ysica 108B (1981) 791-792
orth-Holland Publishing Company

THE NORMAL FRACTION DENSITY IN SUPERFLUID ^{3}He-B

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We have used a torsional oscillator to study the normal fraction density in superfluid ^{3}He-B down to a reduced temperature, T/T_c, of 0.2 and over a wide range of pressures. Below the reduced temperature of approximately 0.27 the normal fraction density is less than 1%. The pressure dependence of the normal density is removed by making corrections for Fermi liquid effects only, in disagreement with present theoretical predictions of the effect of strong coupling on the normal density.

We have measured the normal fraction density of superfluid ^{3}He-B down to a reduced temperature, T/T_c, of 0.2 at pressures ranging from 5 to 29 bar. These measurements are an extension of earlier work[1] to lower temperatures with increased precision in the measurement of both the normal density and the temperature.

The liquid ^{3}He was cooled by the nuclear demagnetization of copper. The experimental cell was a torsional oscillator in which the ^{3}He was confined to a flat slab of thickness 95μm and radius 0.42 cm. The epoxy cell was supported by a BeCu torsion rod, which also served as a fill line. Motion of the oscillator was driven and detected electrostatically. The oscillator was operated in a feedback loop which ensured that it ran at its natural frequency of approximately 904 Hz and at a constant amplitude. Both the period of the oscillation and the drive voltage necessary to maintain constant amplitude were measured as a function of temperature. The temperature was determined from the magnetic susceptibility of 95% La diluted CMN, as measured by a SQUID magnetometer. The salt was located immediately below the fill line to the torsional oscillator. It was calibrated against the nuclear susceptibility of Pt powder, as measured by pulsed NMR. The salt susceptibility appears to follow a Curie-Weiss law down to the lowest temperature attained of 0.34 mK, with deviations of less than 5%, which may partly be due to systematic effects in the Pt thermometry.

The normal fraction density in the superfluid phase is largely given by the shift of the oscillator period from the empty cell period, normalized by the total period shift $\frac{P(T)-P(0)}{P(T_c)-P(0)}$. This must be corrected for slip of the normal fluid fraction. Since the viscous penetration depth is larger than the thickness of the slab, this correction is small. Shown in fig. 1 are values of the normal fraction density as a function of reduced temperature at various pressures. The correction for normal fluid slip has been made using hydrodynamics, over the whole temperature range. Finite mean free path effects and departures from hydrodynamic flow are important in interpreting the measurements of the viscosity of the normal component at the lowest temperatures[2], but their influence on the values of the normal density are small.

One important new feature of our analysis is the determination of the empty cell period P(0). We fit the period as a function of temperature at the lowest temperatures in order to fix P(0) with an estimated accuracy of better than 0.2ns, compared with a total period shift of order 200ns. This procedure is more accurate and less subject to systematic error than that previously employed in such work.

According to Leggett[3] the normal density of a superfluid Fermi liquid is given not simply by the Yosida Function Y(T) but by the relation

$$\frac{\rho_n}{\rho} = \frac{(1 + 1/3\ F_1)Y(T)}{1 + 1/3\ F_1 Y(T)}$$

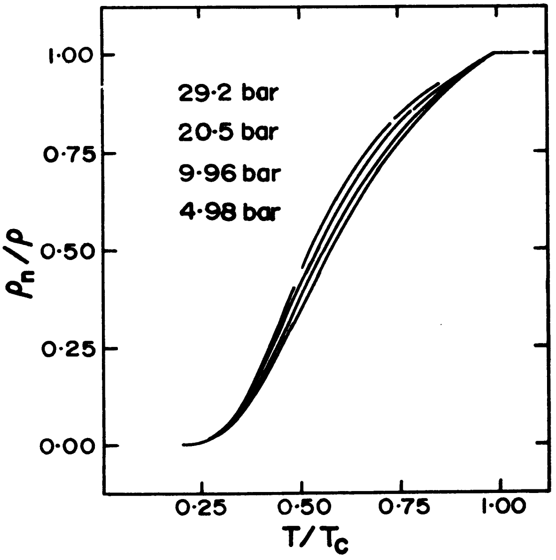

Figure 1: Dependence of normal fraction density on reduced temperature at various pressures.

0378-4363/81/0000–0000/$02.50

where F_1 is the Fermi liquid parameter, $1 + 1/3F_1 = m^*/m$. The data from fig. 1 and experimental values of m^*/m allow us to construct the effective Yosida Function for each pressure. In fig. 2 the deviation of this quantity from the BCS Yosida Function, as interpolated from Mühlschlegel[4], is shown as a function of reduced temperature. The m^*/m values used are those of Alvesalo et. al.[5], which are in good agreement with the measurements, based on the same temperature scale as this work, reported by Zeise et. al.[6] We observe a remarkable absence of pressure dependent strong coupling effects over the entire temperature range. This is not affected by scaling the m^*/m values by the same factor at each pressure. Thus the same conclusion is obtained if the values of m^*/m listed by Wheatley[7] are used. The initial slope of $1-Y_{eff}$ at T_c is pressure independent and 12% smaller than the BCS value. The asymptotic behavior of $Y_{eff}(T)$ at the lowest temperatures is also pressure independent. It deviates systematically from the asymptotic form of the BCS Yosida Function. Since $\omega\tau\sim 1$ at the lowest temperatures, where τ is the quasiparticle relaxation time, this may be the result of deviations from hydrodynamics. This is the subject of further analysis.

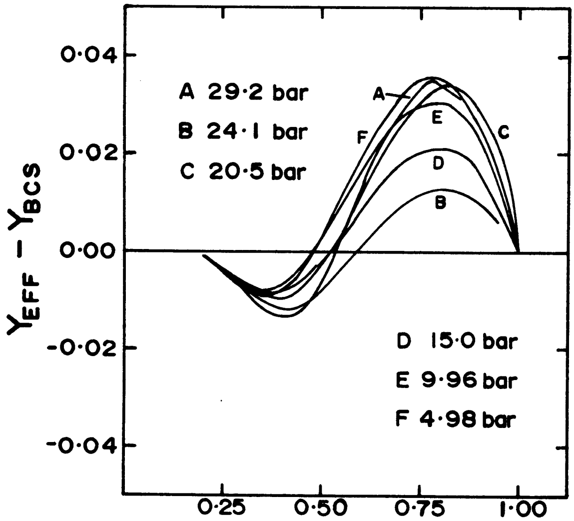

Figure 2: Deviation of effective Yosida Function from BCS Yosida Function versus reduced temperature at various pressures.

Supported by NSF through grants DMR-78-02655, and DMR-77-24221 and by the Cornell Materials Science Center through NSF grant DMR-79-24008. (MSC Report #4418)

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References

(1) Archie, C.N., Alvesalo, T.A., Reppy, J.D., and Richardson, R.C., Phys. Rev. Lett. 43, 139, (1979).
(2) Jensen, H.H., Smith, H., Wölfle, P., Nagai, K., and Bisgaard, T.M., J. Low Temp. Phys. 41, 473 (1980).
(3) Leggett, A.J., Phys. Rev. 140, 1869 (1965).
(4) Mühlshlegel, B., Zeit. für Phys. 155, 313 (1959).
(5) Alvesalo, T.A., Haavasoja, T., Manninen, M.T., and Soinne, A.T., Phys. Rev. Lett. 44, 1076 (1980).
(6) Zeise, E.K., Saunders, J., Ahonen, A.I., Archie, C.N., and Richardson, R.C., these proceedings.
(7) Wheatley, J.C., Rev. Mod. Phys. 47, 415, (1975).