I. 8. Present Status of the Magneto-Optical Trap System for Trapping Rare Radioactive Francium Atoms

Harada K.[1], Ezure S.[1], Kato K.[1], Hayamizu T.[1], Kawamura H.[1,2], Inoue T.[1,2], Arikawa H.[1], Ishikawa T.[1], Aoki T.[1], Uchiyama A.[1], Itoh M.[1], Ando S.[1], Aoki T.[3], and Sakemi Y.[1]

[1]*Cyclotron and Radioisotope Center, Tohoku University*
[2]*Frontier Research Institute for Interdisciplinary Sciences, Tohoku University*
[3]*Graduate School of Arts and Sciences, University of Tokyo*

It is widely recognized that the nuclear spin independent atomic parity nonconservation (APNC)[1)] provides the signature of parity-reversal (P) violation and the permanent electric dipole moment (EDM)[2)] provides the signature of simultaneous violation of P and time-reversal (T). They are sensitive tools for exploring the new physics beyond the standard model of elementary particles. Although the signals induced by these effects are extremely small, several theories predict that both signals are enhanced by total number of protons Z in an atom due to the large effective electric field and are proportional to Z^3.

The electron EDM (eEDM) measurement using thorium monoxide (ThO) molecules[2)] is well known as the most precise measurement. The upper limit of eEDM obtained from the experiment is 8.7×10^{-29} *e*cm. The interaction time between ThO molecules and the external electric field applied by the plates whose length is about 22 cm is almost 2 ms due to the effect of buffer gas cooling technique. The greatest benefit of the experiments using ThO molecules is that the internal effective electric field E_{eff} can be much higher than that in atoms. However, in the atomic or molecular beam experiment the significant systematic effects are caused by the motional magnetic field and by the geometric phase shifts generated by complicated field gradients. These systematic errors mimic the true EDM signal and limit the accuracy of measurement of atomic EDM.

Neutral francium (Fr), being the heaviest alkali atom (Z = 87), trapped by laser lights is one of the best candidates for investigating the violation of fundamental symmetries. The APNC signal in Fr atom is 18 times larger than that of the cesium atom[3)] and the enhancement factor of Fr atom for eEDM is 895[4)]. Moreover, the velocity of atoms is drastically low when they are laser cooled and trapped. Therefore, the systematic errors are strongly suppressed and the interaction time is elongated to a few seconds, which is much longer than that of the conventional atomic and molecular beam experiments. Thus, there are several advantages of using optically cooled and trapped Fr atoms for the measurements.

We report the current status of the experimental apparatus for trapping Fr and rubidium (Rb) atoms at Cyclotron and Radioisotope Center (CYRIC), Tohoku University. As Rb has similar chemical properties to that of Fr and is a stable atom, we utilized Rb for the alignment of entire experimental setup. In the laser experimental room (Lab A), we have developed the laser light sources and its frequency stabilization for magneto-optical traps (MOT) of Fr and Rb atoms are performed[5)]. We use an external cavity laser diode tuned to the $5S_{1/2} \rightarrow 5P_{3/2}$ D2 transition for the trapping light of ^{87}Rb atom. The frequency stabilization for Rb MOT is performed by the frequency modulation spectroscopy using Rb reference cell. On the other hand, as a trapping light source for ^{210}Fr, we employed a single frequency Ti:Sapphire laser light source, tuned to the $7S_{1/2} \rightarrow 7P_{3/2}$ D2 transition of the Fr atom at 718 nm. We use iodine molecules for the frequency stabilization and monitor of Fr MOT as there are no stable isotopes of Fr. We have also developed the double Rb MOT system to investigate the characteristics of loading and decay of atoms in MOT. The investigation is essential to transport rear radioactive atoms efficiently and rapidly to an ultrahigh vacuum region for the APNC and eEDM measurements. Further, we have observed the fluorescence from a single Rb atom trapped in MOT using the lens system composed by four spherical lenses because the probability of getting large number of Fr atoms for being trapped in MOT is less at first. Also an optical dipole trap (ODT) experiment using Rb atoms for the pilot studies of the measurements has been achieved[6)]. A lot of apparatus and techniques described above have been developed.

In the Lab B, which is in the radiation controlled area, we have constructed MOT system with the neutralizer of yttrium (Y) for Fr and Rb ions as they are transported through the beamline as ions from the production area[5)]. The detailed setup is shown in Fig. 1. Optical fibers whose length is 150 m are laid between the Lab A and the Lab B, which transports the laser lights. We performed MOT experiment using Rb atoms before trying it out for Fr atoms. The number of Rb ions coming from the production area was 9.4×10^{10} ions/s. The number of atoms trapped was estimated to be 10^6 (inset, Fig. 1). The fluorescence from neutralized Rb atoms trapped in MOT has been successfully observed using this system.

We have developed the laser light sources, the frequency stabilization system and the MOT system for trapping Fr atoms at the 51 course beamline. We then would like to observe the fluorescence from Fr atoms trapped in MOT. After optimization of Fr MOT, especially the number of atoms, we will perform an ODT experiment, and then APNC and EDM measurements using cold Fr atoms.

References

1) P. A. Vetter, et al., Phys. *Rev. Lett.* **74** (1995) 2658.
2) The ACME Collaboration, J. Baron *et al.*, *Science* **343** (2014) 269.
3) V. A. Dzuba, et al., *Phys. Rev.* A **51** (1995) 3454.
4) D. Mukherjee, et al., *Phys. Chem.* A **113** (2009) 12549.
5) K. Harada, et al., *Proc. Conf.* ARIS2014 (to be submitted).
6) T. Hayamizu, et al., *JPS Conf. Proc.* **1** (2014) 013065.

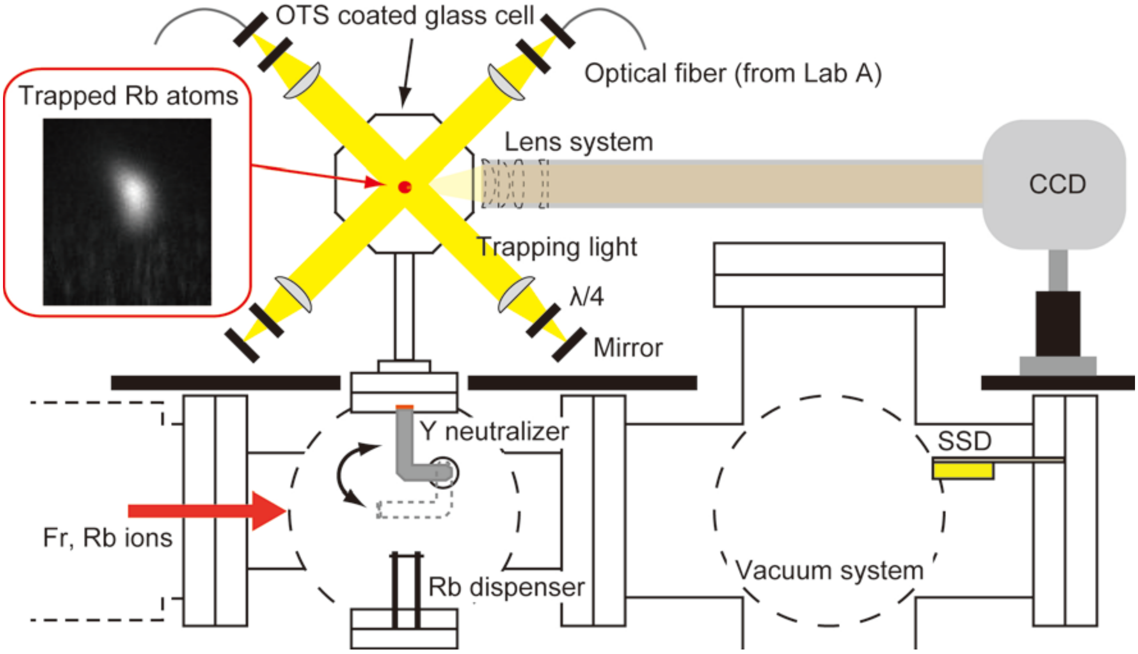

Figure 1. Experimental setup in the lab B. The optical fibers of 150 m length are laid between the labs to carry the laser lights. The laser lights which are exchanged between 718 nm and 780 nm wavelengths by a flipper mirror were transported to the lab B for trapping Fr or Rb atoms. Inset: Photograph of the fluorescence from Rb atoms trapped in MOT.