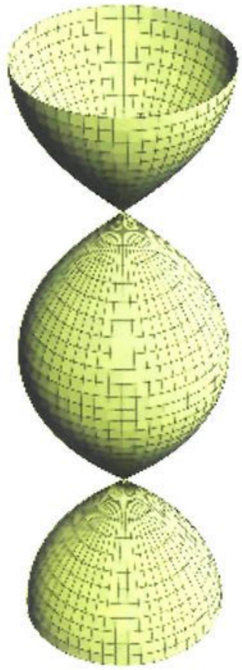

Topology in Ordered Phases

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With CD-ROM

OPTICAL VORTICULTURE

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Lines of topological singularity in the phase and polarization of light are being intensively studied now,[1] motivated in part by a theoretical paper published thirty years ago.[2] However, the subject has a very long prehistory, that is not well known.

In puzzling over Grimaldi's observations of edge diffraction in the 1660s, Isaac Newton narrowly missed discovering phase singularities in light. The true discovery of phase singularities was made by William Whewell[3] in 1833, not in light but in the pattern of ocean tides. The first polarization singularity was observed (but not understood) by Arago in 1817, in the pattern of polarization of the blue sky. A different polarization singularity was predicted by Hamilton in the 1830s, in the optics of transparent biaxial crystals (this was also the first 'conical intersection' in physics).

After reviewing this history, the general structure of the singularities, as we understand them today, will be presented. Phase singularities have several aspects:[4,5] as vortices, around which the current (lines of the Poynting vector) circulates; as lines on which the phase of the light wave is undefined; as nodal lines, where the light intensity is zero; and as dislocations,[2] where the wavefronts possess singularities closely analogous to the edge and screw dislocations of crystal physics. Polarization singularities are lines[5,6] of two types: C lines, where the polarization is purely circular, and L lines, where the polarization is purely linear.

Then, three modern applications of optical singularities will be described. The first[7] is the pattern of optical vortices behind a spiral phase plate, which is a device, commonly used to study phase singularities, that introduces a phase step into a light beam. The intricate dance of the vortices as the height of the step is varied (especially complicated near half-integer multiples of 2π) is a surprising illustration of how vortices behave in practice. Experiment confirms the theory.[8]

The second application is to knotted and linked vortex lines. A mathematical construction[8,10] leads to solutions of the wave equation whose vortices have the topology of any chosen knot on a torus. The knots are described by two integers m, n (if m and n have a common factor N, the 'knot' consists of N linked loops). The construction can be implemented experimentally.[11] Vortex knots and links also exist in quantum waves.[12]

The third application is a prediction of quantum effects near the phase singularities of classical light. This is motivated by a philosophical aspect[13,14] of singularities in physics. They have a dual role: as the most important predictions from any physical theory, and also as a signal that the theory is breaking down. In light, the phase singularities are threads of darkness, offering a window through which can be seen the faint fluctuations of the quantum vacuum;[15] the radius of this 'quantum core' can be calculated. Analogous cores exist in sound waves.

Related articles are contained in the CD-ROM ("M_V_Berry" folder). Extracts from the readme file: "*Welcome to the Bristol vorticulture CD_ROM On this disk are most of the 86 papers, articles and PhD theses on the subject of wave dislocations (phase singularities, optical vortices) and polarization singularities published between 1974 (with Nye & Berry's seminal 'Dislocations in wave trains'[v1]) and January 2005, by authors working in the Physics Department, University of Bristol, UK.* "

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