Direct Measurement of the Bose-Einstein Condensation Universality Class in Ni-Cl_2-4SC$(NH_2)_2$ at Ultra-Low Temperatures

V.S. Zapf (LANL-NHMFL), L. Yin (UF-NHMFL), J.S. Xia (UF-NHMFL), A. Padhuan-Filho (Instituto de Fisica, Universidade de Sao-Paulo), N.S. Sullivan (UF-NHMFL)

Introduction

Experimental studies are reported for measurements of the lower and upper critical fields, H_{c1} and H_{c2}, respectively, for the field- induced Bose-Einstein condensation in the organic compound $NiCl_2$-4SC$(NH_2)_2$. The transitions were determined from measurements of the AC magnetic susceptibility for temperatures down to 1 mK and for fields from 1 to 13 T. The key parameter is the exponent for the temperature dependence of H_{c1} given by $H_{c1}(T)-H_{c1}(0) = aT^{\alpha}$ which is predicted to be 3/2 for a 3D BEC condensation.

Experimental

High sensitivity measurements of the magnetic susceptibility of the organic magnet Ni-Cl_2-4SC$(NH_2)_2$ (or DTN) were used to determine the critical magnetic fields for transitions to the anti-ferromagnetic state. DTN contains two Ni^{2+} atoms that form two interpenetrating tetragonal lattices. At zero field, a uniaxial anisotropy splits the Ni S=1 triplet into a $S_z = 0$ ground state and a $S_z = \pm 1$ excited state. The $S_z = 1$ state is suppressed by an applied magnetic field parallel to the tetragonal c-axis via the Zeeman effect, thereby producing a magnetic ground state above 2 T. Anti-ferromagnetic coupling between the Ni atoms with exchange J_c=1.8K along the c-axis, and J_a=0.18 K perpendicular to the c-axis, produces long range order [1].

Results and Discussion

The temperature dependence of the upper and lower critical fields, H_{c2} and H_{c1} are shown in Fig. 1for a field sweep rate of 0.0068 T/min. The dashed circle shows an abnormal change in slope for H_{c2} at 160 mK. The dashed line is a fit to the equation $H_{c1}(T)-H_{c1}(0) \sim T^{\alpha}$ with α=1.47± 0.1. For further details, see Ref. [2].

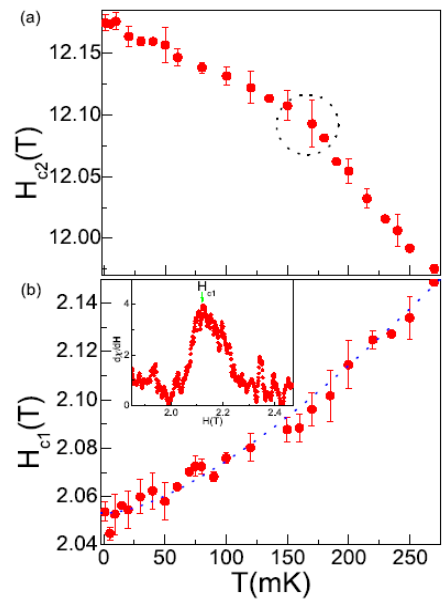

Figure 1. Temperature dependence of: (a) the upper critical field H_{c2}, and (b) the lower critical field H_{c1} for DTN

Conclusions

The results of experiments at ultra-low temperatures have established that the field-induced quantum phase transitions at H_{c1} in DTN belongs to the 3D BEC universality class. This is the first example of a direct measurement of the power law exponent for the critical field at temperatures well below the energy scales for anti-ferromagnetic coupling in a magnetic insulator.

Acknowledgements

This work was carried out at the High B/T Facility of the National High Magnetic Field Laboratory, which is supported by the National Science Foundation Cooperative Agreement No. DMR 0654118 and by the State of Florida.

References

[1] Giamarchi, T, Ruegg, C. and Tchernyshov, O., Nature Physics 4, 198 (2008).
[2] Lin, Y., Xia J.S., Zapf, V., Sullivan, N.S., Padhua-Filho, A., Phys. Rev. Lett, **101**, 187205 (2008).