Pearls and shells

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Pearls

Pearls are formed inside aquatic organisms called oysters when a solid foreign body like a grain of sand gets lodged inside its shell. The organism secretes concentric layers of organic material around this object resulting in a pearl. The exquisite beauty of a pearl is due to this layered structure. It is a near spherical multilayer stack with alternating layers of aragonite and conchyolin, an organic material. Each layer of the pearl is an aggregation of aragonite crystallites packed invariably with their *c*-axis more or less normal to the layers and their *a* and *b* axes having fairly well-defined orientations in the plane of the layers. The small imperfections in the orientation of these axes lead to optical diffusion.

Optical reflection at the successive layers is accompanied by a strong scattering or diffusion spreading the reflected light over a range of solid angles (Figure 1). Thus sharp mirror reflections do not exist. On the other hand, an illusion is created that the pearl itself is a lustrous brilliant object. Thus one of the most admired optical features of a pearl is due to an admixture of multilayer reflection accompanied by scattering due to weak randomness in the alignment of crystallites in each layer. A closer examination of the light reflected by the pearl reveals more information about its optical behaviour. In a majority of pearls, the reflected foggy image of the source of light is saddled on either side by two diffuse spots of the same colour. These spots arise from the inner layers meeting the external surface of the pearl resulting in periodic surface irregularities as in an echelon. The spots will not occur in pearls that are perfectly spherical. The light reflected by the layers gets diffracted at the surface by these external corrugations, thus leading to diffracted images of the source. The different diffraction orders are generally not well separated and are visible only under a magnifying lens. In a perfectly spherical pearl with its layers parallel to the outer spherical surface this diffraction accompanying reflection is totally absent.

Observation of a pearl with a point source of light shows that the reflected image of the source is always surrounded by a chromatic diffusion halo. In the case of a perfectly spherical pearl this halo appears in the form of a diffuse circle. The dominant colour of the halo is complementary to that of the reflected light. This arises from the fact that light which is not reflected by the layers goes through the body of the pearl and in the process gets diffracted by the individual crystallites of aragonite embedded in a network of conchyolin.

Another beautiful optical effect that enhances the appearance of a pearl occurs when a pearl is illuminated over a very narrow region and is observed from a direction nearly perpendicular to the direction of illumination. The entire pearl then becomes visible because any light that gets scattered parallel to the layers gets transported along the layers illuminating the pearl on the way. This is the optical counterpart of the acoustic whispering gallery effect.

Shells

The most-commonly encountered shells are hard structures built by molluscs (of which oysters are a type)

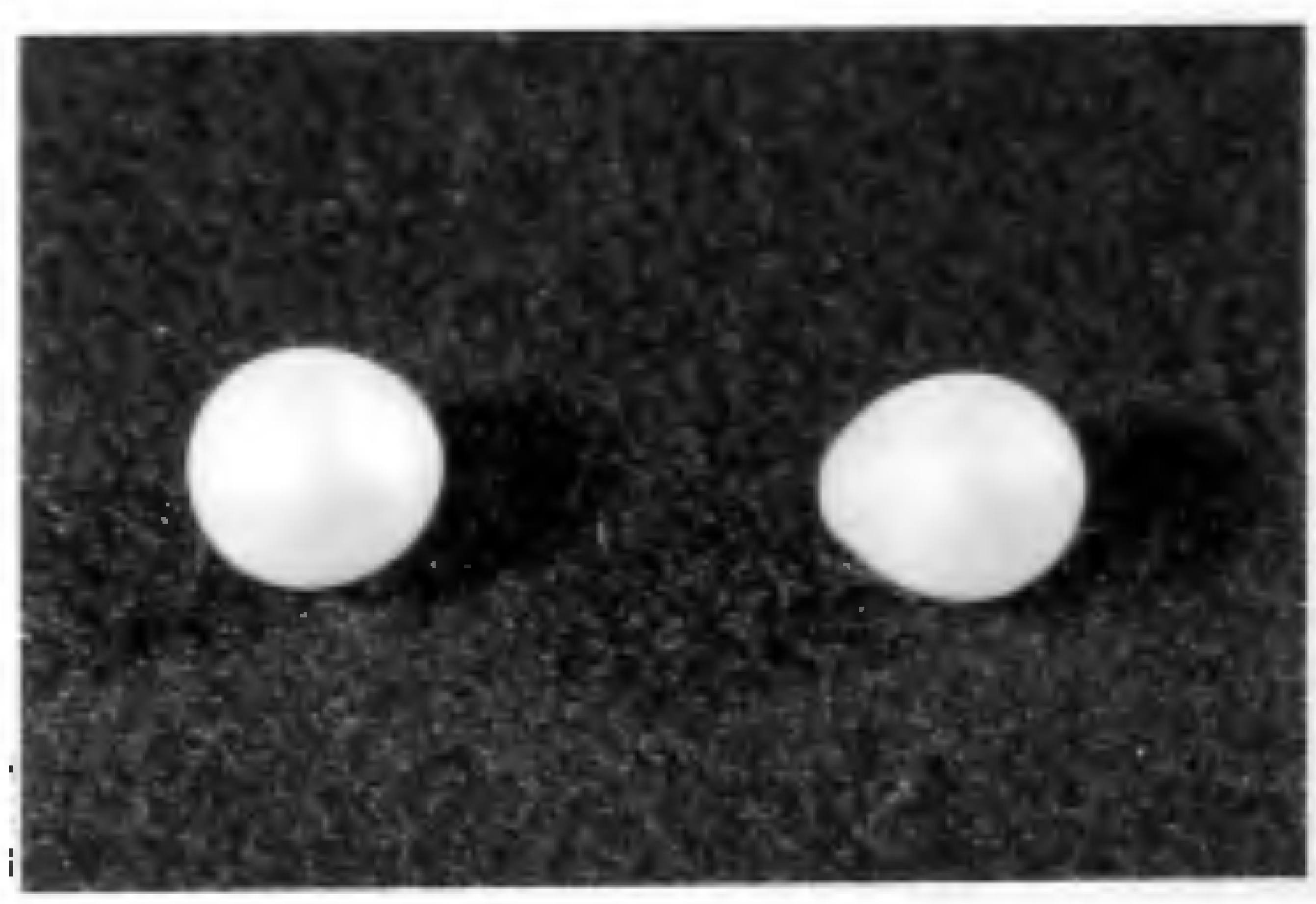

Figure 1. Two natural pearls with a bright lustrous glow caused by diffusion of light illuminating the pearls.

Figure 2. Typical bright metallic sheen seen on the inner surface of an opened up oyster shell.

around themselves primarily for protection from predators. Shells are mainly made up of aragonite and small amounts of other minerals found in the molluscs' environment.

Shells have again a layered structure that is very similar to the pearls and thus exhibit almost all the optical features that we find in pearls. The important structural difference between a pearl and a shell is that the layers of a shell do not close upon themselves as in a perfect pearl. They always meet the external surface of the shell. As a result the shell surface is locally corrugated on a fine scale. Hence, we always get surface diffraction accompanying multilayer reflection. The reflection results in a metallic sheen of the shell and the diffraction orders are well separated from the specular reflections (Figure 2).

As in pearls, here also we find diffusion haloes. While in pearls they are seen in the reflection mode, in shells since they are thin, we can see them in the transmission mode. The halo arises from the diffraction of light by the crystallites of aragonite present in the different layers. Further all the optical properties exhibit marked polarization features.

Diffraction in heterogeneous liquid crystals

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We review briefly optical diffraction exhibited by periodically and non-periodically heterogeneous liquid crystals. Some of the novel features of the diffraction phenomena have been highlighted. We also discuss non-linear optics in such media. Attention has been paid to the present status in this area.

LIQUID crystals are states of matter with a molecular order between that of crystals and liquids. Many of them are optically heterogeneous. The heterogeneity arises from the fact that the index tensor varies from point to point inside the medium. For example, in the cholesterics, chiral smectic C and the twist grain boundary smectics (TGB), the index tensor periodically varies along the twist axis and remains a constant in an orthogonal direction. On the other hand, in the cubic blue phases, the index tensor is a three-dimensional periodic function of space. Further, in polymer dispersed liquid crystals (PDLC), it randomly varies in space. It is therefore to be expected that in all these media, light undergoes scattering, diffraction or both. In this article we briefly review diffraction from such liquid crystals.

Periodic liquid crystals

Cholesterics

The cholesteric liquid crystals (cholesterics) are made up of molecules that are locally aligned preferentially in a particular direction represented by the director, which twists uniformly about an orthogonal direction. This results in a helical structure of a definite pitch. We consider a plane wavefront of linearly polarized light incident along a direction normal to the twist axis. When its electric vector is parallel to the twist axis it emerges as a plane wavefront while for the electric vector in the orthogonal state it emerges as a periodically corrugated wavefront. The latter case leads to diffraction of light as in a phase grating[1]. In general, it is seen[2] that the various diffraction orders are mainly polarized with the electric vector perpendicular to the twist axis whereas the central or the zeroth order is mainly polarized with the electric vector parallel to the twist axis. Further, intensities of the different orders can be such that higher orders are more intense than the lower orders. The intensities are also a sensitive function of sample thickness. These are characteristic features of a phase grating.

Raman and Nath (RN) were the first to solve an equivalent optical problem[3] in the context of ultrasonic diffraction of light in isotropic liquids. In the RN theory, the diffraction pattern is obtained by Fourier transforming the corrugated wave front emerging from the medium. That is, the amplitude $F(q)$ of the diffracted light is given by:

$$F(q) = \int_{-\infty}^{\infty} U(y)\exp(-iqy)\mathrm{d}y,$$

where q is the scattering vector and $U(y)$ represents the corrugated wavefront described by:

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