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Development of Neutralization Apparatus and Francium Source for the Francium Electric Dipole Moment Search

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We developed a neutralization apparatus of francium ions for the permanent electric dipole moment search. The detailed principle and ingenuity are reported in this paper. In parallel, we established the electrodeposition method to make a radioactive francium source. The best condition which achieved to attach almost all the Y atoms on a platinum plate is also reported.

KEYWORDS: Fundamental Symmetry, EDM

1. Introduction

The search for the electric dipole moment (EDM) of elementary particles is expected to be a clue of the origin of the matter dominant universe and a new theory which is beyond the Standard Model (SM)[1]. Despite the small value of EDM predicted in the SM, some theoretical models beyond the SM, the super-symmetric model for example, predict a much larger value which can be reached with our current experimental technique. We use laser-cooled francium (Fr) atoms to measure electron EDM (e-EDM) which could be drastically enhanced with heavy elements such as Fr.

In this paper, we report the development of the neutralization apparatus and Fr source. To realize the magneto optical trap (MOT) of Fr atoms, the neutralization system is required because Fr ions cannot be trapped in the MOT. This system is mainly used for ^{210}Fr which is produced by a nuclear fusion reaction ($^{18}O^{6+}$ + ^{197}Au → ^{210}Fr + 5n) using RIKEN AVF cyclotron. In parallel, we are also proceeding with another experiment using ^{221}Fr produced by alpha decay from ^{225}Ac. The high intensity source of the ^{225}Ac, which can be used for cancer therapy recently, and can be utilized as a generator for ^{210}Fr, and can carry out an EDM search without an accelerator operation.

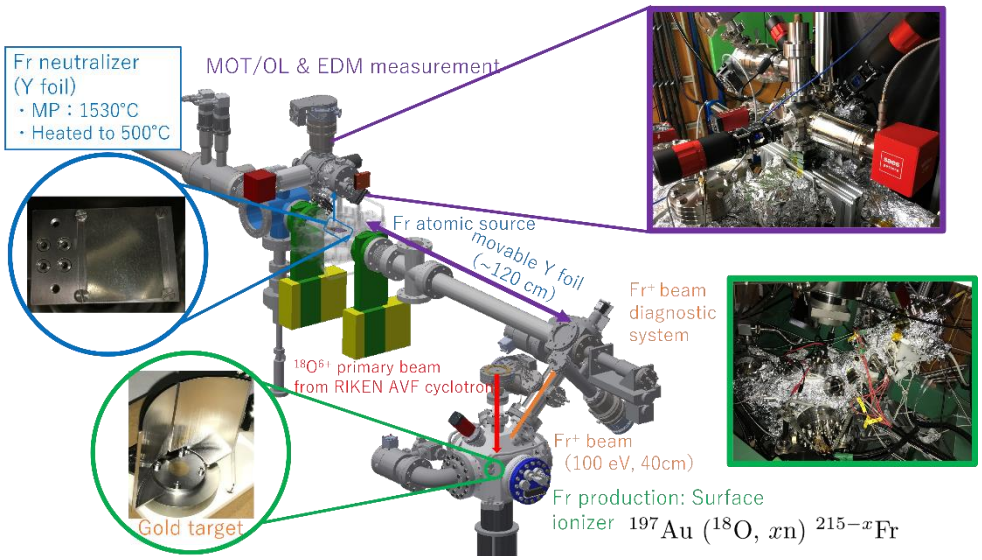

Fig. 1. The overview of the ^{210}Fr beamline.

2. ^{210}Fr Beamline

^{210}Fr is produced via a nuclear fusion reaction using a high intensity primary beam ^{18}O supplied by the AVF cyclotron, and ^{197}Au target. The overview of the neutralization apparatus is shown in Fig 1. [2-5] Fr ions, produced by irradiating $^{16}O^{6+}$ to an Au target highlighted by the green line, are electrically withdrawn along the orange line to the Y target, which is fixed to a rod that can move and rotate. After irradiating Fr ions, the Y target moves under the MOT chamber highlighted by the purple line and releases Fr atoms by heating it to about 500K using an infrared heater. In this process, Fr ions are neutralized. This principle is explained in the following section.

When Fr ions desorb from the metal surface, neutralization occurs with the following probability P_n [6]

$$P_n = \frac{1}{1 + \frac{1}{2}\exp\left(\frac{\phi_{WF} - \phi_{IP}}{k_B T}\right)} \quad (1)$$

In the above equation, φ_{WF} is the work function of the metal and φ_{IP} is the ionization potential of francium. According to Eq. (1) and the conditions of our experiment, almost all Fr ions are neutralized as they desorb from the Y surface.

As explained above, the surface condition is very important in the neutralization process because if there are oxide films or impurities on Y they could not only decrease P_n but may also encourage francium atoms to adsorb on the Y surface. To remove them, we use an argon ion sputter gun. After baking at 100℃ for 1 hour, we irradiate argon ions with 0.5 keV energy and 1.0 μA/cm^2 intensity for 1 hour.

3. ^{221}Fr Source from ^{225}Ac

^{221}Fr is one of the radioisotopes of francium. It has a sensitivity to not only e-EDM but also nuclear EDM. By comparing the EDM of ^{221}Fr with that of ^{210}Fr, we expect to extract the factor related to nuclear EDM.

We can get ^{221}Fr from the alpha decay of ^{225}Ac. Ac is a useful element as a ^{221}Fr source because of the long half-life of 10 days. The method of making such a francium source will be described in the following section.

To attach ^{225}Ac on a metal plate, we use the electrodeposition method, which accumulates Ac on the metal plate used as a cathode by applying a voltage between the plate and a solution of Ac in an organic solvent. The detailed principles of electrodeposition are not well known, but the ratio of electrodeposition is sensitive to the shape of the plate, temperature, voltage, time of voltage application, and so on.

To identify the condition which achieves the highest electrodeposition yield, we carried out research using yttrium which has similar chemical properties to actinium. The electrodeposition rate was calculated by mixing ^{88}Y as a tracer. As a result of the experiment, the highest electrodeposition rate (99.8%) was achieved at room temperature, at a voltage of 1 kV, and at an electrodeposition time of 40 minutes on a 15 mm square platinum plate. The graph with time on the horizontal axis is shown in Fig 2.

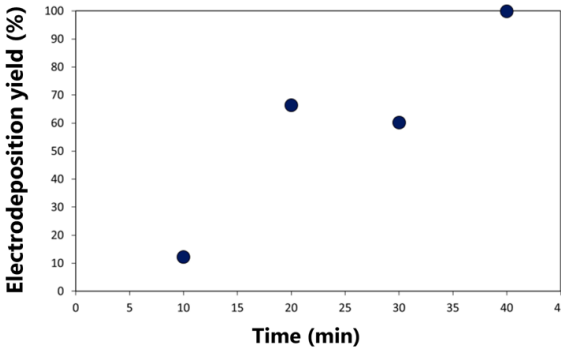

Fig. 2. The result of the yttrium electrodeposition experiment on a platinum plate.

3. Conclusion

We developed a neutralization apparatus of ^{210}Fr ions for the permanent electric dipole moment search. It mounts a surface cleaning system using an argon ion gun. In parallel, we discovered the best condition which achieved to attach almost all the Y atoms on a platinum plate at room temperature, at a voltage of 1 kV, and at an electrodeposition time of 40 minutes.

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