THE SCATTERING OF LIGHT IN QUARTZ

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1. INTRODUCTION

As is well known, when a beam of plane polarised light traverses a crystal of quartz along the optic axis, the plane of polarization is rotated continuously. The rotation increases very rapidly as the wavelength of the light diminishes: it is 26°, 42° and 148° per millimetre respectively for the wavelengths λ 5461, λ 4358 and λ 2537. If the crystal is viewed by an observer in a direction transverse to the beam, the electric vector in the light beam would be alternately parallel and perpendicular to the line of sight for each successive rotation of 90°. Hence, if the light diffused by the crystal is partially or completely polarised, the track of the beam as seen by the observer should exhibit alternate minima and maxima of intensity, the distance from one dark band to the next being the distance of travel of the incident beam in which there is a rotation of 180°. The widths of the bands for the wavelengths λ 5461, λ 4358, and λ 2537 would be 7·06, 4·33 and 1·22 millimetres respectively. A phenomenon of this kind was observed and photographed in *smoky quartz* with *visible light* by the present Lord Rayleigh (1919); it had its origin in the Tyndall scattering by the inclusions present in the crystal to which the smoky colour is ascribed. The present paper records the observation of the phenomenon in *perfectly colourless quartz* having its origin in the diffusion of light by the atomic vibrations in the crystal lattice. Both visible light λ 4358 and the ultraviolet radiation λ 2537 of the mercury arc in quartz have been successfully used to photograph the effect. Owing to the very great intensity of the resonance radiation emited by the water-cooled, magnet-controlled mercury arc which was employed, as also the large scattering power arising from the λ^{-4} law and the high rotatory power of quartz in the ultraviolet, the phenomenon is much more striking as observed with λ 2537 than with λ 4358 radiation.

2. EXPERIMENTAL TECHNIQUE

For the purpose of the experiment, a perfectly colourless and transparent sphere of quartz crystal 5·24 centimetres in diameter was employed.

As was shown long ago by Sir C. V. Raman (1922), such a sphere in which no visible inclusions are present exhibits a uniform blue track when traversed by a condensed beam of sunlight. The use of a sphere is convenient as light can be sent in any required direction. To reduce the surface reflections, the sphere can be immersed in clean distilled water. When the beam of condensed sunlight traverses the sphere along its optic axis and the blue track is viewed transversely, the scattered light shows very marked polarization in which the electric vector is perpendicular to the optic axis. Again, when unpolarised sunlight is sent perpendicularly to the optic axis and the track is observed in a direction transverse both to the optic axis and to the beam of light, the scattered light is strongly polarised with most of the light having its electric vector parallel to the optic axis. However, when the observation is made along the optic axis with the light beam perpendicular to it, the scattered light is completely unpolarised. This is evidently due to the fact that scattered light before reaching the observer traverses the crystal along its optic axis and hence its plane of polarisation is rotated. The amount of rotation varies for the different wavelengths of sunlight and the emerging light hence appears to be completely unpolarised.

The foregoing observations indicated that the phenomenon of the bands could be expected and that for photographing them monochromatic light would have to be used. Another important condition for the successful performance of the experiment is that light should traverse the crystal along its optic axis pretty accurately. To secure this, the sphere is placed between two polaroids, and observed in mercury arc light and adjusted until the melatrope is observed centrally in the field of view with rings around it. By rotating the analysing polaroid clockwise, the rings of any particular colour appear to expand and hence the sphere rotates the plane of polarisation anticlockwise as viewed by the observer. The sphere is hence a left-handed crystal.

To photograph the phenomenon of the bands, the radiation of a water-cooled, magnet-controlled mercury arc was employed as the source of light and an aperture of 5/8″ in diameter placed just in front of the arc limited the beam of light used. Actually, the whole radiation of the mercury arc was used, as the other wave-lengths were weak compared to the $\lambda 2537$ radiation and were also scattered comparatively feebly. The light beam was condensed by means of a 17 cm. lens of 4 cm. aperture into a brass cell fitted on opposite sides with two strain-free vitreous silica windows of 3 cm. aperture. The inside of the brass cell was painted black, and the quartz sphere was placed inside it on an ebonite ring and was immersed in clean distilled water. The light before entering the brass cell was polarised by a large nicol which transmits the λ2537 radiation. The sphere was adjusted so that the light traverses it along its diameter exactly parallel to the optic axis and there was thus no refraction of light at the surface of the sphere. The light emerging vertically from the surface of water was photographed by a camera fitted with a 6·5 cm. quartz lens of aperture 3 cm. and in this way a large quartz window for the observation was dispensed with. The camera and the top of the brass cell were wrapped up in a black cloth to prevent stray light entering the camera directly. A process plate was used and an exposure of one hour was given. A photograph of the track in the transparent quartz sphere showing a large number of bands was obtained, an enlarged reproduction of which is given at the end of the paper. Another photograph with a different arrangement, using the visible 4358 Å line of the mercury arc was also obtained, but a long exposure of 100 hours was needed for this purpose. Even so, the photograph was not dense enough to be satisfactorily reproduced.

3. REMARKS

The width of the bands was measured and the magnification produced by the combination of the sphere, water and the camera was calculated. From this the actual width of each band was deduced. This distance should correspond to a rotation of 180° for the particular wave-length used, and hence enable the rotation per millimetre to be calculated for the two wavelengths λ2537 and λ4358 respectively. The results are given in the table below along with the standard values for comparison.

TABLE I

Wavelength in Å	Measured average width of each band in mm.*	Magnification of the system	Actual width of each band in mm.	Calculated rotation per mm. in degrees	Rotation per mm. in degrees from I. C. T.
2537	1·421 (22)	1·340	1·085	165·9	148·6
4358	4·133 (3)	0·97	4·25	42·4	41·6

* The number in the brackets gives the total number of bands measured whose average width is given.

The fair agreement between the calculated and the actual rotations and the uniform clarity of the bands indicates the highly monochromatic nature of the light scattered and that the other radiations are not recorded. The contrast between the maxima and minima of intensity of the bands shows that the scattering of light in quartz is well polarised. The picture of the bands reveals at a glance the continuous rotation of the plane of polarisation taking place inside quartz and the marked polarisation of transversely diffused light in quartz arising from the atomic vibrations in the crystal lattice.

As will be noticed, the bands are not straight, but are slightly curved. This is because the surface at which light enters the quartz crystal is curved, and hence the points of equal rotation lie along a curve parallel to the surface.

In conclusion I wish to thank Sir C. V. Raman for suggesting the problem and for his constant encouragement. I wish also to take this opportunity to express my grateful thanks to Dr. R. S. Krishnan for his kind help which was always available.

SUMMARY

When a plane-polarised beam of the intense λ 2537 radiation from a water-cooled, magnet-controlled mercury arc is sent along the optic axis of a perfectly clear and transparent sphere of quartz crystal free from inclusions, the track when photographed from a direction transverse to the beam exhibits striking fluctuations in intensity along its length. The effect, which is reproduced in the paper, is obviously connected with the rotation of the plane of polarisation of the polarised λ 2537 radiation as it traverses the crystal. The distance between one dark band to the next corresponds closely to a rotation of 180° of the plane of polarisation of the λ 2537 radiation. A similar effect was observed and photographed in smoky quartz by the present Lord Rayleigh in 1919 using the Tyndall scattering of visible light by the inclusions in the crystal. In the present case the effect is due to the diffusion of light arising from the atomic vibrations in the crystal lattice, and the clearness of the bands indicates that such scattering is strongly polarised.

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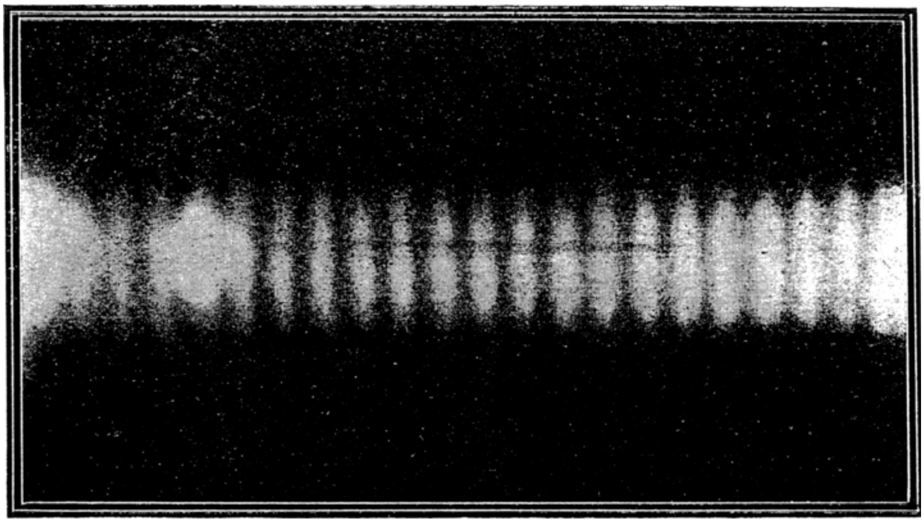

FIG. 1

Track of polarised λ 2537 beam traversing quartz along optic axis