Current Science

Vol. XXIII] JUNE 1954 [No. 6

OPTICS OF THE PEARL

THE pearl stands in a class by itself as a gem-stone which does not need the services of a lapidary to enhance its natural beauty. The characteristic of the pearl most admired is its lustre, though other features such as shape, size and colour are also important. A precise understanding of the optics behind its loveliness is therefore a matter of more than ordinary interest. The inadequacy of the explanations of it given in the text-books on gemmology becomes apparent on a critical examination.

Natural pearls are very expensive, and this is sufficient to discourage anyone who might feel inclined to investigate their structure and optical behaviour. Fortunately, however, the cultured pearls produced by the Japanese industry offer to the student a wealth of material of excellent quality at a modest price. As is well known, their production is the result of an operation by which a spherical pellet of calcareous substance is introduced into the body of the pearl oyster. In the course of years, the mollusc deposits a great many layers of pearly substance around the nucleus thus provided. Since the latter is a polished sphere, the deposited layers are also very regular and smooth. Indeed, it is the case that cultured pearls are optically superior to the more expensive natural pearls. By cutting a cultured pearl into halves, the nucleus can be taken out and the hemispherical shells of pearly material thus detached are in a very suitable form for physical examination. Many interesting observations can be made with them as has been described in a recent paper[1] by the present authors.

Very simple methods of observation suffice to reveal some highly significant facts regarding the optical behaviour of pearls. A small aperture backed by a brilliant source of light is placed a few feet above the head of the observer and the pearl is held in the path of the strong beam of light thus provided. It is then viewed by the observer through a hand magnifier. The optical effects then observed fall roughly into three groups, *viz.*, (*a*) the reflection-diffraction spectra consisting of focussed images of the light source, (*b*) a chromatic diffusion halo surrounding these images and extending over the surface of the pearl over a considerable area, and (*c*) a general diffusion visible right up to the periphery of the pearl We shall proceed to describe each of these phenomena in detail and discuss their origin and significance.

If, as is the case with perfect pearls, the layers of nacreous material are parallel to the external surface, they would conspire to give a single reflected image of the source exhibiting colour as a result of interference between the effects of the successive layers. If, on the other hand, the layers meet the surface obliquely, the latter would present the aspect of an echelon grating. It has been shown by us[2] that in the case of mother-of-pearl the light diffracted at the surface as also that reflected by the internal stratifications appear together as a set of diffraction spectra forming a regular sequence. In the present case as well, similar results are noticed when the illuminated pearl is viewed in focus through a magnifier. The separation of the successive orders of spectra is usually very small, but occasionally they can be seen distinctly separated Fig. 1 is a

FIG. 1

photograph obtained with a natural pearl in a particular setting Three spots in a line can be seen; the sharpest appearing at the centre is the spectrum of zero order; the second is the diffraction spectrum of the first order, while the third spot is the characteristic iridescence appearing as the spectrum of the second order.

We now proceed to consider the second of the effects mentioned above, *viz.*, the chromatic diffusion halo. This phenomenon which does not appear to have been noticed earlier has been briefly described by us.[1] It is characteristic of pearls and plays a fundamental role in their optical behaviour. Its observable features are notably influenced by the shape of the pearl, by the inclinations of the stratifications to the external surface and by the degree of optical perfection of the latter. The chromatic halo takes its simplest form in the ideal case of a spherical pearl in which the stratifications are strictly parallel to the external surface. It then appears as a diffuse circle of light with fainter outlying regions surrounding the iridescent reflection; there is a concentration of intensity in the halo near the opposite ends of one diameter. The predominant colour of the halo is complementary to the colour of the iridescence A photograph of the halo in this typical case is reproduced as Fig 2 A slight

FIG. 2

asymmetry of the intensity on the two sides is usually noticed, and this is very prominent when the successive orders of the reflection-diffraction spectra are widely separated. The colour of the diffusion halo may then be quite different on the two sides of it

The observed effects indicate that the diffusion halo has its origin in the internal stratifications of the pearl and not at its external surface; this is indeed clear from the fact that its colour is complementary to that of the iridescence The origin of the halo is to be sought for in the fact that the material of the pearl consists of individual crystallites of aragonite imbedded in a network of conchyolin. Each crystallite would diffract the light waves incident upon it in various directions, the iridescence appearing in the direction in which the diffracted radiations from the crystallites in any given layer are in agreement of phase. In other directions, they would give rise to a cone of diffuse light.

Fig. 3 illustrates a remarkable effect exhibited by pearls. It is a photograph of a natural pearl illuminated centrally over a very narrow region on the side *opposite* to that from which it was observed and photographed. It will be noticed that the entire pearl is thereby ren-

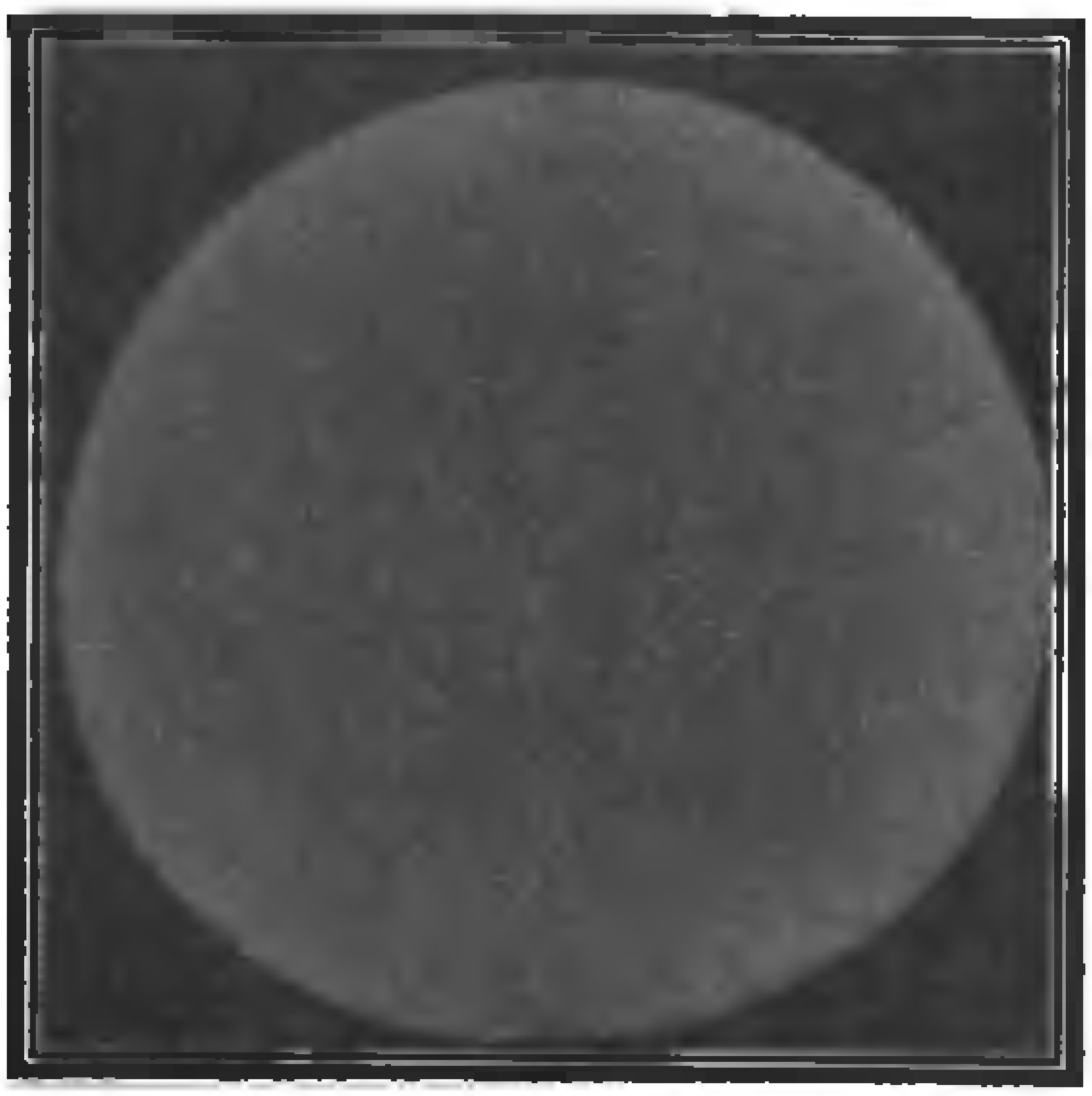

FIG. 3

dered visible, the periphery appearing brighter than the central region. It is evident that the light falling normally on the rear surface of the pearl has travelled around following the laminations of its structure, and not *through* the pearl. A similar effect is observed in all cases, irrespective of the direction in which the illuminating pencil falls on the pearl or the particular area on which the incident light falls.

We shall now turn to the role which the three effects described above respectively play in the optical behaviour of pearls. Fig 4 (*a*), (*b*) and (*c*) reproduce photographs showing respectively (*a*) a polished steel sphere, (*b*) a cultured pearl, and (*c*) a polished spherical segment of mother-of-pearl removed from a cultured pearl. All the three objects were illuminated and viewed in the same fashion, *viz.*, normal to their respective surfaces, the original source of light being of small angular dimensions. But the appearance of the three objects is totally different. In the case of the steel sphere, we see a well-defined optical image of the original source, but the sphere remains invisible except in the immediate neighbourhood of the image of the source where a faint illumination is visible due to the imperfect polish of the surface. In the case of the mother-of-pearl as well, the optical image of the source is a prominent feature, but is much feebler than in the case of the steel sphere. On the other hand, the mother-of-pearl is itself visible by reason of the light diffused in the material.

Writers on gemmology usually attribute the beauty of the pearl to two distinct effects, *viz.*, the reflection of light from the interior of the pearl and the diffraction of light at its exterior surface. The latter effect would be non-existent in the case of a perfect pearl. Moreover, the angular separation of the various orders of the reflection-diffraction spectrum is so small, that with an extended source of light they need not at all be considered as distinct phenomena. Further, the reflection of light at a spherical surface would not suffice to make it visible, much less to make it an attractive object. It is evident therefore we have to look elsewhere for an explanation of the beauty of the pearl. This is to be found in the superposition of the reflected light and the chromatic diffusion halo. Such superposition would necessarily occur when the source of light is of extended area,

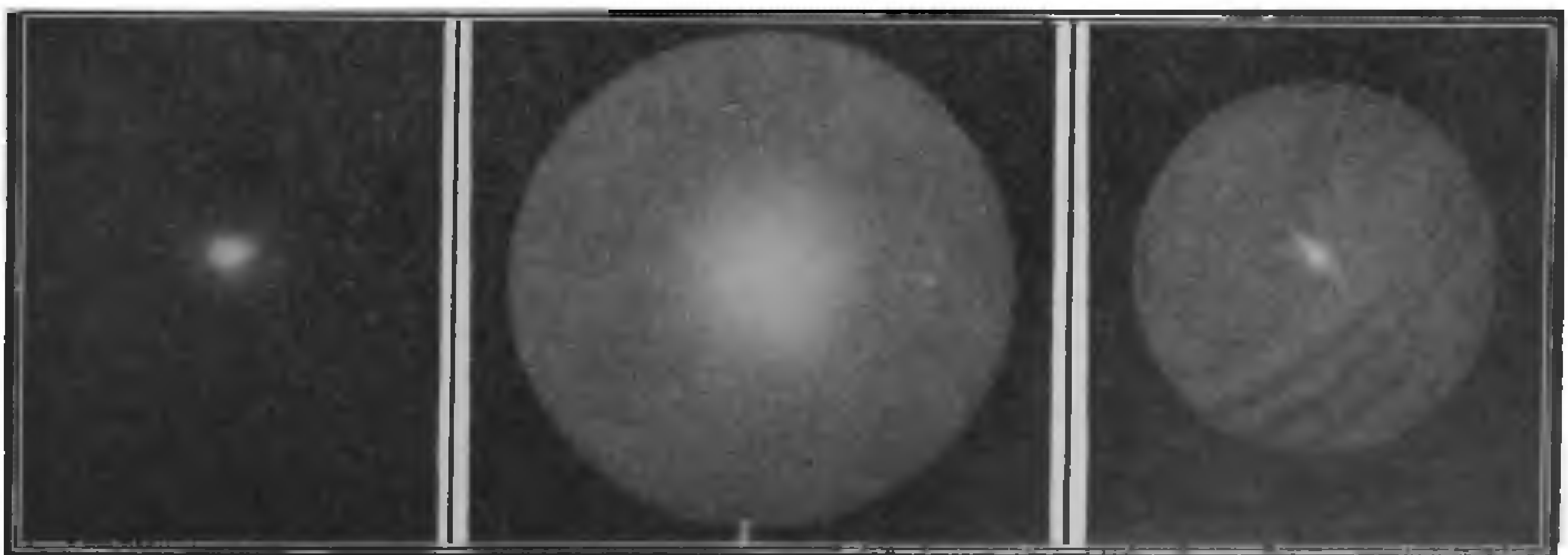

FIG. 4 *a* *b* *c*

and since their colours are complementary, their joint effect would be to make the pearl seem to the observer to be a silvery white and lustrous object, quite unlike a polished sphere which only exhibits the reflected images of external objects. The impression that the pearl is a lustrous object would be further enhanced by the *diffuse light emerging from* the shadowed areas on which no light is directly incident. The brilliance of the periphery would further enhance the general effect by enabling the entire pearl to be clearly seen.

We may sum up the situation by the statement that the coloured reflection of light by the stratifications of the nacre is not by itself an adequate explanation of the beauty of the pearl; the special properties of the material which manifest themselves in the chromatic diffusion halo and in the propagation of light parallel to the stratifications play the leading role in making the pearl appear a lustrous and attractive object.

C. V. RAMAN.
D. KRISHNAMURTI.

1. Raman, C. V. and Krishnamurti, D., *Proc. Ind. Acad. Sci.*, 1954, **39A**, 215.
2. —, *Ibid.*, 1954, **39A**, 1.

RADIO-THULIUM TO REPLACE X-RAYS

DEVELOPMENT of a portable X-ray unit using radioactive thulium in place of electricity was announced recently by the Argonne National Laboratory of the United States Atomic Energy Commission. Weighing less than 10 lb, the unit produces rays comparable to a 100,000-volt X-ray machine without the need of a power source. Its light weight makes it possible for a doctor to carry it to isolated areas where electricity is not available and to take X-rays of persons who cannot be moved.

The active component of the instrument is a tiny particle of thulium which has been made radioactive in the heavy water nuclear reactor at Argonne. Thulium is an extremely rare material which heretofore has found little practical application.

The instrument does not require an electrical power supply as does conventional X-ray equipment. In addition, it is quite inexpensive. Exclusive of irradiation charges, the total cost of the first model was $ 40. The use of thulium as an X-ray source was first suggested by British scientists who have developed a similar but less powerful instrument Excellent rare earth separation facilities and powerful reactors in the U.S.A permitted development of the Argonne instrument, which contains a thulium source several hundred times more powerful than the British units Industrially also, it has potential use as a density determination device. It may find considerable use in the determination of levels and densities of liquids in closed systems.

REORGANISATION SCHEME OF THE BOTANICAL SURVEY OF INDIA

THE main features of the reorganisation scheme are as follows: (1) The division of India into a number of regional circles based on phyto-geographic affinities, each under a Regional Botanist with his headquarters at Dehra Dun or Lucknow, Madras, Calcutta and Poona respectively; (2) Establishment of a Central Directorate under the Chief Botanist, for co-ordinating the activities of the various Regional Circles; (3) The creation of a Central Botanical Laboratory under a Director at a suitable place in India, where the living plant will be studied in relation to its botany and its utility to the nation; (4) The maintenance of a Central National Herbarium which will house the "type specimens" and a fully representative collection of the plants comprising the Flora of India; and (5) Maintenance of a Botanical Museum on modern lines at Calcutta.

Collaboration with Universities and Research Institutions will be encouraged by the granting of stipends to staff and research students to conduct research on problems dealing with the Flora of India, and for collecting material for the long overdue revision of Hooker's "Flora of India".