Obituary

Leonard Mandel (1927–2001)

Leonard Mandel, one of the founding fathers of quantum optics, died at his home on 9 February at the age of 73. Our generation of optical scientists grew up learning from Mandel's work: quite literally, he showed us the light by opening up many new avenues of research. He was an elegant experimentalist and a celebrated theorist. Echoes of his unmistakable slow but clear voice will continue to remind us of the contributions of this remarkable man.

Mandel was born in Berlin, but moved to Britain when he was a boy. He was educated at the University of London, studying cosmic rays for his PhD, which was awarded in 1951. After a short spell in industry, Mandel took up an academic post at Imperial College, London. It was the investigation of cosmic rays that eventually led him to discover what is today known as Mandel's photon-counting formula, which relates the statistical properties of arbitrary optical fields to those of photoelectrons detected experimentally. Mandel worked throughout his career to perfect the photon-counting technique for studying a variety of optical fields, from the thermal light of a candle to sophisticated quantum sources. In the 1960s, this work enabled physicists to understand the statistical properties of lasers operating under different pumping conditions. Such studies gave support to the quantum theory of the laser.

Mandel performed his first major experiment at Imperial, its simplicity in design becoming one of his trademarks. The result, typically, was counterintuitive. The experiment showed how interference between independent photon beams can be observed and that such a possibility is permitted by quantum physics. His demonstration of two-photon interference followed. This was an experiment that laid the foundation for later work on quantum entanglement, a concept of state superposition first introduced by Erwin Schrödinger.

In 1964 Mandel settled permanently in Rochester, New York, having been persuaded to move there by Emil Wolf. Wolf and Mandel wrote several notable papers together, and also organized the Rochester Conferences on Quantum Optics, which laid the foundations of the field and continue to this day. It was at one of the early conferences that debate really began to heat up on the need for a quantum theory of light, and Mandel started to devote much of his research

Pioneer in quantum approaches to light

to searching for the subtle differences between the classical and quantum descriptions of light.

Applying a mixture of theory and experiment, Mandel and colleagues revealed several uniquely quantum-mechanical properties of light. In 1977, for instance, his group observed the 'photon anti-bunching' effect, in which photons from a single two-level atom illuminated by a resonant laser can never be emitted in pairs or more, providing confirmation of a 'quantum jump'. This was followed by the demonstration of sub-poissonian photon statistics, which mean that fluctuations in the photon number of an optical field are smaller than would be expected for random events, such as the fall of raindrops. These were the first reported observations of 'non-classicality' requiring a full quantum description of light, and they changed our perspective on light.

Photon interference was the hallmark of Mandel's work. In the 1980s his group carried out a series of ground-breaking yet ingeniously simple experiments to demonstrate the quantum entanglement of photons and, subsequently, the non-locality of quantum mechanics through violations of Bell's inequalities in the Einstein–Podolsky–Rosen paradox. These studies set the ball rolling for a large number of experiments world wide dealing with the foundations of quantum mechanics, and for newer developments such as quantum teleportation, quantum encryption, and cryptography for quantum-information processing.

As he entered his seventh decade, Mandel was still as productive as ever in addressing some of the fundamentals of physics. One of the problems that bothered Paul Dirac, the founder of quantum electrodynamics, was how to define the phase of a quantized electromagnetic field: phase is crucial in understanding all interference phenomena. The answer remained elusive until the early 1990s, when Mandel introduced the concept of measurable phase, and actually measured the phase characteristics of a quantized field.

In this same period he demonstrated the non-existence of a pilot wave, which is at the heart of de Broglie's wave interpretation of quantum mechanics. And in another conceptually straightforward but mind-boggling experiment, Mandel and his students demonstrated the complementarity of light — that is, its behaviour as either a wave or a particle in different circumstances. It was, of course, known that placing a detector in its path could change the behaviour of light. But Mandel found that an experimental set up that merely has the possibility of making a measurement, even if only in principle, could bring that change about: no actual measurement is required.

Mandel was a private but generous person. Discussions with him were invariably inspiring, often leading to fresh ideas, as we ourselves can attest. Although his voice was weakened by illness, Mandel's mind remained as sharp as ever. Only a few months before his death, he and his colleagues published a paper on squeezing the quantum noise in atomic spin, an approach which may lead to entangled states of atoms.

As well as being a world-class researcher, Mandel was a great teacher. Many of his 39 PhD students became leaders in their fields: Jeff Kimble, for instance, with whom Mandel discovered the photon anti-bunching effect, is working at the forefront of the new field of quantum information science, which is based on the concept of quantum entanglement. The field that Mandel opened up, and to which he made so many contributions, has begun to have an impact on the information age in which we now live. His legacy is to have provided the inspiration for the next generation of researchers pursuing a deeper understanding of the fundamental laws of nature and their applications.

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