Quantum Design

PPMS Application Note 1085-154

Improved Method for Determining Heat Capacity in Large Magnetic Fields

Introduction

Superconductivity, magneto-caloric effects, various forms of magnetism, and the Schottky anomaly are among the many interesting condensed matter phenomena that are revealed when researchers measure heat capacity in a magnetic field. Generally, the results from such measurements are most interesting at low temperatures, where two important instrumentation effects also occur. This note presents methods to reduce instrumentation effects and their influence on your data. The first effect arises from the dependence of the heat capacity of the addenda on magnetic field, which we call the magneto-heat capacity (MHC) effect. Quantum Design has developed a dramatically improved version of the heat capacity hardware that has a dramatically reduced MHC effect and an improved capability to perform heat capacity measurements in magnetic fields. The second effect arises from the dependence of the thermometer resistance on magnetic field, commonly known as the magneto-resistance effect. The Quantum Design heat capacity software helps you manage such effects by automating the collection of calibration data in a magnetic field. For information about ordering the new hardware and the latest version of the heat capacity software, visit the Quantum Design web site, www.qdusa.com.

Magneto-Heat Capacity

When determining the heat capacity of the sample, the Quantum Design heat capacity software first determines the total heat capacity of the sample and addenda system. The software automatically subtracts the addenda heat capacity, which you previously determined and stored in an addenda table, yielding the sample heat capacity. If, due to a significant MHC effect, the addenda heat capacity changes when a magnetic field is applied, then the addenda table must be measured with that field applied in order for the subtraction to yield an accurate sample heat capacity. There are two problems with this subtraction procedure. First, it might introduce noise and inaccuracy into the reported sample heat capacity versus field curve. Second, measuring the addenda heat capacity for each magnetic field of interest is inconvenient and time consuming.

Quantum Design has improved the process of taking heat capacity measurements in a magnetic field by developing heat capacity pucks that do not display the MHC effects of the original design. A comparison of typical data obtained with the original and improved pucks (Table 1) shows an obvious improvement: with the newly designed heat capacity puck the maximum MHC effect is only 2 nJ/K. Indeed, the addenda MHC effect is so small in the standard PPMS temperature range ($T > 1.9$ K) that you will not need to measure the addenda heat capacity in a magnetic field in most circumstances. In the temperature range of the Helium 3 option (0.4 K < T < 1.9 K), you only will need to measure the addenda heat capacity in a magnetic field when the samples have a small heat capacity or when you are trying to resolve a very small field dependence in your sample heat capacity.

Table 1. A comparison of MHC effects for original and improved heat capacity pucks, using typical data for both standard heat capacity pucks and Helium 3 heat capacity pucks. NM means not measurable within the instrument noise.

TEMPERATURE (K)	**ORIGINAL PUCK**		**IMPROVED PUCK**	
	Addenda in zero field (nJ/K)	**Max. addenda change when applying field[1] (nJ/K)**	**Addenda in zero field (nJ/K)**	**Max. addenda change when applying field[1] (nJ/K)**
0.4	130	125	5	1.5
0.6	130	120	7	2
1.0	120	100	15	2
1.5	120	70	25	2
2.5	180	10	90	2
4.0	470	120	310	NM
6.0	1350	200	1000	NM
10	5400	300	4000	NM

[1] "Maximum addenda change when applying field" is the absolute value of the maximum difference between $C(H)$ and $C(0)$ for the range $0 < H < 16$ T. Note that the maximum difference does not necessarily occur at the maximum magnetic field.

The improved heat capacity puck can be distinguished from the original heat capacity puck by the color of the platform. The original heat capacity puck has a white platform, while the improved heat capacity puck has a translucent platform with visible gold metallization on the bottom.

Rather than measuring the addenda heat capacity in all magnetic fields of interest, you could first measure the addenda only in zero (0) field. If you use this approach, you should compare the field dependence of your measured sample heat capacity to that of the addenda heat capacity to ensure that the field dependence of the addenda has not significantly affected your data. From your data, calculate the measured change in the sample heat capacity when applying a magnetic field at a few representative temperatures. Compare these values to those in Table 1 for your version of the heat capacity puck (original or current version). If the changes in Table 1 are comparable to or greater than the change you calculated in the sample heat capacity, then the sample heat capacity data in magnetic field might suffer significant inaccuracy due to the addenda field dependence. Under the latter circumstances, you should perform addenda measurements in field in order to achieve accurate sample heat capacity in a magnetic field.

If you determine that you must perform addenda measurements at each field of interest, be sure to use the appropriate addenda table for each field when you measure sample heat capacity. You can select addenda tables manually or in a sequence, as explained in the *Heat Capacity Option User's Manual,* Sections 6.7.1 and 6.7.2.

Magneto-Resistance

The temperature of the heat capacity sample platform is determined by measuring the resistance of the platform thermometer and then converting that resistance to a temperature by using previously generated calibration data. When a magnetic field is applied and the temperature is held constant, the resistance of the platform thermometer changes, producing an erroneous temperature reading. As shown in Table 2 for 9 T and 16 T fields, the typical error due to magneto-resistance varies by temperature: it is negligible at temperatures of 20 K and above, about 1–2% at 4 K, but 30–40% at 0.4 K.

Table 2. Typical error caused by magneto-resistance effects in 9 T and 16 T fields

MAGNETIC FIELD	**TEMPERATURE**		
	20 K and above	**4 K**	**0.4 K**
9 T	negligible	1%	30%
16 T	negligible	2%	40%

To correct for the magneto-resistance effects, you must calibrate the thermometer in the magnetic fields in which you will perform heat capacity measurements. You can use the heat capacity software to automate the process of collecting calibration data in a magnetic field and storing the data in puck-calibration files. For further information on this procedure, see the *Heat Capacity Option User's Manual,* Sections 5.2.7, 5.4, and 5.6.3.

Assessing the Accuracy of Measurements in a Magnetic Field

You can assess whether the errors associated with measuring heat capacity in a magnetic field have been reduced to an acceptable level by measuring a test sample in a few representative magnetic fields. Quantum Design recommends that you use high purity gold as your test sample, because the heat capacity of gold is well known to be independent of magnetic field.[1] The most rigorous test is to measure a sample of gold with a heat capacity close to that of your sample so that you can see any addenda MHC effects that might affect your data. For comparison, literature values for the heat capacity of gold can be found in various editions of the *CRC Handbook of Chemistry and Physics.*[2]

[1] High purity gold is readily available from Alfa Aesar, who sells gold shot of 99.9999% purity under the brand name Premion (stock number 11355)
[2] David R. Lide, Ed. *CRC Handbook of Chemistry and Physics,* 84th ed. (CRC Press LLC, Cleveland, OH, 2003).