Nature of Pure and Dirty Liquid ^{3}He - Fundamental Investigations and Educational Activities

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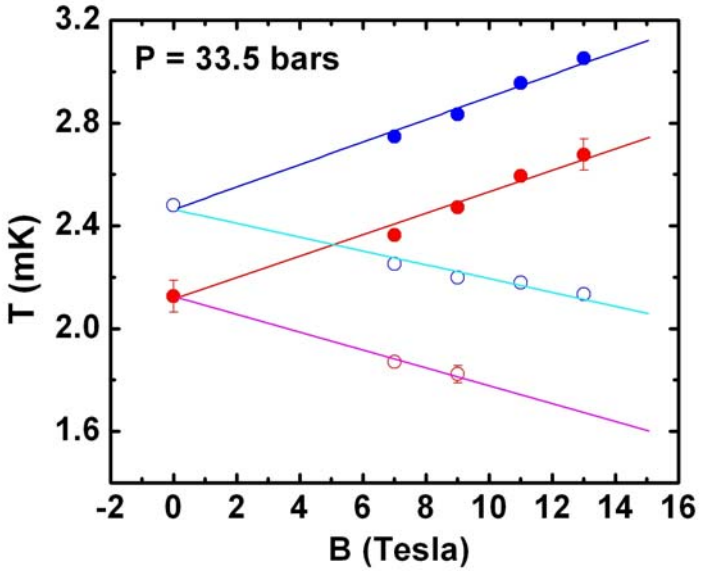
The effect of disorder on a many particle system is one of the most important and ubiquitous problems in condensed matter physics. We study the effect of controlled disorder in otherwise the purest condensed matter system, liquid ^{3}He by utilizing nanometer scale porous medium, silica aerogel. Especially in the low milikelvin range, we can study the influence of disorder on unconventional (*p-wave*) superfluid ^{3}He. In our work, we investigated this effect in the presence of strong magnetic fields (up to 15 T) and discovered the third phase which has not been observed in this system. This research is of fundamental importance as well as providing insights to newly discovered unconventional superconductors in which the presence of disorder is inevitable and crucial.

H.C. Choi *et al*., to be published in Phys. Rev. Lett.



Splitting of transition temperature in magnetic fields. The single superfluid transition in zero field splits into two transitions by inducing a new phase. The blue symbols are for the pure bulk and the reds are for dirty superfluid in 98 % porosity aerogel. The dirty superfluid shows quite similar behavior as the pure superfluid indicating the new phase observed in this work could be the same phase observed in pure liquid.

Liquid 3He is the simplest liquid which is composed of simplest atoms. However, at extremely low temperatures, it shows remarkable nature which has its root in purely quantum mechanical world. One example is the superfluid transition occurring around 2 mK (0.002 K) – superfluidity occurs in liquid ^{4}He (more naturally abundant isotope) below 2.14 K. Below the transition temperature, superfluid ^{3}He shows intriguing phenomena which are similar to those in superconductors. In this case, however, the constituent particles are changeless ^{3}He atoms instead electrons in superconductors. This system has been studied extensively and its intrinsic property is very well understood owing to its extreme purity at low temperatures (practically zero impurity since no other substance can remain liquid at this low temperature). This is in marked contrast to other material systems where the impurity or disorder is inevitable but could change the property of the host system dramatically. We study the effect of impurity or disorder on otherwise the purest system, liquid ^{3}He by impregnating the liquid into very high porosity silica aerogel. Silica aerogel consists of an entangled network of silica (SiO_2) strands of 3 – 4 nm size. Superfluid ^{3}He is very sensitive to the presence of this type of nanometer scale structure. In our study, we found that a new type of superfluid phase was induced by magnetic fields. The nature of this new phase is under investigation to make comparison with the pure superfluid ^{3}He. This study requires two experimental techniques; to produce extreme low temperature below 2 mK and very strong magnetic field up to 15 tesla. This work will be published in Physical Review Letters.

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Education and Outreach

Currently 3 graduate (Ph.D.) students are involved in this research, H.C. Choi, P. Bhupathi, and B. Moon. Total 6 undergraduate students are directly or indirectly involved in this research effort. Among them, 3 students participated through the REU program and one student (A. Gray) graduated and is continuing his Ph.D work at UIUC. Each undergraduate student is paired with a graduate student to conduct research as a team. J. Cancino has been working in my group for three years. E. Calleja joined as an REU student and continues to work in my group into his second year. S. Korenblit just started since May, 2004. Current outreach activity is mainly in two fold. PI visits local schools to do science demos on "Three Phases of Matters". PI host the Weekend Laboratory Program in which local middle or high school students and teachers are invited for research lab tour and hands-on experiments using the resources available in the Department.

About 20 students and science teachers from Hawthorn High School visited our Department on November 15, 2003 and participated in the Weekend Laboratory Program. The program consisted of three research lab tour and hands-on lab activity. Students are touring the Microkelvin Laboratory (picture).