Second Sound Measurements Very Near The Lambda Point

Mary Jayne Adriaans a,1, John A. Lipa b

a Jet Propulsion Laboratory, 4800 Oak Grove Drive; MS 79-84, Pasadena, CA 91109, U.S.A.
b Department of Physics, Stanford University, Stanford, CA 94305-4060, U.S.A.

Abstract

High resolution measurements of the second sound velocity near \( T_\lambda \) in superfluid \(^4\)He at the vapor pressure are reported. Experiments were performed using the resonant technique in cavities 13 mm, 4 mm and 2 mm in height. A disc of paramagnetic salt, copper ammonium bromide, in direct contact with the helium sample and coupled to a SQUID magnetometer, was used as the sensor. The sound was generated by wire-wound heaters embedded in the end opposite the sensor in each cavity. The superfluid density was determined from second sound measurements and the critical exponent \( \nu \) was obtained from fits to the data. The results for the exponent were found to be very sensitive to the treatment of systematic effects in the data.

Keywords: second sound; superfluid \(^4\)He; lambda point

Powerful tests of the renormalization group (RG) theory can be performed near the superfluid transition in \(^4\)He. Measurements of the second sound velocity, and hence the superfluid density, give rise to an experimental evaluation of the critical exponent \( \nu \) which describes the critical behavior of the correlation length in the superfluid. The equation for the second sound velocity, \( U \), is given by

\[
U^2 = TS^2\rho_s/C_p\rho_n, \tag{1}
\]

where \( \rho_s \) and \( \rho_n \) are the superfluid and the normal fluid densities, \( T \) is the temperature, \( S \) is the entropy, and \( C_p \) is the specific heat at constant pressure. The critical behavior of the superfluid density can be described by

\[
\rho_s = [k_0(1 + k_1t)]t^\nu(1 + D_\rho t^\Delta). \tag{2}
\]

The coefficients \( k_0 \), \( k_1 \), and \( D_\rho \) are determined by fits to experimental data and \( t \) is the reduced temperature, \( t = 1 - T/T_\lambda \). The critical exponents \( \nu \) and \( \Delta \) are predicted by RG theory and can also be determined by fitting to the experimental data. This paper presents second sound velocity measurements from three resonators of varying lengths. Data were taken within the reduced temperature range of \( 10^{-7} < t < 10^{-2} \).

Second sound data were taken in resonators of lengths 13 mm, 4 mm and 2 mm with diameters of 4.75 mm, 2 mm and 2 mm, respectively. The resonators were of epoxy construction, with wire wound heaters located at the bottom of the cell. The paramagnetic salt, copper ammonium bromide (CAB), was used as the sensing element for all the resonators. A packed powder pill (13 mm
cell) [1] and single crystals (4 mm and 2 mm cells) of CAB were epoxied in the top of the cells and were in direct contact with the helium sample. Second sound was generated by applying an AC signal to the heater, creating a standing temperature wave in the cell. The temperature was read out by a SQUID magnetometer coupled to the CAB sensor with a superconducting pickup coil. The resonators were thermally anchored to the final stage of a four stage thermal isolation system cooled to 2.0 K.

Multiple, closely spaced, second sound resonances were found while taking data in the 2 mm and 4 mm cells. As the resonance curve for a given temperature was measured, several strong peaks were observed. The location and amplitude of these extra peaks varied with reduced temperature and were present in data from $10^{-6} < t < 10^{-2}$. The extra modes appear to be due to second sound excitations in the fill line. As the lambda transition was approached, and the fluid in the narrow fill line was driven normal by the small heat current, the extra modes disappeared. The data in the 13 mm cell, initially reported in [2], were fit to equation (2), with the small region of multiple mode data deweighted. The resulting critical exponent was $\nu = 0.6758 \pm 0.0006$. Exponents for the 2 mm and 4 mm cell data were $\nu = 0.6733 \pm 0.0002$ and $\nu = 0.6739 \pm 0.0001$, respectively. Previous work by Goldner, et. al. [3], measuring second sound velocities using pulse techniques, obtained an exponent $\nu = 0.6705 \pm 0.0006$. It is believed that the small differences in the exponents are due to systematic effects from the extra modes, and possibly from small errors in the temperature scale calibration.

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References