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Phonon Dispersion in Liquid Helium under Pressure

E. C. Svensson, A. D. B. Woods, and P. Martel
Atomic Energy of Canada Limited, Chalk River, Ontario, Canada
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We have studied one-phonon neutron scattering in liquid helium at a pressure of 24 atm in the range of wave-vector transfers $0.2\ \text{Å}^{-1} \leq |\vec{Q}| \leq 0.7\ \text{Å}^{-1}$ at $T = 1.2$ K. The results give a value $(6.2 \pm 0.6) \times 10^{37}\ \text{g}^{-2}\ \text{cm}^{-2}\ \text{sec}^2$ for the parameter γ which characterizes the phonon dispersion. The one-phonon peaks exhibit tails indicating shortened phonon lifetimes at elevated pressures.

There has recently[1] been much interest in the nature of the phonon dispersion in liquid helium and its variation with pressure. In this Letter, we report, for liquid helium at $T = 1.2$ K and $p = 24$ atm, a direct determination of the parameter γ in the expression for the phonon dispersion, $\omega = cQ(1 - \gamma\hbar^2Q^2 \cdots)$, where $\hbar\omega$ and Q are the phonon energy and wave vector, respectively, and c is the velocity of sound. The results also strongly suggest that phonon lifetimes are shorter at $p = 24$ atm than at $p < 1$ atm.

The neutron inelastic scattering measurements were carried out on a triple-axis crystal spectrometer at the NRU reactor, Chalk River. Two arrangements were used: (1) The scattering angle $2\theta_A$ of the pyrolitic graphite analyzer was set at 74.75° ($\lambda = 4.07$ Å) and a beryllium filter placed in the scattered beam to prevent neutrons with wavelengths less than 4 Å from reaching the detector. Pyrolitic graphite (002) planes were used as the monochromator, and quartz and pyrolitic graphite filters were placed in the incident beam to reduce the fast neutron background and higher-order contamination. (2) The scattering angle of the pyrolitic graphite analyzer was set at 89.9° ($\lambda = 4.47$ Å); Ge (111) planes were used as the monochromator, and, in addition to the quartz filter, a beryllium filter was placed in the incident beam to eliminate virtually all higher-order neutrons.

One-phonon neutron groups for $Q = 0.5$ and $0.7\ \text{Å}^{-1}$ and pressures of 0.7 and 24 atm are shown in Fig. 1. The line shapes are qualitatively different at the two pressures. In particular, the peaks for $p = 24$ atm exhibit distinct wings, especially on the low-energy side. The identification of wings on the high-energy side is hampered by the presence of multiphonon scattering.[2,3] At $p = 0.7$ atm no wings are apparent and the observed widths and line shapes of the peaks are consistent with δ-function line shapes broadened

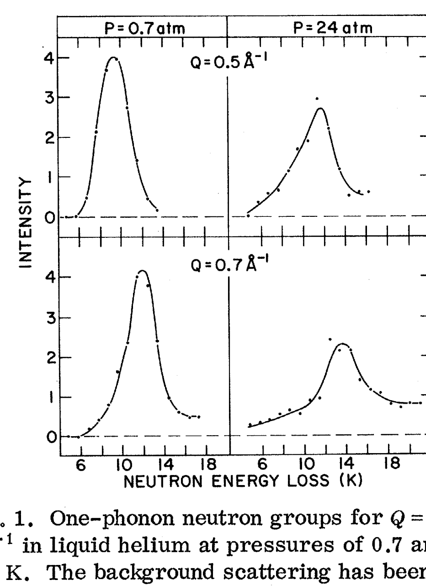

FIG. 1. One-phonon neutron groups for $Q = 0.5$ and $0.7\ \text{Å}^{-1}$ in liquid helium at pressures of 0.7 and 24 atm at 1.2 K. The background scattering has been subtracted, and all distributions have been normalized to the same number of counts/point in the incident-beam monitor. Solid curves are simply a guide to the eye.

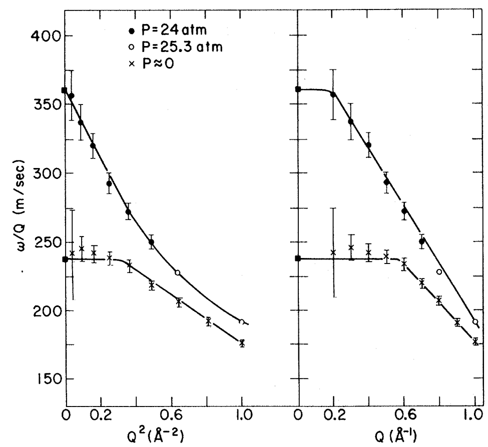

FIG. 2. Plots of ω/Q versus Q and Q^2 for liquid helium at 1.2 K. The present measurements are indicated by solid circles. Also shown are earlier measurements at 25.3 atm (Ref. 4) and at the saturated vapor pressure (Ref. 3). Squares indicate the sound velocity obtained in ultrasonic measurements (Ref. 5). Curves are simply a guide to the eye.

by the experimental resolution. The line shapes observed at $p = 24$ atm indicate that the phonons have nonzero intrinsic widths (inverse lifetimes) at this pressure. In spite of the increase in density (about 18%), the low-Q peak-height intensities at $p = 24$ atm, corrected for a plausible ω^{-1} term in the one-phonon scattering cross section, are only about 60% of the corresponding low-pressure values. Either there is some hitherto unsuspected mechanism operating to reduce the total one-phonon intensity at high pressures or else the lower peak-height intensities must be compensated by real intensity in the tails of the distributions. The latter explanation, if correct, is further evidence that the phonon lifetimes are reduced as the pressure is raised.

In Fig. 2 the values of ω/Q are plotted as a function of Q and of Q^2 and compared with previous results[3] at the saturated vapor pressure. Some of the earlier results of Henshaw and Woods[4] at $p = 25.3$ atm are also shown. The results, when plotted against Q^2, appear qualitatively different at low and high pressures. The results for $p = 24$ atm combined with the sound velocity[5] give $\gamma = (6.2 \pm 0.6)\times 10^{37}$ g^{-2} cm^{-2} sec^2, indicating large negative dispersion, in marked contrast to the small or negligible dispersion, $\gamma = (0 \pm 2)\times 10^{36}$ g^{-2} cm^{-2} sec^2, indicated by the low-pressure neutron-scattering measurements.[3] A much larger value of γ, 19.6×10^{37} g^{-2} cm^{-2} sec^2, has been deduced by Phillips, Waterfield, and Hoffer[1] from their specific-heat measurements at $p = 20.8$ atm, and large negative values of γ have also been suggested.[6] It is difficult to reconcile the latter with the neutron-scattering measurements. Note, however, that the plot of ω/Q versus Q is qualitatively similar at low and high pressures, and the possibility of a region of zero (or even positive) dispersion below $Q = 0.2$ Å^{-1} cannot be ruled out.

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