Bose-Einstein condensation in disorder

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The Bose-Einstein condensation (BEC) is of great interest in a wide variety of systems. It was proposed by Einstein in 1924 and is the microscopic origin of the remarkable superfluid properties of liquid ^{4}He. More recently in some amazing experiments BEC has been realized in dilute gases of alkali atoms confined in magnetic traps. Here 100% of the atoms condense into a single quantum state opening the door to creation of 'atom lasers'. The BEC of 'Cooper pairs' of electrons (Bosons) is the origin of superconductivity, and in the high temperature superconductors, this BEC takes place in doped and disordered materials. Our goal is to observe BEC directly in disorder on the MARI spectrometer.

Liquid ^{4}He confined in porous media is the most flexible example of 'Bosons in disorder' in nature. In addition, the superfluid properties of ^{4}He in several porous media such as Vycor and aerogel have been extensively investigated. Confinement lowers the transition temperature, T_c, to superfluidity below the bulk value (T_λ= 2.17 K). Measurement of elementary excitations of liquid ^{4}He in porous media using low energy transfer neutron scattering techniques has also recently begun. Among many interesting findings, we observe well-defined phonon-roton excitations above T_c in Vycor and Geltech silica. Since well-defined excitations are associated with BEC, this suggests that there is BEC above T_c in Vycor. Above T_c, this BEC is probably localized to favourable regions in the media (a Bose glass).

The atomic momentum distribution, n(y) folded with final state effects, is observed directly on MARI, and is shown in Fig H13.1 for superfluid and normal bulk ^{4}He. The BEC, a macroscopic occupation of the zero momentum state (y=0), appears predominantly as additional intensity at y=0 at T=0.5 K (below T_λ) compared to that in the normal phase at T=2.3 K (above T_λ). Fig H13.2 shows the condensate fraction, n_0(T), in bulk superfluid ^{4}He obtained from data as in Fig. H13.1.

The corresponding atomic momentum distribution of liquid ^{4}He in Vycor above and below T_c =1.95 K are shown in figure H13.3. As before additional intensity at y=0 below T_c signals a condensate. The statistical precision of the data is not, however, so good because the volume of liquid ^{4}He in Vycor is necessarily small and significant background subtractions are necessary. Because of the poorer statistics, we are able to extract only 'one parameter' reliably in a fit to data, the

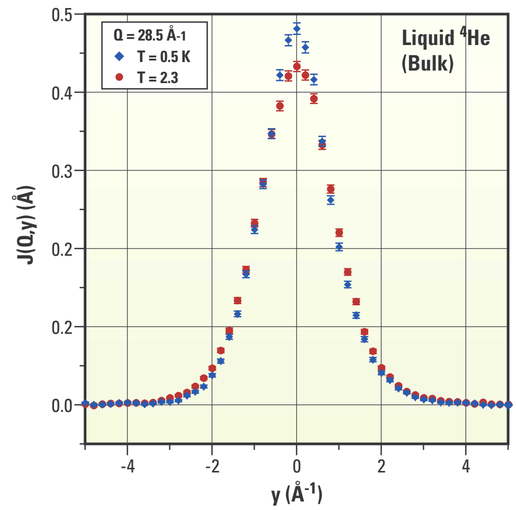

Fig. H13.1. Dynamic structure factor, J(Q,y), of bulk normal (red) and superfluid (blue) ^{4}He observed on MARI.

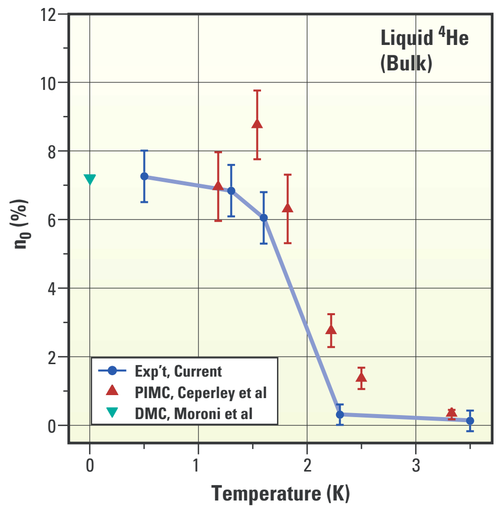

Fig. H13.2. Bose-Einstein Condensate fraction, n_0 (T), in bulk liquid ^{4}He observed on MARI (solid circles) compared with Monte Carlo calculations (PIMC, DMC).

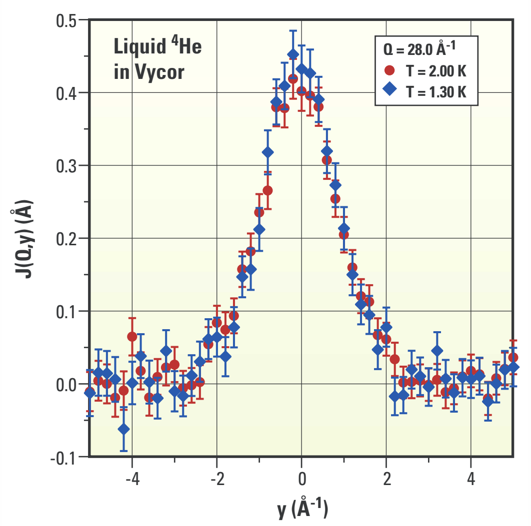

Fig.H13.3. *J(Q,y) of liquid ^{4}He in Vycor in the normal (red) and superfluid (blue) phases.*

atomic kinetic energy, <K>. Fig H13.4 shows <K> of ^{4}He in Vycor and in the bulk obtained using the ‘one parameter’ fit. The two are the same within precision. In the bulk there is good agreement between the ‘one parameter’ and an accurate kinetic energy.

The condensate fraction, $n_0(T)$, both in Vycor and in the bulk are finally obtained from the drop in the kinetic energy in the Bose condensed phase using a well known expression. This approximate expression overestimates $n_0(T)$ somewhat. The resulting condensate fraction in Vycor and in the bulk (see Fig. H13.5) are the same, both overestimated in the same way. Also shown is the accurate value of $n_0(T)$ for the bulk for comparison.

Our pioneering measurements show that there is definitely a condensate in superfluid ^{4}He in Vycor. As in the bulk, BEC accompanies superfluidity in disorder. Within current precision, the condensate fraction is the same in Vycor and in the bulk at low temperature and as a function of temperature. We have not been able to determine whether T_c for BEC in Vycor differs from T_c for superfluidity or not; a challenge for the future.

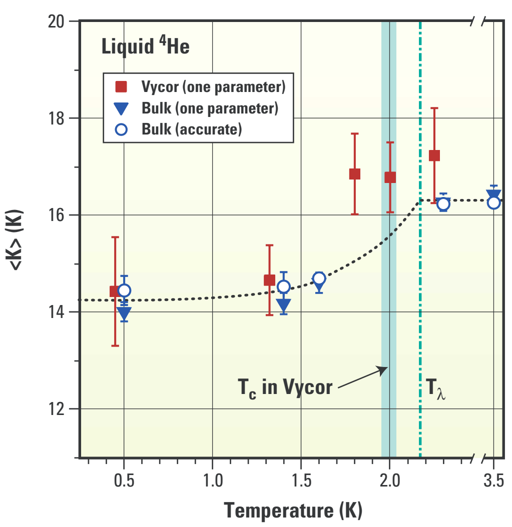

Fig. H13.4. *Atomic kinetic energy <K> of liquid ^{4}He obtained from data as in Figs. H15.1 and H15.3. The shaded region shows the superfluid-normal transition temperature of ^{4}He in Vycor.*

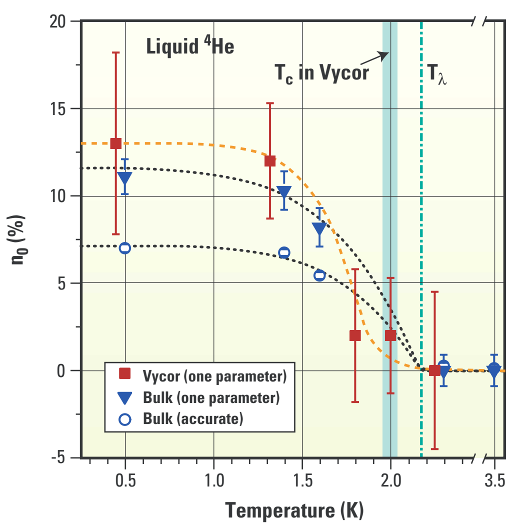

Fig. H13.5. *Condensate fraction, $n_0(T)$, of liquid ^{4}He in Vycor and in bulk. One parameter values uses <K>.*