A Magnesium Optical Clock

J. Friebe, K. Moldenhauer, M. Riedmann, T. Mehlstäubler, G. Grosche*, H. Schnatz*, B. Lipphardt*, E.M. Rasel and W. Ertmer

Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany

*Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The absolute frequency value of the intercombination transition $3^1S_0 \rightarrow 3^3P_1$ of ^{24}Mg was measured with a Ramsey-Bordé beam interferometer. The optical frequency of about 655 THz, generated with a pre-stabilized diode laser with sub-kHz linewidth, was compared with a primary Cs Frequency standard of the PTB via a fiber femtosecond laser. Suppression of first order Doppler effect has been achieved by applying beam reversal technique.[1] With this method we reached an uncertainty of 10^{-11} which is dominated by residual Doppler effect in first and second order.

In the past we have demonstrated[2] a spectroscopic resolution of 290 Hz with cold atoms leading to a short term stability of 10^{-14} in one second. This stability is mainly limited by residual motion of the atoms at temperatures slightly above the Doppler cooling limit at 2 mK. In the case of bosonic Mg it is difficult to advance towards even lower temperatures in the microkelvin range. Standard sub-Doppler cooling schemes are not applicable because of the non-magnetic ground state. We investigated a novel method which is based on a coherent two photon-process which provides higher velocity selectivity. The method extends standard Doppler cooling based on the transition $3^1S_0 \rightarrow 3^1P_1$ by coupling the excited state with an additional laser to the $^1D_2$ level. This gives the possibility to modify the population in the intermediate state 3^1P_1 and thus the mechanical light force, which in our experiments is actually dominated by the photons of the strong cooling transition. The force profile in all three dimensions can be modified with one additional laser beam exciting the $^1P_1 \rightarrow {}^1D_2$ transition. In a 1D molasses configuration temperatures as cold as 500 μK could be realized, which means a reduction of one order of magnitude. This makes the experimental implementation easy, especially in a 3D-MOT. There, temperatures of 1 mK were reached with an additional cooling time of only 1ms and a high transfer efficiency of more than 60%. The observed temperatures could be matched with theoretical predictions by assuming a higher diffusion due to imperfections of the UV laser beams. For eliminated technical heating we extrapolate temperatures of 200 μK and 600 μK in the 1D molasses and MOT configuration respectively. Our model, indicates that the lifetime of the upper state limits the achievable temperature which is restricted in the present case to about 50 μK.

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1 A. Morinaga, F. Riehle, J. Ishikawa, J. Helmcke, "A Ca Optical Frequency Standard: Frequency Stabilization by Means of Nonlinear Ramsey Resonances", Appl. Phys. B **48**, 165 (1989)

2 J. Keupp *et al.*, "A high-resolution Ramsey-Bordé spectrometer for optical clocks based on cold Mg atoms", Eur. Phys. J D **36**, 289 (2005)