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Photons and Mechanics tie strong

Effects of "strong coupling" observed for the first time between light and a micromechanical object

Physicists at the Institute for Quantum Optics and Quantum Information (IQOQI) in Vienna and Innsbruck, Austria, have created an interaction between light and a micromechanical resonator that is strong enough to transfer quantum effects. This is an important step towards quantum physics experiments in the macroscopic domain. They report about their result in the latest issue of the scientific journal *Nature*.

Quantum physics is full of paradoxes that are in conflict with our everyday experience. Do the laws of quantum physics apply to "everyday" objects visible to the naked eye? This question has been posed by physicists like Erwin Schrödinger already since the beginnings of quantum theory. With today's nano- and microfabrication capabilities such experiments are within reach. Researchers worldwide have started to investigate possible quantum experiments with mechanically oscillating objects. Such mechanical resonators can vary in size from a few hundred nanometers up to several centimeters and would therefore constitute by far the biggest objects on which quantum theory has been tested. One approach to achieve this enticing goal is to transfer the properties of an elementary quantum system, for example a single electron, atom or photon, onto the macroscopic mechanical object. However, two conditions have to be met: first, the mechanical resonator has to be cooled down to temperatures close to absolute zero (-273, 15°); second, the force between the mechanical resonator and the electron, atom or photon has to be strong enough to overcome the natural decay of the quantum properties, the so-called decoherence. Thus far none of these conditions has been fulfilled. Now a group of researchers around Markus Aspelmeyer at the Institute for Quantum Optics and Quantum Information (IQOQI) of the Austrian Academy of Sciences (ÖAW) demonstrated the second requirement for observing quantum effects: the "strong coupling" regime between a mechanical object and photons. They report their findings in the latest issue of the scientific journal *Nature*.

Coupled motion of Light and Mechanics

Aspelmeyer's group used a mechanical bridge for their experiments: with a width of a twentieth of a millimeter (50 micrometer) and a length of almost a sixth of a millimeter (150 micrometer) it is already visible to the naked eye. A small mirror (50 micrometer diameter) is attached to it such that photons hitting the mirror are reflected and exert a force onto the mechanical bridge. "This is the same radiation-pressure force that we already used in 2006 to demonstrate mechanical laser-cooling", says Aspelmeyer. "To generate the desired strong coupling we use a well-established method from quantum optics: an optical resonator. Because a single reflection of a photon does not exert a sufficiently large force, we reflect the light back and forth between the small mirror and a second, larger mirror, thereby multiplying the force until the photon escapes through one of the two mirrors due to their non-perfect reflectivity." If the number photons in the light beam is too small, however, it still takes too long for the force between the light and the mechanics to build up. In this case decoherence dominates and the light field between the two mirrors oscillates essentially independently of the mechanical motion of the bridge. "For large laser intensities, however, the situation changes dramatically: the energy exchange

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between the light and the mechanics happens faster than the time the photons need to exit the optical resonator and hence the motion of the light and the mechanics becomes coupled."

An opto-mechanical Pendulum

"The situation is analogous to two pendulums, e.g. two grandfather clocks, that are coupled either via a soft rubber band or via a stiff spring", explains Markus Aspelmeyer. "In the first case the pendulums swing independent of each other, whereas in the second case the two systems exhibit a completely new, characteristic oscillation pattern due to the 'strong coupling'". The experiment of the Austrian scientists is the first to show this effect between a massive mechanical pendulum and an optical light field. Up to now this was only possible in the domain of a few atoms or very small quantum systems. The generated oscillations are neither purely optical nor purely mechanical, but rather a real hybrid opto-mechanical excitation, a feature of particular interest for future quantum experiments. "We have clearly found the oscillation pattern of the strongly coupled 'opto-mechanical' pendulum in the energy spectrum of the light leaking out of the optical resonator", Aspelmeyer adds. After this step the researchers now hope that, with the help of additional cooling like the already successfully implemented mechanical laser-cooling, they can soon observe quantum behavior of mechanical objects: "The next goal is to combine the strong coupling with the cooling of the mechanics", says Simon Gröblacher, first author of the Nature-study and Ph.D. student in Aspelmeyer's team. "With this experiment we are on the cusp of being able to test how far into our macroscopic world the laws of quantum physics are valid."

The research results are the outcome of a fruitful collaboration between experimental and theoretical physicists of the Institute for Quantum Optics and Quantum Information: the theoretician Klemens Hammerer from Innsbruck supported the Vienna team lead by Markus Aspelmeyer with the theory of the experiment and the interpretation of the data. The researchers were supported by the Austrian Science Fund FWF, the European Commission and the Foundational Questions Institute (FQXi).

Markus Aspelmeyer was recently appointed Professor for "Quantum Information on the Nanoscale" at the Faculty of Physics of the University of Vienna, Austria.

Pictures can be found at: http://www.iqoqi.at/media/download

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