The ubiquitous phase grating

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The beautiful iridescent colours of opal, potassium chlorate and some colloidal crystals are due to Bragg diffraction. These materials have a periodic structure with a period in the visible region of the electromagnetic spectrum. There are also other examples for optical iridescence. A cholesteric liquid crystal (cholesteric) is one such material. It has a locally birefringent structure that twists uniformly about a particular direction. The twist axis happens to be a 2-fold screw axis. Cholesterics exhibit Bragg reflection of light over a narrow band of wavelengths giving rise to iridescence. Cholesterics also show a different diffraction phenomenon in another geometry. Here, a beam of natural light undergoes diffraction with the central order being unpolarized and the other orders being completely linearly polarized perpendicular to the twist axis[1]. A related effect is also seen in polycrystals[2] which exhibit strongly polarized diffraction halos. These features are the manifestations of the phase modulations suffered by a plane wavefront as it travels through the heterogeneous medium. In short, the medium acts as a phase grating[3].

A systematic study of phase gratings started with the experiments of Debye and Sears[4] on the ultrasonic diffraction of light in liquids. A longitudinal ultrasonic wave propagating in a liquid leads to a periodic modulation of the

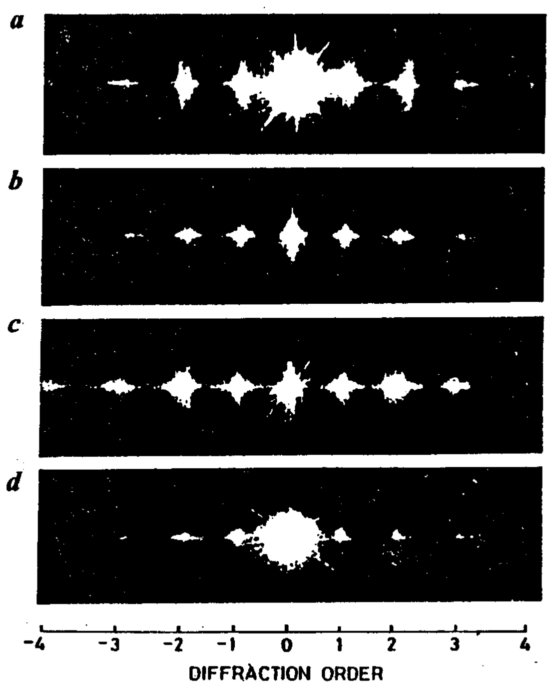

Figure 1. The diffraction patterns for a 50 μm thick BDH SCE-6 sample in the S_c. phase at room temperature. ***a***, The sample is between parallel polaroids and the polariser is parallel to the twist axis; ***b***, The sample is between crossed polaroids and the polariser is parallel to the twist axis; ***c***, The sample is between crossed polaroids and the polariser is perpendicular to the twist axis. Here the second order is more intense than the first order. Such effects are characteristic of phase gratings; ***d***, The sample is between parallel polaroids and the polariser is perpendicular to the twist axis (after Suresh *et al.*[5]).

refractive index along the direction of propagation. In these circumstances, a plane wavefront incident on the medium, at an angle to the direction of modulation, will emerge as a periodically corrugated wavefront resulting in the diffraction of light. Here, for natural light, all the diffraction orders are unpolarized and for polarized light, the state of polarization in all the diffraction orders will be the same as that of the incident light. One other characteristic feature of this diffraction, unlike the diffraction from amplitude gratings, is that the intensity of the orders need not monotonically decrease as one goes to higher orders. In fact, the intensities of the different diffraction orders can wander with the variations in the thickness of the liquid medium or the intensity of the ultrasonic wave. Raman and Nath[3] (RN) were the first to give a satisfactory theory of such a scalar diffraction process. In this model, the internal diffractions are ignored.

In the cholesteric phase grating, the wavefront corrugation is not due to a variation in the mean refractive index but due to a periodic variation in the birefringence. Further, this variation is such that diffraction will occur for linearly polarized light of any azimuth except the one having its azimuth parallel to the twist axis. Another chiral liquid crystal with a comparatively more complicated structure exhibiting diffraction is the chiral smectic C (S_{c^*}). Here the structure consists of a helical stack of layers of uniformly tilted molecules. As one goes from layer to layer, the index ellipsoid spirals about the twist axis at a constant angle, the tilt angle of smectic C. In S_{c^*}, the twist axis is a 1-fold screw axis. This results in extra orders which happen to be the odd orders of the diffraction pattern. In contrast to a cholesteric, in a S_{c^*}, diffraction will occur for incident light of any azimuth.

Recently, Suresh *et al.*[5] reported very unusual polarization and intensity features in diffraction from S_{c^*}. Some of the polarized intensity features associated with this diffraction phenomenon are depicted in Figure 1. The authors find that for any azimuth of the incident light, the diffracted light in all the orders was strongly polarized in the same linear state. Further, depending upon the sample thickness, this linear state was either parallel or perpendicular to the screw axis. These observed intensity and polarization features can be accounted for quite satisfactorily by employing[5] a rigorous theory[6] of diffraction of light in anisotropic dielectric gratings. Unlike RN theory, the rigorous theory incorporates the internal diffractions in the medium. It may be mentioned that in the case of very low birefringence or small sample thicknesses, a generalized RN theory[7] is applicable. In this approximation, the two theories agree and they predict entirely different polarization features. For example, for incident linearly polarized light, the odd orders are always linearly polarized and the even orders are elliptically polarized. Also the intensities of the odd orders are independent of the azimuth of the incident light while it is not true of the even orders. It is interesting to confirm these predictions experimentally.

There are many other examples of phase gratings occurring in a variety of situations. For example, phase grating effects have been studied[8] in a five-fold quasi-crystalline structure formed in water by superimposing five ultrasonic beams arranged according to a regular pentagonal array. Also, in non-linear media, light itself induces refractive index modulations resulting in self-diffraction. It is worthwhile to note that even after six decades, the study of phase gratings continues to be a very active field of research.

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