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Maxwell: A new vision of the world

Maxwell : Une nouvelle vision du monde

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ABSTRACT

The paper outlines the crucial contributions of James Clerk Maxwell to Physics and more generally to our vision of the world. He achieved 150 years ago a synthesis of the pioneering works in magnetostatics, electrostatics, induction and, by introducing the notion of displacement current, gave birth to Electromagnetics. Then, he deduced the existence of electromagnetic waves and identified light as one of them.

Maxwell equations deeply changed a Newtonian conception of the world based on particle interactions by pointing out the vital role of waves in physics. This new conception had a strong influence on the development of quantum physics. Finally, the invariance of light velocity in Galilean frames led to Lorentz transformations, a key step toward the theory of relativity.

RÉSUMÉ

Nous résumons les contributions cruciales de James Clerk Maxwell à la Physique et plus généralement à notre vision du monde. Tout d'abord, il a effectué, il y a cent cinquante ans, une synthèse des travaux antérieurs en magnétostatique, en électrostatique, en induction et, en introduisant le concept de courant de déplacement, il a donné naissance à l'Électromagnétisme. Il en a déduit l'existence des ondes électromagnétiques et a identifié la lumière comme l'une d'entre elles.

Par ailleurs, les équations de Maxwell ont profondément changé une conception du monde newtonienne basée sur l'interaction entre particules en révélant le rôle essentiel des ondes en physique, ce qui eut une influence déterminante sur le développement de la physique quantique. Enfin, l'invariance de la vitesse de la lumière dans les repères galiléens a entraîné la découverte des transformations de Lorentz, une étape capitale vers la théorie de la relativité.

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1. Introduction

Even though his name cannot be considered as a household name like Einstein or Newton, Maxwell is one of the few scientists who deeply changed our conception of the world. Firstly we will outline his life and his career in the frame of Victorian time. Then, Maxwell contributions to Electromagnetics will be described: synthesis of earlier works on electrostatics, magnetostatics or induction, introduction of the displacement current, discovery of electromagnetic waves, identification of light as one of these waves, prediction of the existence of other kinds of electromagnetic waves.

The developments of some domains of Electromagnetics that had strong consequences in Science, Technology and Industry will be outlined. Finally, we will explain why Maxwell's equations are considered as a crucial step toward the two revolutions of Physics that followed: theory of relativity and quantum physics.

2. Maxwell: a scientist in the Victorian time

2.1. Life

James Clerk Maxwell was born in Edinburgh, Scotland, in 1831. His father, John Clerk, was a lawyer. He shortly adopted the additional surname Maxwell. His mother, who played a crucial role in his early education, died when he was 8 years old and then a tutor was engaged by his father.

After brilliant studies in Edinburgh and Cambridge universities, Maxwell became Professor of Physics and Astronomy at King's College (London) in 1860. Most of his scientific discoveries were achieved during the 5 years time in this university. First, he had the opportunity to discuss with Michael Faraday, then in 1861–1862, he published the eponymous equations [1–4]. From these equations, he discovered in 1864–1865 the existence of electromagnetic waves and calculated their speed with a precision of 5%. In 1965, comparing the speed of these waves to the speed of light measured by the French physicist Hippolyte Fizeau [5], he concluded that light was made of electromagnetic waves. He predicted that electromagnetic waves having other frequencies should exist, a fact confirmed in 1888 by the German physicist Heinrich Hertz who evidenced the existence of radio waves [6]. In 1871, Maxwell became the first Cavendish Professor of Physics. He designed and headed the world famous Cavendish Laboratory. He died in 1879 at the age of 48.

2.2. The Victorian era

The first publication of Maxwell's equations coincides with the unification of Italy and the outbreak of the civil war in the USA. In Britain, the Victorian era included enormous political, scientific, social, and cultural innovation and change, many of them being consequences of the industrial revolution. It was a long period of prosperity, at least before the first crisis of capitalism from 1873 to 1895. This crisis had consequences on scientists, as shown further. In the domain of natural sciences, the theory of evolution was published by Charles Darwin in his book *On the origin of Species* in 1859. Authors like Charles Dickens, Arthur Conan Doyle, the Brontë sisters, Lewis Carroll, Oscar Wilde, George Bernard Show, Robert Louis Stevenson, H.G. Wells created a body of literature that still fascinates readers nowadays.

3. Maxwell's equations: the pioneers and the Maxwell contribution

The papers by Maxwell published in 1861–1862 included 20 equations [1–4], given in an integral form. This number was reduced to 8 in 1865 [7]. These works were gathered into a single paper in 1973 [8]. In fact, the modern form, including four differential equations was given by Heaviside in 1884. Among these equations, three were given previously by pioneers of electromagnetics. On the other hand, Maxwell introduced in Ampère's equation of magnetostatics a new term, the displacement current, which added to the electric current. It will be seen that this new term played a vital role in the birth of Electromagnetics, especially for the discovery of the existence of electromagnetic waves. We briefly outline the origin of Maxwell's equations.

– Maxwell–Gauss magnetic equation:

$$\nabla \cdot \vec{B} = 0 \tag{1}$$

This equation was discovered (but not published) by the German physicist Carl Friedrich Gauss in 1835. It is sometimes classified as Maxwell–Thomson equation since the physicist of Irish origin William Thomson (Baron Kelvin in 1892) published it in 1840. The field $\vec{B}$ is sometimes called magnetic field, but nowadays this name is generally given to $\vec{H}$ (otherwise termed as magnetic field strength), $\vec{B}$ being classified as the magnetic flux density. The physical meaning of this equation is that magnetic monopoles do not exist. It is the only Maxwell equation to be sometimes contested by some scientists that assert that they have evidenced magnetic monopoles. The interested reader can refer to [9], a paper that shows the existence of magnetic monopoles in spin ice.

– Maxwell–Gauss electric equation:

$$\nabla \cdot \vec{D} = \rho \tag{2}$$