Confirmation of Sisyphus cooling in a σ^+-σ^- MOT with spin 1/2 atoms on route to building a lattice clock

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Ytterbium as the quantum absorber for optical lattice clocks has shown remarkable results [1] and is the atom of choice for a number of atomic clock projects[2]. With the goal of participating in future ground-clock to space-clock frequency comparisons we are developing a 1D optical lattice clock based on Yb. On route to building the clock we have produced temperatures for magneto-optically trapped atoms well below the Doppler limiting temperature, T_D = 694μK, by use of the $^1S_0$-$^1P_1$ transition. We use a compact magneto-optical trap (MOT) with 52mm separating the anit-Helmholtz coils and 0.3T/m B-field gradient, plus a two-stage tapered Zeeman slower with a zero crossing. The surrounding chamber is made from titanium and optical components are mounted onto the chamber. There is 80cm distance between the source of effusing Yb atoms and the centre of the MOT, and 12.5cm between the exit of the Zeeman slower and the MOT centre.

The temperatures of the atom cloud have been measured by two means: one where the freely expanding atom cloud is imaged with a CCD and the second by use of the release and recapture (R&R) method. In Fig. 1 we show temperatures as low 260μK and 400μK for ^{173}Yb and ^{171}Yb, respectively; measured using the cloud imaging method. Measurements with R&R are consistent, but have greater uncertainty. Although lower temperatures have been previously produced in Yb using the $^1S_0$-$^3P_1$ transition, we wish to point out that here we have temperatures well below the Doppler limiting temperature for the associated transition. This is significant in the case of ^{171}Yb, which has a nuclear spin of 1/2. For F_g=1/2 the corkscrew cooling mechanism usually associated with the σ^+-σ^- configuration cannot occur [3]. Hence, we conclude that the Sisyphus cooling mechanism is taking place: that which is used to describe sub-Doppler cooling in the 1D $\pi^x\pi^y$ light field configuration. Investigations have predicted that the Sisyphus cooling should occur in 3D σ^+-σ^- MOT arrangements [4,5] and sub-Doppler cooling effects have been seen in Yb previously using the $^1S_0$-$^3P_1$ line [6], but here the temperature for ^{171}Yb is well below T_D, providing further evidence that the Sisyphus cooling mechanism is occurring in σ^+-σ^- type MOTs.

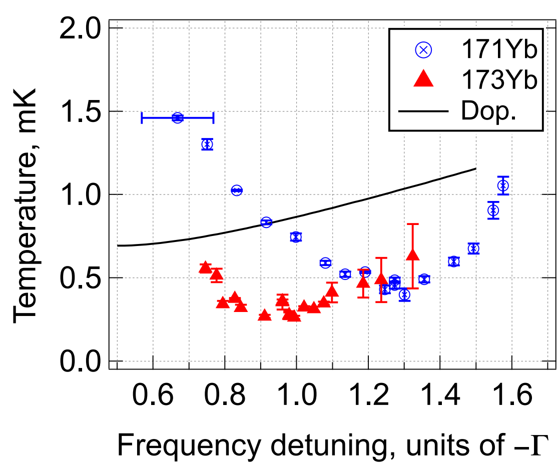

Fig. 1: Temperature versus frequency detuning for ^{171}Yb and ^{173}Yb. The solid line is the prediction from 1D Doppler cooling theory.

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