I. 5. Development of a New Rubidium Ion Source for the Study of a Francium Neutralizer

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The existence of a non-zero electric dipole moment (EDM) of an elementary particle is one of the direct signal for CP-violation that means also T-violation under the CPT theorem. The Standard Model (SM) predicts a very small electron-EDM value, $|d_e|<10^{-37}$ $e\cdot$cm. However, the Super Symmetry model, which is one of the candidates beyond the SM, predicts so large value that can be observed by the current experimental techniques. Owing to the small contributions from the SM, an EDM is a quite sensitive probe to search for physics beyond the SM.

In a paramagnetic atom, an e-EDM enhancement factor increases with atomic number Z[1]. We choose francium (Fr, Z=87) which is the heaviest alkali element and has the enhancement factor~895[2]. Our measurement precision of the EDM can be finally reached to $|d_e|\sim10^{-28}$ e$\cdot$cm. This value is around ten times smaller than the current experimental e-EDM limit obtained in Tl experiment with $|d_e|\sim10^{-27}$ e$\cdot$cm[3].

Unfortunately, ^{210}Fr which is used for the EDM search in this project is a radioactive isotope with a half-life of 3.18 min. However, this is sufficiently long to extract, transport and trap the Fr in the magnet-optical trap (MOT) to measure the EDM. Now, we are developing a Fr factory at Cyclotron and Radioisotope Center in Tohoku University.

The fusion reaction ^{18}O+^{197}Au is employed to produce ^{210}Fr isotope. The francium is extracted and transported as an ion. As we need to trap the Fr as neutral atoms in the final stage, the ion beam must be neutralized and must be slowed down to milli-kelvin order. At present the development of a slow atomic beam system which contains a neutralizer, a transverse cooling system and a Zeeman slower is ongoing. Here, we discuss a new

Rubidium (Rb) ion source used for the development of the system.

The Fr can be produced by the nuclear fusion reaction with the primary beam energy just above the Coulomb barrier supplied from the AVF cyclotron with K=100. Therefore, we need to operate the cyclotron, if we use the Fr beam to perform the test experiment for the neutralizer. To minimize the use of the cyclotron, Rb, whose chemical property is very similar to Fr except for its mass number can be utilized. Therefore, the Rb Ion Source was developed for offline test experiments.

The principle of this ion source is based on surface ionization that is described by the Saha-Langmuir equation[4]. The ratio of the emitted ion and atom from a target depends on the work function of the target material and the ionization potential of the beam. In addition, a high temperature is important for efficient extraction. From these properties, molybdenum (Mo) is chosen for the target. Its work function 4.6 eV is higher than the ionization potential of Rb (4.2 eV) and Fr (4.0 eV). Its melting point 2896 K is high enough to avoid melting.

Rb atoms are supplied from a Rb ampoule by a thermal process, and are ionized on the surface of the heated Mo target by the thermal ionization. A few kV positive voltage is applied to the target, and then Rb ions are extracted by its potential.

The base of this ion source is the prototype of our Fr thermal ionizer[5]. To improve the beam intensity, two major upgrades were applied[1]. To keep the temperature of about 1300 K stably for a long time, the oven heater was changed from a cartridge heater to a Mo plate heater[2]. To achieve a more efficient extraction, the extraction electrode was designed with the optimization of the electric field by a finite-element method simulation using TOSCA software[6]. The Mo target tilted at 45 degrees was employed and the diameter of the extraction hole was extended from 1 mm to 3 mm. Other electrodes were also modified its position to optimize the extraction electric field. Designed values are the Rb extraction efficiency 10%, the beam emittance 350π mm･mrad and the beam intensity 300 *e*nA when the Mo target temperature is 1300 K, the Rb ampoule temperature is 60 °C and the extraction voltage is 5 kV.

In September 2011, test experiment was performed at TOF room. Figure 1 shows overview of Rb Ion Source. The experimental setup is shown in Fig. 2. A triplet-Q electrode whose length is about 40 cm was connected to focus the Rb ion beam. A zinc-sulfide viewer and Faraday cup next to the triplet-Q were used to detect the beam. A gram of rubidium can be inserted into an ampoule holder and heated to around 50 °C by a ribbon

heater. Figure 3 shows an experiment result. The target temperature was kept at 1100 K during about two hours and finally reached about 1300 K. The maximum extraction voltage was 1.5 kV, that was limited by the withstand voltage of a high voltage circuit. The temperature of Rb ampoule followed the target temperature with a little lag. This is due to the heating of the Rb in the ampoule by the radiant heat from the heater surrounding the Mo target. Therefore, the maximum value of the Rb temperature and the beam intensity were recorded after the target temperature maximum. The maximum beam intensity was about 600 *e*nA at 1300 K. This intensity is around ten times larger than Rb ion beam produced by the existing Fr thermal ionizer.

This ion source has worked well over few hundred hours, and can be utilized for the offline developments of the neutralizer, laser cooling, and the MOT that are installed in the Fr beam line without operating accelerator. In the future, we plan the coexistence of Rb Ion Source and the Fr beam line using "mirror reflector". Rb Ion Source will be attached perpendicularly to the Fr beam line. Then, the extracted beam can be deflected to 90 degrees by the mirror reflector, and will be injected into the neutralizer. This gives us a high-intensity Rb test beam without the rearrangement of the beam line. An upgrade of the ion source itself is also planned. Owing to the redesign of the supply of Rb atoms and the chambers, the improvement of the beam intensity and emittance can be prospected. Because of the all improvements, the beam intensity will reach to 1 *e*μA.

References

1) Sandars P.G.H., Phys. Lett. **14** (1965) 194 and Phys. Lett. **22** (1966) 209.
2) Mukherjee D., Sahoo B.K., Nataraj H.S., Das B.P., J. Phys. Chem. A **113** (2009) 12549.
3) Regan B.C., Commins E.D., Schmidt C.J., DeMille D., Phys. Rev. Lett. **88** (2002) 071805.
4) Dresser M.J., J. Appl. Phys. **39** (1968) 338.
5) Hayamizu T., et al,. CYRIC Annual Report 2009 (2010) 12.
6) http://www.vectorfields.com

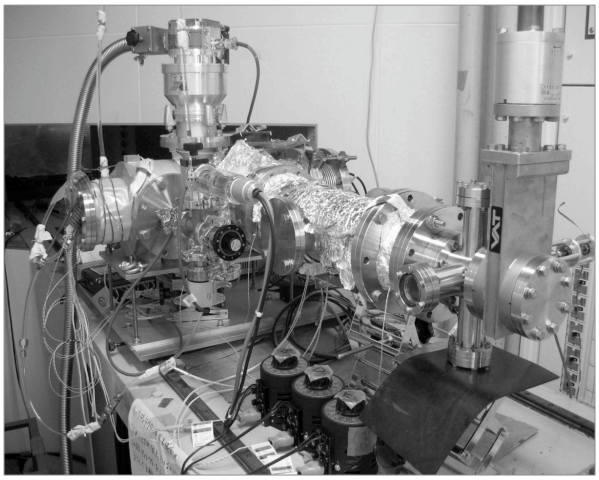

Figure 1. Overview of Rubidium Ion Source.

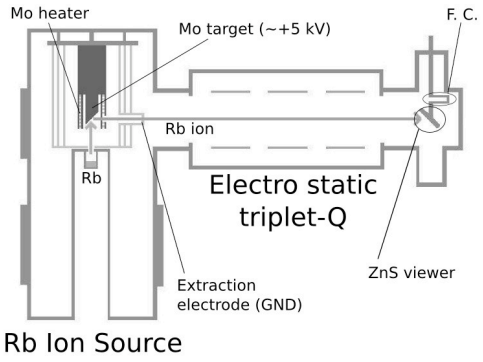

Figure 2. Experimental setup.

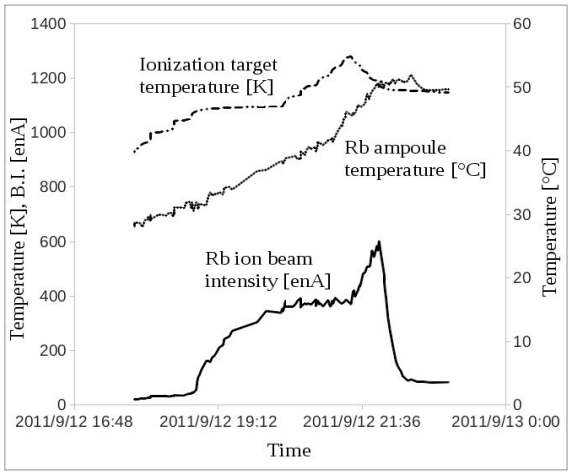

Figure 3. Test experiment result.