I. 5. Neutralization of Radioactive Francium Atoms Using a Rotatable Yttrium Target

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Magneto-optical trapping is one way to precisely measure the properties of francium. A yttrium target that can neutralize francium ions was developed for the magneto-optical trap. In this experiment, a signal that seems to be from the neutral francium atoms was obtained, although an accurate performance estimate was too difficult to accomplish.

Introduction

Francium (Fr), a radioactive element having no stable isotope, is a naturally occurring element that was only recently discovered[1)]. Consequently, the properties of Fr are understood very little, even now.

In order to study its properties, physical quantities are often measured by capturing Fr atoms in a magneto-optical trap (MOT). In the case of stable isotopes, researchers can usually produce an atomic beam and measure in flight. In the case of radioactive isotopes, by contrast, the particle density is too low to adequately measure because the number of atoms is very small. Trapping the atoms increases the number of atoms to be measured per unit time, thus allowing for adequate measurement.

Executing a MOT of Fr requires the neutralization of Fr ions. Our group produced Fr via the nuclear fusion reaction of an oxygen beam and a gold target, extracting positive ions by electrostatic fields. The ion must be converted to a neutral atom because the objective is to study the properties of neutral Fr. There are several methods to carry out this neutralization, such as a charge exchange with alkali vapor[2)] and a recombination with an electron[3)]. A thermal neutralization process at the metal surface is usually utilized for MOT[4)]. The particle desorbs with neutralization at the surface of the metal, having a smaller

work function than the ionization potential of the incident particle. A yttrium (Y) target is generally employed for Fr MOT[5]. The neutralization experiment with Fr ions was performed using the Y target.

Experiment

Magneto-optical trap

The experimental apparatus was developed by combining the Y target with a glass cell for MOT[6]. First, ions in the beam accumulated on the surface of the Y target for some time. Next, the target was rotated toward the glass cell and heated for thermal desorption. Finally, the neutralized atoms were captured via MOT inside the cell. The atoms originating in a rubidium ion beam were successfully trapped in the pilot experiment.

On the basis of achieving the Rb MOT, we tried to demonstrate the Fr trapping experiment. However, no signal seeming to originate from the Fr MOT was observed in this experiment.

Detection of the α particles

The experiment demonstrated the possibility that the number of Fr atoms from the neutralizer could be quite small. The paucity of the atoms is considered to be one of the reasons why the signal of Fr trapping was not observed. The glass cell was replaced with a solid state detector (SSD) for the particle identification by detecting the decay-α particles from Fr, as shown in Fig. 1. The relationship among the beam accumulation, Y target rotation, Y target heating, and SSD measurement is presented in Fig. 2.

Figure 3 shows the acquired α spectrum. The energy resolution was very poor due to the malfunction of a pre-amplifier for the SSD. Therefore, satisfactory particle identification was impossible. It is speculated from the original beam intensity that the large peak at ~2860 ch would correspond to the Fr isotopes with mass of 208-211.

The lifetime of this peak event was measured and can be seen in Fig. 4. The time constant derived from fitting roughly coincides with the lifetime of ^{210}Fr and ^{211}Fr.

The dependence of the detector count on the ion reflection voltage was investigated in Fig. 5. Since positive ions from the Y target will be swept out by applying positive voltage to the catcher, it is expected that the total count decreases and that the only component of the neutral atoms is measured unalterably. This behavior was roughly confirmed. However, quantitative interpretation is difficult. It is assumed that the ionized

particle desorbs from the Y surface with only thermal energy because no acceleration voltage is applied to it. If so, just 10 V exceeding the thermal energy could sweep out all the ions, meaning there should be no changes beyond that voltage. In reality, the detector count decreased gradually with the increase of the reflection voltage up to 100 V. The expected behavior did not occur due to the complex fields generated by a complex configuration around the detector. Additional information is necessary to judge whether the local decrease at 0 V originated simply from statistical error or was a significant change. Some of the particles could desorb with neither neutralization nor positive ionization, but with negative ionization instead[7].

Figure 6 shows the dependence of the count on the loading time of the ion beam. When the loading time is lengthened, the number of Fr accumulating on the Y target will increase with a decrease by radioactive decay. The loading time dependence was measured, and the result roughly corresponds to the prediction. Considering the increase of a background component on the Y, an optimum loading time must be maintained for efficient trapping.

Summary

We plan to perform the magneto-optical trapping in order to precisely evaluate the properties of Fr. An apparatus has been developed to convert Fr ions to neutral atoms and deliver the atoms to the MOT region. The experiment demonstrated Fr neutralization using this apparatus with a SSD. The apparatus met the minimal performance level and proved to emit the neutral component of radioactive isotopes looking like Fr. Still, detailed understanding will require more experiments. It is advantageous to study Fr in that the same method of particle identification can be employed for both an ion and an atom by detecting the decay-α particles. However, detailed experimental data are difficult to acquire because the machine time of our cyclotron is limited and may be not able to produce Fr. The quantitative evaluation of the neutralization will be achieved when a more reliable method of particle identification is employed for both an ion and an atom of stable Rb isotopes.

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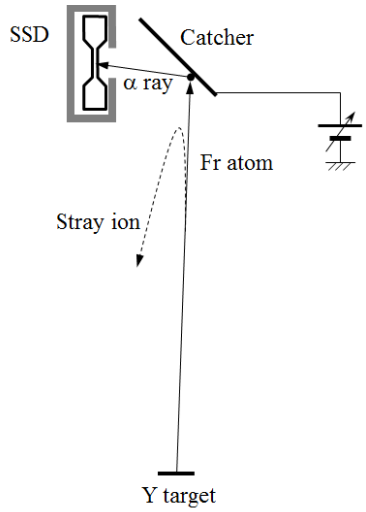


Figure 1. Schematic of the apparatus in the situation that the Y target rotates upward and heats up for the atomic desorption.

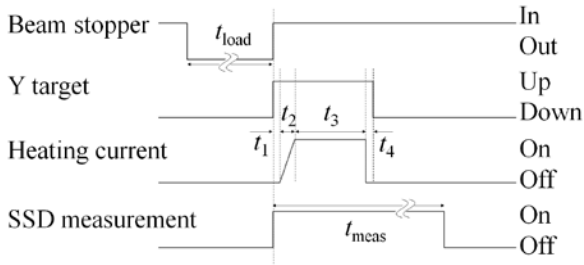


Figure 2. Time sequence of the measurement. The time periods t_1, t_2, t_3, t_4, and t_{meas} are fixed at 1, 2, 10, 1, and 300 sec, respectively. The loading time t_{load} is normally 50 sec except for the t_{load} dependence measurement.

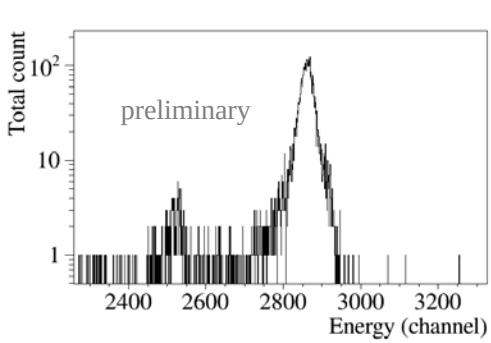


Figure 3. Total energy spectrum acquired during this experiment. The total measurement time is 16162 sec. The peaks at ~2860 ch and ~2530 ch are considered to originate from the Fr isotopes and their daughter nuclei, respectively.

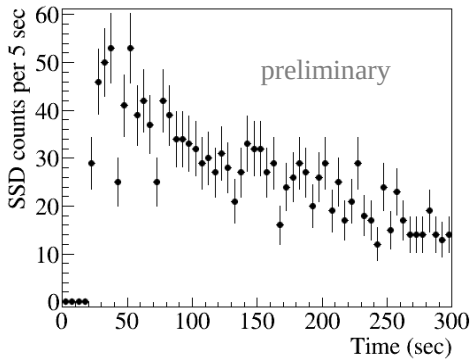
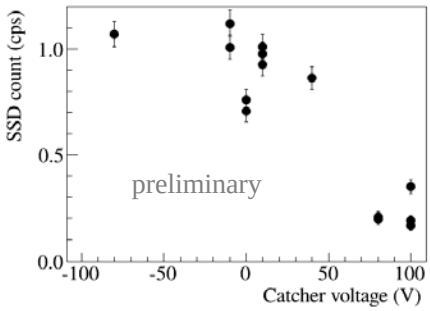


Figure 4. Total time spectrum. According to Fig. 2, the events start after the Y target heatup.



Figue 5. The dependence of the SSD count on the ion reflection voltage applying on the catcher.

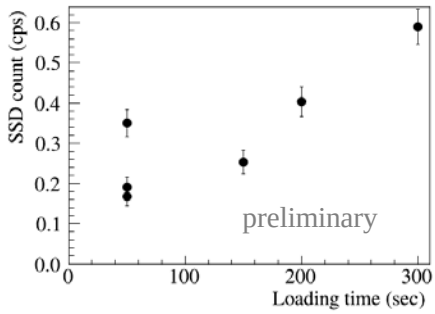


Figure 6. The dependence of the SSD count on the loading time t_{load}.