

Manipulating matter states with quantum light

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Stochastic methods and in particular Langevin equations are often employed to describe processes of thermalization and diffusion of classical motion such as in the famous example of Brownian motion of pollen particles inside a fluid environment. The extension of these methods to the quantum world can be done by employing quantum Langevin equations. We make use of stochastic methods to show how quantum light can be used to read out vibrations of nuclei in molecules or to cool down the motion of photonic crystal mirrors or membranes, close to their quantum ground state.

At the macroscopic level, photon-phonon interactions in opto-mechanics occur via the radiation pressure effect and can be exploited to control the motion of solid-state-based mechanical resonators. A first technique employs the cavity self-cooling effect and can be improved by designing hybrid cavities with photonic crystal mirrors that inhibit re-heating [1]. A second technique employs an electronic feedback loop that can be either analytical (cold-damping) or designed via machine learning methods. Feedback techniques can be successfully applied to the simultaneous cooling of many mechanical resonances, i.e. for the partial refrigeration of a mechanical object subject to an external thermal bath [2].

At the microscopic level, the opto-vibrational coupling occurs in a hybrid fashion as mediated by electronic transitions. When an electronic transition is activated by a photon, the nuclei reorganize themselves into a new configuration leading to vibronic coupling between electrons and nuclear vibrations. This coupling is responsible for the difference in the emission and absorption spectra of molecules and for the FRET (Förster resonance energy transfer between donor and acceptor molecules) widely used nowadays in biomedical research and drug discovery. As recently shown [3], the application of quantum Langevin equations to this system can provide a quantitative description of molecular emission, absorption and FRET donor-acceptor dynamics within the volume of an optical cavity. Moreover, the interaction of one or more molecules with a phononic environment can lead to non-Markovian vibrational relaxation as well as to collective relaxation similar to the phenomenon of superradiance in radiative systems [4].

References

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