Heat Capacity Application Note 1085-151

Anomalously Low Heat Capacity Below 1 K

Problem

At temperatures below about 1 K, the measured heat capacity is observed to decrease more rapidly than expected as the temperature is decreased. For example, Fig 1 shows the measured specific heat of a 20 mg sample of copper compared to the expected value. Note that this data is obtained using a measurement time of 1 time-constant.

Figure 2 shows another example of this effect for a 65 mg sample of gold. In this case the measurements were obtained with measurement times of 1 time-constant and 2 time-constants. Note that the measurement obtained at 2 time-constants does not show the downturn.

Figure 3 shows the effect of varying the measurement time at a fixed temperature (0.350 K) for the gold sample. Measurements are shown with measurement times of 0.5, 1, 2, and 3 time-constants, respectively. Note the systematic decrease in the reported specific heat at measurement times less than 2 time-constants

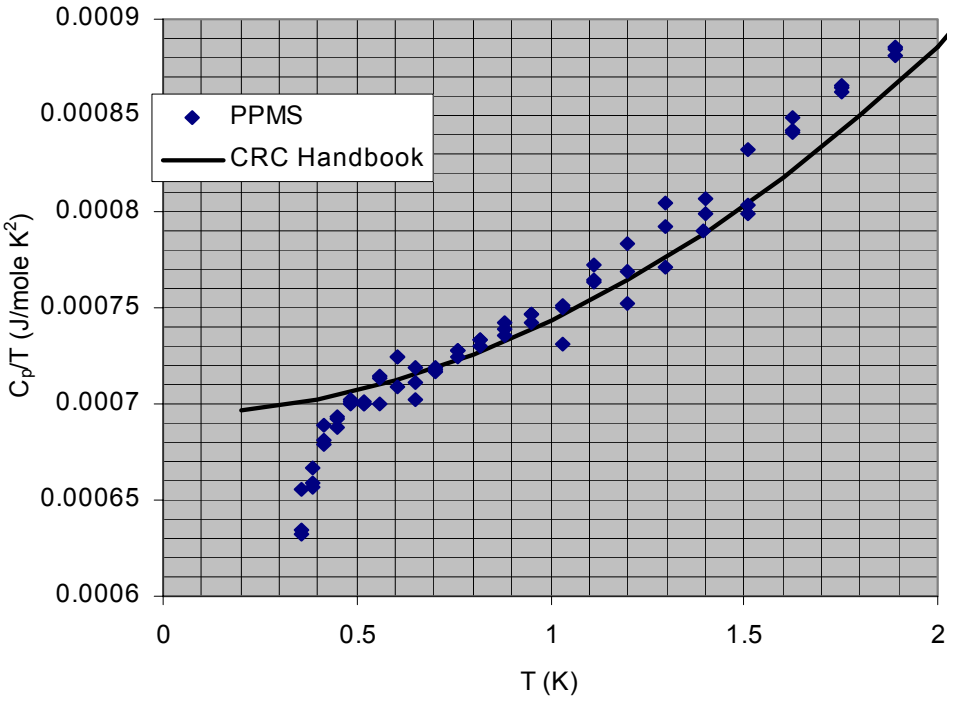

Figure 1: 20 mg copper sample at low temperatures. Measurement obtained with a measurement time of 1 time-constant.

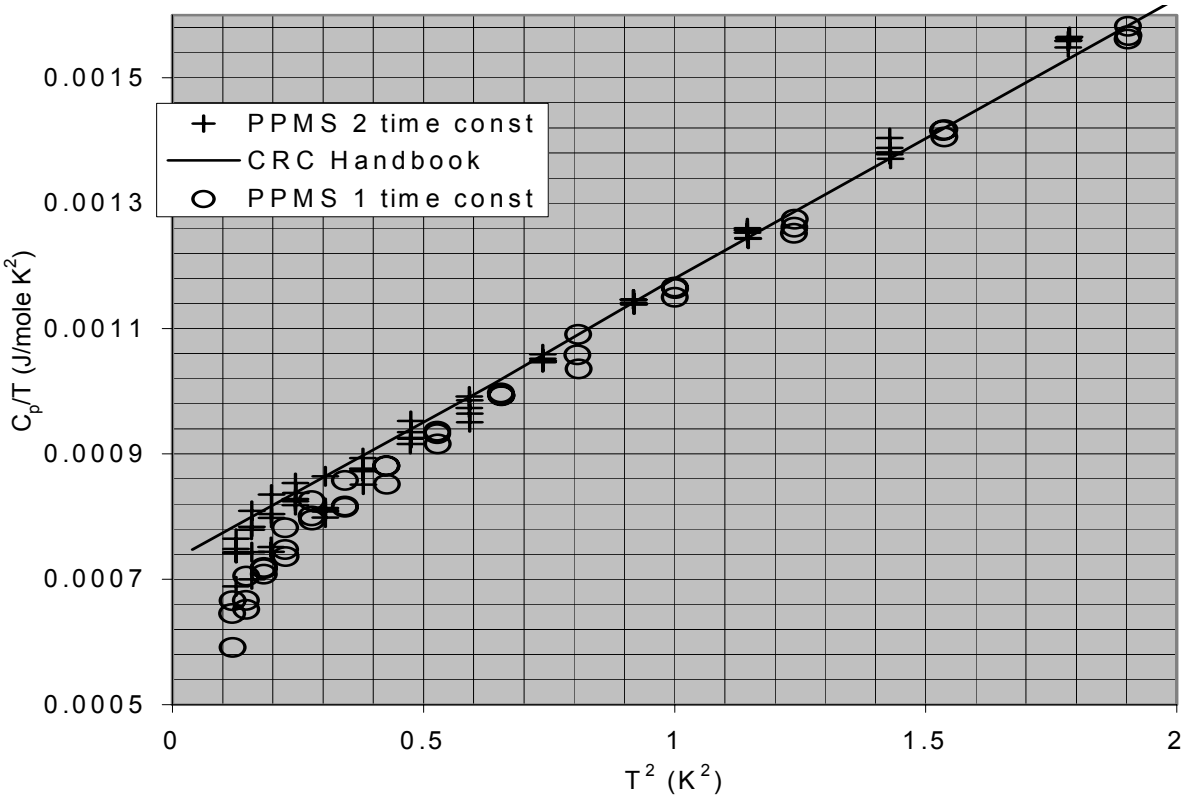

Figure 2: 65 mg gold sample obtained with a measurement time of 1 time-constant and 2 time-constants.

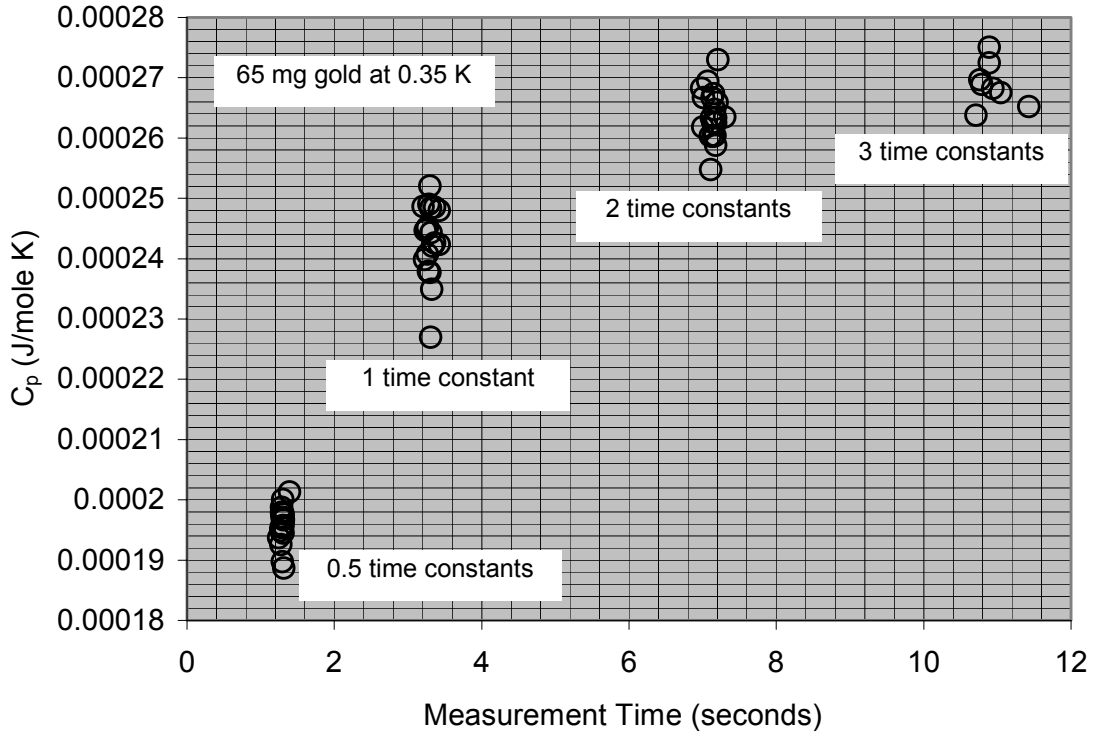

Figure 3: Specific heat measurements of 65 mg of gold at 0.35 K at different measurement times (0.5, 1, 2, and 3 time constants).

Explanation

Ideally, the reported specific heat value will be independent of the specified measurement time. However, this will be true only to the extent that the sample holder and sample behave as idealized point-like specific heats, and the wires are mass-less thermal resistors. In reality, there are multiple thermal relaxation times in the calorimeter and wires that result in different reported specific heats for different measurement times. At higher temperatures this effect is usually negligibly small, but it becomes problematic below 1 K, where the thermal boundary resistance, or Kapitza resistance, becomes large between the various materials comprising the calorimeter.

The addenda heat capacity was obtained with a measurement time of 2 time constants in Figs. 1 thru 3. Because of the nature of the fitting model used in the Heat Capacity software, a substantial improvement in the accuracy of the data is obtained if the sample measurements are also obtained with the same measurement time (2 time constants) as used for the addenda measurements.

Solution

To obtain the best accuracy below 1 K, it is recommended that specific heat measurements be obtained using 2 time-constants for the measurement time to best match the thermal conditions of the calorimeter when the addenda measurements were obtained.