Optical pumping and population transfer for the measurement of the clock transition excitation probability in thulium atoms

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An essential aspect of experiments with quantum systems is the overall control of their states. In our laboratory we conduct experiments with thulium atoms. Their inner-shell 4f transition between fine sublevels of the ground state is well shielded from external electric fields, what makes this transition suitable for using in an optical frequency standard. In P.N. Lebedev Physical Institute we have successfully laser-cooled thulium atoms to temperatures of about 10 K [1], performed direct excitation of the clock transition and experimentally determined optical lattice magic wavelength [2, 3]. At this point it is necessary to improve our ways of excitation and measuring number of excited atoms, and in this work we demonstrate some of the solutions we applied.

To begin with, in our experiments we use $|m_F = 0\rangle \rightarrow |m'_F = 0\rangle$ component of the 1.14 m clock transition, which has several advantages. First of all there is no linear Zeeman shift. Also, the shift due to vector polarizability as well as the shift caused by magnetic dipole-dipole interaction is equal to zero. To improve the signal to noise ratio, we are to prepare as many atoms in the initial $|m_F = 0\rangle$ state as possible. This can be done using a method of optical pumping. The main idea of this technique is using so-called "dark states" — states, in which atoms cease to interact with light. For example, in case of a linearly polarized light, exciting the transition between levels with $F = F'$, the state with $m_F = 0$ is dark, and due to spontaneous decay atoms begin to accumulate in this state. To implement this method, we have chosen the transition at 418.8 nm, which we can excite with the second harmonic of a CW Ti:Sa laser. Optimal parameters, such as intensity and frequency detuning of pumping radiation, magnetic field, and pumping duration were determined using both numerical simulations and experimentally, which allowed to pump approximately 60% of the trapped atoms to a central magnetic sublevel. The reason of the reduced efficiency is the atom heating during the pumping which leads to losses.

With a significant number of atoms on the $|m_F = 0\rangle$ sublevel, we can move to the improvement of the measurement techniques. In the works [1, 3, 2], the primary way to estimate excitation probability was measuring the number of atoms in the ground state after the excitation. This requires accumulating data to average fluctuations in the total number of trapped atoms. The problem can be overcome by measuring the number of excited atoms simultaneously. It can be achieved using an additional short-lived level coupled to both clock levels. After measuring the number of non-excited atoms, the population from the higher clock level can be moved through this intermediate level to the ground state, and measured. A suitable transition at 402 nm was found and its hyperfine splitting was measured. Experiment on the repumping atoms from the excited to the ground state demonstrated applicability of this method and proved that it can be used in further experiments.

Both these techniques are implemented and being used in current experimental setup. They helped to reduce the time required to accumulate statistics and raise the quality of a single measurement. This allowed us to start works on the laser stabilization to the clock transition in thulium atoms, what is the next step on the way of building thulium optical clock.

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References

[1] *Sukachev D.D., Kalganova E.S., Sokolov A.V., Fedorov S.A., Vishnyakova G.A., Akimov A.V., Kolachevsky N.N., Sorokin V.N.*, Secondary laser cooling and capturing of thulium atoms in traps. Quantum Electronics, **44**(6), P. 515 – 520, (2014).

[2] *Golovisin A.A., Fedorova E.S., Tregubov D.O., Sukachev D.D., Khabarova K.Yu., Sorokin V.N., Kolachevsky N.N.*, Inner-shell clock transition in atomic thulium with a small blackbody radiation shift. Nature communications, **10**(1), P. 1724, (2019).

[3] *Golovizin A.A., Kalganova E.S., Sukachev D.D., Vishnyakova G.A., Semerikov I.Y., Soshenko V.V., Tregubov D.O., Akimov A.V., Kolachevsky N.N., Khabarova K.Y., Sorokin V.N.*, Detection of the clock transition (1.14 m) in ultra-cold thulium atoms. Quantum Electronics, **45**(5), P. 482, (2015).