated to the latter is varied and a passage of current in it is observed. This is a confirmation of the dynamic nature of the phenomenon of the electromagnetic induction (1892) [20].

This time he built a tight coil crossed by an electric current and therefore capable of generating a magnetic field directed along its axis, and inserted it inside a larger coil, moving the former vertically. This operation allowed him to vary the flux of the magnetic field linked with the largest coil in a controlled manner, not relying upon the too rapid variation produced by turning on and off the current in the primary circuit of the first experiment.

He observed that in this way a current was produced: it was circulating in the second coil as long as the magnetic field flux continued to change over time. These experiments provided Faraday the final confirmation that the electromagnetic phenomena were represented with lines of force that pervaded the surrounding space and that made such phenomena much easier to illustrate with respect to the law of the action at distance, borrowed by the principles of Newtonian mechanics.

It should be stressed that, at that time, "action at distance" was a scientific cornerstone, that had been substantiated by the work of the French physicists, such as Coulomb and Ampère, strongly linked to the rationalist tradition of French science, the guardian of the modern formulation of Newtonian mechanics, rewritten in the language of rational mechanics.

Faraday, fortunately for us, was an experimental scientist of great talent, very little inclined to be fascinated by metaphysical paradigms. His conception of lines of force constituted a rather different point of view, in some ways antithetical to that of the French rationalists.

His position was definitely not free of romantic influences, which tended to question the scientific rationalism of the time, but certainly his intellectual honesty and his intuition led him to strongly support the idea of a "fluid dynamics" approach to electromagnetic forces, which, in this first level of understanding, had to occur through the presence of a material medium interposed in the space where such phenomena were observed. Since his early scientific experiences Faraday had strongly supported these ideas, even discussing them in a scientific correspondence with Ampere, who recognized in the English scientist a correspondent worthy of great consideration, although their ideas on electromagnetic phenomena were indeed quite antithetical.

Indeed, Faraday was probably intimidated by his lack of mathematical background, so instead of quarrelling with Ampère, he preferred to stick to his experimental observations:

> *I am unfortunate in a want of mathematical knowledge, and the power of entering with facility into abstract reasoning. I am obliged to feel my way by facts closely placed together, so that it often happens I am left behind in the progress of a branch of science not merely from the want of attention but from the incapability I lay under of following it, notwithstanding all my exertions. It is so just now, I am ashamed to say, with your refined researches in electromagnetism or electrodynamics.*
> *On reading your papers and letters I have no difficulty in following the reasoning but still at last I seem to want something more on which to steady the conclusions. I fancy the habit I got into of attending too closely to experiment has somewhat fettered my powers of reasoning and chains me down and I cannot help now and then comparing myself to a timid ignorant navigator who though he might boldly and safely steer across a bay or an ocean by the aid of a compass which in its actions and principles is infallible, is afraid to leave sight of the shore because he understands not the power of the instrument that is to guide him [21].*

However, it is worth stressing that Faraday's approach was quite more modern than Ampère's view. By systematically using iron filings, he was able to mentally visualize the existence of the magnetic field, thus separating Ampère's interactions among circuit in two steps: the generation of the magnetic field (which can originate also from a magnet) and the effect of the magnetic field on a circuit (or another magnet).

After the formulation of the laws of electrolysis, that we already mentioned, Faraday, between 1837 and 1839, devoted himself to the study of dielectric materials (the very name "dielectric" is due to him), which are in fact insulators.

These studies aimed at testing how the electromagnetic fields act on matter through the lines of force. Faraday also introduced the concept of dielectric constant,

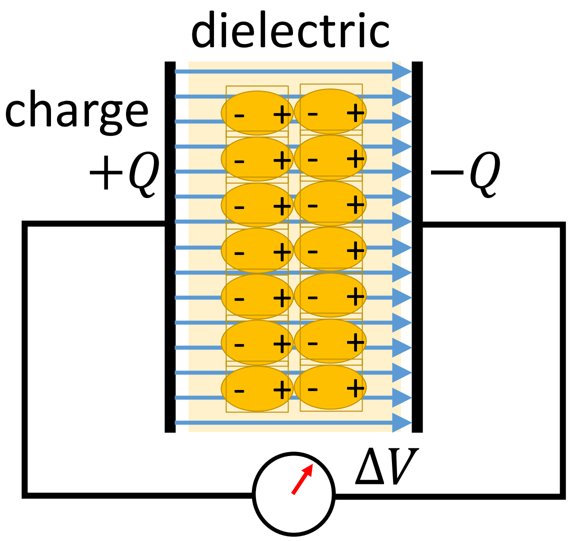

Figure 18. A measure of the relative dielectric constant K can be obtained by interposing the dielectric material (insulator) between the plates of a charged capacitor and measuring the potential difference in the absence and in the presence of the dielectric: K =ΔV0/ΔV > 1 [16].

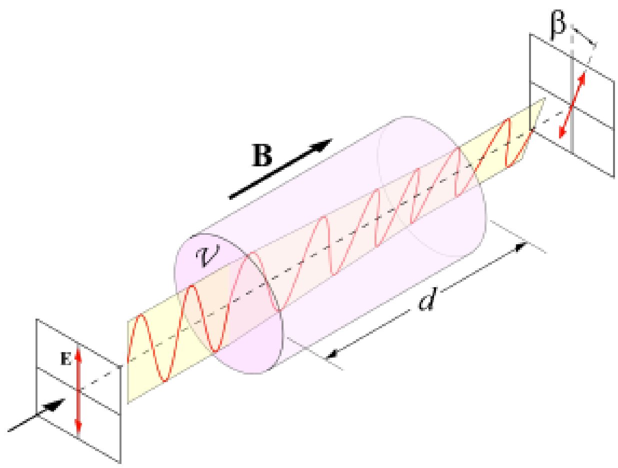

Figure 19. The Faraday effect. Faraday observed the rotation of the polarization plane of the light when this crosses a glassy material (lead silicoborate) subjected to an intense magnetic field: this effect is due to interaction of the light (electromagnetic wave) with the electrons present in the glass atoms. The phenomenon is the basis of the microwave technology and of optical insulators used in modern communications technologies [22].

while providing an operational definition for its measurement (Figure 18).

After a period of inactivity of almost four years in 1845 Faraday returned to his experiments on magnetic materials, classifying them in diamagnetic and paramagnetic, depending on their propensity to oppose or promote the penetration of the magnetic field.

These early studies paved the way for the important developments in research on the magnetic properties of matter in the following decades. Faraday was already aware of the complementary nature of electric and magnetic phenomena and continued investigating this topic, by addressing specific questions about the nature of the optical effects of magnetic fields.

As usual, he faced the problem with his brilliant experimental intuition and in 1845 he discovered the phenomenon known as “Faraday rotation”. After a series of unsuccessful experiments, he succeeded to develop an experimental apparatus capable of detecting a rotation of the polarization plane of light when this crossed a material (glass) merged into a strong magnetic field, directed in the direction of propagation of light (Figure 19).

The last years of the scientific life of Faraday were devoted to improve his understanding of paramagnetic materials and to perform some unsuccessful attempts to find a relationship between electromagnetic and gravitational forces. It is hard not to be amazed by facing this last great Faraday’s intuition, that anticipates some of the most recent discoveries in physics, related to the possibility of representing a unified theory of all force fields (sub-nuclear, nuclear, electromagnetic and gravitational).

In 1849 he wrote in his laboratory diary:

> *Surely this force [gravity] must be capable of an experimental relation to Electricity, Magnetism and the other forces, so as to bind it up with them in reciprocal action and equivalent effect…What in Gravity answers to the dual or antithetical nature of the forms of force in Electricity and Magnetism? Perhaps the to and fro, that is, the ceding to the force or approach of Gravitating bodies, and the effectual reversion of the force or separation of the bodies, quiescence being the neutral condition. Try the question experimentally on these grounds [23].*

Faraday began a long series of experiments that did not provide him any evidence of his expectations. He concluded this stage of his research on the diary by noting

> *[The negative results] do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists [24].*

This shows that although Faraday was an empirical scientist, however he did not consider only the results of his experiments. In fact, due to his deep philosophical beliefs he was convinced that the laws of nature must have a unique common origin, as a manifestation of something that deeply and mysteriously permeates the universe.

Figure 20. Statue of Michael Faraday in Savoy Place, London [26].

In the case of Faraday, we can certainly say that this was intrinsic to his ethical and religious convictions. But we have also to make clear that Faraday had no sanctimonious attitude, nor he was motivated by any superstition or dogmatic belief.

Some historians believe, with some justification, that his self-taught training and his free spirit played a crucial role in providing him with a unique talent as a creator of crucial experiments, while escaping the cultural traps of a traditional mathematical background, that, in his time, was attributed the value of incontrovertible truths. George Gamow (the famous Russian scientist of the twentieth century) wrote about Faraday

Impressive as Faraday's experimental discoveries were, they are matched by his theoretical ideas. Having had very little education and having known practically no mathematics, Faraday could not be what is usually called a theoretical physicist. But the fact is that, for conceiving a theoretical picture of a puzzling physical phenomenon, a knowledge of intricate mathematics is often quite unnecessary and sometimes even harmful. The explorer may easily be lost in the jungles of complicated formulas and, as a Russian proverb says, "cannot see the forest for the trees" [25].

Figure 21. A 20-pound banknote with the Faraday effigy [27].

Thanks to his tireless and amazing work as experimentalist, famous during his life and after his death, James Clerk Maxwell developed his theory of electromagnetic field, which is one of the cornerstones of the building of modern physics. It can be said, without doubt, that Maxwell's scientific path would hardly have come to fulfilment without Faraday having largely prepared it.

Considering his shyness, it is possible that Faraday would not be pleased by the huge number of studies dedicated to him, nor by the present public recognition of his character (Figures 20 and 21).

SOME EXCERPTS BY FARADAY

It may be asked, what lines of force are there in nature, which are fitted to convey such an action, and supply for the vibrating theory the place of the ether? I do not pretend to answer this question with any confidence; all I can say is, that I do not perceive in any part of space, whether (to use the common phrase) vacant or filled with matter, anything but forces and the lines in which they are exerted. The lines of weight or gravitating force are, certainly, extensive enough to answer in this respect any demand made upon them by radiant phenomena; and so, probably, are the lines of magnetic force: and then, who can forget that Mossotti has shown that gravitation, aggregation, electric force, and electro-chemical action may all have one common connexion or origin; and so, in their actions at a distance, may have in common that infinite scope which some of these actions are known to possess?
The view which I am so bold as to put forth considers, therefore, radiation as a high species of vibration in the lines of force which are known to connect particles and also masses of matter together. It endeavours to dismiss the ether, but not the vibrations. The kind of vibration which, I believe, can alone account for the wonderful, varied, and beautiful phenomena of polarization, is not the same as that which occurs on the surface of disturbed water, or the waves of sound in gases or liquids, for the vibrations in

these cases are direct, or to and from the centre of action, whereas the former are lateral. It seems to me, that the resultant of two or more lines of force is in an apt condition for that action which may be considered as equivalent to a lateral vibration; whereas a uniform medium, like the ether, does not appear apt, or more apt than air or water. The occurrence of a change at one end of a line of force easily suggests a consequent change at the other. The propagation of light, and therefore probably of all radiant action, occupies time; and, that a vibration of the line of force should account for the phenomena of radiation, it is necessary that such vibration should occupy time also. I am not aware whether there are any data by which it has been, or could be ascertained, whether such a power as gravitation acts without occupying time, or whether lines of force being already in existence, such a lateral disturbance of them at one end as I have suggested above, would require time, or must of necessity be felt instantly at the other end [28].

Years ago I believed that electrolytes could conduct electricity by a conduction proper; that has also been denied by many through long time: though I believed myself right, yet circumstances have induced me to pay that respect to criticism as to reinvestigate the subject, and I have the pleasure of thinking that nature confirms my original conclusions. So though evidence may appear to preponderate extremely in favour of a certain decision, it is wise and proper to hear a counter-statement. You can have no idea how often and how much, under such an impression, I have desired that the marvellous descriptions which have reached me might prove, in some points, correct; and how frequently I have submitted myself to hot fires, to friction with magnets, to the passes of hands, &c., lest I should be shutting out discovery;—encouraging the strong desire that something might be true, and that I might aid in the development of a new force of nature [29].

Magnetic lines of force convey a far better and purer idea than the phrase magnetic current or magnetic flood: it avoids the assumption of a current or of two currents and also of fluids or a fluid, yet conveys a full and useful pictorial idea to the mind [30].

All your names I and my friend approve of or nearly all as to sense & expression, but I am frightened by their length & sound when compounded. As you will see I have taken dioxide and skaiode because they agree best with my natural standard East and West. I like Anode & Cathode better as to sound, but all to whom I have shown them have supposed at first that by Anode I meant No way[2] *[31].*

Although we know nothing of what an atom is, yet we cannot resist forming some idea of a small particle, which represents it to the mind ... there is an immensity of facts which justify us in believing that the atoms of matter are in some way endowed or associated with electrical powers, to which they owe their most striking qualities, and amongst them their mutual chemical affinity [32].

I require a term to express those bodies which can pass to the electrodes, or, as they are usually called, the poles. Substances are frequently spoken of as being electro-negative, or electro-positive, according as they go under the supposed influence of a direct attraction to the positive or negative pole. But these terms are much too significant for the use to which I should have to put them; for though the meanings are perhaps right, they are only hypothetical, and may be wrong; and then, through a very imperceptible, but still very dangerous, because continual, influence, they do great injury to science, by contracting and limiting the habitual view of those engaged in pursuing it. I propose to distinguish these bodies by calling those anions which go to the anode of the decomposing body; and those passing to the cathode, cations; and when I have occasion to speak of these together, I shall call them ions [33].

I wanted some new names to express my facts in Electrical science without involving more theory than I could help & applied to a friend Dr Nicholl [his doctor], who has given me some that I intend to adopt for instance, a body decomposable by the passage of the Electric current, I call an 'electrolyte' and instead of saying that water is electro chemically decomposed I say it is 'electrolyzed'. The intensity above which a body is decomposed beneath which it conducts without decomposition I call the 'Electrolyte intensity' &c &c. What have been called: the poles of the battery I call the electrodes they are not merely surfaces of metal, but even of water & air, to which the term poles could hardly apply without receiving a new sense. Electrolytes must consist of two parts which during the electrolization, are determined the one in the one direction, and the other towards the poles where they are evolved; these evolved substances I call zetodes, which are therefore the direct constituents of electrolytes [34].

I have taken your advice, and the names used are anode cathode anions cations and ions; the last I shall have but little occasion for. I had some hot objections made to them here and found myself very much in the condition of the man with his son and ass who tried to please every body; but when I held up the shield of your authority, it was wonderful to observe how the tone of objection melted away [35].

[The new term] Physicist is both to my mouth and ears so awkward that I think I shall never use it. The equivalent of three separate sounds of i in one word is too much [36].

[2] Here "No way" is presumably not an idiomatic exclamation, but a misinterpretation from the Greek prefix, *-a* "not" or "away from," and *hodos* meaning "way." The Greek ἄνοδος (*anodos*) means "way up" or "ascent."

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See also the Wikipedia entry on Faraday with many references and biographies [37].

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