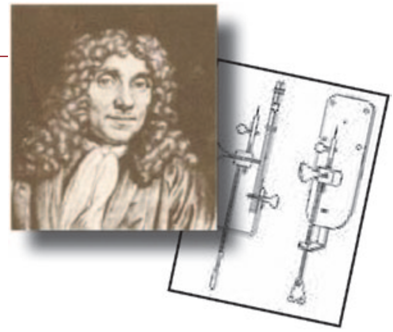
Pioneers in Optics: William Rowan Hamilton and John Kerr



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William Rowan Hamilton
(1805–1865)

Considered a child prodigy, William Rowan Hamilton could read Hebrew, Latin, and Greek at the tender age of five and had undertaken the study of at least six other languages before his twelfth birthday. The native of Dublin, Ireland, lived with and was educated by an uncle who was an Anglican priest, because his father's legal career required him to spend much of his time in England. In his youth, Hamilton was introduced to Zerah Colburn, an American mathematical prodigy who exhibited his amazing calculating dexterity for entertainment. Competitive bouts of computations between the young men apparently inspired Hamilton to increase his knowledge of mathematics, and he embarked on a course of study that included the works of Euclid, Clairaut, Lloyd, Newton, Lagrange, and Laplace. By 1822, his mathematical abilities had advanced to such an extent that he discovered an important error in Laplace's treatise *Celestial Mechanics*, a feat that garnered him the attention of the Royal Astronomer of Ireland, John Brinkley, who he would shortly thereafter replace.

Once he entered Trinity College, Hamilton's reputation for superior ability continued unabated, and he obtained the extraordinary distinction of receiving an "optime" in both science and classics. In 1824, he presented a paper, *On Caustics* (in optics, caustics refer to bundles of light rays), to the Royal Irish Academy. While it was not accepted for publication in its original form, the group acknowledged the merit of the paper and urged Hamilton to develop the subject matter further, which he did over the course of several years. In 1827, an expanded form of Hamilton's work with caustics was submitted to the Academy and was ordered to be printed. The important treatise entitled *Theory of Systems of Rays* described a theory that integrated optics, mathematics, and mechanics into a single characteristic function. By using this function, Hamilton was able to mathematically address in detail caustic curves, the density of the light in close proximity to caustic surfaces, and the foci of reflected light. Largely based on the strength of his theory of the characteristic function of an optical system, Hamilton won the position of Royal Astronomer of Ireland, which was vacated by Brinkley when he became a bishop. Also, later in 1827, Hamilton received an appointment as a professor of astronomy at Trinity College. Despite his significant abilities, some prominent individuals considered an undergraduate an inappropriate choice for such distinguished posts and, therefore, viewed Hamilton's acceptance of these positions with skepticism.

Prior to establishing himself in Dunsink Observatory, located just outside of Dublin, Hamilton engaged in travel throughout England and Scotland. During this tour, he became acquainted with the British romantic poet William Wordsworth, and the two formed a lasting friendship. Over the course of their correspondence, Hamilton often shared his own poetry with the famed writer, which he apparently began writing when he found out his first love, Catherine Disney, was to marry someone else. His scientific skill, however, appears to have been greater than his poetical prowess, a view Wordsworth was not too timid to share with him. Nevertheless, Hamilton's penchant for scribbling verses continued throughout his life, perhaps because he never quite reconciled himself to losing Catherine, with whom he sporadically corresponded despite his eventual marriage to Helen Maria Bayly. Hamilton and Wordsworth also often engaged in lively debates about the nature of science and poetry and whether or not there were parallels between the two seemingly divergent spheres.

It was not long after he was installed in Dunsink that Hamilton found that his real interests lay more in the realm of mathematics than astronomy, but as he was allowed to spend his time as Royal Astronomer in whatever manner he saw fit, he was able to indulge his personal preference. During the early years of his career, he developed three lengthy supplements to his treatise on systems of rays, the first of which (1830) expands his theory to optical systems in which light is refracted, the second of which (1831) concerns the study of plane systems and systems of revolution, and the last of which (1832) addresses the wave theory of light, aberration, and the transmission of light in biaxial crystals in relation to his theory of the characteristic function. Hamilton outlined in this third supplement the mathematical prediction that light refracted by a suitably pure biaxial crystal will form a hollow cone if a single ray of light is incident at certain angles on the face of that crystal. It was for this prediction that Hamilton received the most acclaim during his lifetime. His prediction of conical refraction was quickly verified through experimental means by another professor at Trinity College, Humphrey Lloyd, and both he and Hamilton

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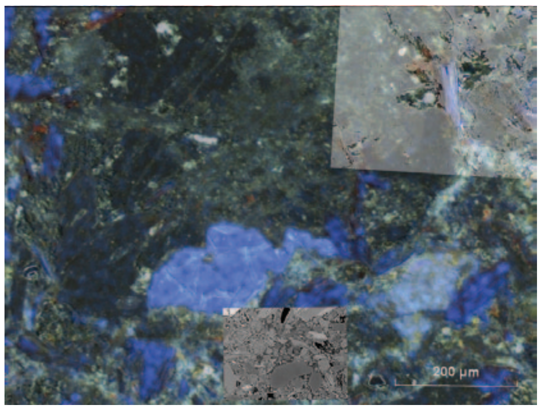

Light microscope image of Suevite breccia where the entire image is overlapped with EDS map (Fe) and the relocated ROIs are extended by the corresponding SEM (BSE detector) images in Shuttle & Find

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became well established in scientific circles. Today, many of the possibilities for the practical use of conical refraction are just beginning to be realized because of the remarkable difficulty in obtaining optical quality biaxial crystals, such as the aragonite used by Lloyd. However, because of recent improvements in the fabrication of synthetic crystals, the phenomenon first predicted by Hamilton may soon find use in high-tech devices, such as specialized optical tweezers, as well as in holography and other laser applications.

After the success he experienced in 1832, Hamilton began to concentrate his efforts on the study of dynamics and produced several important papers in the field. Hamiltonian mechanics became even more appreciated as the discipline of quantum mechanics began to take shape in the twentieth century.

In the late 1830s Hamilton's focus shifted again, this time to the basic principles of algebra. His work in the area resulted in a theory of conjugate functions, or algebraic couples, in which complex numbers are formed as ordered pairs of real numbers. Subsequently, Hamilton attempted to develop a theory of triplets that could be applied to three-dimensional geometric problems, but without any success. Eventually, in 1843, he realized suddenly during a walk with his wife along the Royal Canal that the theory he sought should involve quadruplets, not triplets, and his excitement at his discovery caused him to pause and carve the equations that would underlie such a theory in a nearby bridge. Thus, began more than twenty years of work on Hamilton's theory of quaternions, which would greatly impact the development of the modern system of vector analysis and is sometimes used today in computer graphics, attitude control systems, and the control theory used in engineering.

Hamilton received many honors and awards throughout his life for his work in optics, mathematics, and mechanics. He was knighted in 1835 during an assembly of the British Association for the Advancement of Science, appointed president of the Royal Irish Academy in 1837 (a post he held until 1846), and made a foreign member of the St. Petersburg Academy. He was also elected the first corresponding member of the American National Academy of Sciences a short time before he died from gout on September 2, 1865.

John Kerr
(1824–1907)

John Kerr was a Scottish physicist who discovered the electro-optic effect that bears his name. Born in Ardrossan, Ayrshire, Kerr was the son of a fish seller and was educated in the village of Skye before attending Glasgow University, from which he received a Master of Arts in Physical Science with highest distinction. As a student, Kerr carried out research under his contemporary, William Thomson, better known as Lord Kelvin. The pair became close friends and remained so until their deaths in 1907. In addition to science, Kerr was interested in religion, and he studied divinity before becoming an ordained minister of the Free Church of Scotland. Instead of practicing as a minister, however, he accepted a position as a mathematics and physical science lecturer at the Glasgow Free Church Teacher Training College where he would teach for more than forty years.

In 1875, John Kerr first reported on the electro-optic phenomenon that would come to bear his name. By using a simple slab of glass with two holes drilled into its long axis so that approximately a one-half inch of solid glass separated them, an induction coil with two metal probes that were placed in the holes, and a polarizer and an analyzer aligned so that they were perpendicular to one another, Kerr demonstrated that when an electric potential is applied to an optical medium, light passing through it is doubly refracted. In other words, strong electric fields alter the molecular structure of glass and other substances, as Kerr later observed, so that the index of refraction (a measurement signifying the extent to which a beam of light is bent) in the direction of the electric field is different from the index of refraction of the vibration perpendicular to the field. As Kerr also found, the double refraction or birefringence that is induced is directly proportional to the square of the electric field to which it is exposed.

Kerr's original glass, induction coil, and crossed polarizer set-up is considered the first Kerr cell. Modern Kerr cells usually consist of a transparent shell containing nitrobenzene or some other liquid, rather than being composed of glass. The principle on which they are based is still the same, however, and exposure to an electric potential allows light to pass through the analyzer, which is positioned so that it blocks all light under ordinary conditions. Pulses of light can be controlled so quickly with a modern Kerr cell that the devices are often used as high-speed shutter systems for photography and are sometimes alternately known as Kerr electro-optical shutters. In addition, Kerr cells have been used to measure the speed of light, are incorporated in some lasers, and are becoming increasingly common in telecommunications devices. The invention of lasers has led to the discovery of a special case of the Kerr effect, known as the AC Kerr effect, which is induced when the electric field a material is exposed to stems from light itself.

A year after his studies of the electro-optic Kerr effect, Kerr observed a similar phenomenon related to magnetic fields, which is now called the Kerr magneto-optic effect. To demonstrate this effect, he reflected a plane-polarized light from the polished pole of an electromagnet. When Kerr turned the magnet on, the light became elliptically polarized. As he showed, the extent of the effect depends on the position of the surface from which the light is reflected with respect to the magnetization direction as well as to the plane of the light's incidence.

Another notable interest of Kerr's was the metric system, and the physicist greatly pushed for its adoption in his homeland. In 1864, following the publication of a pamphlet of his on the subject as well as the release of a book he wrote entitled *Rational Mechanics*, he was awarded an honorary doctorate degree. His later accomplishments were recognized by election into the Royal Society (1890) and the receipt of that organization's prestigious award, the Royal Medal (1898).

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