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INELASTIC SCATTERING FROM $^3$He UNDER PRESSURE

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Abstract.— Results are presented for the inelastic neutron scattering from liquid $^3$He at S.V.P., 10 bars and 20 bars pressure. Measurements were obtained for wavevector transfers in the region $1.1 - 2.4 \text{ Å}^{-1}$, and for energy transfers up to 27 K. The experiments were performed at a temperature of 0.7 K. At low wavevector transfers, there was no evidence for a well defined zero sound mode, even at a pressure of 20 bars. At 1.9 $\text{Å}^{-1}$ (the position of the roton minimum in the $^3$He superfluid), the observed scattering has a broad distribution, whose peak frequency decreases by more than a factor of 2, on increasing the pressure from S.V.P. to 20 bars.

Neutron scattering experiments on liquid $^3$He at the saturated vapour pressure have shown that none of the currently available microscopic theories of $^3$He is wholly satisfactory. Measurements were initially performed using the INS time of flight spectrometer at the Institut Laue-Langevin, at 1.3 K /1/, and 0.6 K /2/. These measurements showed that the scattering has a broad spectrum for wavevector transfers, Q, between 1.1 and 2.5 $\text{Å}^{-1}$. No evidence was obtained in these measurements for scattering which could be attributed to a well defined zero sound mode. Subsequent experiments /3/, performed at 0.015 K, suggest that there is a fairly well defined zero sound mode for wavevectors between 0.8 and 1.4 $\text{Å}^{-1}$. Despite several theoretical efforts /4/, there has not yet been in our view, a convincing explanation of this temperature dependence. Since the velocity of sound and the effective mass, $m^*$, of the $^3$He atoms are known to increase with increasing pressure, it is to be expected that at higher pressures, it will be more difficult for the zero sound modes to decay into particle hole pairs than at the saturated vapour pressure. This report is on measurements performed at higher pressures in the hope of elucidating the nature of the zero sound mode in pure $^3$He.

The experiments were performed at 0.7 K; the only significant change from our earlier experiments was that a single crystal of sapphire was chosen as the window of the sample container /5/. The choppers determining the incident neutron energy were phased to produce neutrons of wavelength 4.5 Å. The 400 counters available, were arranged in eight blocks, chosen so as to give a range of wavevector transfers between 1.1 and 2.4 $\text{Å}^{-1}$. Under these conditions the full width of the incoherent vanadium calibration peak was 3.65 K (FWHM). After substraction of an appropriate background the time of flight spectra were corrected for the variation of counter efficiency with scattered neutron energy, the variation of absorption in the $^3$He with neutron wavelength, and the variation of scattered intensity with the density of $^3$He. Conversion was then made to energy spectra. Typical results are shown in figure 1 for three different scattering angles.

Fig. 1 : Typical energy distributions for liquid $^3$He, at 0.7 K, for S.V.P., 10 bars and 20 bars pressure. The three angles shown correspond to wavevector transfers of approximately 1.2 $\text{Å}^{-1}$, 1.55$\text{Å}^{-1}$ and 2.0 $\text{Å}^{-1}$ respectively.
All of our data is summarized in figures 2 and 3. Figure 2 shows the peak and half-height frequencies for each of the energy spectra, while figure 3 shows the distribution of scattered intensity at the three different pressures.

![Figure 2: Peak positions and half height positions of the energy distributions at S.V.P., 10 bars and 20 bars pressure. The dotted lines refer to $\hbar^2 Q^2 / 2m^\ast$, with $m^\ast = 3.08 m_e$ at S.V.P., 4.4 $m_e$ at 10 bars and 5.2 $m_e$ at 20 bars.](image)

![Figure 3: Plots of equal intensity contours for $S(Q,\omega)$ for liquid $^3$He at 0.7 K, shown for S.V.P., 10 bars and 20 bars pressure.](image)

with our earlier measurements and we do not observe a well defined zero sound mode at 0.7 K. Calculations of the excitation spectrum of $^3$He at high pressures suggest that the zero sound mode at 20 bars occurs at $Q = 1.2 \AA^{-1}$, for energy transfers in the region of 20 K, and at $Q = 1.6 \AA^{-1}$, the zero sound mode appears to merge with the particle hole continuum. Our results show no evidence of a well defined excitation, neither at 10 bars nor at 20 bars, for energy transfers up to 25 K.

A qualitative understanding of our results may be obtained when it is remembered that the scattered neutron intensity is proportional to the sum of the mass density correlation function and the spin density correlation function. Calculations then suggest that for $Q = 1.4 \AA^{-1}$, the scattering at S.V.P. consists almost equally of the spin density and mass density components. At elevated pressures the effective mass increases, so that the spin density component may be expected to decrease in energy, with a corresponding increase in peak intensity, while at high energy transfers, the scattering is dominated by the mass density fluctuations. If the zero sound modes are broadened by decay into multi-particle hole states, it may well be that the scattered intensity from the mass density fluctuations is spread over such a wide frequency range that the zero sound excitation cannot be detected above the background in our experiment. These arguments provide a qualitative understanding of the behaviour at smaller wavevector transfers. At larger wavevector transfers ($Q = 1.9 \AA^{-1}$), the decrease in peak energy with increasing pressure is more rapid than can be accounted for solely by the change in effective mass. This suggests that the appropriate effective mass for these energy and wavevector transfers is somewhat larger than is obtained in macroscopic measurements. We hope that these results will stimulate further calculations of the pressure dependence of the excitations in liquid $^3$He.
References

/5/ Hilton, P.A., Cryogenics 17 (1977) 532