Nicolaas Bloembergen

(1920–2017)

Laser and optics pioneer whose work led to magnetic resonance imaging.

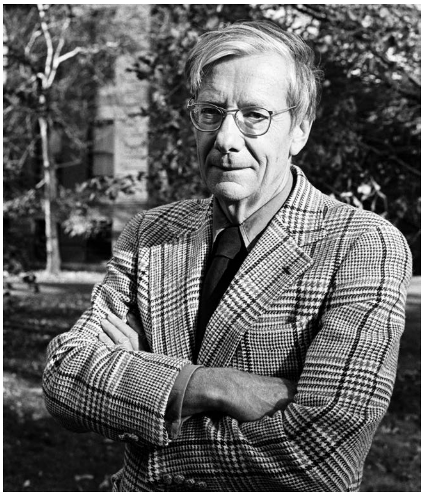
Nicolaas Bloembergen had three major achievements, any one of which could have warranted his Nobel Prize in Physics. He was a pioneer in nuclear magnetic resonance (NMR) and in non-linear optics, as well as in lasers, the work mentioned in the Nobel citation. Self-effacing, he sometimes called himself "a glorified engineer". He was thrilled that his intellectual pursuits turned out to be useful in wider society. I recall him excitedly telling a weekly group meeting in the early 1970s, "NMR is now being used for medical imaging!"

Bloembergen died aged 97 in Tucson, Arizona, on 5 September. Born in 1920, in Dordrecht, the Netherlands, he passed through the crucible of the Second World War. He studied physics at Utrecht University in the Netherlands, but his education was interrupted when Nazi authorities closed the university. During the Dutch famine in 1944, he recalled, he ate boiled tulip bulbs. One in ten of his college fraternity brothers perished, having been caught and killed as members of the underground, shot as hostages or deported as Jews, or having succumbed to illness and malnutrition.

In January 1946, he boarded a ship for the United States, bound for graduate studies with Edward Purcell at Harvard University in Cambridge, Massachusetts. Just five weeks earlier, Purcell had co-discovered NMR — the concept that atomic nuclei can absorb radio-frequency electromagnetic radiation in the presence of a magnetic field. There followed 18 months of intense experimental work, in which Bloembergen laid out the physics of nuclear magnetic relaxation: how NMR could be used to sense the motions of, for example, water molecules, through the radio-frequency response of its protons.

This formed the basis of his PhD thesis, which became such a useful guide to the new technology that hundreds of unauthorized photocopies were soon in circulation. His thesis was ultimately reissued as a book, *Nuclear Magnetic Relaxation* (Springer, 1948) that sold well for decades. Bloembergen spent a year back in the Netherlands at Leiden University, before returning to Harvard, where he was made an associate professor in 1951.

During his thesis work, Bloembergen's first striking physics discovery was the concept of motional narrowing. This is the



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counter-intuitive observation that spectral lines become sharper and narrower the more frequently the nuclear spins are disturbed. The concept is used to explain the shape of lines in all facets of spectroscopy, in all research fields and across all frequency bands. The sharp spectral lines that Bloembergen observed for protons in water were later used for medical magnetic resonance imaging, enabling physicians to view soft tissue inside the body for the first time.

Working to enable the precursor of the laser — the maser — he found a practical way to generate a population inversion, an unusual situation in which more members of a physical system exist at a higher energy level than at a lower one. Population inversion is a prerequisite for lasers, and Bloembergen's scheme, three-level pumping, enabled the development and widespread adoption of the laser. His colleague Lester Hogan teased rivals at Bell Labs, telling them that, once they realized how simple Bloembergen's idea was, "you will kick yourself in the pants".

In 1961, Bloembergen and his research group at Harvard examined how light of sufficient intensity can change the properties of a material that it interacts with. For example, refractive index becomes a function of light intensity — hence the phenomenon now called non-linear optics. His group published three long papers in *Physical Review* in 1962–64, exploring the phenomenology and fundamentals of this concept. Among the more minor insights was quasi-phase matching, today used to create the green in green laser pointers.

A more fundamental concept was non-linear susceptibility, the optical response of illuminated material. Normally, this response would depend on the input light frequencies. Bloembergen realized that non-linear susceptibility would also contribute to the amount of free energy in the material (free energy depends on both the input and output frequencies). Thus, there is always one extra frequency in non-linear susceptibility.

Bloembergen and his team also made clear that many seemingly disparate physical effects (including second-harmonic generation and change in refractive index with electric field) all stem from the same physical process. Similarly, there are vast numbers of third-order non-linear optical effects, which seem different, yet have the same origin. Today, Internet communication to data centres, as well as under-sea optical communication cables beneath the Pacific and Atlantic oceans, need to take full account of these non-linear effects to function.

After retiring from Harvard in 1990, Bloembergen worked as a visiting scientist at the University of Arizona in Tucson, where he accepted a professorship in 2001.

He often said that he was just lucky to be at the right place, at the right time. But there were many other scientists at that time — and Bloembergen always seemed to be at the right place, over and over again.

His achievements arose from his great scientific and personal integrity. He never deceived himself about what was important in physics, and he never went for the easy solution. He was both a theoretician and an experimentalist. And although he seemed to have a laissez-faire attitude in his lab, that may be because he was always so busy. He was a role model, loved by his students. He was always excited when they brought him new data, and he took every opportunity to brag about their achievements. They were his greatest pride. ■

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