Sample Self-Heating in the Portable Dilution Refrigerator

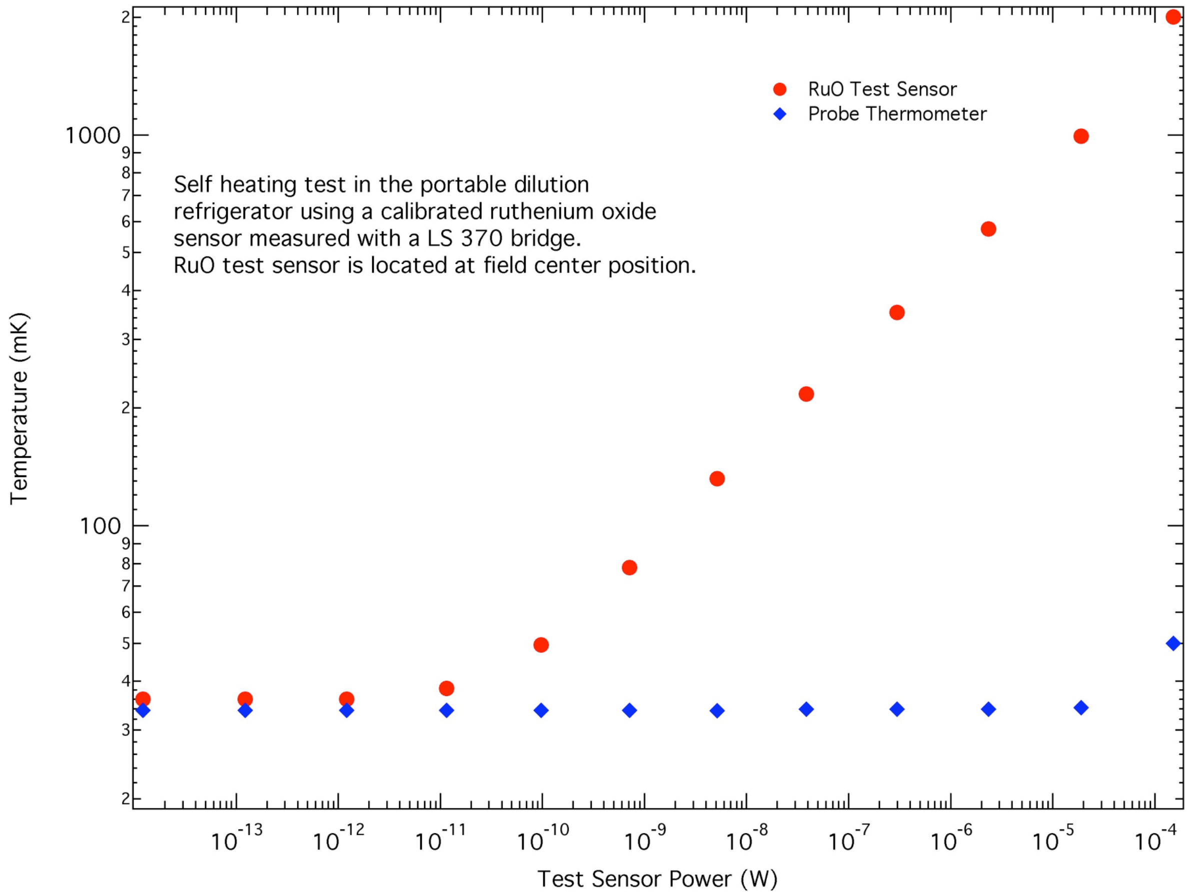
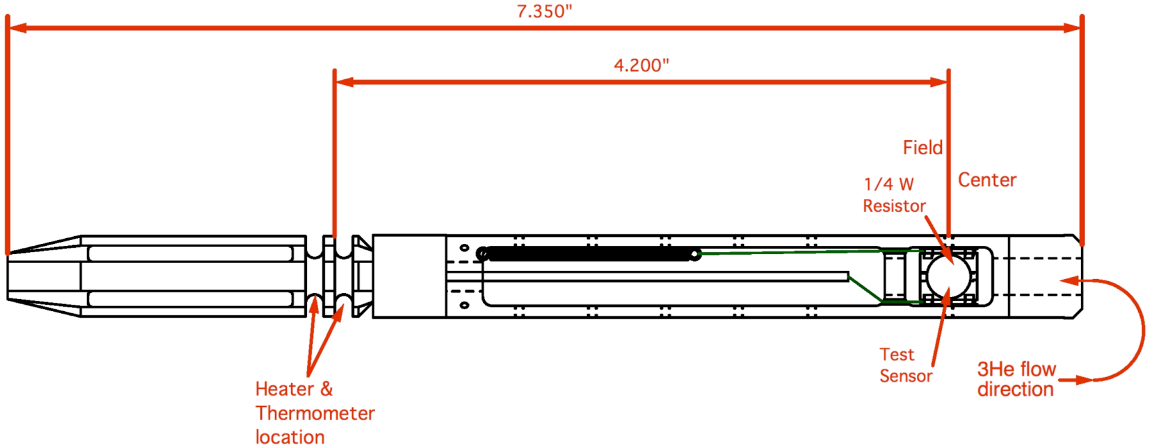


Figure 1. Self-heating of a model sample in a dilution refrigerator. Sample temperature is plotted as a function of the power generated by the sample current.

An experiment that is frequently performed in the dilution refrigerators in the DC Users Facility at the NHMFL is measuring resistivity as a function of temperature and magnetic field. On occasion a user has run enough current through the sample to increase the temperature of the mixing chamber. We were curious as to what the internal temperature of the sample may have been as it was heating the entire mixing chamber, so we devised and performed the following simple experiment.

We used a calibrated, 1 kΩ, RuO_2 sensor, 2 mm x 1.3 mm, as our "test sample". It was mounted in the field center position (labeled "sample space" in Fig. 2) of the portable dilution refrigerator (PDF) in order to measure the increase in its internal temperature as the applied power was increased while simultaneously monitoring the permanently mounted probe thermometer. The geometry of the sensor locations is shown in Fig. 2. Using a Lake Shore 370 AC resistance bridge we measured the temperature of the test sensor as a function of current (power) with the results displayed in Fig.1. When the power dissipated in the "test sample" rises above ~ 6 pW, self heating begins to occur. The most dramatic result of this test was that a temperature of 1K can be achieved in the "test sample" before any heating begins to show on the probe thermometer. Going to the maximum current output on the 370 yielded an internal temperature of 2 K in the "test sample" with only 50 mK showing on the probe thermometer.

Does mounting a temperature sensor close to the sample solve the problem? To answer this question we located a ¼ W metal film resistor inside the sample space ~ 3 mm away from the test sensor. We generated 10 μW in the metal film resistor, and monitored the temperatures of the two sensors. From Figure 1 we estimate that the metal film resistor was at ~500 mK. Both the probe thermometer and the test sensor registered ~34 mK .



It is clear from these measurements that users should be extremely careful when making resistivity measurements at low temperatures. The sample resistance may be quite low, in the milli-ohm or even micro-ohm regime but the resistance of the contacts is usually at least an ohm, often much more. Since the transfer of thermal energy from the sample to the temperature sensor(s) via the mixture is extremely poor, the sample can heat significantly before a thermometer in the liquid senses the heat at all. As this experiment shows, as little as 20 μW heated the sample to more than 1K, which certainly defeats the purpose of the dilution refrigerator! Since making good measurements on low resistivity samples at low temperatures can be difficult, we stand ready to assist users in obtaining error free data.

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