DIELECTRIC CONSTANTS OF CRYSTALS

I. Different Types of Quartz

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Received March 26, 1947

(Communicated by Prof. S. Bhagavantam, F.A.Sc.)

1. INTRODUCTION

Various authors determined the dielectric constants of colourless quartz. Results reported are at variance with each other to an appreciable extent. Cady, 1 agreeing with Sosman, 2 gives the most probable values of $K_\perp$ ($L'$ to the optic axis) as 4.5 and $K_\parallel$ ($L''$ to the optic axis) as 4.6 for quartz.

In the case of colourless quartz, data are available not only in respect of the dielectric constants but also in respect of their dependence on temperature, frequency and so on. No work appears to have been done on amethyst, smoky quartz or other coloured types. There are different opinions as to the origin of the colour in each case. One view 3 is that amethyst owes its colour to a compound of ferric iron which is stable up to 260°C. Other views have been expressed in the literature. Similarly, the cause of colour in smoky quartz is taken as the presence of an inorganic pigment by some and as free silicon liberated by radioactive radiations by some others. 4 The latter view has gained much strength in view of the facts that smoky quartz occurs generally in the neighbourhood of radioactive ores, and that in general it is possible under X-radiation to convert colourless quartz into smoky quartz. This problem of the origin of colour of smoky quartz and amethyst has not yet been fully cleared up and in the hope that their dielectric behaviour may throw some light on the subject, the author has undertaken a study of the same.

2. EXPERIMENTAL

The usual method for determining the dielectric constant of a solid body is to take it in the form of a plate and find the change in capacity it produces when placed between the plates of a parallel plate condenser. The latter forms part of the tank circuit of an oscillator in a heterodyne unit. A mixture method is also in vogue for solids and is widely used in the case of powders. The dielectric constants of a number of mixtures of two suitable liquids are found when they are pure and when they contain a
particular amount of the solid. The values in the latter case will be different from the former. By taking suitable liquid mixtures of dielectric constants above and below that of the solid and drawing a graph between the original values of the mixtures and the change produced by the solid, the dielectric constant of the solid, which corresponds to the value of mixture having no change on the introduction of solid, can be obtained. In this investigation, the mixture method is employed in a modified form. Instead of determining the dielectric constants of several liquid mixtures with and without the solid inside, a liquid mixture is adjusted to have the same dielectric constant as the solid by varying the proportions of the constituents.

A liquid cell with two parallel plates, the distance between which can be suitably adjusted, is connected to the tank circuit of one of the oscillators of a heterodyne unit. Another small variable condenser consisting of two parallel plates, one of which can be moved from a distance by an insulating handle, is also connected parallel to the above. The plate distance in the liquid cell is adjusted to be a little more than the thickness of the crystal section under study. The crystal is fixed to a glass fibre suspension with a small drop of shellac. The suspension head can be moved up or down by means of a pulley arrangement. A mixture of benzene and nitrobenzene is poured in the liquid cell. The oscillators are adjusted for the beat note of a low frequency and from a distant control, the crystal is moved in between the plates of the liquid cell. By the change in the beat note, even a very small difference in the dielectric constants of the liquid mixture and the crystal plate can be recognized. The liquid mixture proportions are thus suitably adjusted such that it has the same dielectric constant as the crystal plate. The dielectric constant of the liquid mixture so arrived at is determined using a special liquid cell supplied by Kipp & Zonen, Holland. In this determination, the leads correction, obtained by using double distilled benzene, is taken into account. Measurements repeated on different occasions show that values which differ from each other by less than 1% are obtained.

The liquid level is kept more than one centimetre above the plates in the liquid cell used for containing the crystal. When the final adjustment is made, it is seen that the crystal plate is completely immersed in the liquid. The immersion does not produce any change in the capacity due to changes in the liquid level because the liquid level is already well above the condenser plates.

Two Y cut and two Z cut plates of colourless quartz, four specimens of amethyst with different shades of colour cut into thin plates perpendicular
to the Z axis and two plates of smoky quartz cut from a lump without any definite orientation have been studied in this investigation.

The amethyst and smoky quartz plates have been heated in the air oven at about 400°C for four to five hours and then transferred to a desiccator. As the amethyst bits developed cracks on heating, it was found necessary to keep them free from moisture. On heating, the smoky quartz plates

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Orientation</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Author</td>
</tr>
<tr>
<td>1</td>
<td>Y cut</td>
<td>4.40</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>4.50</td>
</tr>
<tr>
<td>3</td>
<td>Z cut</td>
<td>4.60</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>4.70</td>
</tr>
</tbody>
</table>

**TABLE II**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Description of the Section</th>
<th>Dielectric constant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before heating</td>
</tr>
<tr>
<td>1</td>
<td>Smoky quartz. Light smoky brown in colour. Uniform throughout. After heating colour is completely lost, leaving a yellowish tinge all through.</td>
<td>4.50</td>
</tr>
<tr>
<td>2</td>
<td>Smoky quartz. This also has a quite uniform smoky brown colour of slightly less intensity than that of No. 1. After heating colour has entirely vanished with the same yellowish tinge as for No. 1 remaining.</td>
<td>4.50</td>
</tr>
<tr>
<td>3</td>
<td>Amethyst. Violet colour all through with three intense streaks resembling sectors in shape. After heating, background colour is completely lost, but the streaks are still present with much less intensity.</td>
<td>5.40</td>
</tr>
<tr>
<td>4</td>
<td>Light violet colour in the background with two patches of less intensity than those of No. 3. After heating, the patches only stand with less intensity.</td>
<td>5.15</td>
</tr>
<tr>
<td>5</td>
<td>It has got the usual lightly violet background colour two patches of different intensities, both of them being less intense than in No. 4. After heating, the background colour and the less intense patch have almost vanished. But the other patch still remains weak.</td>
<td>4.90</td>
</tr>
<tr>
<td>6</td>
<td>Throughout it possesses very light and uniform violet coloration with no patches. After heating colour is completely gone, leaving a dull yellow tinge.</td>
<td>4.90</td>
</tr>
</tbody>
</table>
Dielectric Constants of Crystals—I

lost the colour completely within half an hour. One amethyst bit lost the
colour completely on heating for four hours. Though the others lost it
to a great extent, some light patches of colour remained here and there. The
dielectric constants of all the above sections have been redetermined after
heat treatment.

3. Results

In determining the dielectric constant of the neutralising liquid
mixture, the value for benzene was taken to be 2.27 at the room temperature
26° C. for finding the leads correction for the liquid cell. The determina-
tions were made at frequencies ranging between one and two mega-cycles
per second. The results obtained with colourless quartz plates are given
in Table I.

The results obtained with amethyst and smoky quartz sections are
given in Table II.

4. Discussion of Results

There is a definite difference between the dielectric constants of the two
specimens of quartz studied as Y cut plates. The same applies to the pair
of Z cut plates. A repeated determination consecutively of the values of
the above specimens gave the differences consistently. This shows beyond
doubt that the dielectric constants of quartz may vary slightly from speci-
men to specimen.

The dielectric constant of a single plate of amethyst is not uniform
throughout. By the changes in the beat note, it is found that different
portions of the plate have slightly different values. In the case of specimen
No. 3 the values for the two halves of the plate taken are given. For some
other plates also there are slight variations but the values for the central
portions only are given. For the colourless quartz and smoky quartz the
values are uniform throughout the plate.

There are slight differences in the values of the decolourised specimens
when compared with the corresponding coloured specimens. Nothing
definite can, however, be said about them. Some of these differences are
within experimental errors and some may be due to traces of moisture
absorbed by the bits in handling.

It is interesting to note that the dielectric constants of smoky quartz
agree with those of colourless quartz whereas the constants of amethyst
are definitely higher. The colour of the smoky quartz is generally believed
to be due to irradiation by radioactive substances and not due to metallic
content. The fact that the dielectric constant of smoky quartz is not
different from that of colourless quartz is significant in this respect, because as appreciable metallic content may be expected to change the dielectric constant.

The dielectric constant of amethyst is definitely higher than that of normal quartz and also it remains the same even though the specimen is decolourised. In view of the appreciable iron content in amethyst as shown by Holden, this is explicable. As the amethyst plates are not uniformly coloured with gradations in intensity, a regular relation between intensity of colour and dielectric constant could not be obtained. Though specimens No. 5 and No. 6 are of different intensities, there is no difference in their dielectric constants. But Nos. 3 and 4 whose colour intensity is higher than that of No. 5 or No. 6 have higher dielectric constants. Thus in general amethysts of greater colour intensity appear to have higher dielectric constants.

5. Summary

The dielectric constants of colourless quartz, smoky quartz and amethyst are found by a modified liquid mixture method. The constants of different specimens of colourless quartz are slightly different from each other. The smoky quartz has its dielectric constant agreeing with that of colourless quartz. This value remains the same before and after decolourisation by heat treatment. Amethyst specimens have higher dielectric constants than colourless quartz and such values are unchanged by decolourisation.

The author wishes to express his grateful thanks to Prof. S. Bhagavantam under whose guidance the above investigation has been carried out. His thanks are due to Mr. Bh. Krishnamurty for lending the amethyst and smoky quartz sections prepared by him.

References

4. N. M. Mohler Ibid., 1936, 21, 258.