Editorial

Curiosity-driven research: What light shows us

The New Zealand Association of Scientists exists to act as an advocate for science and scientists. We strive to further the community's appreciation of the value of scientific enquiry: both cultural, in deepening our understanding of the world we live in, and technological, in terms of the benefits that flow from using science to create new devices and new ways of doing things. This issue of *Science Review* takes up an opportunity to do this in relation to all aspects of the science of light. In six essays we present ongoing work in New Zealand that explores the nature of light and applies it to a variety of branches of science.

To celebrate the cultural, scientific, technological and medical importance of light, the United Nations General Assembly, at the request of UNESCO, has designated 2015 as the Year of Light and Light-based Technologies. Physics societies, illumination engineering organisations, technology manufacturers, and many others across the world are organising functions to arouse global awareness of how light-based technologies provide solutions to problems in agriculture, energy, health, and the built environment. A New Zealand committee has been established, and the Royal Society of New Zealand is running a wide-ranging set of ten talks that will be delivered at different venues around the country and made available over the internet. All this activity provides an excellent opportunity to create a greater appreciation of the benefits that flow from the effort over many centuries to understand what light is and how we can use it to understand our world.

Curiosity about light has contributed enormously to the progress of Physics. In the late 17th Century Isaac Newton adopted and developed a corpuscular theory of light, in which light was a stream of particles travelling in a straight line and reflected in a predictable way. This view of light was predominant through the 18th Century. Geometrical optics, based on tracing rays of light, follows from it and pretty much suffices for the design of lenses and mirrors and for instruments employing them, such as telescopes, microscopes, and cameras.

An alternative theory, formulated by Huygens contemporaneously with Newton, treats light as waves propagated in a postulated otherwise-undetectable medium, the *luminiferous aether*, now known to be the electromagnetic field. Providing the wavelength is taken to be short, this can explain rectilinear propagation, reflection, refraction, interference between waves, and colour. It did not, however, gain widespread acceptance until Thomas Young, in 1801, split sunlight into two coherent beams and demonstrated interference between them. The wave theory of light led to an understanding of colour and spectral phenomena and the invention of diffraction gratings, spectrophotometers and devices based on double refraction in crystals.

It was an attempt to understand light, in the form of spectral lines emitted by atoms, in particular the hydrogen atom, that led to Bohr's model of Rutherford's atom. And it was a search for understanding of the way in which light ejected electrons from metal surfaces that led to Einstein's theory of the photoelectric effect. These were critical drivers of the old quantum theory. The interaction of light and matter is a crucial part of the formulation in the 1920s of quantum mechanics, but was not fully explored for many years.

A new era in the understanding of light opened up with the publication in 1958 of the basic theory of a laser, following the construction of the maser, and leading to the invention of the first laser in 1960. The underlying principle of these devices is the theory of stimulated emission of light as set out by Einstein some 40 years earlier. With laser light available renewed effort went into understanding the quantum properties of light. This started with the application, in particular by Roy Glauber at Harvard, of quantum theory to the electromagnetic field to study the optical coherence of quantised electromagnetic fields and opened up the subject now known as quantum optics. Discoveries and topics of investigation over the next three decades included the prediction and observation of photon antibunching, phase-dependent properties of light such as squeezed states, and the entanglement of photons. An Auckland graduate, the late Dan Walls, was in on this from almost the beginning as a doctoral student of Glauber. On returning to New Zealand after postdoctoral work in Germany, Dan established research schools at Waikato University and later at Auckland University which published world-leading research in quantum optics. An important component of this work is described by Howard Carmichael in the first essay, together with the implications for our understanding of quantum mechanics.

Lasers and an understanding of their light have contributed enormously to science and to industrial and medical technology. Lasers arranged in an appropriate configuration can be used to trap and cool gases of certain atoms to extremely low temperatures and thereby induce a phase transition to a new state of matter, a Bose-Einstein condensate. Similarly lasers can be used to trap and move very small objects, not only atoms but also virus particles and even bacteria. Niels Kjaergaard explains these matters in the third essay. Quantum mechanics underpins modern materials physics and has provided the tools to design much improved photodetectors; in the second essay Natalie Plank and Justin Hodgkiss describe how this has led to the development of photovoltaic cells that convert sunlight to electricity to provide power at a cost comparable with other electric power sources. Lasers also have many applications in medical technology; in the fifth essay Kylie Price and Mike Berridge describe the use of optical techniques for cell sizing and sorting and how this contributes to medical research.

Precise and reproducible measurement of light intensity and illumination levels is required in many contexts; in the fourth essay Annette Koo explains how this is done at New Zealand's national measurement institute and describes how our measurements are kept consistent with those around the world.

Photonics—technologies utilising sources, detectors and novel materials developed with the understanding provided by quantum optics and quantum mechanics—offers many opportunities for industrial growth. Cather Simpson, in the sixth essay, describes several, including micromachining, sperm sorting, and applications of nonlinear effects, that are being developed at Auckland University. Finally, it is important to appreciate that we already have an optical manufacturing industry in this country that produces internationally competitive products. Vega Industries are supplying sophisticated beacons and navigation lights to clients around the world using LED and conventional light sources. KiwiStar are building precisely-specified lens assemblies and novel spectrophotometers for some of the largest telescopes in the world.

John Clare
Guest Editor