I. 6. Study of the Magneto-Optical Trap Using Rubidium with a Glass Cell*

Aoki T.[1], *Ando S.*[1], *Arikawa H.*[1], *Ezure S.*[1], *Harada K.*[1], *Hayamizu T.*[1], *Inoue T.*[1,2], *Ishikawa T.*[1], *Itoh M.*[1], *Kato K.*[1], *Kawamura H.*[1,2], *Uchiyama A.*[1], and *Sakemi Y.*[1]

[1]*Cyclotoron and Radioisotope Center, Tohoku University*
[2]*Frontier Research Institute for Interdisciplinary Sciences (FRIS), Tohoku University*

Our final goal is to measure the permanent electric dipole moment (EDM) which violates the time reversal symmetry directly. To trap francium (Fr) atoms in a magneto-optical trap (MOT) is a needed process in our plan of the search for the electron EDM[1)].

There are technical issues to trap Fr atoms in MOT. One of them is that the fluorescence from the trapped Fr atoms might be too weak to observe even if Fr was trapped in our setup. This issue requires the optimization of experimental parameters to observe a small number of trapped atoms. The optimization experiment prefers an element whose properties are well-known. Rubidium (Rb), which has stable isotopes, is easy to measure its atomic frequencies and to trap it. Moreover, Rb atoms can be used for the equipment development instead of Fr atoms because Rb has similar chemical properties to Fr.

The experimental setup is shown in Fig. 1. This experiment used ^{87}Rb. Since we concentrated on searching for the optimum parameters that are required for the observation of a small number of trapped Rb atoms by a CCD camera, Rb dispenser providing neutral Rb atoms stably was utilized. Thanks to the dispenser, the ion production, transportation, and neutralization are not required. The amount of supplying Rb atoms can be adjusted by applying current on the dispenser. A glass cell for MOT is made from quartz. Both inner and outer walls of this cell were originally coated with an anti-reflection coating. The inner wall was washed with what we call “piranha solution”

---

[*]Condensed from the article in Proceedings of 7th International Workshop on Fundamental Physics Using Atoms 2014 (FPUA2014)

and was coated with octadecyltrichlorosilane (OTS). OTS is used to prevent from sticking Rb atoms on the glass surface.

The trapped Rb atoms were observed by a CCD camera. The number N of trapped atoms is estimated by the following equation:

$$N = \frac{P}{\hbar\omega} \cdot \frac{1 + 6(I/I_s) + (2\delta/\gamma)^2}{6(I/I_s)(\gamma/2)} \cdot \frac{4R^2}{r^2}, \qquad (1)$$

where P is the intensity of fluorescence from trapped Rb atoms, $\hbar\omega$ is the energy of the fluorescence originating from trapped Rb atoms, I is the intensity of trapping laser per unit area, I_s is the saturation intensity per unit area, δ is a detuning of trapping laser, γ is a natural line width of F = 3 of $P_{3/2}$ level, R is a distance between trapped area and a CCD camera lens, and r is a radius of a CCD camera lens. There are 6 trapping beams for MOT and this is the reason why we multiply I/I_s by 6. The image brightness was calibrated by reference laser and was converted to watt that is used for Equation (1).

The parameters of this experiment were the following: I/I_s=1.16, $\hbar\omega$=1.61 eV, δ=20 MHz, γ=6.06 MHz, R=50 mm, and r=25.4 mm. Using these parameters, the fluorescence originating from one atom was estimated at approximately 6.0 fW. The exposure time of the CCD camera was 500 ms and the applying current to the Rb dispenser was 3.5 A.

The photograph indicating the weakest fluorescence taken in this experiment is shown in Fig. 2. The brightness of this fluorescence was estimated at 6.5±0.60 fW. This value corresponds to the calculated value of the fluorescence from one Rb atom. We were able to observe the small number of trapped Rb atoms by a CCD camera.

This work was supported by Grants-in-Aid for Scientific Research (Nos. 21104005 and 25610112) and Tohoku University's Focused Research Project. We acknowledge Furumoto S. and the staffs of Division of Radiopharmaceutical Chemistry for help of the OTS coating.

References

1) Sakemi Y., et al., *J. Phys. Conf. Ser.* **302** (2011) 012051.
2) Mukherjee D., Sahoo B.K., Nataraj H.S., Das B.P., *J. Phys. Chem.* A **113** (2009) 12549.
3) Sandars P.G.H., *Phys. Lett.* **22** (1966) 290.
4) Nataraj H.S., Sahoo B.K., Das B.P., Mukherjee D., *Phys. Rev. Lett.* **101** (2008) 033002.
5) Simasarian J.E., et al., *Phys. Rev. Lett.* **76** (1996) 3522.
6) Ishikawa T., et al., *FPUA2014 proceedings*.

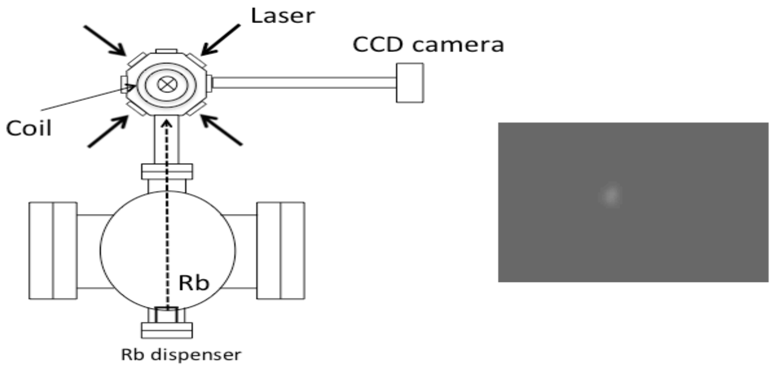

Figure 1. Experimental setup. This setup is used to neutralize ions and to trap neutral atoms[6)]. The right figure is the photograph of the fluorescence from approximately 2000 Rb atoms captured by the CCD camera.

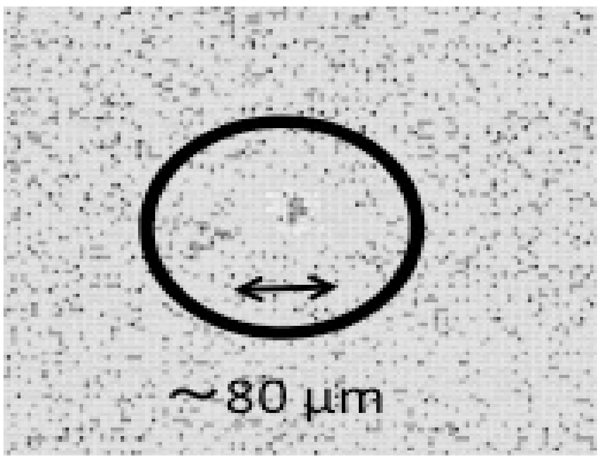

Figure 2. This photograph indicates the fluorescence corresponding to one Rb atom. The Rb atoms should be trapped in the area surrounded by a circle.