Production of a high-intensity francium ion beam for the measurement of the electron electric dipole moment

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The striking imbalance between matter and antimatter observed in the universe is known to be one of the biggest mysteries in modern physics. For decades, physicists have been attempting to investigate CP (C: charge conjugation, P: parity transformation) violations for different physical systems, which could lead to the discovery of the fundamental reasons for this mystery. One of these intriguing systems is the electric dipole moment of an electron (eEDM). The existence of an absolute value of the eEDM implies that CP symmetry has been violated. At the same time, this would also reveal the existence of a new theory beyond the standard model of particle physics.

Since the eEDM is expected to be small,[1)] it is necessary to adopt a system that enhances the eEDM to a sufficiently large value. For this purpose, we have chosen francium. Francium has an eEDM enhancement factor of approximately 10^3, which is known to be the largest among any ground-state atom.[2)] The ideal environment for Ramsey spectroscopy to measure the eEDM using francium atom is one in which a large amount of francium atoms are trapped in a tiny volume where the interactions with other particles are highly suppressed. To this end, we are planning to develop a three-dimensional optical lattice to confine laser-cooled francium atoms.

In this study, we constructed a surface ionizer to create a high-intensity francium ion beam. The surface ionizer consists of a vacuum chamber, a gold target, deflection electrodes, and an infrared radiation heater, as shown in Fig. 1. An $^{18}O^{6+}$ beam (6.28 MeV/nucleon) provided by the AVF cyclotron in RIKEN RIBF will be irradiated on the gold target to induce the following fusion reactions inside the gold: $^{197}\mathrm{Au}(^{18}\mathrm{O}, xn)^{215-x}\mathrm{Fr}$. By heating up the target using the infrared heater, the thermal diffusion process of the franciums will occur, and some fractions will reach the surface. Most of the franciums at the surface will be ionized according to the Saha-Langmuir equation[3)] and, subsequently, thermally released into the vacuum. Since high voltages are applied to the target ($\sim$1000 V) as well as to the deflection electrodes ($\sim$930 V), the thermal francium ions will experience the electric-field gradient and be transported as a secondary beam ($\sim$1 keV), which will be guided at an angle of 45° with respect to the $^{18}O^{6+}$ beam. The francium ion beam generated will finally be monitored using a beam diagnostic system. The beam diagnostic system consists of a micro-channel plate (MCP) to monitor the beam's characteristics and a silicon semiconducting detector (SSD) to observe α radiation caused by the α decay of the franciums. An α radiation source (Am) is placed near the SSD to calibrate the energy of the α radiation.

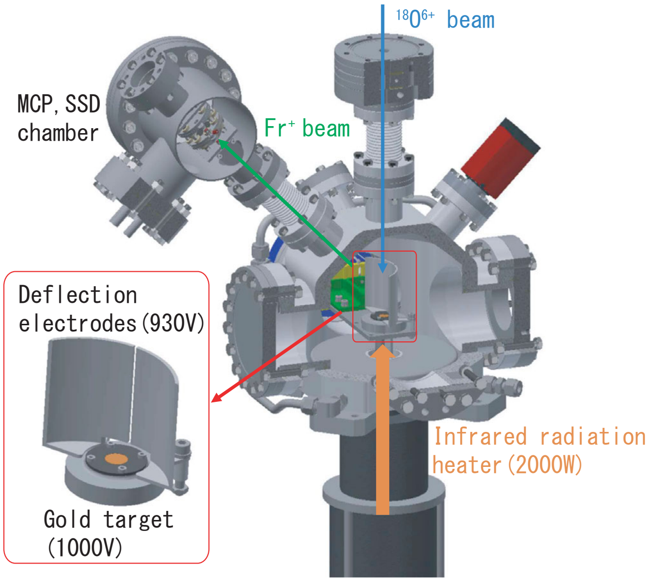

Fig. 1. Schematic of the experimental apparatus to produce a high-intensity francium ion beam.

In September 2019, we constructed this experimental apparatus and performed an offline test. During the offline test, we heated up the target to 400 $\sim$ 800°C using the infrared heater and thermally ionized particles already existing on the surface. These ionized particles were monitored by the MCP, which allowed us to optimise the voltages applied to the target and the deflection electrodes. We have confirmed that the optimised voltages are consistent with our previous simulation using SIMION 8.1. After the offline test, we performed online experiments on October 25, 2019 and November 22, 2019. Through data analysis, we verified that we had succeeded in producing a $^{210}\mathrm{Fr}^+$ beam with an intensity of 1.3×10^6/s.

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