

LOW TEMPERATURE SPECIFIC HEAT OF SINGLE-WALL
CARBON NANOTUBES

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Previous Cp experiment [1] gave first evidence for 1D quantum confinement of vibrational modes in SWNT, crossing over to 3-D behaviour at very low T where tube-tube interactions become important. These measurements were limited to 2 K. The data did not follow a linear extrapolation to T = 0, which provided a strong motivation to extend the measurement to mK regime. Here we report the first data and analysis of such experiment on the exact same sample, which consists of ropes of SWNT (around 40 tubes in one rope).

Specific heat was measured in the temperature range from 0.1 to 5 K or 7 K. Great care was taken to avoid contamination of the sample by air or oxygen, but the role of adsorbed He⁴ has been systematically studied. Several runs were done during a two-month period of time, in between which the sample and calorimeter were finally pumped under secondary vacuum at room temperature for five days, to ensure that the effect of helium adsorption is minimized. For this fully outgassed state, the analysis of the data from 0.1 to 4.5 K yields the following 3-component behavior:

$$C_p = C_n T^{-2} + 0.043 T^{0.62} + 0.035 T^3 \text{ (mJ/gK)}.$$

The $C_n T^{-2}$ contribution dominates the specific heat below 0.5 K, and is assigned to a hyperfine nuclear magnetic contribution from the residual small metallic clusters of Co and Ni (about 0.7 at.%) which were used as catalysts during the laser ablation synthesis. The vibrational contribution to C_p shows a crossover from T^3 to a less rapid variation, at T=4.5 K, which is consistent with the expected dominant inter-tube interactions in the rope lattice at very low T. The relationship between the vibrational contribution to C_p and the recently measured vibrational DOS obtained from neutron scattering on a similar sample [2] is discussed.

[1] J. Hone et al., Science **289**,(2000) 1730.

[2] S.Rols et al., Phys. Rev. Lett. **85**,(2000) 5222 .

The Penn contribution to this work was supported by the US Department of Energy, DEFG02-98ER45701.