Creating one dimensional and two dimensional quantum solids on carbon nanotubes

S. O. Diallo, J.V. Pearce, B. Fak, M.A. Adams, O.E. Vilches, M. R. Johnson, and H.R. Glyde

Carbon nanotubes are sheets of carbon atoms rolled into seamless cylinders of 1-2 nanometers diameter and thousands of nanometers long. They self assemble into long bundles or ropes containing many tubes. The cross-section of a bundle is shown opposite. Nanotubes are of great interest for their unique, nearly one dimensional (1D) character, their rigidity, light weight, electronic properties and potential to adsorb large amounts of gas.

We have made the first measurements of the structure [1] and dynamics [2] of helium absorbed on nanotube bundle surfaces using neutron scattering. The aim is to create and stabilize 1D and 2D solid helium and to test many remarkable predictions for 1D and 2D solids. As helium is added, it is adsorbed first in 1D lines in grooves on the outer surface of the bundles (upper figure). As more helium is added, it is adsorbed in 3 lines, still 1D solids (middle figure). When the bundle surface is covered (lower figure) we have a 2D solid. We find a 1D ^{4}He lattice spacing of a_1 = 3.40 Å and a 2D triangular lattice spacing of a_2 = 3.63 Å .The 1D spacing in grooves has been reproduced recently in Monte Carlo calculations[3].

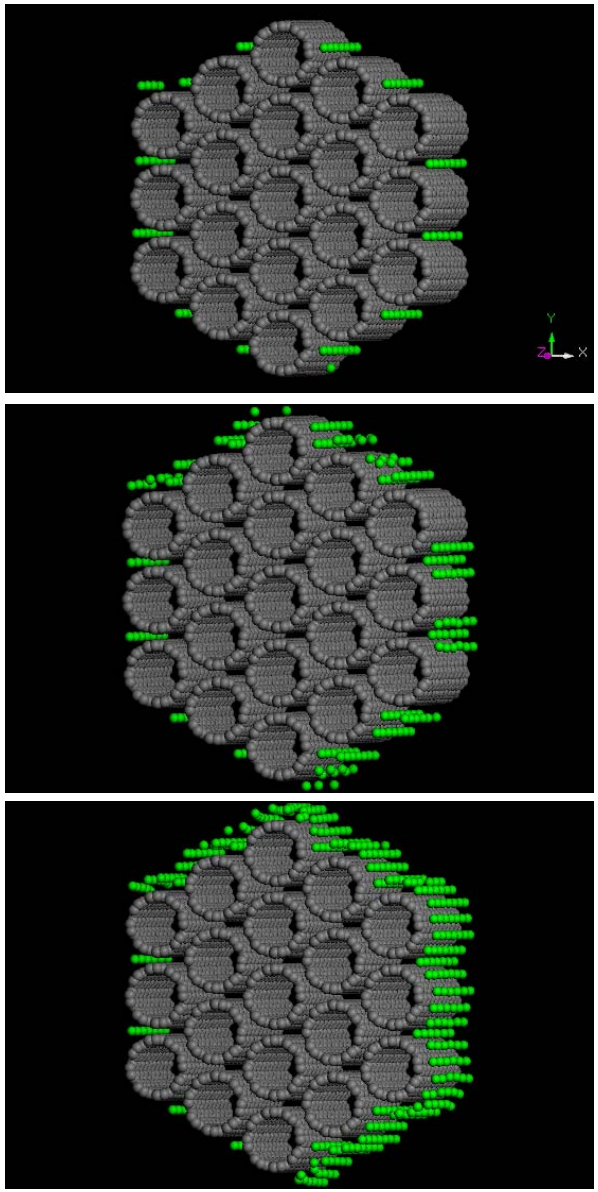

Figure: Helium on closed end nanotube bundles; green spheres are ^{4}He atoms, grey spheres are carbon atoms. The configurations, generated using molecular dynamics simulations, reproduce neutron measurements. Top: 1D lines of ^{4}He atoms, middle: "3-line phase", bottom: 1 monolayer coverage (2D system).

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Dynamics of Helium on Nanotubes:

Ideal, freely suspended 1D helium is predicted to be a highly dilute liquid with mean interatom spacing of R = 27.8 Å.. The interaction with the nanotubes compresses the 1D liquid into a solid with spacing a_1 = 3.4 Å.. Top right we show the inelastic scattering from the helium integrated over all energies, $S_{inel}(Q)$. From the maximimum in $S_{inel}(Q)$ for 1D we obtain the MS amplitude of vibration of the 4He atoms along 1D grooves $\langle u^2 \rangle$ = 0.28 Å^2 or Lindemann ratio $\gamma = \langle u^2 \rangle^{1/2}/a_1$ = 0.15. This is much greater than that for the 2D solid on nanotubes value but less than the bulk solid ^{4}He value near melting. The vibrational density states **(**DOS**)** $S_{inel}(\omega)$ (bottom right) of the 2D solid shows a gap at an energy of 0.75 meV indicating a commensurate solid, as found for helium on graphite surfaces. In contrast the 1D DOS shows no gap or one spread over an energy range by disorder in the groove potential.

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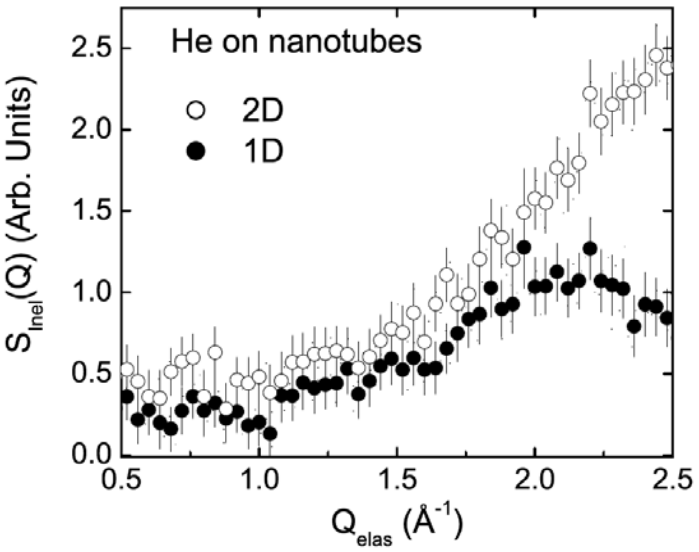

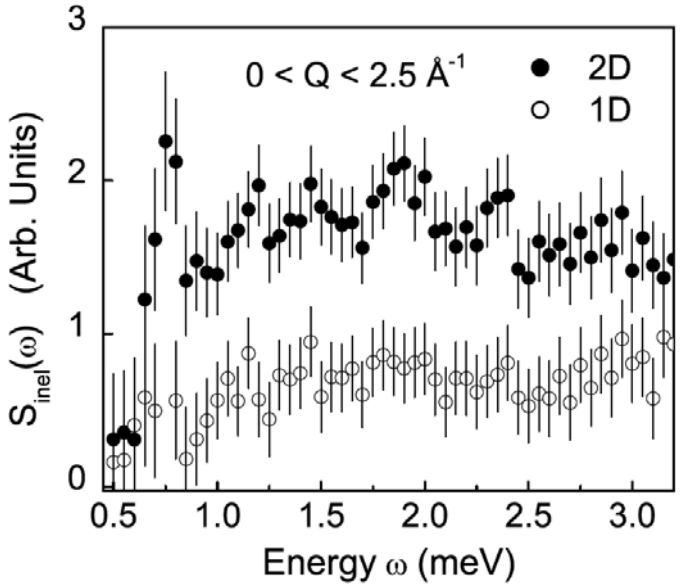

[1] Pearce et al. Phys. Rev. Lett. 95, 185302 (2005). [2] Diallo et al. Eur. Phys. Lett. (to be submitted) (2008), [3] Gordillo, Phys. Rev. Lett. 95, 185302 (2008).