PhD Thesis Defense SIMON COOP 'Nonlinear Behaviour of Ultracold Atoms in Optical Dipole Traps: Large Atomic Light Shifts, a Quantum Phase Transition, and Interaction-Dependent Dynamics'

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September 06, 2018

Thursday, September 6, 11:00. ICFO Auditorium

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Atomic Quantum Optics

ICFO-The Institute of Photonic Sciences

This thesis reports on theory and results from two experiments related to nonlinear behaviour in ensembles of optically-trapped ultracold atoms.

The first experiment, performed at ICFO in Barcelona, regards the prediction and measurement of strong ac Stark shifts (light shifts). We present a numerical method based on Floquet?s theorem for calculating light shifts to all orders with fewer approximations than the usual calculation based on second-order perturbation theory. The method is experimentally validated by performing absorption spectroscopy of a optically-trapped cloud of cold 87Rb atoms in three scenarios.

1) The atoms are trapped in a singly-polarised monochromatic dipole trap with a wavelength detuned aprox 30nm from the nearest atomic transition.

2) A bichromatic two-polarisation trap, where one wavelength is much closer to atomic transitions (aprox 0:01nm detuning), and finally 3) Another monochromatic trap but with the wavelength variable and scanned close to atomic transitions, again with aprox 0:01nm detuning but three times the intensity of the near-resonant light in the previous experiment, producing nonlinear light shifts of the D2 transition up to aprox 1 GHz. We discuss the potential application of the method to the accurate measurement of electric dipole transition matrix elements. The method is extended to calculate atomic energy level shifts in the presence of light and static magnetic fields.

The second experiment was performed at LENS in Florence, and involves 39K atoms with tunable interactions cooled into the ground- and first-excited state of a two-mode optical potential. We derive a diferential equation to describe behavior of a two-mode quantum system with tunable interactions, and then solve it to model behaviour of the system in the three distinct regimes of attractive, zero, and repulsive interatomic interactions. With attractive interactions the system is shown to exhibit a quantum phase transition, and with repulsive interactions is shown to exhibit nonlinear dynamics, including behaviour analogous to a superconducting Josephson junction.

As background material the thesis presents a summary of standard laser cooling and trapping techniques, namely Doppler cooling, o+ o- polarisation gradient cooling, magneto-optical trapping, and optical trapping. Optical traps are discussed in detail. We discuss relevant basic physics, derive and analyse a technique for using light shifts to characterise an optical trap, discuss optical Bose-Einstein condensation and control of light intensity to reduce noise-induced heating. Also described is a theoretical proposal for optical evaporation with a constant-depth trap.

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