Professor John Frederick Nye, internationally renowned physicist, died on 8 January 2019, a month before his 96th birthday. John Nye was born in Hove, Sussex. He was a student in Cambridge, and carried out postdoctoral research at Bell Laboratories in the USA. In 1953 he moved to the University of Bristol, where he was a member of the physics department, while employed and after formal retirement, for 66 years.

He made major achievements to physics in three areas: crystals, ice and light. In crystals, his emphasis was on the defects that disrupt the regular arrangement of their atoms; in the spirit of his Bristol colleague Charles Frank: “Crystals are like people: it is their imperfections that make them interesting.” His first contribution to science, in 1947, was a collaboration with the Nobel Prizewinner Sir Lawrence Bragg; they explored crystal
defects with an analogue experiment, in which the atoms in a crystal were represented by a raft of bubbles. He was among the first to realise that for some purposes a crystal can be regarded as a gas of continuously distributed defects. This phase of his research culminated in his 1957 text *Physical Properties of Crystals*; this is still in print, and remains a uniquely accessible treatment of a difficult subject.

We now discuss his contributions to glaciology and optics in more detail.

**Glaciology**

John Nye’s contribution to glaciology was very important. Through most of the earlier parts of the twentieth century, most work on glacier theory had been based on treating ice as a Newtonian viscous liquid with a very high viscosity. New laboratory work had shown that this was far from the case, and Nye’s first paper, in 1951, took a completely different model. It treated ice as a perfectly plastic material, i.e. one which was completely rigid until a certain shear stress was reached when it would flow as much as necessary to retain this level of stress. This means that a wide glacier or ice sheet would have a definite thickness related to the slope of its bed and if the bed slope changed the ice would shear until the right stress for the new slope was achieved. This lead him to predict the strain that would need to occur and thus to predict the pattern of shear strain in the glacier. One of us (JWG) accompanied him on a visit to Switzerland where we found evidence of thrust planes, discontinuities of some glaciers which reflected his theoretical predictions.

In 1953 he wrote a further paper which compared measurements made of the rate of closure of tunnels in glaciers, laboratory measurements and the measurements made on the movement of a borehole drilled through a large glacier. He showed that these were all consistent apart from one set of measurements: those of the rate of closure of a tunnel in the Arolla Glacier in Switzerland, which was closing much faster than expected; he discussed possible reasons for this.

A further paper in 1957 discussed the distribution of stress in glaciers and ice sheets, using longitudinal velocity gradient as the determining factor,
and a further paper in 1958 applied kinematic wave theory (which had been
developed to explain movement of traffic on roads) to explain the
occurrence of surges in some glaciers and ice sheets.

In 1959 he considered temperature and its effect on the rate of ice
flow and showed that consequently much of the shear strain occurring in
many glaciers will be concentrated in the lowest layers, and also showed
how surface waves on the Antarctic Ice Sheet are due to mountains under the
ice. He followed this in 1960 with a paper on the response of glaciers and
ice sheets to seasonal and climatic temperature changes which shows why
glaciers are such sensitive indicators of climatic change. This led in 1963 to
a paper on the theory of the advance and retreat of glaciers and also to the
theory of how glaciers change in response to changes in nourishment and
wastage.

In 1967 Nye turned to understanding “regelation”: the process by
which a wire under stress moves through ice by melting beneath it and
refreezing above. He showed that this involved both a heat-flow problem
and a water flow problem that are not independent and in later paper showed
how this was relevant to the flow of a glacier over a wavy bed.

A further paper proposed a method for determining the movement of
large ice sheets by detailed mapping of the radio echoes from the bed which
would remain the same as the ice sheet flowed over them thus allowing
measurements on the glacier surface to determine where the details of the
bed were situated. This was the starting-point of his original research in
optics and electromagnetism, discussed below.

Further evidence of Nye’s remarkable originality was his emphasis, in
a 1970 paper on glacier sliding, on the fact that the rock bed contains
irregularities on a wide range of scales, so it is impossible to separate
roughness from geography. In envisaging a statistically self-similar
distribution of heights, he anticipated the central idea in what was later to
emerge as a major area of applied mathematics: ‘fractal geometry’.

Over all this time John Nye was quite preeminent in using advanced
mathematical techniques to solve glaciological problems. He also played
his part in the proceedings of the body which, after name changes, became
The International Glaciological Society, including a term presiding over its council. He received the prestigious Seligman Crystal (“awarded from time to time to one who has made an outstanding scientific contribution to glaciology so that the subject is now enriched”).

**Optics**

John Nye was always interested in the physics of light. *Physical Properties of crystals*, included a treatment of polarised light in anisotropic media. This was a pedagogical account of standard material, self-contained, and with the clarity that characterised all his writing. It was around 1970 that his original and fundamental contributions to our understanding of electromagnetic waves, and light in particular, began, and continued for almost half a century until his death in 2019.

The spark that ignited this change in his scientific direction was the measurements of the thickness of ice sheets by radio echo-sounding. In this technique, a quasimonochromatic pulse was reflected from the the bottom, and information about the underlying topography was obtained from the delay between emission and the reception of the first part of the echo, reflected from the rock directly below the source. Nye realised that the long disorderly tail of the echo was scattered by distant roughness and contained potential information about it. To investigate this in the laboratory, he devised a student project, in which the radio waves of wavelength ~5m were replaced by ultrasound of wavelength ~5mm, and the roughness of the ice-rock interface was modelled by crinkled aluminium kitchen foil. The relatively low frequency (~100kHz) enabled the oscillations in the reflected wave to be studied in detail.

While moving the source-receiver, Nye noticed something unexpected: occasionally, two oscillations would separate and a new one would be born between them, or, in the time-reversed phenomenon, an oscillation would disappear. His genius was to realise what this implies for the geometry of the wavefronts in the reflected wave: these can have edges, and the birth and death of oscillations happens when such an edge
encounters the detector. He understood the morphological similarity to the dislocations in crystals that he had studied in his early research: a wavefront with an edge resembled a half-plane of atoms – a defect disrupting the regularity of the crystal lattice. Therefore he denoted the edges by the term ‘wavefront dislocations’.

It quickly became clear that wavefront dislocations were a fundamental feature of waves of all kinds, not previously recognised as such. The deepest way to think about them is to model the wave as a complex scalar field, whose wavefronts are moving surfaces of constant phase. The edges are moving lines in space, on which smoothness and singlevaluedness implies that the phase of the wave is undefined and the wave amplitude is zero. Therefore wavefront dislocations are also ‘phase singularities’ and ‘nodal lines’. The trajectories normal to the wavefronts, which can be regarded as the local wavevectors, along which wave energy flows, circulate around the dislocation lines, so yet another term for them is ‘wave vortices’. They are the most delicate features of waves, representing intricate topological structure on scales much smaller than the wavelength.

The paper reporting this discovery was initially rejected by the Royal Society’s anonymous referee, on the grounds that the calculations were too simple for the idea to have significance. A second referee, later self-identified as Frank Nabarro, who had been in Bristol in the crystal dislocation years, agreed with our rebuttal that simplicity was a positive, rather than a negative, feature, adding that wavefront dislocations were (MB quotes from memory) “missed by Lord Rayleigh who should have discovered them”. The paper has now attracted more than 2000 citations, and ‘optical vortex theory’, as it has come to be called, is a thriving area of what has come to be called ‘singular optics’, described in several textbooks and review articles, and hundreds of papers.

Nye next turned his attention to optics on the coarsest scale, where a field of light is represented by a family of rays, and the singularities are the caustics: envelopes of the ray families, on which the light is focused. Caustics are familiar as the cusped curve in an illuminated coffee-cup, and the dancing patterns of sunlight refracted onto the bottoms of swimming-
pools. Two new aspects of this ancient branch of optics had led to the study of caustics being reinvigorated in Bristol in the early 1970s. The first was the mathematics of ‘catastrophe theory’, providing a library of the sometimes-unexpected forms that caustics can take when they are stable under perturbation – termed ‘natural focusing’ by our colleague John Hannay – in contrast to the artificial focusing by lenses and telescope mirrors. The second was the discovery that each of the stable caustics is decorated by a characteristic pattern of interference: ‘diffraction catastrophes’, the simplest being the Airy function of 1838, now recognised as describing first in a hierarchy of patterns.

An early application had been to the study of the caustics underlying the distorted images of streetlights viewed by people wearing spectacles through raindrop ‘lenses on the lenses’ Nye entered this field with several experimental and theoretical studies of lensing by water-drops deformed by gravity. A central aspect was the way in which catastrophe theory explains the way in which the intricate patterns of caustics change as parameters vary.

There is a sense in which caustics are complementary to wavefront dislocations. Observing dislocations requires the scrutiny of waves on the finest scale, where the caustics are obscured because their geometry is blurred by diffraction. Observing caustics requires viewing on large scales, where phase detail, including dislocations, is too small to see distinctly. This complementarity was recognised in the original dislocations paper. Nevertheless, dislocations and caustics are connected. because each diffraction catastrophe, beyond the simplest Airy wave, possesses an intricate pattern of dislocations, constituting a skeleton underlying it. Nye made a fundamental contribution to this connection across optical scales, by providing much of the conceptual understanding, and experimental confirmation, in an analysis, with Francis Wright and MB, of the ‘elliptic umbilic diffraction catastrophe’. Later, he elucidated the dislocation structure of other diffraction catastrophes.

Phase, organised by wavefront dislocations, and intensity, dominated by caustics, are two important features of waves. In the case of
electromagnetism, there is the additional property of polarisation: the third in the trilogy of fundamental concepts. Here too Nye made fundamental contributions, by identifying the singularities of polarisation. He started by pointing out the analogy between singularities in the pattern of directions in polarised light and the ‘disclination’ singularities of nematic liquid crystals. This was soon followed by his definitive contribution: recognising the two distinct polarisation singularities in general optical fields. First are his ‘C lines’, on which the polarisation is purely circular; these are singularities because the principal axes of the polarisation ellipse are undefined when it is a circle. Second are his ‘L lines’, on which the polarisation is purely linear; these are singularities because the normal to the polarisation ellipse is undefined when it collapses to a line.

Nye’s seminal paper, with Jo Hajnal, identified these singularities, and Hajnal investigated them experimentally in microwaves. To distinguish these geometric features in the presence of confusing waves (for example those reflected from boundaries), they developed the ‘modulated scatterer’ sensing technique, for which he and Hajnal were awarded the 1986 Metrology Award by the UK National Physical Laboratory.

In 1999, Nye summarised his central contributions to the three pillars of singular optics, namely the singularities of phase, caustics, and polarisation, in his book *Natural focusing and fine structure of light*. He explains the physics of the mathematics, and the natural philosophy of the physics, combining theory, computer simulation, and beautiful experimental photographs, with a clarity that cannot be improved upon. The underlying organising principle, emphasised throughout, is ‘structural stability’: the singularities are natural, in the sense that they are preserved under perturbation.

Nye’s list of publications reveals many applications and connections of his three main contributions to singular optics. A few of these scientific treasures are: wave dislocations and phase saddles in the tides (with Jo Hajnal and John Hannay); settling the old problem of specifying an optically black screen (with John Hannay and W Liang); caustics in seismology; rainbows from ellipsoidal raindrops; and a new type of fully electromagnetic
singularity (with John Hannay). In his 96th year, he published a technical paper on an optical aspect of the Riemann-Silberstein electromagnetic vector. And in the days just before he died, he speculated on the curious fact that “stars are often represented on national flags and depicted in paintings either symbolically or with apparently intended realism, as blunt stellated polyhedra, whereas the human eye sees a very small point source, far below the limit of resolution, rather as a glint surrounded by radial lines and points”.

**Personal qualities**

John Nye was admirable personally as well as scientifically. He was always a most courteous man who helped explain the complications of theory to less mathematical able colleagues. As John Wettlaufer wrote from Yale:

“I learned a great deal, technically and personally, from [John] and Georgiana. I recall a visit to Bristol in 1994 in which I was (unfortunately) in the … position of criticizing a piece of work by Charles Frank, and John masterfully saved me from being eaten alive… [such was the variety of his research, that] if someone looks [John Nye] up in a scientific database it would …[seem]… that there are multiple individuals with the same name and affiliation. …John had a herculean influence on so many fields and people, in such a subtle and subdued manner…[he was a] jewel of theoretical physics and geophysics”.

“Subtle and subdued” well describes John Nye. He was the epitome of the English scientific gentleman: wise, engaged, determined yet always polite, with a gentle wit, and always giving due credit to others: a quiet man who did not need to shout.

He is greatly missed: by glaciologists worldwide, by his students and colleagues in the Bristol School of Physics and in the wider university, and by his wife Georgiana and their three children Stephen, Hilary and Carolyn.