International Year of Light Blog

James Clerk Maxwell, the man who changed the world forever II

 JUNE 15, 2015JUNE 11, 2015 LIGHT2015 LEAVE A COMMENT

A Dynamical Theory of the Electromagnetic Field

Maxwell left us contributions to colour theory, optics, Saturn's rings, statics, dynamics, solids, instruments and statistical physics. However, his most important contributions were to electromagnetism. In 1856, he published *On Faraday's lines of force*; in 1861, *On physical lines of force.* In these two articles he provided a mathematical explanation for Faraday's ideas on electrical and magnetic phenomena depending on the distribution of lines of force in space, definitively abandoning the classical doctrine of electrical and magnetic forces as actions at a distance. His mathematical theory included the aether, that «most subtle spirit», as Newton described it. He studied electromagnetic interactions quite naturally in the context of an omnipresent aether. Maxwell stood firm that the aether was not a hypothetical entity, but a real one and, in fact, for physicists in the nineteenth century, aether was as real as the rocks supporting the Cavendish Laboratory.

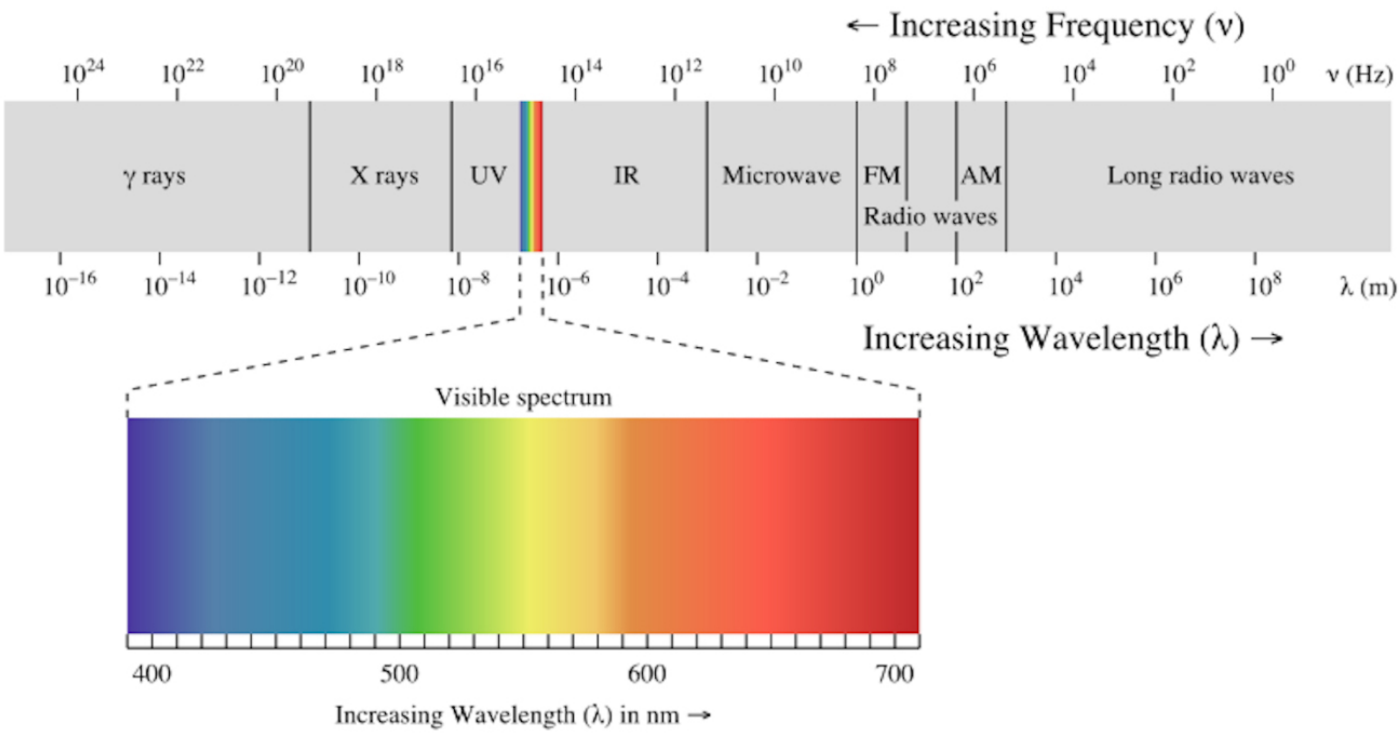
(https://light2015blogdotorg.files.wordpress.com/2015/06/figure_3.jpg)

As was mentioned on the first post (http://light2015blog.org/2015/06/12/james-clerk-maxwell-the-man-who-changed-the-world-forever-i) of this series, in 1865 –when Maxwell was 33– he published *A Dynamical Theory of the Electromagnetic Field* –probably his most important paper–, where he presented a complete electromagnetic theory and which included twenty equations he called «General Equations of the Electromagnetic Field.» He links them to twenty variables governing the behaviour of electromagnetic interaction. The article is 53 pages long and is divided in seven parts. His general equations, which summarised the experimental laws of electromagnetism, provide a complete theoretical basis for the treatment of classical electromagnetic phenomena. In 1884, Oliver Heaviside (http://en.wikipedia.org/wiki/Oliver_Heaviside) rewrote the twenty equations of the electromagnetic field using vectors into the today's modern notation: the four equations of electromagnetic field. Since then, these equations were known as Hertz-Heaviside's equations or Maxwell-Hertz's equations, until 1940 when Albert Einstein coined the term «Maxwell's equations» that we use today. The Austrian physicist Ludwig Boltzmann (http://en.wikipedia.org/wiki/Ludwig_Boltzmann) considered them such beautiful equations in their simplicity and elegance that, with a quote from Goethe's Faust, he asked himself: *«War es ein Gott, der diese Zeichen schrieb?»* (Was it a god who wrote these signs?).

In the sixth part of his 1865 paper, «Electromagnetic Theory of Light», in which he refers to the paper titled *Thoughts on Ray-vibrations* published by Faraday in 1846, saying «… the electromagnetic theory of light as proposed by him, is the same in substance as that which I have begun to develop in this paper, except that in 1846 there were no data to calculate the velocity of propagation.» Maxwell also concludes that «light and magnetism are affections of the same substance, and that light is an electromagnetic disturbance propagated through the field according to electromagnetic laws.» As Arthur Zajonc pointed out in his book *Catching the Light*, «In this single sentence, Maxwell proposed a profound change in our image of light, one is which light, electricity, and magnetism would now, and forever after, be entwined. Two arenas of physics, which to all outward appearances have nothing in common, were to be united.» When he wrote «affections of the same substance», that substance was the *aether*. Although Maxwell's mathematical formulation did not require the *aether*, it was still omnipresent. He proved that the equations of the electromagnetic field could combine into a wave equation and suggested the existence of electromagnetic waves. Calculating the speed of propagation of these waves, he obtained the value of the speed of light, and concluded that it was an electromagnetic wave. Einstein referred to that crucial moment of Maxwell by pointing out: «Imagine [Maxwell's] feelings when the differential equations he had formulated proved to him that electromagnetic fields spread in the form of polarised waves, and at the speed of light! To few men in the world has such an experience been vouchsafed» Maxwell deduced that electromagnetic waves are transverse waves and he got what is now known as «Maxwell relation» between the refractive index of a medium and the square root of its dielectric constant.

In 1888, nine years after Maxwell's death, Heinrich Hertz (http://en.wikipedia.org/wiki/Heinrich_Hertz) probed experimentally the existence of electromagnetics waves. This meant not only the confirmation of Maxwell's theory but also a win over telegraph engineers as William Preece, Engineer-in-Chief of the British General Post Office, which denied the applicability of Maxwellian physics to engineering. If Maxwell had lived in 1901 when the Italian engineer and Nobel Prize in Physics in 1909 Guglielmo Marconi (http://www.nobelprize.org/nobel_prizes/physics/laureates/1909/marconi-bio.html) made the first transatlantic radio communication across the Atlantic ocean, from Cornwall (England) to St. John's, in Newfoundland (Canada) –using the electromagnetic waves whose existence Maxwell had predicted in 1865– perhaps Maxwell's fame would be far greater today.

The significance of Maxwell's concept of electromagnetic waves, as subsequent history has shown, goes far beyond its application to light. Gamma rays, X rays, ultraviolet radiation, visible light, infrared radiation, microwaves and radio and television waves constitute the spectrum of electromagnetic waves, whose existence was predicted by Maxwell 150 years ago.



(https://light2015blogdotorg.files.wordpress.com/2015/06/figure_4.jpg)
Electromagnetic spectrum with visible light highlighted. Credit: Wikipedia (Author Philip Ronan)

With his work, **Maxwell unified electricity, magnetism and light**, which are known as **«Maxwell's synthesis.»** Such a synthesis set a milestone in the history of the unification of forces that were so powerful that many nineteenth-century physicists thought the physical laws were already sufficiently comprehended. This led physicist and Nobel Prize in Physics in 1907 Albert Michelson (http://www.nobelprize.org/nobel_prizes/physics/laureates/1907/michelson-bio.html) to write in his book *Light and Their Uses* published in 1903: «The more important fundamental laws and facts in physical sciences have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote … Our future discoveries must be looked for in the sixth place of decimals.» Nothing could be further from the truth. In the first years of the twentieth century there were two Kuhnian paradigm shifts in physics: Planck's quantum theory (1900) and Einstein's theory of special relativity (1905), both consequences of Maxwell's electromagnetic theory and related to light, which laid the groundwork for these two revolutionary ideas. It is clear that Maxwell opened the doors for twentieth century physics.

Maxwell's legacy

Although Maxwell's work on electromagnetism was essential, it had got some limitations, like trying to reconcile Newtonian mechanics and maxwellian electromagnetism. This problem was finally solved in 1905 when Einstein published his theory of special relativity. After Einstein's works, the luminiferous aether –the focus of nineteenth century physics– was dead and buried. Even Albert Einstein recognised that «the special theory of relativity owes its origins to Maxwell's equations.» In 1931, at the centenary of Maxwell's birth, in an article titled *Maxwell's influence on the development of the conception of physical reality*, Einstein claimed that «one scientific epoch ended and another began with James Clerk Maxwell» and **«the work of James Clerk Maxwell changed the world forever.»**

Richard Feynman (http://www.nobelprize.org/nobel_prizes/physics/laureates/1965/feynman-bio.html), Nobel Prize in Physics in 1965 for his work in *quantum electrodynamics* (QED), the quantum theory of the electromagnetic field, pointed out: «From a long view of the history of mankind, seen from, say, ten thousand years from now, there can be little doubt that the most significant event of the 19th century will be judged as Maxwell's discovery of the laws of electrodynamics.»

MORE INFORMATION:

Augusto Beléndez, "Electromagnetic Unification: 150th Anniversary of Maxwell's Equations", Mètode Nº 84, Winter 2014/15. (http://metode.cat/en/Issues/Article/La-unificacio-electromagnetica)

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2. Campbell and W. Garnett, The life of James Clerk Maxwell (MacMillan and co., Londres 1882). (http://ir.nmu.org.ua/bitstream/handle/123456789/144168/b417ada143d3d930e27ad532eb61880f.pdf?sequence=1)
3. Forbes and B. Mahon, Faraday, Maxwell, and the Electromagnetic Field: How two men revolutionized Physics (Prometheus Books, New York 2014). (http://www.prometheusbooks.com/index.php?main_page=product_info&products_id=2207&zenid=jtcf8i7b3lqbqdcj2rp46i2df7)
4. Flood, M. McCartney and A. Whitaker (eds.), James Clerk Maxwell. Perspectives on his Life and Work (Oxford University Press, Oxford 2014). (http://ukcatalogue.oup.com/product/9780199664375.do)

More posts on James Clerk Maxwell, the man who changed the world forever Series

James Clerk Maxwell, the man who changed the world forever I (http://light2015blog.org/2015/06/12/james-clerk-maxwell-the-man-who-changed-the-world-forever-i)

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He is active in public outreach: he has published numerous articles in popular science journals, and in the media. In 2009 he started the blog "Física para tod@s (http://blogs.ua.es/fisicateleco)", and he has given some talks to general public on science.

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