Coherent Manipulations in Ultracold Gases

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The creation of ultracold molecules and molecular Bose-Einstein condensates open the way to study novel collective phenomena and ultracold chemistry. The enormous progress achieved in recent experiments inspired the present theoretical work on new possibilities to coherently manipulate ultracold matter. In the talk, three different proposals for the interaction of lasers with ultracold matter will be presented.

First we propose to create molecules from pairs of ultracold atoms in a tightly confined Bose-Einstein condensate or Mott insulator state by adiabatically crossing an optical Feshbach resonance. This corresponds to tuning both intensity and frequency of a CW laser. Our calculations are performed for ^{87}Rb atoms. We find that for sufficiently tight traps up to 50% of the atom pairs can be transferred to the last vibrational level of the ground state.

An alternative route to the formation of ultracold molecules is given by employing pulsed instead of CW lasers. It has recently been shown that chirped picosecond pulses excite pairs of atoms to an electronically excited state. A molecular wave packet is thus created which is spatially focussed at certain times [1]. This wave packet can be dumped to the electronic ground state by a second laser pulse. We show that if this second pulse is short, the system is reduced to an effective two-level system and adiabatic following conditions can be found. The dump pulse then probes the excited state dynamics as a function of pump-dump delay.

In the two cases, as well as others realized experimentally, the created molecules are translationally cold, but vibrationally highly excited. We therefore propose shaped laser pulses to transfer these excited molecules to their vibronic ground state. Optimal control theory is employed to find the light field carrying out this task. We show that the goal can be reached to within 99% if the initial guess field is physically motivated. The analysis is able to identify the ranges of intensity and pulse duration which are able to achieve this task before other competing processes take place.

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[1] E. Luc-Koenig, R. Kosloff, F. Masnou-Seeuws, and M. Vatasescu, Phys. Rev. A **70**, 033414 (2004). E. Luc-Koenig, F. Masnou-Seeuws, and M. Vatasescu, Eur. Phys. J. D **31**, 239 (2004)