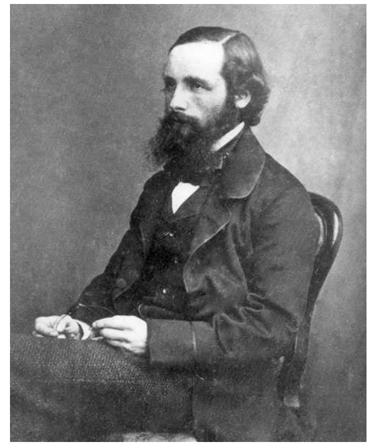
James Clerk Maxwell



Scottish mathematical physicist **James Clerk Maxwell** (June 13, 1831 – November 5, 1879) is especially known for his application of mathematics to the study of electricity. Albert Einstein stated that Maxwell's work resulted in the most profound change in the conception of reality since the time of Newton. Maxwell showed that magnetism, electricity, and light were simply different manifestations of the same fundamental laws. He developed the theory of electromagnetism and was the first to predict the existence of electromagnetic radiation, and to describe light as an electromagnetic wave (traveling waves of energy). He recast the discoveries of British physicist Michael Faraday and others in mathematical form, describing all of these by a unique, elegant, and concise system of equations, the fundamental laws of electromagnetism, which are usually referred to as *Maxwell's equations*.

Maxwell was born in Edinburgh. His father John was a lawyer and a fellow of the Royal Society of Edinburgh. Our subject was a precocious child, always asking questions about what and why. He made his own scientific toys before he was eight, and at 14 he wrote a paper on a method for constructing perfect ovals that was read to the Royal Society of Edinburgh. When Maxwell was eight years old his mother died. His father hired a sixteen-year-old boy as a tutor, who thinking young Maxwell stupid and inattentive abused him. Maxwell then was sent to Edinburgh Academy where he was something of a misfit. His rustic accent, stuttering and making mathematical models marked him for ridicule by his insensitive classmates. Considered dull and unfriendly, he was given the nickname, "Daffy."

At age 16 Maxwell entered Edinburgh University where he spent three years studying physics, mathematics and philosophy. In 1850 he left Scotland for Cambridge University. He started at

Peterhouse but moved to Trinity where he believed it would be easier to obtain a fellowship. Maxwell joined the "Apostles," an exclusive debating society for the intellectual elite. He received a fellowship and graduated with a degree in mathematics in 1854, and was second wrangler and first Smith's prizeman. The Smith's prize, established 1768, is named for Robert Smith a Master of Trinity College who had been Plumian Professor of Astronomy. It is a prestigious competitive award for an essay that incorporates original research. Maxwell's publication *On Faraday's lines of force*, read to the Cambridge Philosophical Society in two parts, launched his electromagnetic researches. The paper helped make respectable Faraday's "field" approach to electricity by drawing extensive mathematical analogies with hydrodynamics. In it Maxwell showed how to express magnetic induction in the differential form that was later to prove the key to electromagnetic waves and in fact all of field theory.

Maxwell declared that a vector requires three quantities (components) for its specification and these can be interpreted as lengths along the three coordinate axis of three-dimensional space. The differential form of Maxwell's equations [Figure 6.3] describes the dependence of the electric and magnetic fields point-by-point. The *Del operator* ∇ (also known as The Hamilton-Tait operator or *nabla*) is used to define the relationship between the electric field and the electrostatic potential. E is the electric field, B the magnetic field, ρ the *charge density,* ε_0 the *permittivity* [the constant of proportionality existing between electric displacement and electric field intensity] of free space and μ_0 is *permeability* [measure of the ease with which magnetic lines of force are carried by a particular material] of free space. Maxwell's four equations are statements of 1. Gauss' Law for Electricity, electric field diverges from electric charge. 2. Gauss' Law for Magnetism, there are no isolated magnetic poles. 3. Faraday's Law of Induction, electric fields are produced by changing magnetic fields and 4. Ampere's Law, circulating magnetic fields are produced by changing electric fields and by electric currents.

Maxwell's Equations

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon_0$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \boldsymbol{j}_c$$

where

$$\nabla = \hat{\mathbf{i}} \frac{\partial}{\partial x} + \hat{\mathbf{j}} \frac{\partial}{\partial y} + \hat{\mathbf{k}} \frac{\partial}{\partial z}$$

Figure 6.3

In 1856 Maxwell was appointed Professor of Natural Philosophy at Marischal College in Aberdeen. When Marischal College and King's College merged in 1860, Maxwell, the junior of the department, lost his post. He also failed to secure the Chair of Natural Philosophy at Edinburgh that went to his close friend Peter Guthrie Tait. In 1860 Maxwell was appointed to the vacant chair of Natural Philosophy at King's College in London, where he spent his most productive period. Maxwell resigned his post in 1865 in order to work privately on his investigations at his family estate. In 1871, he reluctantly left Scotland to become the first Cavendish Professor of Experimental Physics at the University of Cambridge, where he designed the Cavendish laboratory that was formally opened on June 16, 1874.

Maxwell died of cancer at the age of 47, but in his short life he made fundamental contributions to the theory of gases, the study of heat and thermodynamics, and above all to electromagnetism. Much of his work on field theory was published in his masterpiece, *A Treatise on Electricity and Magnetism* (1873). Maxwell's "ether," the vast sea of space that made possible the transmission of light, heat and radio waves was a convenient metaphor that made it possible for scientists and engineers who later came to think of “waves.” It provided an imaginative model that allowed them to proceed with their experimentations in electromagnetism. These led to the wireless telegraph, radio, television, radar and the laser. Maxwell was not accorded the honors that his contributions warranted during his lifetime. This was partly due to the fact that most of his contemporaries did not accept his theory of electromagnetism, because they did not understand his mathematics.

Quotation of the Day: “All the mathematical sciences are founded on relations between physical laws and laws of numbers, so that the aim of science is to reduce the problems of nature to the determination of quantities by operations with numbers.” – James Clerk Maxwell