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The optical properties of amethyst quartz

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Abstract. Circularly-polarized waves of light, in passing through a section-plate of amethyst quartz would obviously be retarded unequally in the alternate laminae having right- and left-handed optical activities. Diffraction effects must therefore arise, and these can actually be observed even in almost colourless varieties of the quartz. The section-plate behaves in effect as a phase-change diffraction grating, and the question of the visibility of its structure with and without the aid of polarizers and analysers is discussed in the light of Abbe's theory of microscopic vision.

Introduction

The periodic alternation of layers rotating the plane of polarization in opposite directions, so beautifully shown by amethyst quartz when a section-plate cut normal to the optic axis is viewed between nicols, has often been observed and described. Some fine illustrations of the type of sectorial repeated twinning characteristic of amethyst quartz are reproduced as plates XXV and XXVI of Tutton's new and very attractively written book, *Natural History of Crystals*, in which several pages are devoted to a description of amethyst, and his account will no doubt stimulate interest and inspire fresh studies of the properties of this remarkable substance. The view now generally accepted is that the twinning is of the simple Brazilian type in which the plane of twinning is parallel to a pair of faces of the second-order hexagonal prism, the actual surfaces of junction of oppositely active parts being, however, very varied in their distribution and character. The effects observed in the polarization microscope are explained in a simple way as due to the superposition of the opposite rotations of the plane of polarization produced by the two types of quartz. Parts of the section-plate in which equal thicknesses of the oppositely active parts occur would appear quite black between crossed nicols, other regions exhibiting illumination and colour varying with the thickness of the two kinds traversed by the light. The effect of rotating either the polarizer or the analyser on the structure seen is similarly elucidated.

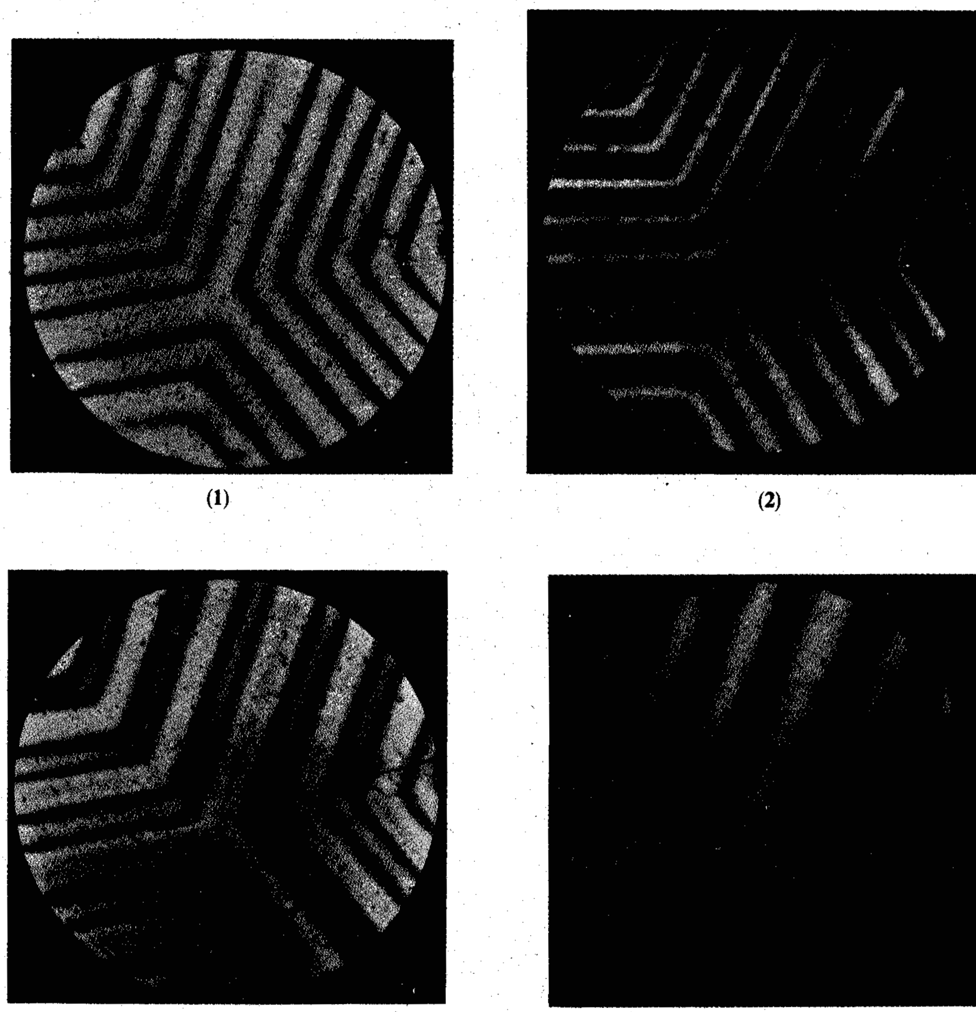
We wish to draw attention to another class of optical effects arising from the structure of amethyst, and to suggest a new viewpoint from which to consider the phenomena observed in the polarization microscope with this substance.

Diffraction effects

Consider the case of a section-plate cut normal to the optic axis, the alternate strips of oppositely active parts being assumed to be of equal width and separated by planes normal to the plate. If the incident waves of light be unpolarized, they may be resolved into two wave-fronts circularly polarized in opposite senses but having no determinate phase-relation which may therefore be considered separately. An incident circularly-polarized wave, assumed to be initially plane, traverses the alternate strips with different velocities, and on emergence from the plate must therefore become corrugated. The corrugated wave-front should, according to well known principles*, give rise to diffraction effects and should in fact, at a sufficient distance from the crystal, resolve into sets of plane waves corresponding to a central undeviated pencil and diffraction spectra of the first, second, and higher orders. The same result should occur when the boundaries of separation between the twins are not plane or parallel to the optic axis, or if the alternate strips are not equal in width, the distribution of intensity in the diffraction spectra being alone influenced by these factors.

That amethyst does give rise to diffraction effects as indicated by theory is easily verified by observation. For this purpose the polarizing and analysing nicols are not necessary and may be removed. A narrow source, e.g., a "Pointolite" lamp, should be used, and the light so adjusted that it passes normally through the plate. Coloured diffraction fringes, arranged periodically and running parallel to the lines of the structure, are then seen in the field behind the plate. The fringes (which are of the Fresnel type) are shown just as conspicuously by nearly colourless varieties of amethyst as by the more deeply tinted ones, and this circumstance, together with the fact that they disappear completely when the viewing microscope or eyepiece is focussed on the plate, proves clearly that the diffraction effect is due to the periodic change of phase produced by the structure and not to any periodic variation of transparency. The diffraction spectra of the Fraunhofer type due to the structure may also be seen when the observing eyepiece is focussed on the image of the source of the light formed by the objective.

*Rayleigh, "On the Dynamical Theory of Gratings," *Scientific Papers*, **5**, p. 388.



(1) (2)

(3) (4)

Figures 1–4

Amethyst as phase-change grating

Since a section-plate of amethyst quartz is thus in effect a phase-change diffraction grating, its appearance in the polariscope may be interpreted in the light of the Abbe theory of microscopic vision, and in fact furnishes very convenient illustrations of that theory. The first point worthy of remark is that little or no structure is observable when the polarizer and analyser (either or both) are absent, though, as we have seen, they are not required to enable the structure to give rise to diffraction effects. This has a bearing on the general question of the visibility of phase-change structures. Lummer and Rieche* have discussed the case of a *sudden* change of phase, and found that the boundary at which this occurs should be visible as a distinct minimum of intensity. This is borne out by observations with structures having sharply-defined laminar boundaries†, but when the boundaries are less sharp, their visibility is greatly prejudiced and becomes practically zero. In the present case, the phase-changes arise in traversing a considerable thickness of the crystal, and even if the boundaries between the oppositely active parts of the crystal were perfectly plane and normal to the surface of the section, the wave-front on emergence from the crystal cannot present any *discontinuous* changes of phase over its area. The failure to observe any marked structures in the absence of the polarizer or analyser is thus intelligible. When the polarizer and analyser are put in, the structure ceases to be merely a phase-change grating and becomes one in which there is also a periodicity of effective transparency, and an enormous increase in the visibility of the structure is the result. An improvement in the visibility of the structure of twinned crystals of potassium chlorate when polarized light is used has been noted by Lord Rayleigh‡.

Visibility of structure

The matter may also be regarded in another way. When the incident light is unpolarized, it may be resolved into two components circularly polarized in opposite senses and having no determinate phase-relations, and the diffraction spectra given by them are merely superposed. If, however, the incident light be polarized, the two sets of circularly-polarized diffraction spectra are in a definite relation of phase which is different from that of the central undeviated pencils, since the accelerated parts of one wave correspond to the retarded parts of the other and vice versa. Hence, the introduction of an analyser enables the relative

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*Lummer and Rieche, *Bildentstehung im Mikroskop*, F. Vieweg und Sohn (1910), pp. 74–76.
†N K Sur, *Proc. Indian Assoc. Cultiv. Sci.*, **7** (1922) 125–144.
‡Rayleigh, *Proc. R. Soc. London*, **A102** (1923) 669–670.

intensity of the central image and of the diffraction spectra to be varied, and therefore, in accordance with the Abbe theory, also the appearance of the structure under the microscope.

The four pictures reproduced in the plate are photographs in the polarization microscope of a practically colourless piece of amethyst quartz 2·5 mm thick. They were taken with analyser and polarizer in different relative positions, and using monochromatic light of different wavelengths. The differences in the appearance under the varying conditions are sufficiently striking. In figure 1, the nicols were crossed and green light was used. In figure 2, the nicols were parallel and violet light was used. Figures 3 and 4 correspond to intermediate positions of the nicols, figure 3 being obtained with violet and figure 4 with green light.