The setup for laser cooling and trapping of calcium atoms

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Abstract. We have assembled the experimental setup for laser cooling and trapping of calcium atoms in a magneto-optical trap. As a part of this setup on air-cooled Zeeman slower for calcium atomic beam was developed. By using the atomic beam we recorded the resonance of fluorescence. The spectral width of the resonance 58.6 MHz is comparable with the natural width of cooling transition 4s$^{2}S_{0}^{-}4s4p^{1}P_{1}$.

1. Introduction
Our research of ultracold plasmas and ultracold gases of Rydberg atoms [1–3] are important for fundamental physics and applications in modern quantum technologies. Calcium is of particular interest in connection with the possibility of recording ions in the optical range, it can be used for the study of nonideal plasma. The study of cold atoms in Rydberg states can be used for the development of quantum computer science [4]. Our work is focused on researching Rydberg atoms and ultracold plasma of alkali and alkaline earth metals. Our group conduct experiments on registration Rydberg state of cold lithium atoms in a magneto-optical trap (MOT) [5,6]. Now we have assembled a setup for trapping calcium atoms in MOT. We have created two hot quartz cells with cold windows for frequency stabilization of cooling laser by the Doppler-free absorption resonances [7]. Calcium is an alkaline earth metal and after ionization, there is still one valence electron with strong optical transitions. This will make it possible to diagnose calcium plasma.

2. Experimental setup and results
The first step in the creation and trapping of ultracold calcium atoms in MOT is an assembly of the setup and preparation a deep vacuum. The picture of setup is shown in figure 1.

The experimental setup consists of a vacuum system and an optical part. We developed an oven (atomic beam source) in which a piece of metallic calcium is evaporated at a temperature of 450–500 °C. An oven consists of a reservoir for a metallic calcium and thin tube for collimating the atomic beam. We developed a heating system to create a certain gradient of temperature along the thin tube by high-temperature heater tapes. We control the temperature of an oven with the help of five thermocouples. Calcium atoms are sent from an oven to the MOT through a Zeeman slower where the first step of cooling takes place by using counter-propagating a two-component laser beam: a cooling laser radiation 423 nm and a pump laser radiation 672 nm. The energy level diagram for a neutral Ca atom is shown in figure 2. We need to use pump laser to avoid the relaxation of atoms to the metastable states 4s4p$^{3}P$. The electron has a lifetime.
of about 0.5 ms in a metastable state [8]. Then we will trap calcium atoms in MOT by laser beams directed from six sides.

The first step is the development and creation of a Zeeman slower for calcium. The Zeeman slower consists of six coils with a decreasing number to create an inhomogeneous magnetic field along the axis. Atoms move along the Zeeman slower and absorb resonance counter-propagating laser radiation with a transition frequency $4s^{21}S_0—4s4p^1P_1$. The absorption of this photon brings the atom to it is excited state. In 4.6 ns (lifetime of level $4s4p^1P_1$ [9]) the atom decays back to the ground state via spontaneous emission. After reducing the atomic velocity, the resonant frequency of the atomic transition changes due to the Doppler effect $kv$. We use a method based on the Zeeman effect $\mu_B/(\hbar B)$, in which the frequency of the atomic transition is adjusted by a magnetic field at each point of the Zeeman slower:

$$kv(z) = \frac{\mu_B}{\hbar} B(z),$$

where $k$ is wavevector, $v(z)$ is the velocity of atoms at a point $z$, $\mu_B$ is Bohr magneton, $\hbar$ is reduced Planck constant, $B(z)$ is magnetic flux density at a point $z$.

It is necessary to create a deep vacuum in the system to cooling and trapping atoms in MOT. Before pumping, the vacuum part of the setup was baked and degassed at 300 $^\circ$C for one week. We used rotary and turbomolecular pumps for a first step preparation of vacuum. When we created a vacuum about $10^{-5}$ Torr we got the opportunity to turn on ion and ion-getter pumps with a pumping speed of 100 l/s. This combination of vacuum pumps allowed a vacuum of better than $10^{-10}$ Torr. Such pressure in the system is sufficient to realize of the Bose–Einstein condensate.

Getting a vacuum made it possible to conduct an experiment on observing the beam of calcium. The observed the fluorescence of an atomic beam by resonance laser radiation 423 nm shown in figure 3.

The laser-radiation wavelength was scanned around the frequency of the atomic transition of $4s^{21}S_0$ to $4s4p^1P_1$. The radiation was recorded using a photomultiplier. The width of the fluorescence resonance is 58.6 MHz, which is comparable to the natural width of the calcium line 34 MHz [9]. The narrow width of the resonance indicates that the calcium beam emanating from the oven is collimated. This resonance can be used to stabilization of laser frequency for the preparation of MOT beams.
3. Conclusions
Was built up the setup for laser cooling and trapping calcium atoms. A deep vacuum of better than $10^{-10}$ Torr was obtained. Zeeman slower for calcium was developed and assembled. The oven for the preparation of the atomic beam was constructed and the resonance of fluorescence of the atomic beam with width 58.6 MHz was observed.
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