Evidence for a New Phase Transition in Solid He-3

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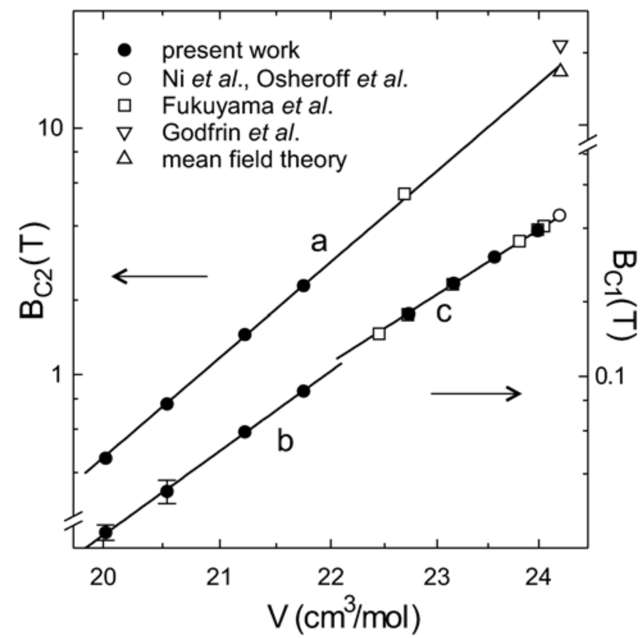
Evidence for a new magnetic phase transition in solid He-3 near v=22 cc/mole has been found from Hc1(v), the critical field between the low-field and high-field phases. Using two-stage demagnetization of the He-3 from T~100 muK and H=2.5 T, where its entropy S~0, the He-3 spins have been cooled to a record low T~10 muK. For v>22 cc/mole, we find $Hc1 \sim v^{14.22}$ and for v<22, $Hc1 \sim v^{16.15}$, with the change in volume-dependence indicating that there is a possible phase transition near v=22 cc/mole. Additional work is needed to verify the transition.

To be submitted to PRL



Critical fields, Hc1 (Bc1) and Hc2 (Bc2), versus V. The break in Hc1 near V=22 is evidence of a new phase transition.

Along with electricity, magnetism is one of the fundamental areas of physics that provides widespread applications in industry, science, and technology. There may be a grain of truth in the Dick Tracy comic strip pronouncement, “He who controls magnetism controls the universe.” Applications of magnetism are all around us: refrigerator magnets, motors, generators, data storage, controls or all sorts, magnetic resonance imaging (MRI), “frictionless” levitation of trains, etc., etc. Clearly it is essential to understand fundamentals of the physics underpinning magnetic phenomena. Solid He-3 has long been considered the ideal system in which to study magnetic phenomena. The theory of “ring exchange,” developed to explain phenomena observed in solid He-3 at millikelvin temperatures, has now been applied to many other systems. Interactions involving nuclear “spins” or “magnetic moments” of He-3 are about 1000 times smaller than for those involving electrons; hence, much lower temperatures are necessary. Because of the ultra-low temperatures involved, less that 0.001 Kelvin above absolute zero (-458 ^{0}F), the technique of magnetic refrigeration is used. We have used “direct, two-stage demagnetization” of the He-3 itself to cool to temperatures of only 0.00001 Kelvin, a record low for any insulating system. In the presence of a magnetic field, H, the solid He-3 has several different “phases” (arrangements of the “magnetic moments”) that are bounded by “critical fields” where a “phase transition” to a different magnetic structure takes place. In our measurements, we see a break in how the lower critical field Hc1 depends on the volume of the solid He-3. (The volume is adjusted by changing the pressure on the solid.) This is evidence of a “new phase transition,” that represents an important new development for this system and may require further theoretical work in order to understand it fully.

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Education:
The education of students at all levels and of postdoctoral associates is a major part of the research program in ultra-low temperature physics. During the past few years, there have been three postdoctoral associates, three graduate students, one foreign visitor and several undergraduates, one in the REU program, involved.

Societal Impact:
Understanding fundamentals of magnetism is important since many devices make use of magnetic phenomena.

Taey Curry, REU student, and Carlos Vicente, postdoctoral associate, assisting Todd Sherline, Ph.D. student, prepare his experiment.