Sympathetic cooling in two-species atomic clock

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Multi-species atomic clocks attract significant interest due to the potential for improving their accuracy and stability using multiple elements. The frequency stability of multi-species optical clocks may be enhanced through simultaneous measurements performed on multi-species ensembles of many atomic absorbers. Improving frequency accuracy could involve leveraging atoms with two reference transitions exhibiting different sensitivities to external fields. An example here could be a mercury atom[1]. Utilizing of multi-component systems as the basis for atomic clocks requires precise measurements of their mutual interaction. One of the significant consequences of the mutual interaction between components is sympathetic cooling, which can lower the temperature of one of the components, thereby permitting longer coherent laser-atom interaction times and, consequently, shorter averaging times.

In this study, we conducted measurements to evaluate the sympathetic cooling effect in a two-species system within a double Rb-Hg magneto-optical trap setup[2]. Since the Doppler cooling limit for mercury (30.5 μK) is lower than that for rubidium (145 μK), we measured the temperature of rubidium to assess the performance of sympathetic cooling. The temperature of the Rb cloud was determined both in the presence of a cooled Hg atomic cloud and in its absence, and the results were then compared. While the absence of structure splitting in the ground state of Hg bosons prevents the application of sub-Doppler cooling methods, the ^{87}Rb isotope used in the experiment can be sub-Doppler cooled below the Doppler limit.

To determine the temperature of the cooled Rb atomic cloud, we employed a measurement method involving the observation of the cloud's size during its ballistic expansion in free fall after turning off the trapping potential, including both magnetic field and cooling laser beams. Subsequently, we tracked the spatiotemporal evolution using a fluorescence imaging technique assisted by a probe laser beam. The temperature of the Rb cloud, obtained from fitting the data to the ballistic expansion equation, indicates a reduction from 149(6) μK to 87(2) μK. These findings demonstrate a significant sympathetic cooling effect in the Rb-Hg double MOT system.

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[1] M. Witkowski et al., "New physics searches with isotope shifts of two Hg clock transitions," in 2022 Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS), April 24-28, 2022, Paris, France: proceedings, doi: 10.1109/eftf/ifcs54560.2022.9850819.

[2] M. Witkowski, et al., "Dual Hg-Rb magneto-optical trap," Opt. Express, vol. 25, pp. 3165–3179, (2017).