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Reduction of the Superfluid Fraction of ^{3}He in Sintered Silver

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We have measured the superfluid density of ^{3}He liquid confined within the pores of a silver sinter plug. The silver was of nominal 70 nm size, and was packed to 54% of solid density. The mean pore size as measured was ~ 200 nm. The plug was mounted on a torsional oscillator, and the superfluid density can be measured by studying the decrease of the resonant period. We have measured the pressure and temperature dependence of the period shift and find that the superfluid density is suppressed to ~ 14% at 0 bar and is ~ 53% of its bulk value at 29 bar. There is substantial temperature dependence even at the lowest values of T/T_c (~ 0.25) achieved in these experiments.

1. INTRODUCTION

The reduction of the superfluid density due to finite size effects represents one of the most simple measurements which manifests the suppression of the order parameter near a boundary. Since the characteristic distance over which the order parameter is reduced varies by a factor of five with pressure, the extent of the suppression can be easily be modified within a particular experimental configuration. Unfortunately, there exists no simple substrate with a large enough volume to provide adequate sensitivity for this experiment. Ideally, the perfect substrate would be either a parallel plate geometry or a cylindrical pore with a characteristic size on the order of a few coherence lengths or between 100 and 300 nm. We have chosen to approximate this geometry by constructing a porous substrate composed of grains of nominal 70nm diameter silver powder (1) which was packed under pressure and then sintered together. Silver sinter was chosen because of its small and relatively uniform grain size, together with the ability to vary the porosity and consequent pore size by sintering the powder after compression to densities between 0.29 and 0.7 of bulk values. The present results were carried out in a sinter packed to 54% of its bulk density.

2. Experimental Details

2.1 Characterization of Sinter

The silver powder was compressed in a stainless steel form with a 0.75 cm diameter to a height of 1cm. The silver was packed in mm thick increments, with each layer being compressed to the final density. The stainless form and sinter were then heated in a vacuum furnace to a temperature of 210°C for 45 minutes. The resulting sinter was self supporting and could be handled with ease. The surface area was measured to be 0.8m^2/g by the BET method, which together with the porosity yields an effective pore diameter of 200nm providing the pores are assumed to be cylindrical. Mercury intrusion measurements on a similar sample yielded a pore size distribution which was in good agreement with the results of the BET method and are shown in Figure 1.

2.2 Cell Construction

The cup shaped epoxy head of the torsional oscillator was attached to a beryllium copper torsion rod assembly and the silver sinter plug inserted into the head using partially set epoxy as a glue. After curing a 0.75mm diameter hole was drilled into the silver plug on axis and along its whole length to promote thermal contact The cell's motion was driven and detected electrostatically.

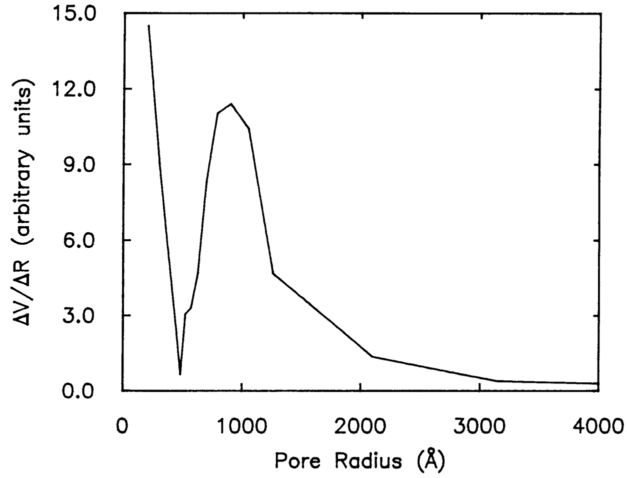

Fig. 1. The pore size distribution of the silver sinter sample as measured by mercury intrusion.

3. EXPERIMENTAL PROCEDURE

The period and dissipation of the torsional oscillator were measured after demagnetizing the nuclear stage to its lowest temperature. The magnet was then slowly energized so as to warm the experiment to the superfluid transition over a period of 30h. The dissipation of the cell was observed to decrease at the transition temperature but was otherwise slowly varying . The observed superfluid transition temperature in the cell coincided with the bulk superfluid transition as observed in a LCMN thermometer which had been calibrated against the $T_c(P)$ curve of Greywall (2). The period signal was converted to superfluid density by forming the ratio

$$\rho_s pore(T)/\rho = [\{P(T_c) - P(T)\}/\{P(T_c) - P(0)\}] \times n$$

where P(T_c) is the period at the transition temperature and represents the contribution of the entire fluid moment of inertia due to complete locking in the pores, P(T) is the period at any temperature T, P(0) is the period of the empty cell. and n the hydrodynamic correction factor due to the nature of the porous medium. We found this factor to be 2.15 by calibrating the cell with ^{4}He.

4. RESULTS

The effective superfluid density was computed and the results plotted against the reduced temperature T/T_c in Figure 2. Three features are noteworthy. Firstly, the superfluid density decreases by ~ 4 as the pressure is decreased. Secondly, there is no apparent suppression of T_c and finally, the low temperature data do not indicate a saturation of the superfluid density at our lowest temperatures. The absence of the suppression is clearly attributable to the pore size distribution. This can be verified by noting that the superfluid density does not have the characteristic linear temperature dependence of the bulk near T_c, but shows a more rapid increase as the superfluidity in smaller pores is initiated.

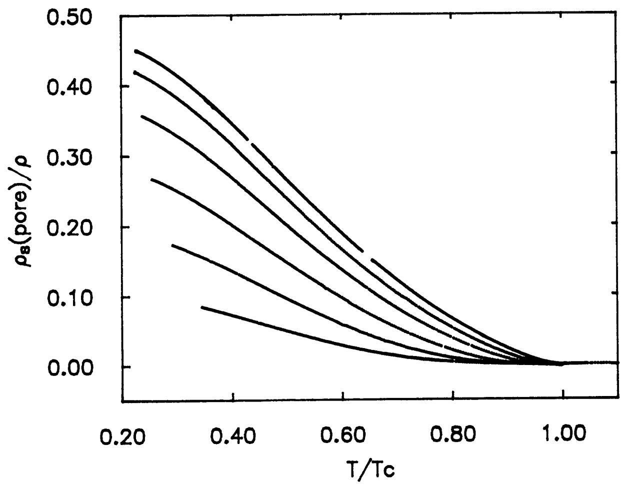

Fig. 2. The superfluid density of ^{3}He confined within the sinter. The data shown are for (from top to bottom) 29, 17, 10, 5, 2, and 0 bar pressures. the temperatures were normalized to the bulk transition temperature.

We believe that the temperature dependence at temperatures below T/T_c of 0.35 indicates that the order parameter in pores is distinctly different from that of the bulk. At these temperatures, the isotropic order parameter would be close to its zero temperature value and the correlation length would also be ~ ξ_0. The usual consequence of these temperature dependence is to produce an exponentially vanishing normal fraction at low temperatures. Thus the existence of a nearly linear development of the superfluid density in this temperature regime suggests the existence of a non-isotropic energy gap or alternatively, a pathologically varying pore size distribution. The difference between the usual bulk dependence and that observed in this experiment is illustrated in Figure 3, where we have divided $\rho_s$pore(T) by $\rho_s$bulk(T). The expected bulk behaviour at low temperatures would show up as a horizontal line on this figure.

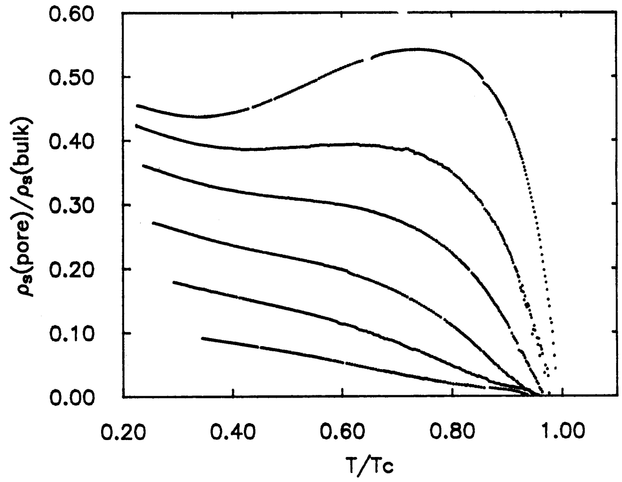

Fig. 3. The results of the measured superfluid density, normalized by the superfluid density of the bulk(see text).

The extrapolated zero temperature values of the superfluid density are shown in table 1, together with the zero temperature coherence length ξ_0 as calculated from values of m* and T_c of Greywall. At present we have not analyzed our data in a manner similar to that of Ichikawa et. al. (3).

Table I. The extrapolated zero temperature values of the superfluid density in silver sinter, together with values for the zero temperature coherence length.

Pressure (bar)	0	2	5	10	17	29
$\rho_s$pore/ρ	0.14	0.24	0.32	0.43	0.50	0.53
ξ_0(nm)	77	57	42	30	22	17

5. CONCLUSION

We have observed substantial suppression of the superfluid fraction of ^{3}He when confined within the pores of silver sinter. In addition, the low temperature data show a different temperature dependence from that of the bulk indicative of an order parameter distinct from that of the bulk B phase. Further experiments on silver sinters with different packing fractions are underway.

6. ACKNOWLEDGEMENTS

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REFERENCES

1) Ulvac Vac. Met. Co, Ltd., Shonan Bldg., 14010, 1 Chome-Chuoku, Tokyo, Japan.
2) D.S. Greywall, Phys.Rev. B., 33, 7520, 1986.
3) K. Ichikawa et.al, to be published in Phy. Rev. Lett.