Application Note

High-Precision Heat Capacity Measurement Platform for Quantum Materials

Heat capacity measurements serve as a fundamental tool to understand the physical properties of quantum materials. We present a heat capacity setup compatible with the L-Type Rapid cryostat, designed for fast and precise characterization from millikelvin to room temperature and in applied magnetic fields. The system features fully automated sample loading and cooling, efficient thermalization, and precise temperature control, ensuring high-resolution data acquisition.

Keywords: Heat capacity, quantum materials, thermodynamic properties, phase transitions.
Products: kiutra L-Type Rapid.

Introduction

Heat capacity measurements are indispensable in quantum materials research as they provide critical insights into the underlying thermodynamic and microscopic properties of a material. These measurements are essential in understanding quantum phenomena, testing theoretical models, and uncovering emergent behaviors in novel materials, making them a cornerstone in the study of condensed matter physics and materials science.

At cryogenic temperatures, where heat capacities become exceedingly low, highly sensitive calorimetric techniques and precise thermal control are required to detect minute temperature changes and ensure accurate yet fast experiments. Here, we showcase the advantages of a sophisticated heat capacity setup in the kiutra L-Type Rapid. The ability to perform heat capacity measurements in a fast characterization cryostat opens new avenues for efficient and comprehensive material characterization.

Heat capacity setup

The L-Type Rapid features a puck-based system for easy sample preparation and loading. The heat capacity setup is prepared and tested outside the cryostat using the kiutra Sample Puck Station. The entire experiment is then transferred into the cryostat using an automated sample loader and automatically cooled down to the desired temperature. An optional sample magnet enables measurements under applied field. The entire process is fully controlled via modern instrument control software for intuitive operation and real-time monitoring.

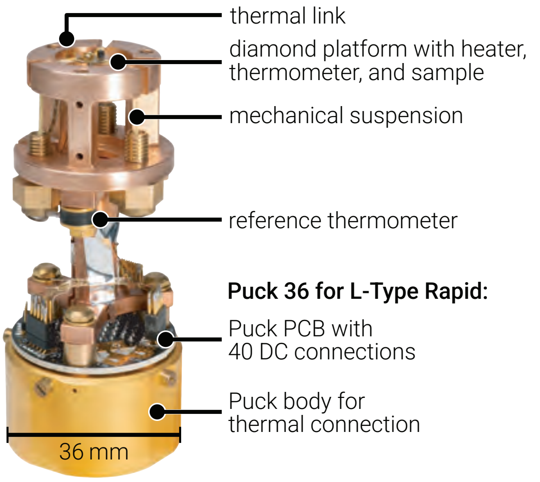

Figure 1: Heat capacity setup mounted on a kiutra Puck 36. The diamond experiment platform is suspended via Kevlar threads, and thermally connected via a silver link to the thermal bath provided by the copper body of the setup. The platform hosts the sample, heater, and thermometer.

Measurements of heat capacity at low temperatures require careful experimental design. Fig. 1 shows the heat capacity setup mounted on an L-Type Rapid Puck 36. The copper body of the setup acts as the thermal bath for the experimental platform which is coupled to the bath through an interchangeable link and suspended via Kevlar threads. In combination with the short turnaround time of the kiutra L-Type Rapid this interchangeable link al-

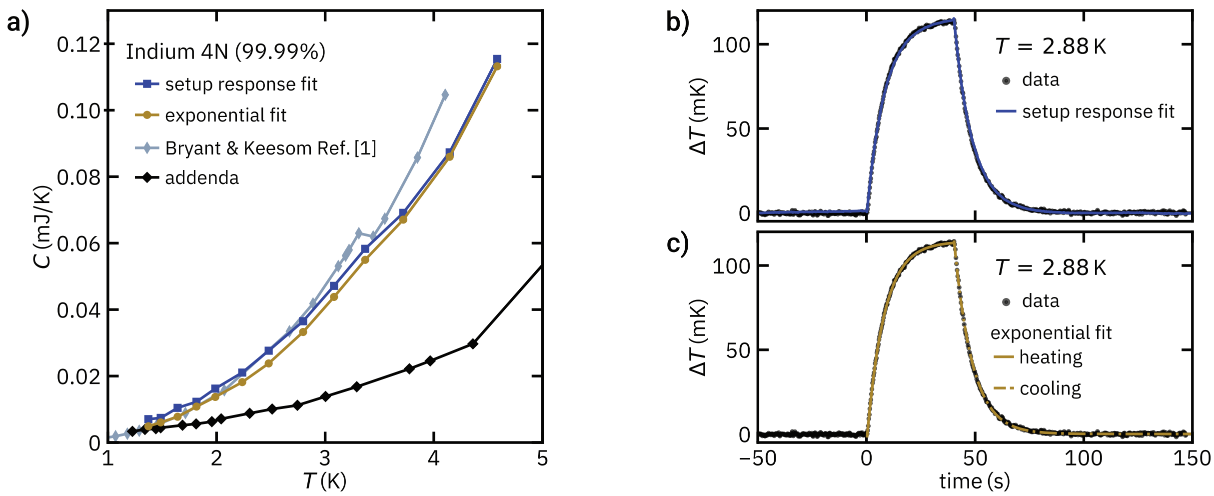

Figure 2: a) Heat capacity of Indium as a function of temperature obtained via the thermal relaxation method. Two different approaches for fitting the experimental data were used, showing that both methods yield the same result. The addenda heat capacity of the platform is shown in black and already taken into account for the data. b,c) Thermal relaxation method to obtain heat capacity. a) shows the "setup response method" where the entire temperature change is fit simultaneously, while in b) the "exponential method" is shown, where the temperature increase and decay are fit independently.

lows a fine control of the time constant of the experiment, which can vary widely depending on sample mass and material studied. Adjusting this link allows to find an optimum for resolution and speed of measurements. The thermometers and heater of the setup are connected to the DC connections on the puck PCB and will interface with the cryostat wiring upon loading. The contribution of the heat capacity of the platform and all its components—the addenda—is determined and subtracted from the data. In addition, the coupling between the platform and the sample is very well controlled to reduce the τ_2-effects.

Experimental data

To showcase heat capacity measurements in the L-Type Rapid we have studied the heat capacity of Indium and compared to data from literature[1], as shown in Fig. 2a). The heat capacity was obtained using the thermal relaxation method. Thereby, the sample is heated using a constant heat input resulting in an exponential increase in temperature. Turning off the heating gives an exponential decay back to the starting temperature. Fig. 2b) and c) show the temperature during one characteristic heat pulse using this method. The heat capacity of the sample can then be extracted by fitting an exponential to the heating and cooling phases[2], respectively, called the "exponential method" in Fig. 2b). The "setup response method"[3], cf. Fig. 2c), uses an algorithm presented by Hwang et al. that takes the addenda and τ_2-effects into account and allows for a larger variety of sample sizes and time constants in adiabatic and non-adiabatic conditions. Note that for the shown heat pulse τ_2-effects and addenda are intrinsically small and both methods yield good results.

Conclusion

Accurate heat capacity measurements at millikelvin temperatures and under applied magnetic fields are essential for studying quantum materials. The L-Type Rapid facilitates these measurement with fully automated sample loading and cooling, efficient thermalization, precise temperature control, and minimized heat losses. These features enable reliable, high-resolution data acquisition, supporting investigations of quantum phase transitions, electronic correlations, and other fundamental properties.

About us

kiutra is a pioneering cryogenics company headquartered in Munich, Germany. We want to turn cooling from a bottleneck into a key enabler for quantum science and technology. We do this by providing simplified, fast and modular cooling solutions as well as services at ultra-low temperatures. To learn more, visit www.kiutra.com.

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