ATTENUATION OF HYPERSONIC WAVES IN QUARTZ

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We have measured the acoustic absorption in crystalline quartz at frequencies between 1000 Mc/sec and 4000 Mc/sec from room temperature to 4.2°K. Figure 1 shows the experimental arrangement. A cylindrical quartz rod, 25 mm long and 3 mm in diameter, with both end faces polished optically flat and parallel, extended between two cavities of the same frequency. Sound waves were generated by surface excitation, as described previously,[1] in the electric field of one cavity and similarly detected in the other.

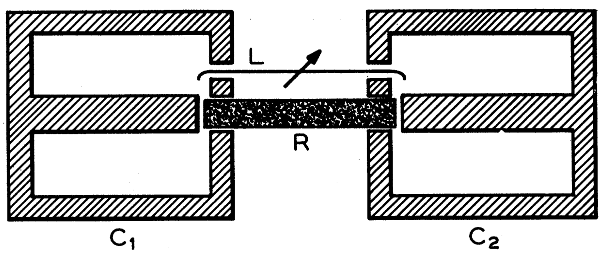

FIG. 1. Schematic diagram of the two cavities coupled acoustically by the quartz rod R and a variable electric coupling L.

The transmitter cavity C_1 was coupled to a pulsed rf-power source, and the receiver cavity C_2 to a sensitive receiver and oscilloscope. A variable electric coupling between the two cavities provided a means to compare the acoustically transmitted pulse with a calibrated electric leakage signal. This made it possible to measure relative changes of the acoustic attenuation, since changes in the quality factor of the cavities with temperature affected both signals in the same way. Changes in the electrical coupling due to thermal expansion were negligible below 70°K and were corrected for at higher temperatures.

Three different crystal orientations were used. For longitudinal waves, the rod axis was parallel to the x axis. For transverse waves, two rotated y-cuts were used: an AC-cut and a BC-cut, with the rod axis making an angle of -59° and +31°, respectively, with the z axis. In these two orientations transverse waves travel parallel to the rod axis and have no cross-coupling to other modes.

Some of the results for longitudinal and transverse waves are shown in Figs. 2 and 3, where

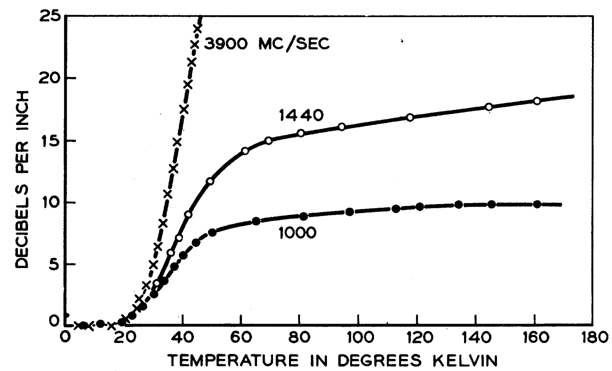

FIG. 2. Temperature-dependent part of attenuation of longitudinal waves vs temperature at different frequencies.

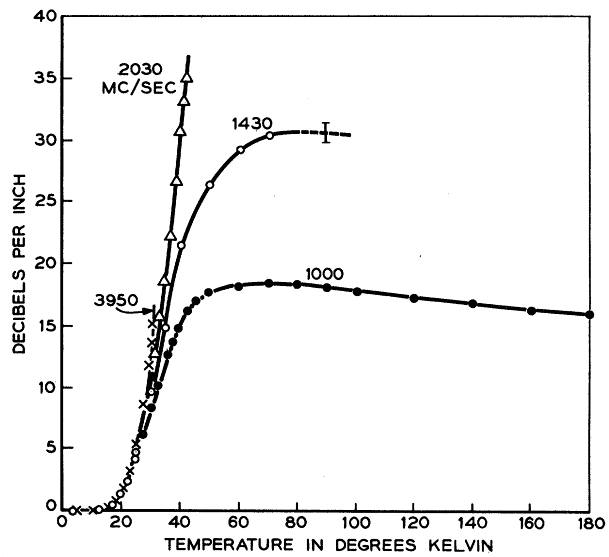

FIG. 3. Temperature-dependent part of attenuation of transverse waves vs temperature at different frequencies.

the temperature-dependent part of the absorption is plotted versus the temperature. The attenuation changes relatively little between room temperature and 60°K, but drops fast between 60°K and 20°K. It was only below 20°K that a large number of echoes could be observed, as shown in Fig. 4, thus making it possible to determine the absolute value of the absorption. The residual temperature-independent attenuation below 15°K was always only a small fraction between 1% and 10% of the room-temperature value and is not shown in Figs. 2 and 3. Therefore, below 20°K there should be no difficulty in extending such measurements to appreciably higher frequencies. None of the relaxation peaks observed in earlier work[2] at lower frequencies could be

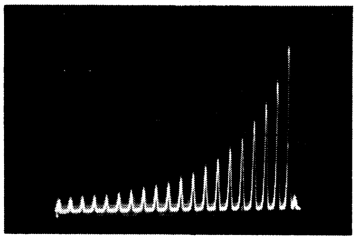

FIG. 4. Multiple reflections of longitudinal waves at 1000 Mc/sec and 15° K.

seen at 1000 Mc/sec and above. The uncertainty of the absolute values of each curve in Figs. 2 and 3 is estimated to be about 10%. The relative values are considerably more accurate, the main source of error being the calibration of the leakage signal. The frequency dependence of the attenuation is different at high and at low temperatures. Below about 25°K there is practically no variation with frequency, while above 60°K the frequency dependence appears to be between linear and quadratic. Further experiments over a wider frequency range will clarify this point.

At present we have no satisfactory explanation for our observation. It appears to be more difficult to account for the magnitude of the absorption than for its temperature dependence. It is interesting to note, in this connection, that the attenuation drops to half of its high-temperature value where the mean free path of the thermal phonons is of the same order as the acoustic wavelength, particularly in the case of transverse waves; thus this appears to be an example of interaction between sound waves and the thermal phonons. The small variation of the attenuation above this temperature may be related to the fact that here the product of the total phonon energy[3] E and the phonon mean free path l is nearly constant. A naive assumption of a "phonon-viscosity,"

$$\eta = E \times l / 3\bar{c}, \quad (\bar{c} = \text{average sound velocity})$$

would therefore qualitatively explain the temperature dependence, but it would account for only about 15% of the observed absorption of transverse waves above 60°K. In the case of longitudinal waves our data would, in addition, require the assumption of a considerable compressional viscosity.

Absorption due to heat conduction, as calculated for example by Lücke[4] and others, is one order of magnitude smaller than observed and would not account for the absorption of transverse waves.

Akhieser[5] and Pomeranchuk[6] treated the interaction between sound waves and thermal phonons in ideal crystals. Unfortunately Akhieser only considers temperatures much higher and much lower than the Debye temperature, so that a comparison with our results is not yet possible. Pomeranchuk's results do not agree with our observed temperature dependence.

Eshelby,[7] Leibfried,[8] and Nabarro[9] estimated the sound absorption arising from the fact that the motion of dislocations is damped by interaction with thermal phonons. But the observed temperature dependence and the strong longitudinal absorption are difficult to understand on the basis of their models.

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[3]We are indebted to Dr. E. F. Westrum of the University of Michigan, Ann Arbor, for permission to use his data on the specific heat of crystalline quartz prior to publication.

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RESONANCE PHENOMENA IN LARGE-ANGLE HELIUM ION–HELIUM ATOM COLLISIONS*

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When He^+ ions are scattered from He atoms at kev energies, a small fraction of these collisions result in large-angle scattering of the incident particle. Scattered particles from this collision (and other combinations as well) have been analyzed to determine their charge state in two previous papers,[1,2] the data being taken at 25, 50, and 100 kev incident energies. Two interesting facts appear from the He^+ on He data of these

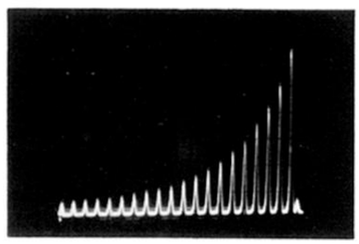

FIG. 4. Multiple reflections of longitudinal waves at 1000 Mc/sec and 15° K.