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Calorimetric In-Situ Calibration of Resistance Thermometers in High Magnetic Fields

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Introduction

Relaxation calorimetry requires at least two thermometers, one on the thermal reservoir and the other on the sample platform. Most commonly they are resistance thermometers because of their small heat capacities and fast response times. In our calorimeters dedicated for experiments at the NHMFL DC-Field Facility, we normally use a sanded-down 220 Ω Speer carbon resistor [1] on the thermal reservoir and a small chip cut from another 220 Ω Speer carbon resistor on the sample platform. After nearly two decades of use, both the reservoir thermometer and the platform thermometer of one of our calorimeters started to show signs of degradation. Occasional jumps in the resistance and strong non-linear dependence on the excitation current suggested that those thermometers have developed cracks due to thermal cycling.

We replaced the reservoir thermometer with a 1 kΩ RuO_x resistor from KOA and the platform thermometer with a new chip cut from a 220 Ω Speer carbon resistor. They were subsequently calibrated in-situ by using three standard materials.

Experimental

The calibration is made by measuring the relaxation times of two standard materials whose specific heats are accurately known at zero magnetic field and can be calculated reliably in magnetic fields. At any magnetic field, the specific heats of the two materials must have different temperature dependences such that, after a small correction for the contribution of the addenda, the ratio of the relaxation times of the two materials yields the temperature uniquely. Pure metals are obviously the best choices for this purpose, since they are available with high purities and they have high thermal conductivities. We primarily use platinum [2] and silver [3] for three reasons: (1) the two metals have quite different ratios of the Debye temperature to the Fermi temperature, so that the ratio of their specific heat is a relatively strong function of temperature for temperatures above about 1 K, even at zero field; (2) the nuclear Zeeman specific heat of silver is negligible at most temperatures and magnetic fields and, where it is not negligible, the long nuclear spin-lattice relaxation time, T_1, makes the nuclear contribution “invisible”; (3) in contrast, platinum has a large nuclear Zeeman specific heat in magnetic fields, with one of the shortest T_1 of all pure metals. As a result, even at temperatures below 1 K, the ratio of the relaxation times of platinum and silver samples yields the temperature, provided that the magnetic field is not too weak.

At zero field and fields below about 2 T, we replace at temperatures below about 1 K one of the metals with indium [4], whose accurately known nuclear quadrupole specific heat plays the role analogous to that of the nuclear Zeeman specific heat of platinum.

Using these three standard materials, we have performed the calibration of the two thermometers at temperatures ranging from 60 mK to 5 K in magnetic fields up to 18 T in a superconducting magnet at the DC-Field Facility.

Results and Discussion

The calibration was originally planned to be made in two consecutive weeks. We lost about a half of the first week, when the dilution refrigerator had to be warmed up to room temperature to remove a blockage caused by air. A third week of measurements was added three months later to complete the calibration. The calorimeter is now ready for regular use for specific-heat and magnetocaloric-effect experiments at the DC-Field Facility.

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References

[1] Sample, H.H, Neuringer, L.J, and Rubin, L.G., Rev. Sci. Instrum., **45**, 64-73 (1974).
[2] Martin, D.L., Phys. Rev. B, **8**, 5357-5360 (1973).
[3] Martin, D.L., Phys. Rev. B, **17**, 1670-1673 (1978).
[4] Karaki, K., Kubota, M., and Ishimoto, H., Phys. Rev. B, **54**, 427-432 (1996).