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The Reflection Spectrum of Quartz in the Region of 9 mu

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The reflection spectrum of quartz, cut perpendicularly to the optic axis, has been previously studied in the region of 9μ. It was felt advisable to repeat this work by using polarized light and a crystal section cut parallel to the optic axis. With the same high resolution spectrometer and a new type of resonance radiometer which employs a Nichols type radiometer, sufficient sensitivity was obtained to bring out a maze of fine structure. It is to be noted that much of this fine structure is produced at identical frequencies for both the ordinary and the extraordinary rays. This might indicate that these frequencies are produced by a lattice rather than by an ionic motion, or that such agreement is entirely fortuitous because of the extreme complexity and closeness of the lines.

INTRODUCTION

THE reflection spectrum of quartz has been studied many times. Recently, the author in conjunction with J. D. Hardy[1] studied the 9μ reststrahlen with a grating spectrometer of high resolution and the newly developed resonance radiometer. The results obtained at that time confirmed the general position of the bands and the reflecting power as obtained by previous investigators. In addition, an unsuspected degree of fine structure was obtained for both crystal and fused quartz. These indications of complexity were found for a section of crystal quartz which was cut and polished perpendicularly to the optic axis. The incident, and therefore, the reflected beams were unpolarized. It occurred to the present author that the problem should be attempted again with a polarized beam incident upon a section cut parallel to the optic axis. By this means one is easily able to separate the ordinary and the extraordinary rays by securing the proper orientation of electric vector and optic axis and to study each one individually.

EXPERIMENTAL

The spectrometer employed was the same as the one used in the earlier investigation in this laboratory.[1] A few minor changes were made. Among these was the substitution of a globar element for the usual Nernst glower; a special water-cooled mounting was devised, to be described elsewhere, which gave excellent service. The radiation from the heater was rendered parallel and allowed to fall upon a selenium plate at the Brewsterian angle. Following the directions for producing a selenium polarizer which were given by Pfund[2] many years ago several plates as large as 15×8 cm were prepared. The figure of the one finally selected was about equal to that of good window glass. In visible light it was possible with a crossed nicol completely to extinguish the light from a bright filament. The polarized radiation then fell upon the quartz plate at an angle of incidence of 20°, this being the smallest angle possible with the present set-up.

In place of the old resonance radiometer with two thermocouples and two under-damped galvanometers, a new instrument was built. The time of response of the old galvanometer system was somewhat long, and although electromagnetic disturbances were so slight as to be negligible, two difficulties were encountered. One was drift due to temperature fluctuations; this is only partially avoided at the high sensitivities by a compensated couple. The other was drift due to changes in the torsion of the suspensions and slight warping of the supports in the subbasement room in which the apparatus is situated. Because of previous encouraging results obtained in this laboratory it was felt that the

[1] Hardy and Silverman, Phys. Rev. **37**, 176 (1931).

[2] Pfund, Astrophys. J. **24**, 19 (1906).

compensated Nichols type radiometer offered possibilities. In general, to obtain large deflections with the radiometer, the system is built as lightly as possible. Such an instrument, in the ideal case, has a high, sharp sensitivity maximum at a pressure of about 0.02–0.06 mm mercury and is critically damped at this pressure. In our case, inasmuch as we were seeking resonance, we desired an underdamped system. This meant either a light system, working at a pressure so far below optimum conditions as to produce very small sensitivity; or a heavy system with relatively low sensitivity which would be underdamped at optimum pressure. The last alternative was accepted for several reasons. First, the loss in sensitivity is much smaller than was at first feared; our final radiometer was fully half as sensitive in "straight" deflection as the lighter ones. Secondly, it was much more rugged and more stable. Thirdly, the period could be managed so as to bring it up to a value where the resonance was of maximum benefit. Last, and perhaps most important, the dependence of sensitivity and damping upon pressure are very slight in the region of 0.01 mm, so that small leaks were of no importance, and it was possible to maintain uniform sensitivity for days, without recourse to pumping. The radiometer as finally built consisted of two vanes made of charred lens paper, as described by Pfund and Silverman,[3] dimensions 0.7×8 mm separated by 8 mm. The mirror was a piece of silvered glass 4×4 mm. The suspension was a quartz fibre, 12 cm in length, so chosen for thickness as to yield a period of 10 seconds. The entire mass was 0.020 gram, moment of inertia (calculated) 3×10^{-4} c.g.s. units. The amplifier consisted of two very coarse grids, 1 cm wide. This is necessary to allow for large angular displacement, as the radiometer has a considerably higher "deflection" sensitivity than does the thermocouple-galvanometer. As the Brownian motion limit is apparently very nearly the same for the radiometer as for the galvanometer-thermocouple circuit, the degree of useful amplification obtainable is correspondingly reduced. In place of the second thermocouple a Weston photronic cell and short-period, high resistance Leeds and Northrup galvanometer were used. The latter was critically damped and very closely followed the long, periodic impulse from the swinging radiometer. One difficulty was encountered. The light from the amplifier bulb was focussed upon the radiometer mirror and very severe disturbances were immediately set up, probably due to convection currents from the heated mirror or the radiometer-effect itself upon the mirror. Filters of copper chloride and green glass were introduced, until finally the focussed spot could be cut on and off without producing any disturbance. The radiation from the globar itself was interrupted by means of a magnetically operated shutter which was controlled by a carefully tuned electromagnetic pendulum.

The radiometer was so damped that it required 9 or 10 swings to return to rest and 5 complete periods to attain maximum deflection. An amplification of 50 was used, which by calculation showed our experimental accuracy to be quite near the theoretical limit set by the Brownian motion. The instrument was some 4 to 5 times more sensitive than the old one, due chiefly to the longer period, increased stability and the possibility of sharper resonance.

The instrument yielded, under these conditions, readings of 30 cm and above, which could be reproduced to within 2 mm. The random zero disturbance ranged from 5 to 12 mm, depending upon wind and building conditions. These deflections were as large as those obtained on the previous instrument with an energy source of similar power, in face of the handicap of the selenium polarizer which has a reflecting power of only some 35 percent.

The standard MgO filter was used. This consists of a mirror coated with a sufficiently heavy layer of the oxide to quench completely overlapping orders of shorter wave-lengths. Readings were taken with the electric vector parallel and then perpendicular to the optic axis; immediately following, the quartz plate was replaced by a gold mirror and the reading repeated. The curves (Fig. 1) were plotted by taking ratios. Readings were taken for wave-length settings separated by 0.005μ and are accurate to 0.0015μ.

[3] Pfund and Silverman, Phys. Rev. **39**, 64 (1932).

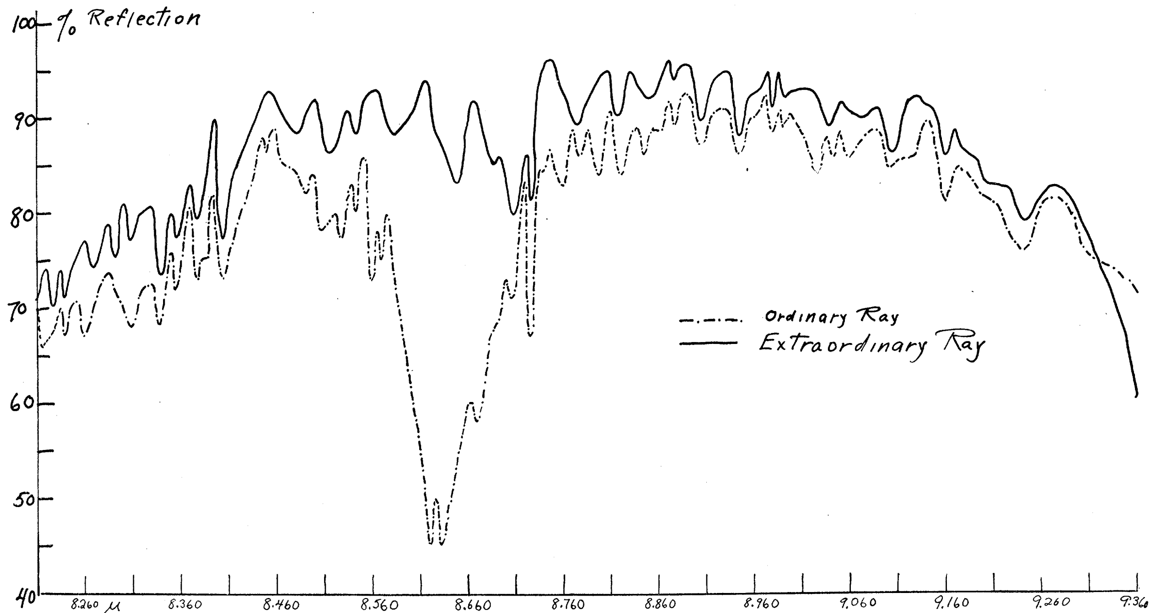

FIG. 1. Reflection spectrum of quartz.

RESULTS

As observed in the literature[4] the envelope of the extraordinary ray remains above that of the ordinary ray, and fails to show the deep triple minimum around 8.63μ. It is seen, however, that both bands possess a great amount of fine structure. The wave-lengths of the deep minima of the ordinary ray checked to within the experimental error those of the previous work.[1] Some new complexities were uncovered in this experiment due to the increased sensitivity. It is to be noted further that much of this structure is coincident for both bands. Inasmuch as the two rays are due to two vibrations at right angles to one another, it is amazing to find such a reproduction of frequencies in two such dissimilar vibrations. This might lead one to believe the fine structure to be caused by a superposition of a lattice frequency upon an ionic one. However, despite this coincidence and a similar observation concerning the resemblance of the reflection and absorption spectrum of calcite,[5] it must be born in mind that complete resolution in the case of solids is a matter of extreme doubt, and it is very possible that the structure is so complex that there exists a sufficient number of lines to make such agreement fortuitous and almost inevitable.

In conclusion, the author wishes to thank Professor R. W. Wood who has ruled the excellent echelette grating used in this spectrometer and Professor A. H. Pfund for many valuable suggestions. He also wishes to express his indebtedness to Dr. R. Canfield of the Naval Research Laboratory who has generously supplied the quartz plates.

[4] Lecomte, *Le Spectre Infrarouge*, page 145 ff.

[5] Silverman, Phys. Rev. **39**, 72 (1932).