Application Note

Magneto-optical trapping of mercury to search for physics beyond the standard model

T. Groh, Q. Lavigne and S. Stellmer, Institute of Physics, University of Bonn, Germany (August 2021)

Introduction

A large share of today's physics research is devoted to searches for so-called physics beyond the standard model: new particles, new forces or yet undiscovered symmetries that might help us to explain some of the largest contemporary mysteries: how did the Universe evolve, what is the nature of dark matter and dark energy? In the realm of atomic physics, many of these beyond-standard-model phenomena increase dramatically with increasing charge Z of the nucleus: that's why it is favorable to use a very heavy atom.
Mercury is the heaviest element with stable isotopes that can be laser-cooled. The technique of laser cooling (Nobel Prize 1997) allows to reduce the temperature of a gas of atoms to about a millionth of a degree above absolute zero. At this temperature, the atoms come to a standstill, which is highly beneficial for precision spectroscopy. Thus far, laser-cooled mercury has been employed for optical lattice clocks, but not for fundamental physics research or ultracold quantum gases. Here, we show how laser cooling of mercury can be improved substantially.

Experiment

We operate a magneto-optical trap (MOT) of mercury on the 1S0 – 3P1 transition. This line has a width of 1.3 MHz, which allows for convenient trapping of atoms from the background gas. This transition is at a wavelength of 254 nm, and we employ a frequency-quintupled laser system to reach this UV wavelength. We are able to trap up to 100 million atoms at a temperature of about 100 μK. Fig. 1 shows an absorption image of a magneto-optical trap.

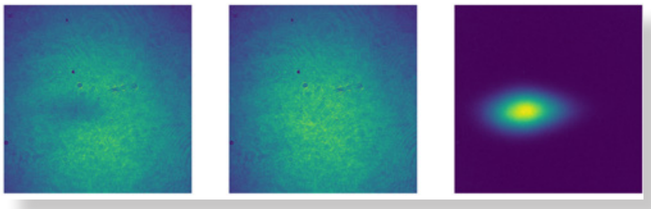

Fig. 1: Absorption image of a cloud of about 100 million atoms of mercury, cooled to a temperature of about 100 μK. Left: A shadow of the atomic cloud is imprinted on a laser beam. Center: An image of the same beam without the atoms. Right: Calculating the difference between these two images removes all inhomogeneities and enhances the visibility of the atomic cloud tremendously.

Such images allow us to precisely determine atom number and temperature; see Fig. 2.

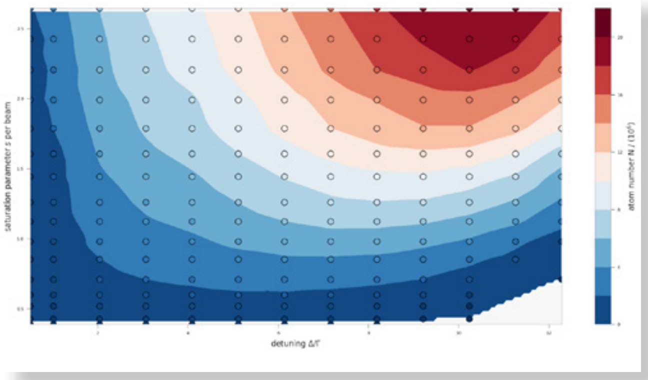

Fig. 2: Optimizing laser cooling: A detailed study of the MOT atom number on the intensity of the laser beams and on their detuning from the resonance. Highest atom numbers are obtained at peak intensities of a few times the saturation intensity and a detuning of about 10 atomic linewidths.

For these measurements, we employ two iXon3 DU885 KCS-VP EMCCD cameras from Andor, which have a high quantum efficiency at 254 nm, very low read-out noise, and a reasonable detector size.
These laser-cooled atomic samples can then be used for precision measurement. As an example, we perform isotope shift measurements on various optical transitions, with uncertainties on the order of a few kHz. These allow us to constrain parameter ranges for hypothetical light bosons that could provide a Yukawa-type coupling between neutrons and electrons.

Contact

Prof. Simon Stellmer
Quantum Metrology
Institute of Physics
University of Bonn
Nussallee 12
53115 Bonn
Germany

Mail: stellmer@uni-bonn.de
Web: http://www.quantum-metrology.uni-bonn.de/