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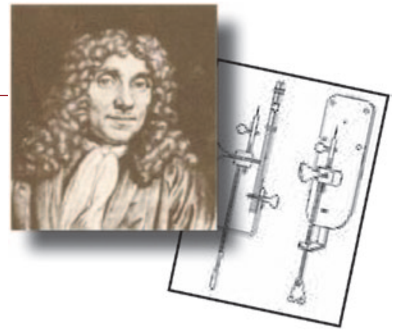
Pioneers in Optics: James Clerk Maxwell and Chandrasekhar Venkata Raman



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James Clerk Maxwell
(1831–1879)

James Clerk Maxwell was one of the greatest scientists of the nineteenth century. He is best known for the formulation of the theory of electromagnetism and for making the connection between light and electromagnetic waves. He also made significant contributions in the areas of physics, mathematics, astronomy, and engineering. He is considered by many to be the father of modern physics.

Maxwell was born in Edinburgh, Scotland, in 1831. Even though most of his formal higher education took place in London, he was always drawn back to his family home in the hills of Scotland. As a young child, Maxwell was fascinated with geometry and mechanical models. When he was only fourteen years old, he published his first scientific paper on the mathematics of oval curves and ellipses that he traced with pins and thread. Maxwell continued to publish papers on a variety of subjects. These included the mathematics of human perception of colors, the kinetic theory of gases, the dynamics of a spinning top, theories of soap bubbles, and many others.

Maxwell's early education took place at Edinburgh Academy and at the University of Edinburgh. In 1850 he went on to study at the University of Cambridge and, upon graduation from Cambridge, Maxwell became a professor of natural philosophy at Marischal College in Aberdeen until 1860. He then moved to London to become a professor of natural philosophy and astronomy at King's College. In 1865, Maxwell's father died, and he returned to the family home in Scotland to devote his time to research. In 1871 he accepted a position as the first professor of experimental physics at Cambridge where he set up the world-famous Cavendish Laboratory in 1874.

While at Aberdeen, Maxwell was challenged by the subject of the Adams Prize of 1857: the motion of Saturn's rings. He had previously thought and theorized about the nature of the rings when he was only sixteen years old. He decided to compete for the prize, and the next two years were taken up with developing a theory to explain the physical composition of the rings. He was finally able to demonstrate, by purely mathematical reasoning, that the stability of rings could only be achieved if they consisted of numerous small particles. His theory won him the prize and, more significantly, nearly a hundred years later, the Voyager 1 space probe proved his theory right.

Much of modern technology has been developed from the basic principles of electromagnetism formulated by Maxwell. The field of electronics, including the telephone, radio, television, and radar, stem from his discoveries and formulations. Although Maxwell relied heavily on previous discoveries about electricity and magnetism, he also made a significant leap in unifying the theories of magnetism, electricity, and light. His revolutionary work lead to the development of quantum physics in the early 1900s and to Einstein's Theory of Relativity.

Maxwell began his work in electromagnetism by extending Michael Faraday's theories of electricity and magnetic lines of force. He then began to see the connections between the approaches of Faraday, Reimann, and Gauss. As a result, he was able to derive one of the most elegant theories yet formulated. Using four equations, he described and quantified the relationships between electricity, magnetism, and the propagation of electromagnetic waves. The equations are now known as Maxwell's Equations.

One of the first things that Maxwell did with the equations was to calculate the speed of an electromagnetic wave and found that it was almost identical to the speed of light. Based on this discovery, he was the first to propose that light was an electromagnetic wave. In 1862 Maxwell wrote, "We can scarcely avoid the conclusion that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena."

This was a remarkable achievement, for it not only unifies the theories of electricity and magnetism, but of optics as well. Electricity, magnetism, and light can now be understood as aspects of a single phenomenon: electromagnetic waves.

Maxwell also described the thermodynamic properties of gas molecules using statistical mechanics. His improvements to the kinetic theory of gases included showing that temperature and heat are caused only by molecular movement. Though Maxwell did not originate the kinetic theory, he was the first to apply probability and statistics to describe temperature changes at the molecular level. His theory is still widely used by scientists as a model for rarefied gases and plasmas.

Maxwell also contributed to the development of color photography. His analysis of color perception led to his invention of the trichromatic process. By using red, green, and blue filters, he created the first color photograph. The trichromatic process is the basis of modern color photography.

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Maxwell's particular gift was in applying mathematical reasoning to solve complex theoretical problems. Maxwell's Electromagnetic Equations are perfect examples of how mathematics can be used to provide relatively simple and elegant explanations of the complex mysteries of the universe. Richard Feynman wrote of Maxwell, "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 nineteenth century will be judged as Maxwell's discovery of the laws of electrodynamics."

Maxwell continued his work at the Cavendish Laboratory until illness forced him to resign in 1879. He returned to Scotland and died soon afterwards. He was buried with little ceremony in a small churchyard in the village of Parton in Scotland.

Chandrasekhar Venkata Raman
(1888–1970)

When Chandrasekhar Venkata Raman was born in Trichinopoly, Madras, India, on November 7, 1888, there was little opportunity for inhabitants of the country to pursue scientific research as a career. Nevertheless, this setback did not hinder Raman, the son of a college lecturer and the second of eight children. Instead, throughout his lifetime Raman would consistently create his own opportunities, at the same time changing the scientific climate of India and heightening the prospects of his countrymen.

Raman was educated at the Presidency College in Madras where he graduated at the top of his class. Afterward, he considered relocating to England to continue his studies but decided to remain in his homeland, where he enrolled in the masters program in physics at Presidency College. Allowed to pursue his own interests, Raman conducted experiments involving the diffraction of light through rectangular apertures and compiled his findings into a manuscript that he submitted to the *Philosophical Magazine* in London. Their publication of the work was particularly remarkable because it was the first article to originate from Presidency College, and its author was only eighteen years old.

Having completed his M.A. in 1907, Raman was faced with the harsh reality that there was no place in India where he could pursue physics research professionally. Thus, he sat for a competitive examination for a government post in finance. He won the coveted position and for the next ten years carried out independent research while simultaneously fulfilling his professional duties in Calcutta. The pertinence of his work led Calcutta University to offer him their first endowed physics chair in 1917, a position he accepted despite the fact that it would pay significantly less than his government post.

It was during his years at Calcutta University that Raman made what would be his primary contribution to optics. While studying light diffraction, Raman discovered that when an intense light was passed through a transparent medium, a small fraction of the light surfaced in directions other than the incoming beam, and an even smaller part of this fraction of light exhibited different wavelengths than the incident light. After his findings were made public in 1928, the scattering of the light molecules came to be known as Raman scattering, which was considered a result of the Raman effect, the change in wavelength of light when it is deflected by molecules. Though the Raman effect is weak, its discovery greatly impacted future research regarding molecular structure and radiation. The importance of Raman's discovery was widely recognized, and he was knighted by the British government in 1929 and awarded the Nobel Prize for Physics a year later.

In 1933, Raman left Calcutta University to head the physics department at the Indian Institute of Science in Bangalore. During his time at the institution, he carried out a study with his colleague Nagendra Nath, which resulted in the development of the Raman-Nath theory on the diffraction of light by ultrasonic waves. He also influenced a great number of students and founded the Indian Academy of Sciences as well as the *Indian Journal of Physics* as forums to promote scientific discussion and debate. Raman retired from the university in 1948 and soon opened the Raman Research Institute, an establishment for which he personally planned and carried out the fundraising. He continued his research there for many years—ultimately publishing more than 450 papers over the course of his lifetime—before his death on November 20, 1970. His ashes were scattered among the trees surrounding the institute.

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