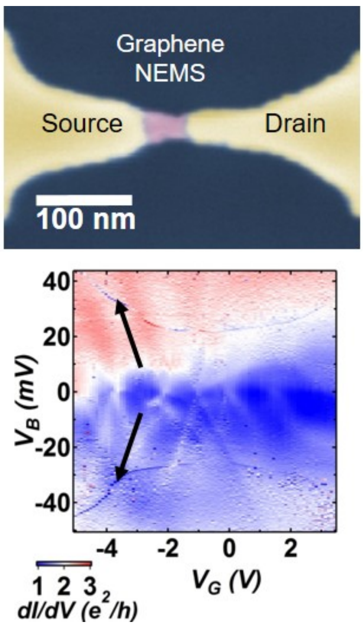
Concordia University
Arts and Science
Department of Physics

Ph.D. in Experimental Quantum Physics in Molecular-scale Carbon Nano-Electro-Mechanical Systems

Fall 2021 in the group of Prof. Alex Champagne, Department of Physics,

Concordia University, Montréal, Canada



This PhD project will most likely be part of the "QSciTech: Bridging the Gap between Quantum Science and Quantum Technologies" (NSERC-CREATE training program). This program includes a network of 11 research teams in quantum science and technology across Canada, offers transdisciplinary courses, and can offer you a one-semester-long paid industrial internship as part of your PhD. *The candidates must be well prepared for this research, with past experience either in advanced nanofabrication skills, or/and electron transport measurements, or/and an advanced understanding of quantum mechanics.*

Experimental Quantum Physics in Molecular-scale Carbon Nano-Electro-Mechanical Systems

We propose to explore the gap in the understanding of quantum nano-electro-mechanical systems (QNEMS) between the molecular and 100-nm scale. This PhD project starts with a focus on developing an applied theoretical model, while getting trained on experimental methods. The student will gain a deeper understanding of transport in quantum dots, electron-phonon coupling, and QNEMS physics. After four semesters, the PhD student will have completed their course work, technical training, and a short applied theoretical project leading to a publication. They will then focus on nanofabrication and quantum transport measurements leading to their thesis. They will learn about data analysis, writing scientific manuscripts, and giving effective presentations.

To deliver on the promises of nanoscale quantum materials, we must understand the strong interdependence between their mechanics and electronics. Single-molecule electronics have struggled to deliver devices for decades because of a lack of precise electro-mechanical control in these devices. We have a unique set of instruments (ultra-low temp cryostat, 3D vector magnet, in-situ mechanical strain) and devices (ultra-clean nano-scale carbon NEMS) to study QNEMS and explore quantitatively their electronics, mechanics and most importantly their electro-mechanical interactions. Fig. (a), shows an ultra-small suspended graphene layer acting as a QNEMS. Fig. (b) shows quantum transport data in a similar device where ultra-high frequency electro-mechanical resonances can be measured.

The frequency-quality factor product, (fQ), is a measure of the sensitive of NEMS, and generally increases as carbon NEMS get smaller. We aim to test the scaling-limit of the mechanical performance of NEMS, with applications as oscillators in integrated circuits, exquisite mass sensors, or RF mixing components. To model electro-mechanical resonances, we will adapt for our device design a model explaining how mechanical vibrations (vibrons) create pseudo-vector fields, $\partial A(x,y)/\partial t$, and scalar fields, $\partial \phi(x,y)/\partial t$ which lead to electro-vibron couplings or even coherent charge pumping. Additionally, strong electro-mechanical coupling in molecular NEMS leads to an effective attraction between dressed electrons (polarons), and can result into negative charging energies in quantum dots. We aim to achieve this in our ultra-short (20-nm) SWCNT QDs. Another fascinating prospect is to add superconducting contacts on these QDs, to create S-N-S Josephson junctions. We expect both a gate-tunable charging energy and strong Kondo effect in these devices, which could permit the study of states including the Kondo state, Andreev bound states, and Shiba states.

Concordia's Department of Physics is growing rapidly. We have over 45 graduate students, several postdocs, and are regularly hiring new faculty members in cutting edge research fields such as Condensed Matter Physics (theoretical, computational, and experimental), Photonics, Molecular Biophysics, Medical Physics / Imaging, Theoretical High Energy Physics, and Physics Education. Successful PhD applicants to this position will be offered financial packages consisting of RA, TA and various awards of at least 24,000 CAD per year, for 4 years. International students will be offered tuition remissions or other awards to compensate for the international tuition fees. For information about this specific position, please contact Prof. Alex Champagne (a.champagne@concordia.ca). For information about our graduate programs in general, please contact Prof. Valter Zazuvobits (valter.zazubovits@concordia.ca).