Combining Nano-mechanics with Quantum Optics

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Quantum mechanics is one of the most successful theories in the history of modern science. It accurately describes effects such as superconductivity and Bose-Einstein condensation as well as superposition and entanglement of states. Many of the effects predicted by quantum theory seem counter-intuitive and at odds with our classical everyday intuition and, in fact, are typically only observed on a microscopic scale. However, quantum theory itself does not pose any limit to the size or the mass of a system in which its effects should be observable.

Scientists have been trying to demonstrate quantum behavior on ever-bigger physical systems for decades. In particular, over the past years opto-mechanical systems have emerged as promising candidates for studying quantum effects on a truly macroscopic scale. With such systems it seems feasible to answer some of the most fundamental questions in quantum physics today, such as: Why is the world around us classical and not quantum? Is there a size- or mass-limit to systems for them to behave according to quantum mechanics? Is quantum theory complete or do we have to extend it to include mechanisms such as decoherence? Will it be possible to use the quantum nature of macroscopic objects to, for example, improve the measurement precision of classical apparatuses?

The basic system studied in Simon Gröblacher's Thesis is a mechanical oscillator that is highly reflective and part of an optical resonator. Typical dimensions of the mechanical oscillator are from hundreds of microns to a few tens of microns, just enough to be visible to the naked eye. Such a system is truly macroscopic when compared to standard systems used in quantum experiments – it consists of up to 10^{18} atoms and has a mass of a few tens of nanograms. The vibrational motion of the mechanical oscillator interacts with the optical cavity mode via the radiation-pressure force, where both the dynamics of the mechanical oscillation and the properties of the light field are modified through this interaction. In their experiments, Gröblacher *et al.* use quantum optical tools with the goal of ultimately showing quantum behavior of the mechanical center of mass motion.

The experiments discussed in Gröblacher's Thesis include the very first passive radiation-pressure cooling of a mechanical oscillator in a cryogenic optical resonator, as well as the experimental demonstration of radiation-pressure cooling close to the mechanical quantum ground state. Cooling the mechanical motion to a low-entropy state is an important pre-condition for observing quantum effects of the mechanical oscillator. In another experiment, Gröblacher *et al.* demonstrate that they are able to enter the strong coupling regime of the opto-mechanical system, a regime where coherent energy exchange between the optical and the mechanical subsystems is possible, as their coupling rate is bigger than their individual decoherence rates. This experiment constitutes an important milestone in showing macroscopic mechanical quantum behavior. Finally, they have observed non-trivial correlations between the optical and the mechanical system. These correlations are used for probing radiation-pressure based down-conversion. – a pre-requisite for opto-mechanical entanglement.

By combining the experiments presented in Gröblacher's Thesis it will ultimately be possible to create and control quantum states of truly macroscopic systems.