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Quantum optics with ultracold quantum gases

As matter influences the propagation of light waves, light can be used to manipulate matter waves. In typical situations as optical traps or cavity QED one of the two effects dominantes. However, confining a cold gas in a high finesse optical resonator creates a novel situation, where particles and photons dynamically influence their motion by momentum exchange on equal footing. The particles create a dynamic refractive index diffracting the light waves, which interfere and in turn form structured optical potentials guiding the particles motion. The ultimate limit of a quantum degenerate gas in an optical lattice inside a cavity represents a key model for quantum optics with quantum gases, where a quantum description of both light and atomic motion is equally important. Due to the dynamical entanglement of atomic motion and light, the measurement of the scattered light detects atomic quantum statistics and projects the many-body atomic state. For a generic case we present an analytical solution for this measurement dynamics valid for macroscopic Bose-Einstein condensates (BEC) with large atom numbers. The theorycan be well applied for optical large optical lattices or even a BEC in a double-well potential [1].
Beyond measurement dynamics we study the selfconsistent light forces on high field seeking atoms between two mirrors. Above a certain threshold illumination intensity the particles order in a regular crystalline structure, where they form ordered periodic patterns with Bragg planes optimally coupling the pump laser into the resonator. At T 0 this model shows a quantum phase transition analogous to the Dicke phase transition and the resulting atomic state exhibits typical characteristics of a supersolid [2].

[1] I. B. Mekhov, C. Maschler, and H. Ritsch, Nature Phys. 3, 319 (2007)
[2] H. Ritsch et. al.,http://arxiv.org/abs/1210.0013

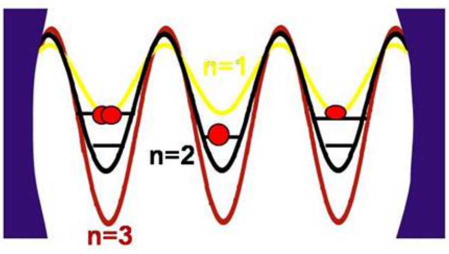

Figure 1: Atoms in a quantum optical potential

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