Ultracold Calcium Atoms for Optical Frequency Standards and Cold Collision Studies

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Alkaline earth metals are of special interest for atom-interferometry and for optical frequency standards because of their narrow intercombination lines. Their simple electronic structure with no hyperfine structure and their singlet ground-states makes them ideal candidates for optical clocks and for the study of cold collisions. However, the lowest temperatures that can be achieved using laser cooling on the strong $^1S_0 - ^1P_1$ resonance line are restricted to the Doppler-limit in the order of one millikelvin. Utilizing the $^1S_0 - ^3P_1$ intercombination line for further cooling has been successfully applied to produce ultracold strontium atoms. For the lighter alkaline earth metals this method is not applicable because of the small scattering force due to the smaller linewidths of their intercombination transitions. E.g. in calcium, the maximum scattering force is only slightly bigger than gravity. To overcome this limitation, the method of quench cooling is applied to reduce the lifetime of the upper state of the intercombination transition [1]. With this method calcium atoms are cooled down to a temperature of a few microkelvin.

With the ultracold atoms it will be possible to reduce the uncertainty of the optical calcium frequency standard. E.g. the residual first-order Doppler-effect will be reduced, that was the major source of uncertainty in our latest optical frequency measurement of the calcium intercombination line. The ultracold atoms have been already used in an asymmetric frequency dependent four pulse Ramsey-Bordé interferometer. In contrast to the Doppler cooled atoms the Fourier width of the exciting laser pulses is broader than the Doppler width of the atomic ensemble. This allows almost all atoms to take part in the interferometry. A shelving detection method was applied to the ultracold atoms. In principle this methods allows detection efficiencies close to unity and should lead to a stability of the frequency standard approaching the limit of the quantum projection noise.

With the ultracold atoms we will continue our photoassociation spectroscopy (PAS) measurements. In PAS experiments a bound molecule is formed under the influence of light. PAS can yield information about many atomic properties such as excited states lifetimes, ground state scattering lengths and long range potentials. The lack of hyperfine structure makes the comparison between experiment and theory more simple than in the case of alkali metals where atomic fine and hyperfine structure has to be taken into account. Here we present PAS measurements performed with atoms cooled to the Doppler limit. The detuning of the photoassociation laser ranges from −67 GHz to −1 GHz below the dissociation limit. The relative intensities of the vibrational lines were determined and the rotational structure of the vibrational lines was resolved for large detunings. Both are in good agreement with a full quantum mechanical calculation.

[1] T. Binnewies et al., *Phys. Rev. Lett.* **87** 123002-1 (2001)