# Evaluation the Number of Atoms in Conical Magneto-optical Trap

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***Abstract* — Compact and robust magneto-optical trap (MOT) with simple design has obvious advantage in the development of atomic sensors. One of the key elements of atomic fountains is a cold-atom source. We have developed and investigated the conical magneto-optical trap as a source of slow atoms.**

***Keywords— metrology, time and frequency standard, atomic fountain, cold atoms, conical trap.***

## I. Introduction

One of the key elements of atomic fountains is a cold-atom source. For convenience the source should be simple, reliable and robust with a high flux of loaded atoms [1]. While maintaining the same measurement accuracy on the rubidium fountain, a higher atom flux makes allows to reduce the time of the measurement cycle of the fountain and improve the signal-to-noise ratio. We have developed and investigated the conical magneto-optical trap as a source of slow atoms [2]. This source has a relatively simple construction, since it has a single laser beam to produce the optical fields required for laser cooling and easy vacuum chamber ("Fig. 1"). Moreover, the number of trapped atoms in the conical MOT are comparable with conventional MOTs.

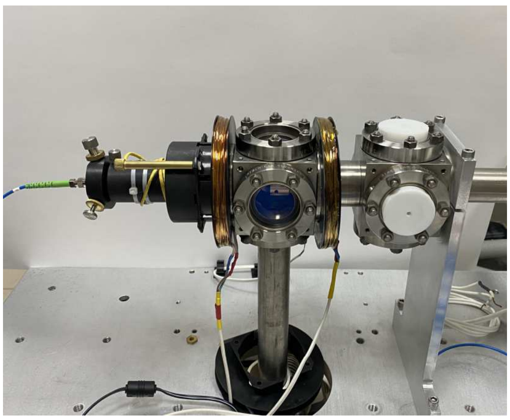

Fig.1. The source of slow atoms with the conical mirror reflector.

## II. Evaluation the number of trapped atoms

The variation of the number of atoms in the MOT is described by the expression:

$$\frac{dN}{dt} = R - \frac{N}{\tau}, \quad (1)$$

where $N$ is the number of atoms in the trap, $\tau$ – is the lifetime of atoms in the MOT, $R$ – the loadings rate of atoms. This equation neglect losses resulting from two-body collisions between atoms in the trap, since in our model this contribution is relatively small and not significant.

Solving this equation and assuming $N(0) = 0$, we obtain:

$$N(t) = N_{ss}(1 - e^{-\frac{t}{\tau}}), \quad (2)$$

where $N_{ss}$ is the steady-state number of atoms. In [3] have shown that the steady-state number of atoms in the trap is given by:

$$Nss = R\tau = \frac{1}{\sqrt{6}} \frac{V^{\frac{2}{3}}}{\sigma} \vartheta_c^4 \left(\frac{m}{2k_BT}\right)^2, \quad (3)$$

where $\vartheta_c$ – velocity for an atom to be captured by the trap, $V$ is the trapping volume and $\sigma$ is the cross section for collisions between trapped atoms and background Rb atoms. Thus, in order to predict the number of atoms in the trap, it is necessary to know the capture velocity $\vartheta_c$ and the surface area of the trapping region.

We have developed a model of the atoms behavior in a conical trap. This model calculates the scattering forces on the individual atoms as they interact with the magnetic and optical fields. Due to the simulation, we got the typical value for the capture velocity $\vartheta_c$~15 m/s for Rb. Applying a value for the radius of the laser beam r = 2 cm and assuming $\sigma = 3\cdot10^{-13}$ cm$^2$ for Rb [4], we obtain the number of atoms in N = 2,6 $\cdot10^7$ in the conical MOT. A photo of a trapped rubidium atoms is presented in the "Fig. 2".

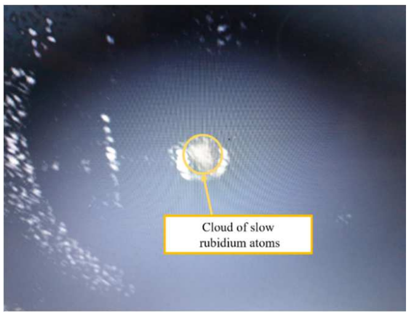


Fig.2. The cloud of trapped rubidium atoms in the conical MOT.

## III. EXPERIMENTAL RESULTS

We used the MOT as a source of slow atoms. For this, a

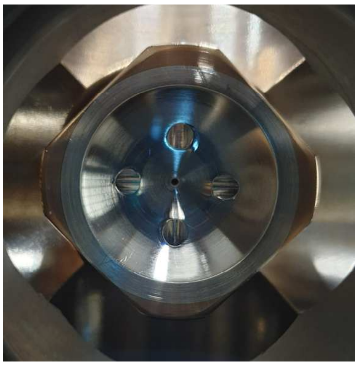

Fig.3. The conical mirror reflector in a vacuum chamber. Because of the four holes in the reflector, the cloud of trapped atoms is observable and controllable.

small hole with a diameter about 1 mm is made at the apex of the reflector (“Fig. 3”).

In this case, atoms are first captured in the trap and then pushed through the hole at the apex of the reflector due to the resulting imbalance in the intensity of laser radiation. During the experiment, a photodetector was mounted on the upper window of the detection section of the MOT. The detection beam, detuning at frequency from the resonance transition $5^2S_{1/2}$ F=2 → $5^2P_{3/2}$ F’=3 $Rb^{87}$ at 140 kHz, passed through the transverse window of the detection section. Thereby detection laser beam was directed transversely through the atomic beam and detected on a photodiode.

In order to observe the cloud of cold atoms, we used two additional magnetic coils, which were located along the vertical axis of the source and drived from two independent current sources. By moving the field-minimum position of these coils within the hollow region we could move the trapped atoms therein, shifting it from the horizontal axis of

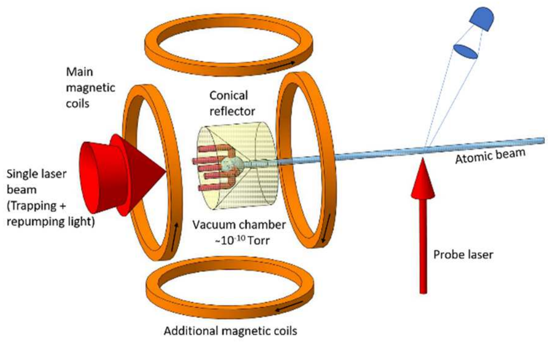


Fig. 4: Sketch of the experimental setup.

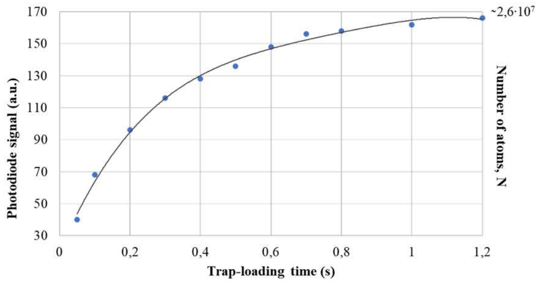


Fig.5. Measured time dependence of the number of atoms in the conical MOT.

the source, along which B = 0. At the same time, we observed a decrease in the fluorescence signal in the detection section and a more intense atomic flux.

The flux of an atomic beam was determined from the fluorescence signal. For a cold-atom beam travelling with mean velocity $\vartheta_z$ through a resonant probe laser with diameter $\Delta z$, the integrated atom flux $\Phi_{flux}$ is given by [5]:

$$\Phi_{flux} \sim \mathcal{J}\,\frac{4\pi}{d\Omega}\frac{\vartheta_z}{\Delta z}\left(\frac{\Gamma}{2}\frac{S_0}{1+S_0}\right)^{-1}, \qquad (4)$$

where $\mathcal{J}$ is the photodiode signal (a.u.), $d\Omega$ – collection solid angle, $S_0 = I/I_{sat}$ is the saturation parameter for the probe laser, $\Gamma$ is the natural linewidth of the atomic transition. The obtained experimental data are shown in the Fig. 5.

## IV. CONCLUSION

We have demonstrated a compact magneto-optical source for rubidium atoms. The estimated number of trapped atoms in the conical region of the MOT was $N = 2{,}6 \cdot 10^7$. The main characteristics of the atomic beam were measured, the mean velocity of atomic flux is $v_{mean}$ = 10,9 m/s. Due to its relative simplicity, controllability and compactness, a magneto-optical trap, using a single laser beam, realized in a conical configuration can become a useful tool for atomic fountains and other atomic sensors. The obtained results prove that the conical MOT can be successfully used on the atomic fountains.

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