Heat Capacity Cell for Angular Measurements in High Magnetic Fields

S. T. Hannahs [a,1], N. A. Fortune [b],

[a] National High Magnetic Field Laboratory, Florida State University, 1800 E. Paul Dirac Dr., Tallahassee, FL 32310, U.S.A.
[b] Smith College, Northampton, MA, USA 01063

Abstract

We present our design and initial results for miniature rotatable heat capacity cells (7.5 mm - 11 mm diameter) suitable for use in magnetic fields up to 45 tesla. Our most recent design for a top-loading dilution refrigerator allows full rotation of the cell at sample temperatures from below 50 to over 4000 mK. The magnetic field dependence of the thermometry has been characterized for fields up to 18 tesla (and is currently being extended to higher field), allowing programmatic temperature control of the cell over the full field and temperature range to better than 0.1%. This characterization over all fields and temperatures has been reduced to a minimum number of fitting constants

Key words: Instrumentation; Heat Capacity; High Magnetic Fields;Angular Rotation

1. Introduction

The study of low dimensional layered materials in high magnetic fields has quite a rich history. Materials as diverse as organic superconductors[1], 2-D quantum wells[2], copper oxide superconductors and layered heavy fermion conductors[3][4] have been studied under angle dependent magnetic fields. These materials have contributed greatly to our understanding of the role dimensionality plays in determining the properties of these materials. Many laboratories have developed apparatus for measuring transport properties as a function of angular position but thermodynamic properties have always been more of a challenge. With the advent of low dissipation rotators that can operate continuously at millikelvin temperatures in high magnetic fields[5], we have developed a heat capacity cell that can take advantage of this experimental opportunity. The cell is constructed from a variety of materials to optimize the design for operation between 50 mK and 20 K while operating in the dilution refrigerators available at the NHMFL.

[1] Corresponding author. E-mail: sth@magnet.fsu.edu

2. Experimental Details

The temperature regulated platform is a silver disk with thermometers and heaters mounted on the underside. Electrical leads are epoxied to the circumference of the disk and the actual sample The cell uses an indium-plastic low temperature vacuum seal and cryogenic pump out for thermal isolation of the temperature regulated platform. The cell base, can and locknut are constructed out of Parmax[6] plastic. This high strength, high hardness plastic is easy to machine and quite robust at low temperatures. Stycast 1266 was also used in cell prototypes but it was rejected due to thermal anomaly around 4 K. The thermal link is equally through the central post which is 0.05 "stainless steel hypodermic tubing filled with 46 AWG phosphor-bronze wires and stycast 2850FT epoxy and thru the 20 electrical leads to the platform. The thermal link is designed to allow temperatures up to 20 K without exceeding the 4 mW limit of the top-loading dilution refrigerators.The electrical leads are twisted pairs of 36 AWG phosphor-bronze wire. The thermometer is a commercially available thick film ruthenium oxide thermometer[7] and the heater is a thin film NiCr resistor[8]. The thermometer has quite low magnetoresistance, with a temperature error of about 4% at 33 tesla at 200 mK. These thermometers have a reasonable specific sensitivity (dlnR/dlnT) over this temperature range varying from about 1 at 50 mK to 0.1 at 20 K. The temperature was regulated using tchebyshev poly-

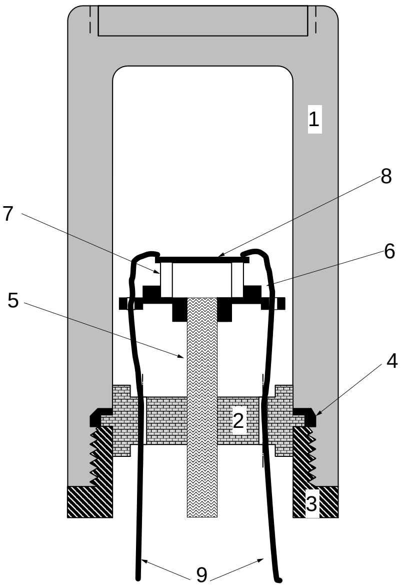

Fig. 1. Schematic of Heat Capacity Cell, 1-Can, 2-Base, 3-Locknut, 4-Indium Seal, 5-Thermal Link, 6-Ag Platform, 7-Sapphire Ring, 8-Si Wafer, 9-Electrical Leads

nomial fits to the resistor calibrations. The coefficients of this fit are then fit as a function of magnetic field by padé approximates.[9] The temperature controller set point is continuously updated with the corrected temperature or resistance to keep the actual temperature constant. This compensates to a high degree the varying heat load of ramping the magnetic field in a resistive magnet.

The sample platform is mounted on a sapphire ring for electrical isolation. The sample platforms are $5\,\mu$ thick silicon wafers with NiCr heaters and AuGe[10] thermometers sputtered on the substrate. This platform is connected to the electrical leads with 0.001 ”phosphor bronze wires.

3. Results

We have measured the superconducting transition H_{c2}in the layered heavy fermion material $CeCoIn_5$at several different angles. The transition quite rapidly progresses to higher fields as the planes of the layered material are rotated parallel to the magnetic field.

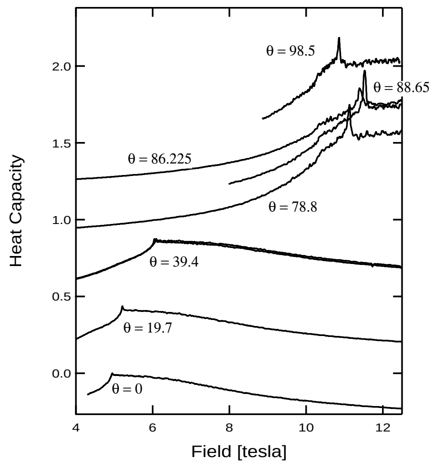

Fig. 2. Field dependent heat capacity of $CeCoIn_5$at several different angular positions. The curves are offset proportional to the angle setting of the rotator.

Acknowledgements

This work was performed at the national High Magnetic Field Laboratory, which is supported by NSF cooperative agreement No. DMR-0084173 and by the State of Florida.

References

[1] W. Kang, S. T. Hannahs, and P. M. Chaikin; *Phys. Rev. Lett.*; 69 (1992) 2827-2830.

[2] J. P. Eisenstein, R. Willett, H. L. Stormer, D. C. Tsui, A. C. Gossard, and J. H. English *Phys. Rev. Lett.*; 61 (1988)997-1000.

[3] T. P. Murphy, D. Hall, E. C. Palm, S. W. Tozer, C. Petrovic, Z. Fisk, R. G. Goodrich, P. G. Pagliuso, J. L. Sarrao, and J. D. Thompson; *Phys. Rev. B*; 65 (2002) 100514.

[4] K. Izawa, H. Yamaguchi, Y. Matsuda, H. Shishido, R. Settai, and Y. Onuki; *Phys. Rev. Lett.*; 87 (2001) 057002.

[5] E. C. Palm and T. P. Murphy; *Rev. Sci. Inst.*; 70 (1999) 237-239.

[6] Parmax is a high strength and hardness polyphenylene plastic developed by Maxdem corporation, San Dimas, CA, USA ¡http://www.maxdem.com¿. Topolsky V. J., Walsh R. P., Tozer S. W., and Motamedi F.; *NHMFL Annual Reports - Research Review* (1998) 260.

[7] Vishay Dale CRCW0402, RuO_2 thick film resistor, 1 kΩ, 1.0 X 0.5 mm.

[8] Vishay Electro-Films WSFN20210000F, NiCr thin film resistor on 0.5 X 0.5 mm Oxidized Silicon substrate, 1 kΩ,

[9] N. Fortune, G. Gossett, L. Peabody, K. Lehe, S. Uji and H. Aoki; *Rev. Sci. Inst.*; 71 (2000), 3825.

[10] N. A. Fortune, M. J. Graf and K. Murata; *Rev. Sci. Inst.*; 69 (1998) 133.