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MELTING CURVE THERMOMETRY AND THE PHASE DIAGRAM OF ^{3}He

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A melting curve thermometer has been used to calibrate a Lanthanum diluted Cerium Magnesium Nitrate thermometer. Temperatures at which the superfluid transitions of ^{3}He occur are measured with the LCMN thermometer. The resulting phase diagram provides a useful technique for comparison with the Platinum and zero sound based LCMN scales commonly used in this temperature range.

1. INTRODUCTION

Although there is no universally accepted thermometric standard for use in the millikelvin range, in recent years there has been considerable progress toward a consensus as regards thermometry below 3mK(1,2,3). With the relative ease of construction of small capacitive "melting curve thermometers" (4), it was realized that the melting curve of ^{3}He could provide a simple and sensitive technique to calibrate a SQUID based LCMN thermometer which is immersed in liquid ^{3}He together with an Andronikashvili type torsional oscillator. By observing the superfluid transition in the torsional oscillator, and by monitoring the LCMN thermometer, the melting curve scale can be compared to other scales (1 and 2) via the pressure dependent superfluid transition temperature T_c. We present in this paper the results of such a comparison.

2. EXPERIMENTAL DETAILS

The experiments were carried out on a nuclear demagnetization cryostat utilizing 1/4 mole of $PrNi_5$ compound. The melting curve thermometer (MCT) consisted of a OFHC copper body with an integral screw fastened to a large copper platform in intimate thermal contact with the nuclear refrigerant and the main ^{3}He cell heat exchanger. The MCT incorporates a sponge of 700 Å silver powder (Area = 1m^2), which was pressed into a silver plated cavity in the copper body. A sufficient amount of open volume was left above the sinter so that when the solid sample formed by the blocked capillary technique was set at 34 bar (enough to maintain a finite amount of solid at T_N), the minimum in the melting curve could be measured with no appreciable dependence on the amount of solid present.

The strain gauge element was calibrated at 1.5K against a Paroscientific Quartz pressure transducer (5)(accuracy ±.01%), and monitored with a General Radio 1615-A capacitance bridge. The calibration, performed in 0.25 bar steps between 28.5 and 35.0 bar exhibited a scatter on the order of 0.2 mbar. In this apparatus the pressure head of helium could not be easily determined as the temperature profile of the filling capillary was not sufficiently well characterized. Accordingly we chose to offset our values for the pressure at the minimum of the melting curve to reflect those measured by other investigators (3,4). The pressure offset for a high molar volume sample was found to be 13 mbar, (in rough agreement with estimates for the hydrostatic pressure head), and reproducible within 0.7 mbar at lower molar volumes. We find with our working sample that the measured value of P_A-P_{min} is 3.5 mbar greater than that quoted by Halperin et al (3), and further that P_B-P_A=19.96±.1 mbar and P_N-P_A=52.4±.2 mbar in excellent agreement with values quoted by Halperin (3) and Osheroff (6). Here P_{min}, P_A, P_B and P_N denote the pressures of the minimum, the A, B, and solid ordering transitions along the melting curve.

The LCMN thermometer was calibrated by allowing the cryostat to warm up under the influence of the ambient heat leak of 0.7 nW. Under these conditions the T_N, T_B and T_A signatures within the MCT were clearly visible. Hysteresis between the LCMN and MCT at T_A and T_N were found to be 1μK and 10μK respectively. Thermal gradient effects were estimated to produce an additional uncertainty on the order of 10μK. The overall accuracy of the thermometry was therefore not greatly decreased relative to the 5% uncertainty in the melting curve scale itself. It should be noted that we find the transition at 0 bar to be 37μK higher than the solid ordering temperature of 1.10mK (3).

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3. RESULTS

In Figure 1 we plot the temperatures assigned to the superfluid transitions at eight pressures together with the data of the Helsinki group (1) and the LaJolla group (2). It is clear that the three thermometry schemes do not differ by more than 10% over the whole range shown in the figure.

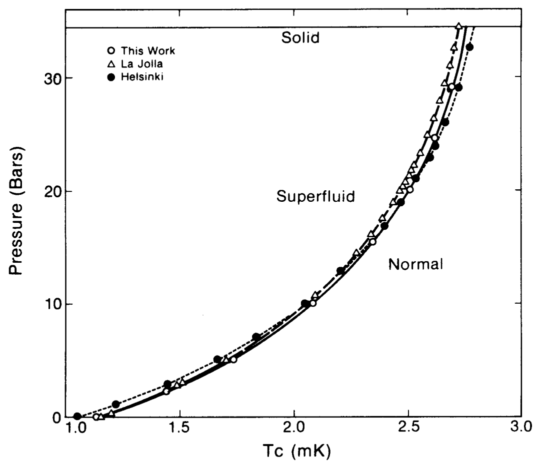

FIGURE 1
The phase diagram for ^3He normal-superfluid transitions showing measurements of the Helsinki and LaJolla groups together with our results. Our data are listed in Table 1.

A test of the differences in the temperature scales is the value of $[T_A]/[T_C\ (0\ \text{bar})]$, the two extremal fixed points available in this temperature range. We find this ratio to be 2.68, 2.36, 2.42 for the Helsinki, LaJolla and melting curve scales respectively. It is evident that our results are in closer agreement with the LaJolla scale, rather than the Platinum based Helsinki scale. However, such a comparison makes no allowance for the relative curvature in the scales. We have carried out a cubic spline fit to interpolate between the data points in Table 1 and from references (1) and (2). A straight line fit to the data from ref. 1 (T_{HEL}), and ref. 2 (T_{LJ}) results in the two equations (temperatures in mK)

$$T_{MC} = 0.193\ (\pm.005) + 0.922\ (\pm.002)\ T_{HEL}$$
and
$$T_{MC} = -0.023\ (\pm.006) + 1.022\ (\pm.003)\ T_{LJ}$$

each with a RMS deviation of 7μK. It must be emphasized that we can make no claims as to the absolute accuracy of this temperature scale.

4. CONCLUSIONS

We have compared our melting curve based temperature scale to the Platinum and zero sound based temperature scales, and find close agreement with the latter. We anticipate continuing our measurements , particularly to investigate and eliminate thermal gradients, and hope to extend our comparisons to the B→A transitions.

REFERENCES

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(6) D.D. Osheroff, private communication.

TABLE 1
The measured transition temperatures on the melting curve scale for several values of pressure.

P (bar)	0.0	2.18	5.10	10.00	15.40	19.96	24.47	29.15
Tc (mK)	1.137	1.4362	1.7350	2.0850	2.3485	2.5080	2.620	2.694