

## Amethyst—its nature and origin\*

Amethyst is a variety of crystalline quartz which, instead of being colourless and transparent like the ordinary form of rockcrystal, exhibits a beautiful purple colour, in consequence of which it has been esteemed as a gem-stone since ancient times. Mineralogists have naturally been much interested in the question of the origin of this colour. Problems of the same nature arise in regard to numerous other minerals and it was customary in the past to explain the colour in such cases as due to impurities assumed to be present in the material and diffused through it in an atomic or a colloidal form. A different view regarding the origin of colour in many minerals has latterly been gaining favour, namely, that it is a consequence of defects in the regularity of structure such as would be caused, for example, by the crystal having been subject over long periods of time to radiations traversing its substance. Explanations along one or the other of these two lines are to be found in the extensive literature concerning amethyst, but it can scarcely be claimed that they are based on evidence of a convincing nature. Still another view regarding amethyst which for a long time held the field is that it consists of quartz in which layers of the right-handed and left-handed varieties alternate. Why such alternation should result in colour is a question which was left unanswered.

The problem of amethyst has been under investigation at my Institute in Bangalore during the past year and conclusions regarding the nature of this material have been reached which are different from anything which has been so far suggested. They are based on the results of fact-finding research on those properties of amethyst which appeared to us most likely to throw light on its physico-chemical constitution.

The first series of studies undertaken by Mr A Jayaraman and myself were precise measurements of the density of amethyst quartz. For such measurements to have scientific value, it is necessary to work with selected material free from cracks, inclusions and visible impurities. Accordingly, cut and polished gemstones believed to be of Ceylonese origin were used for the determinations. The specimens employed varied notably in their depth of colour. Differences of the order of one or two units in the third decimal place were indeed noticed in their densities, but such differences exhibited no correlation with the depth of the colour of the specimen; neither did the values differ significantly from that of colourless quartz.

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Careful studies have also been made regarding the behaviour of amethyst in magnetic fields. Quartz is diamagnetic, and exhibits a very feeble diamagnetic anisotropy. Metallic oxides such as those of manganese or iron to which the colour of amethyst has been attributed in the past are highly paramagnetic and hence, if present, might be expected to reveal themselves by an altered magnetic susceptibility. Here again our results were entirely negative. All our amethyst specimens were diamagnetic and their susceptibility showed no significant variations from that of colourless quartz.

The next property investigated was the scattering of light in its passage through the solid. As is well known, this is a severe test of the regularity of the structure of the material and of the absence of inclusions, the latter, if present, revealing themselves immediately by a largely enhanced intensity of light-scattering. Clear quartz of the best quality does indeed exhibit light-scattering, but this is extremely feeble. In smoky quartz, on the other hand, a Tyndall effect is very conspicuous. But in amethyst no such phenomenon is observable. The difference is illustrated in figure 1 in which the tracks of a beam of sunlight in smoky quartz

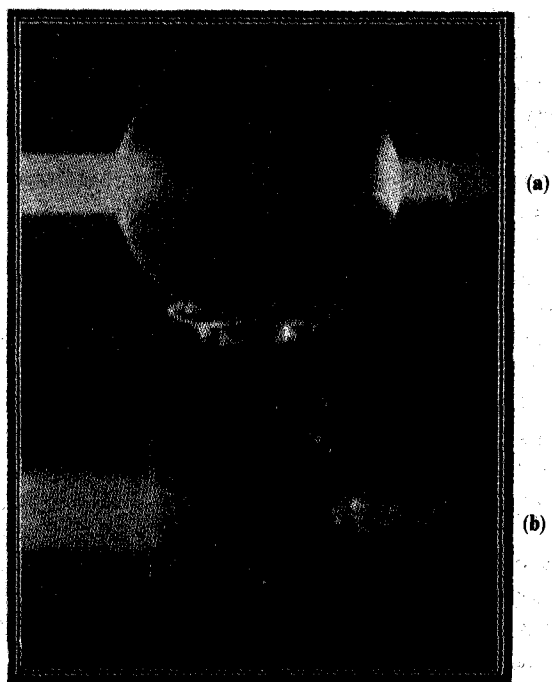


Figure 1. a. Smoky quartz. b. Amethyst.

and in amethyst are exhibited side by side, the specimen in each case being immersed in a cell containing benzyl alcohol to avoid refraction effects.

Thus we are led to the view that amethyst is a crystal with a regular structure and that the cause of the colour is to be looked for in the ultimate constitution of the crystal itself. This view is independently confirmed by the results of research in two other and quite different directions. The first is a study of the X-ray diffraction by amethyst carried out by Mr Jayaraman and myself, and the other, a detailed investigation of its optical properties by Mr S Pancharatnam. I shall now proceed to summarise the findings reached.

In view of the close association of colourless quartz and amethyst as found in nature, one could scarcely expect to find any readily measurable differences in the spacings of their three-dimensional crystal lattices. What we have to look for are differences in the electronic distribution and therefore also the reflecting powers for X-rays of the lattice planes in the two crystals. To establish the existence of such differences by the usual methods followed in X-ray structure determination would obviously be laborious and might even be infructuous. We have therefore employed a method which has proved itself to be both simple and effective. The section-plate of amethyst finally chosen for the study was cut obliquely to the optic axis of the quartz and by etching tests was ascertained to be free from either optical or electrical twinning over its effective area. It however exhibited a pattern of colour bands and colour sectors of the kind almost invariably to be seen in amethyst. The section-plate was irradiated by an X-ray pencil over its whole area and gave a Laue pattern in which each Laue spot was itself an extended picture of the crystal. It was found that the Laue spots also exhibited the features optically observable in the section-plate but in a very different way in the different spots, thus clearly showing that the variations in the colour observed over the area of the plate correspond to variations in the X-ray reflecting power which are different for the different lattice planes, as is to be expected on the foregoing view regarding the nature of amethyst.

The optical investigation by Mr Pancharatnam has also yielded highly significant results. They may be summarised by the statement that amethyst is optically biaxial, that it exhibits trichroism and that these two properties taken together show amethyst to possess only monoclinic symmetry instead of trigonal symmetry as in the case of colourless quartz. The studies have also revealed that the diad axis of monoclinic symmetry coincides with one of the three electrical axes of the associated quartz. The latter is different for the three colour-sectors usually observed in a section-plate of amethyst, their diad axes being inclined to each other at an angle of  $120^\circ$ .

Whereas it has hitherto been supposed that amethyst exhibits a single absorption band in the green region of the spectrum, Pancharatnam has found that there are three different absorption spectra differing enormously in the strength as well as in the position of the absorption band, corresponding to the vibrations along the three colour axes within the crystal. The weakest of the three absorptions is for vibrations along the diad axis; the absorption maximum for it is near  $5000 \text{ \AA}$  and the transmitted light is light orange in colour. The two other

colour axes lie in a perpendicular plane and make angles of about  $45^\circ$  on either side of the trigonal axis of quartz. For one of them the absorption is particularly intense and is centred round  $5250 \text{ \AA}$ , the transmitted light being a deep reddish purple. For the third axis, the absorption maximum is near  $5750 \text{ \AA}$  and the transmitted light is blue in colour.

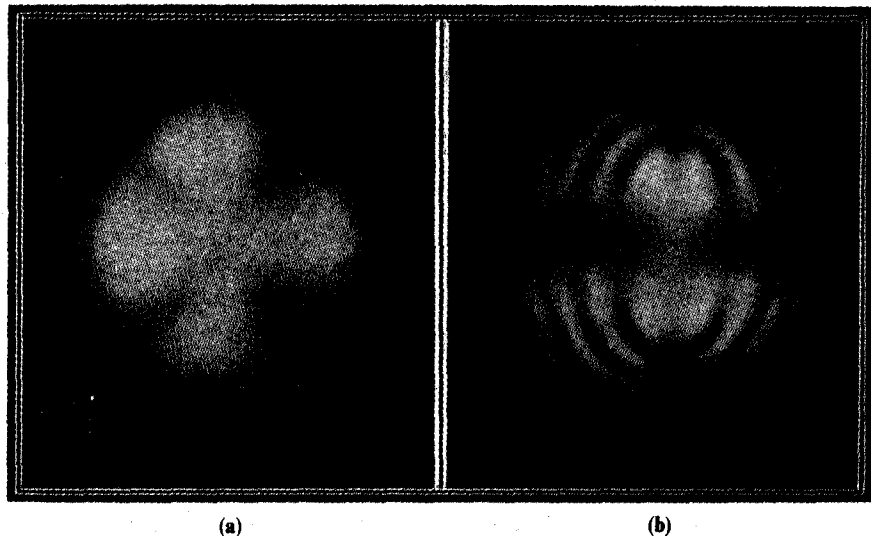


Figure 2. a. Idiophanous figure. b. Biaxial figure.

Figures 2 (a) and (b) respectively are photographs of the so-called idiophanous figure of absorption exhibited by amethyst in convergent unpolarised light and of its biaxial figure as seen between crossed polaroids. The former figure was photographed in the green monochromatic light of a mercury lamp and the latter in deep red light, the crystal in both cases being viewed along the trigonal axis of the quartz.

Very small and not improbable displacements of the silicon atoms along the electric axes on which they lie would suffice to alter the trigonal symmetry of colourless quartz to the monoclinic symmetry of amethyst. The accompanying deformation of the oxygen tetrahedra surrounding each silicon atom would offer a pathway to the explanation of the pleochroism exhibited by amethyst. We shall not pause here to discuss these points in further detail, but will pass on to consider the very interesting question as to the circumstances in which silica crystallises as amethyst instead of as colourless quartz. The study of a great number of specimens collected from near Hyderabad City in South India points to certain conclusions regarding this matter. A feature very commonly observed in the individual specimens is that a region of intense colouration is observed separated from another which is comparatively free from colour by internal planes parallel

to the external rhombohedral faces of the crystal. X-ray shadowgraphs of the specimens disclose that along the boundary between these two portions of the material, there is invariably a deposit of fine particles which chemical examination reveals to be ferric oxide. The conclusion is thus almost irresistibly suggested that amethyst is formed from silicious material containing ferric impurities and is consequent on the progressive elimination of these impurities during the growth of the crystal. At some stage in the process, the impurities separate out into distinct particles, and then cease to play any further role in the crystallisation, which accordingly continues as clear quartz. Figures 3 (a) and (b) illustrate the foregoing remarks. The former is a section-plate cut perpendicular to the trigonal axis; the hexagonal ring containing the ferric oxide particles is very

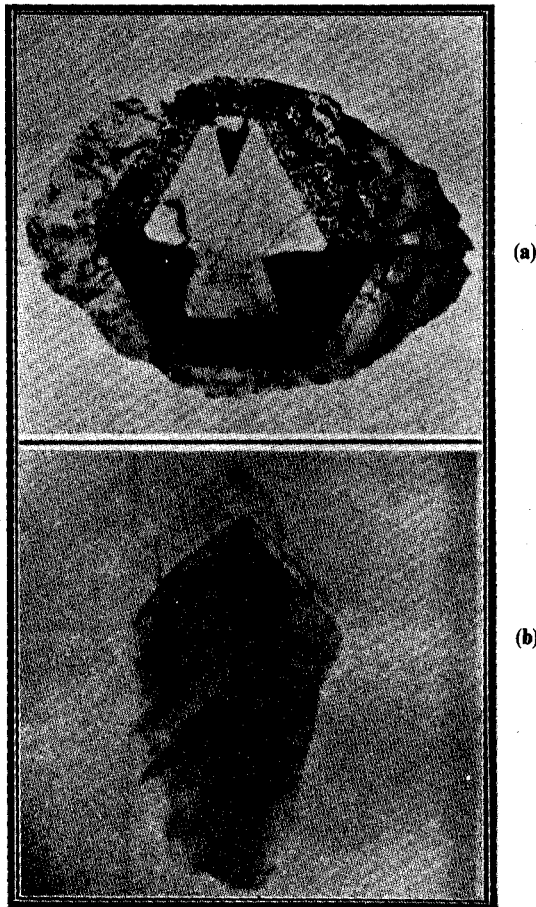


Figure 3. a. Transverse section. b. Complete crystal.

conspicuous and surrounds the inner region of quartz in which the three colour sectors adjacent to the three of the rhombohedral faces are clearly seen. Figure 3(b) is a picture of an entire small crystal of amethyst immersed in benzyl alcohol and viewed transversely by sodium light. Regions of colourless and coloured quartz are clearly seen in the picture, separated from one another by a sharply defined boundary which carries a dark deposit of ferric oxide.

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