Charge-exchange reaction of francium ions using an yttrium neutralizer

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The large imbalance in the amounts of matter and antimatter currently observed in the universe demands physics beyond the standard model, which violates fundamental symmetries.[1] Recently, the search for a nonzero permanent electric dipole moment (EDM) of an elementary particle has taken place actively world-wide, because the existence of EDM violates charge conjugation parity symmetry.

It is predicted that the EDM of an electron (eEDM) is enhanced in paramagnetic atoms.[2] Francium (Fr), being the heaviest alkali element, is known to possess the largest eEDM enhancement factor amongst any ground-state atom.[3] Therefore, we aim to search for the eEDM with unprecedented precision using Fr atoms trapped in an optical lattice. To achieve this goal, it is necessary to prepare a large number of Fr atoms trapped in a magneto-optical trap (MOT) before transporting them to an optical lattice. The number of trapped atoms in a MOT strongly depends on the desorption efficiency of Fr atoms from a neutralizer, where the charge-exchange reaction of Fr ions takes place. Here, we report the characterization of the efficiency of Fr atoms desorbed from an yttrium (Y) neutralizer during beam time in 2022.

An $^{18}O^{6+}$ beam (7 MeV/nucleon) provided by the AVF cyclotron in RIKEN RIBF is irradiated on the gold target to induce the following fusion reactions: $^{197}\mathrm{Au}(^{18}\mathrm{O}, xn)^{215-x}\mathrm{Fr}$. Heating up the target using an infrared radiation heater results in thermal diffusion of the produced Fr, and some fractions will reach the surface. Subsequently, most of the Fr on the surface will be thermally ionized and extracted as a secondary beam (100 eV, typically 5×10^6 s^{-1} for ^{210}Fr). The Fr ions are transported through the electrostatic beam line and irradiated on a Y foil for 3 minutes. The Y foil is then moved mechanically to the so-called silicon semiconductor detector (SSD) chamber to characterize the number of Fr atoms deposited on the surface of the foil. After the characterization, the foil is transported to the so-called neutralization chamber to heat the foil up to a maximum of 750°C and release the Fr as neutral atoms into a vacuum. Finally, the foil is transported back to the SSD chamber to characterize the number of Fr atoms remaining on the surface. Before conducting this experiment, the Y foil is bombarded by an argon (Ar) ion beam (10^{-2} A m^{-2}, 500 eV, 300 K) for 1.5–2 hours to clean its surface.

Figure 1 shows an example of count rate of alpha particles emitted via the alpha decay of $^{208-211}$Fr detected by an SSD, as a function of time. By evaluating all the data collected during the beam time, we derived a desorption efficiency of $\epsilon_{\mathrm{des}} = 29 \pm 15\%$, when the foil was heated to 750°C for approximately 3 seconds. Considering an experiment to measure the desorption energy of rubidium (Rb) on a Y surface,[4] almost all the Fr on the surface should be released into the vacuum by heating the foil up to 350°C for several seconds. Note that Rb is an alkali element akin to Fr and has chemical properties similar to those of Fr. This discrepancy implies that the cleaning procedure of the Y surface before the measurement was insufficient to realize an ideal surface, which does not have any impurities nor passive layers.

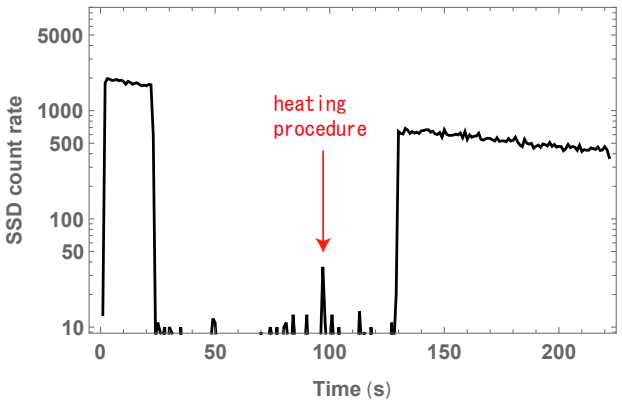

Fig. 1. Count rate of alpha particles emitted via alpha decay of $^{208-211}$Fr detected by a silicon semiconductor detector (SSD), as a function of time.

In 2023, we are planning to realize an ideal Y surface by optimizing the sputtering procedure using the Ar ion beam and by annealing the Y foil to reconstruct the surface structure. Consequently, this will allow the more efficient release of Fr on the surface at a minimum heating temperature, which will enable us to maximize the MOT efficiency of the Fr atoms.

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