Sound Velocity in Liquid $^4$He Under Pressure*

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We have measured the temperature dependence of the sound velocity in liquid $^4$He at pressures from the vapor pressure to near the solidification pressure. The data were obtained at frequencies from 12 to 105 MHz and covered the temperature range from below 0.1 to nearly 1.0 K. The velocity data at high pressures do not show any anomaly that can be associated with a distinct shoulder found earlier in the sound attenuation. As observed previously at the vapor pressure, the frequency dependence of the velocity data undergoes an inversion at low temperatures; this unexpected behavior is in agreement with recent theoretical treatments.

1. INTRODUCTION

In previous measurements\(^1\) of the sound attenuation in liquid $^4$He under pressure, we observed an anomaly at high pressures; the usual $T^4$ temperature dependence which is seen at low pressures and temperatures was found to develop a pronounced shoulder at pressures between 10 and 20 atm and at temperatures between 0.3 and 0.6 K. This has been explained by Jäckle and Kehr\(^2\) in terms of a restriction imposed on the three-phonon attenuation mechanism by a region in the elementary excitation spectrum where the thermal phonon velocity falls below the acoustic phonon velocity. Since the same three-phonon process also contributes to the temperature dependence of the velocity, we were interested in finding out whether the proposed restriction in this process at high pressures would also show up as an anomaly in the velocity data.

Another feature of the velocity which interested us was its frequency dependence. It has previously\(^3\) been observed that the zero-pressure velocity shift at temperatures above 0.3 K showed a frequency dependence that was negative (velocity shift decreasing with frequency). This is opposite to the frequency dependence of most theories,\(^4\)\(^ – \)\(^7\) although recent theoretical

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treatments by Maris\textsuperscript{8} and by Meier and Beck\textsuperscript{9} predict such a frequency dependence. In addition, our previous data had suggested that at temperatures below 0.2 K the frequency dependence was positive. The accuracy of these data was not sufficient, however, to properly characterize this frequency dependence.

In order to clarify some of these points and also to map out the general behavior of the velocity under pressure, we initiated the experiments reported here. Measurements were made of the temperature dependence of the velocity from below 0.1 K to nearly 1.0 K at frequencies of 12, 15, 36, 45, 60, 84, and 105 MHz and at pressures of 0, 8.4, 15.5, and 24.7 atm. A simultaneous determination of the attenuation was also made, but the bulk of this data will not be discussed as it essentially agrees with previous results.\textsuperscript{1}

2. EXPERIMENTAL TECHNIQUES

Our ultrasonic measurement techniques are particularly well suited to the determination of the very small changes in sound velocity that occur below 1 K. Figure 1 shows a block diagram of our ultrasonic comparator. The rf output of the oscillator is split into a reference channel and a He channel. In the He channel a rf switch passes the power in a pulse that is applied to a quartz piezoelectric transducer; the ultrasonic pulse that is generated then travels through the He to a similar transducer where it is detected. The resultant rf signal is balanced against a reference-channel pulse whose amplitude and phase delay can be accurately controlled. The use of pulses is only an operational convenience and is not intrinsically necessary to establish the balance condition. The off-null error signal is due to the difference in phase of the rf signals from the two channels (and/or a difference in their amplitudes), and, therefore, a sensitivity to delay changes of a small fraction of an ultrasonic period can be achieved. Typically, a change

![Fig. 1. Simplified block diagram of the ultrasonic comparator.](image-url)