Longitudinal vibrations of suspended carbon nanotubes - Franck-Condon effect, cotunneling, and nonequilibrium

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Low-temperature transport measurements on quantum dots formed in single wall carbon nanotubes have led to the discovery of a wealth of interesting physics. In addition, carbon nanotubes provide an exemplary nano-electromechanical system. The Franck-Condon effect makes it possible to observe vibron-assisted processes in single electron tunneling as harmonic excitation spectra at low energy [1].

Observations, however, are not limited to first order tunneling alone. In our measurements, a mechanical mode can be pumped via a strongly coupled electronic excited state into non-equilibrium occupation. As consequence, the Franck-Condon steps become visible as lines of cotunnel-assisted sequential tunneling [2] within the Coulomb-blockade regime [3]. The visibility of the mechanical mode in transport enables a first, albeit weak, estimate for the mechanical quality factor of the longitudinal vibration mode.

[1] S. Sapmaz *et al.*, Phys. Rev. Lett. **96**, 026801 (2006).

[2] R. Schleser *et al.*, Phys. Rev. Lett. **94**, 206805 (2005).

[3] A. K. Hüttel *et al.*, Phys. Rev. Lett. **102**, 225501 (2009).