Department of Physics
Condensed Matter Physics
Clarendon Laboratory, Parks Road, Oxford OX1 3PU

UNIVERSITY OF
OXFORD

CONDENSED MATTER SEMINAR

Thursday 16 May at 2.15pm

“Electromechanics at the quantum frontier with vibrating carbon nanotubes”

Dr Edward Laird

Department of Physics, Lancaster University

By incorporating moving parts into quantum electronic circuits, we can create new devices for sensing delicate forces and for exploring quantum physics on a mesoscopic scale. This is the field of quantum electromechanics, in which motion joins voltage and current among the circuit’s working degrees of freedom.

To realise the full potential of this field, we must create nanomechanical resonators that can be protected from environmental noise, measured accurately, and manipulated in precisely controlled ways. Suspended carbon nanotubes – resembling vibrating guitar strings only a micron long – are the smallest electromechanical resonators that can be built, and are uniquely suited to address these requirements1. I will show how to create circuits in which their properties are harnessed for sensing and fundamental physics.

Until recently, the only way a nanotube resonator could be measured was by monitoring the average current through the device. Much more can be revealed by a time-resolved measurement. My group has realised this goal by devising a cryogenic optomechanical setup in which the nanotube’s displacement is monitored via a radio-frequency cavity2. As I will show, this allows sensitive measurements, approaching the quantum limit of precision, which reveal the effects of individual electrons on the motion.

In these nanomechanical experiments, backaction is an inescapable accompaniment to measurement3. Often this is a nuisance, but we have harnessed it to create an acoustic analogue of a laser. The lasing medium is a quantum dot defined along the nanotube; the phonon cavity is provided by the vibrating segment; and the excitation is provided by an electrical bias. I show that the resulting emission is coherent, and demonstrate other laser characteristics, including injection locking and feedback narrowing of the emitted signal4. Unlike previous phonon lasers, this is a novel architecture in which measurement backaction, rather than stimulated emission, drives the self-amplified oscillations.

These experiments open exciting prospects for creating new probes of matter in the mesoscopic regime. I will discuss the potential for ultra-sensitive scanning force transducers to acquire magnetic resonance images with nanometre resolution. Finally, I will present a proposal to test quantum superposition by constructing an on-chip interferometer in which an entire nanomechanical resonator, containing a million nucleons, forms the particle under test5.

1. Laird, E. A. et al. Quantum transport in carbon nanotubes. Rev. Mod. Phys. 87, 703 (2015).
2. Ares, N. et al. Resonant optomechanics with a vibrating carbon nanotube and a radio-frequency cavity. Phys. Rev. Lett. 117, 170801 (2016).
3. Wen, Y et al. Measuring carbon nanotube vibrations using a single-electron transistor as a fast linear amplifier. Appl. Phys. Lett. 113, 153101 (2018).
4. Wen, Y. et al. A coherent nanomechanical oscillator driven by single-electron tunnelling. arXiv:1903.04474 (2019).
5. Khosla, K. E. et al. Displacemon electromechanics: how to detect quantum interference in a nanomechanical resonator. Phys. Rev. X 8, 021052 (2017).

Host: Prof Robert Taylor, Simpkins Lee Room, Beecroft Building