

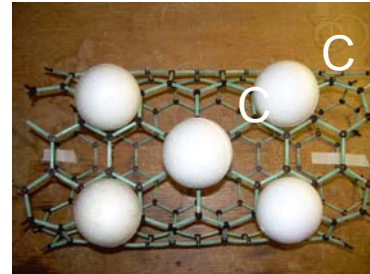
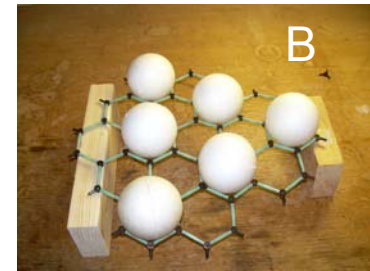
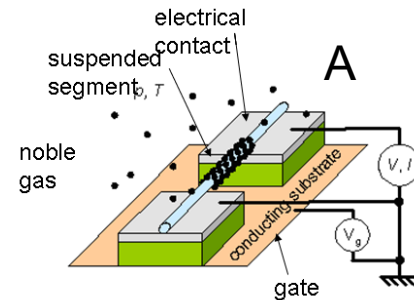
# A Yocto-kilogram ( $10^{-24}$ kg) balance

Oscar E. Vilches and David H. Cobden (U. of Washington),  
DMR-Award # 0606078

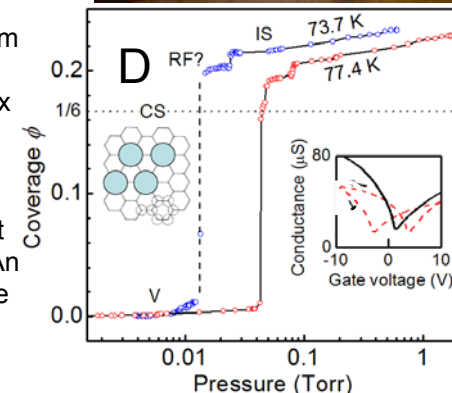
This grant supports the research of faculty, graduate and undergraduate students studying the phases of, and the interaction between atoms deposited on the graphite-like surface of single wall carbon nanotubes when a few, and no more than one layer of atoms is deposited. Two projects have been carried out during this past year:

- The development and use of an extremely sensitive mass balance using a single carbon nanotube as adsorbent surface and detector of atoms deposited (pictures and description at right and below), and
- Neutron diffraction measurements of the structures that Neon atoms form on the surface of carbon nanotube bundles (with European collaborators, not shown).

The sensitivity of the balance that produced the results of Fig. D at right was about  $10^{-24}$  kg (a yocto-kilogram). With similar devices we are doing an extensive mapping of the phases of Ar and Kr deposited on a variety of nanotubes, and studying the electrical conductivity of nanotube devices as a function of amount of gas adsorbed on their surface. Our research may lead to the development of very sensitive practical mass detectors, past the study of phases of matter in this particular type of nano-surface..



**A.** The essential elements of the yocto-balance: a single wall carbon nanotube is freely suspended between electrodes; in reality it is one-thousand times longer than its diameter. Its vibration frequency is measured, which decreases when atoms are deposited on its surface. **B.** On flat graphite (the hexagonal lattice), Krypton atoms (the styrofoam spheres) form an equilateral triangular lattice (one Kr atom per six C atoms, called a *commensurate solid*, or CS). **C.** A non-equilateral commensurate triangular structure may form on a carbon nanotube, but this depends on nanotube type. **D.** An adsorption isotherm of Kr on a single carbon nanotube: Coverage means the fraction of Kr atoms to C atoms, Pressure means the pressure of Kr gas in equilibrium with the adsorbed gas on the surface. The vertical jumps are phase transitions of the adsorbed



Kr, from vapor (V) to CS (1/6 coverage) to a re-entrant fluid (RF?) and to incommensurate solid (IS).

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The research in these projects involve several graduate and undergraduate students, all being trained in a variety of techniques useful in surface science and nano-technology: growth of carbon nanotubes, fabrication of devices, lithography, optical and electron microscopy, atomic force microscopy, area calibrations, and very sensitive electronic measurements. The study of the electronic properties of carbon nanotubes and the thermodynamics and structure of adsorbed atoms are the scientific goals of these projects..

**Participants in the last year:** Peter Morse (BS 2008), Kristine Kim (BS 2008), Holly Hess (BS 2009), Djordje Savovic (BS 2009), Erik Fredrickson (junior Physics major), Zenghui Wang and Jiang Wei (Physics graduate students). **Foreign**

**Collaborators:** Mark Johnson and Stéphane Rols (ILL-Grenoble), and Benjamin Demirdjian and Michel Bienfait (CINAM, Marseille).

**A.** Erik Fredrickson examines the quality of the catalyst deposited on electrodes next to micrometer wide trenches in a silicon wafer using an optical/video microscope. Erik will grow a single carbon nanotube across the trench to make a device. **B.** Cobden, Wang, Fredrickson and Vilches pose around the discussion table. **C.** Zenghui trains Erik, who is learning to analyze adsorption data.