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Search for quantum cavitation in liquid ^{3}He

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Abstract

We present new experimental measurements of cavitation in liquid ^{3}He between 40 and 500 mK. Cavitation was predicted to be temperature independent below 120 mK if it takes place by quantum tunneling rather than by thermal activation. However, we found no such plateau despite several improvements in our experimental techniques. We thus believe that quantum cavitation may occur at lower temperatures than predicted. We also propose a different experimental method for further experimental studies of liquid helium at negative pressure. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cavitation; Fermi liquid; ^{3}He normal liquid; Phase transition

As previously explained [1,2], we found that cavitation occurs in liquid ^{3}He at less negative pressure than in ^{4}He, and that the cavitation threshold keeps increasing down to much lower temperatures. This is in agreement with calculations by Maris [3], and with the predicted cross-over temperature from thermally activated cavitation to quantum cavitation (120 mK in ^{3}He instead of 240 mK in ^{4}He). However, due to the limited accuracy of our previous measurements, it was difficult to decide whether a temperature-independent regime existed in ^{3}He or not. Since, we have improved this accuracy and we found no evidence for quantum cavitation in ^{3}He below 120 mK. This is an important issue, because macroscopic quantum tunneling in configuration space might be different in superfluid ^{4}He and in a Fermi liquid such as ^{3}He [2].

Our experimental cell is attached to the mixing chamber of a dilution refrigerator with optical access [4]. Inside this cell, a hemispherical transducer produces 1 MHz ultrasound bursts which are focused onto a region about 100 μm large, far from any wall. Cavitation is detected by light scattering of a laser beam focused onto the acoustic focal region. By sending series of 100–400 bursts of only three oscillations at 1 MHz and counting the number of cavitation events, we measured the cavitation probability. We define the cavitation threshold as the sound amplitude at which this probability is $\frac{1}{2}$. This amplitude was measured from the voltage applied to the ceramic. In our previous report [1], we pointed out some heating due to mechanical dissipation in the ceramic. The heat takes a long time to escape from the ceramic into the liquid, so the sound wave reaches the focal region much before this heat diffuses there. However, this heat flow induces a small temperature gradient between this ceramic and our thermometer on the cell walls. Furthermore, a correction had to be applied on the acoustic wave amplitude to account for the damping over its 8 mm flight. Using the value of the viscosity [5], we applied such a correction, but it is very sensitive to the exact value of the temperature in the ceramic region below 100 mK.

We first measured the heat produced by the ceramic by monitoring the heating current in the temperature regulation of our refrigerator for several repetition rates. We found 2.6 μJ for bursts of 6 μs width. Since the quality factor of our ceramic is ~120, the wave amplitude is nearly proportional to time at short burst widths and we have 1.3 μJ for 3 μs bursts. We could not work with shorter bursts because of the power limitation of our amplifier. Then we found the cavitation threshold to be dependent on the repetition rate which forced us to decrease this rate down to 50 mHz below 100 mK. We

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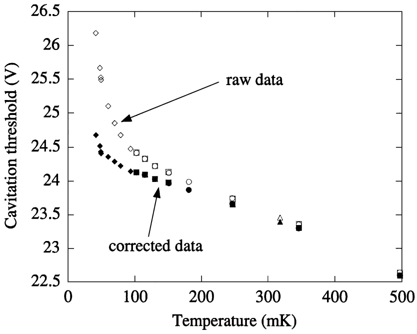

Fig. 1.

also noticed that it took 90 min for the system to reach a new steady state after each temperature or repetition rate change. A stability of the experiment on a time period of around one day was thus required. Since the cavitation probability depends exponentially on the sound amplitude, we also needed a stability for this amplitude of $\sim 10^{-3}$ during 1 d. For this purpose, we made new coax lines with copper inner conductors (0.24 mm diameter) so that the excitation of the ceramic was independent of the liquid helium level in the 4 K bath. Eventually, we checked that the effect of the repetition rate agrees with the existence of the small temperature gradient which we could calculate from the known dissipation and the thermal conductivity of liquid ^{3}He. Our improved measurements are shown in Fig. 1. At each temperature we only selected the data corresponding to negligible dissipation (optimum repetition rate). The upper set of points corresponds to raw data; the lower one to the data corrected for the temperature-dependent attenuation of the sound wave. A proper account of the width dependence of the amplitude confirms that the cavitation threshold pressure is about 3 times less negative in ^{3}He than in ^{4}He. This threshold is found to depend on temperature down to 120 mK, as predicted by Maris [3], but in fact down to 40 mK, our lowest temperature. The crossover temperature in ^{3}He might be lower than predicted in Ref. [3]; but the sharp increase observed below 50 mK suggests that we might have underestimated the correction due to the damping of the wave.

The theory and the experiment now need to be further improved. Maris suggested [2] that the velocity of zero sound does not vanish in a Fermi liquid at its spinodal limit; as a consequence, he pointed out the urge for a new theory, which accounts for the cost in energy of the fast deformation of the Fermi surface during the quantum tunneling. Such a calculation could lead to a prediction of a lower crossover temperature in liquid ^{3}He. As for the experiment, by inserting a glass plate at the focus, we plan to measure the local instantaneous density from the reflectivity of light at the glass/helium interface. This measurement needs a good resolution in space and time, and is in progress in our lab. We could then monitor the exact magnitude of the density oscillation at the focus, regardless of the sound attenuation.

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