Measurement of excitation functions of the $^{206/207/208}$Pb(^{11}B, x)^{212}Fr reactions

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Francium (Fr) is the heaviest alkali metal with the atomic number 87. It is one of the least-studied elements among the naturally occurring elements because all its isotopes are short-lived; the half-life of its longest-lived isotope, ^{223}Fr, is only $T_{1/2} = 21.8$ min. Owing to experimental difficulties, the chemical properties of Fr have not been studied in detail so far. It is considered that the chemical properties of Fr are similar to those of its lighter homolog, Cs. However, the chemical properties of Fr cannot be simply deduced from the extrapolation from the lighter homologs because relativistic effects come into play in such a heavy atom as Fr.[1)] Therefore, it is of great interest and importance to clarify the chemical properties of Fr and to elucidate the influence of relativistic effects on the chemical properties of Fr. Recently, Haverlock et al reported on the complex formation of Fr^+ with calix[4]arene-bis(benzocrown-6) (BC6B).[2)] They reported that Fr^+ is more effectively extracted with BC6B than Cs^+; however, the reason for the selectivity is unclear. We plan to investigate the stability of the complex formation of Fr with crown ethers by systematically varying their cavity size and substituent group to understand their influences on the selectivity in the complex formation and solvent extraction of Fr. In this study, we will use the long-lived isotope ^{212}Fr ($T_{1/2} = 20$ min), which can be produced in the $^{206/207/208}$Pb(^{11}B, x)^{212}Fr reactions. Because no experimental excitation functions are available for these reactions, we measured the excitation functions of the $^{206/207/208}$Pb(^{11}B, x)^{212}Fr reactions to optimize the production conditions of ^{212}Fr.

The excitation functions were measured using the stacked-foil technique. The $^{206/207/208}$Pb targets were prepared by vapor deposition on 3.1-μm Al foils (> 99% chemical purity). The size of all foils was 10×10 mm^2. The target stacks consist of 20 sets of ^{206}Pb (99.51%-enrichment, 791-μg/cm^2 thickness), ^{207}Pb (99.40%-enrichment, 851-μg/cm^2 thickness), or ^{208}Pb (99.59%-enrichment, 642 μg/cm^2 thickness). The 3.1-μm Al foils were inserted between the $^{206/207/208}$Pb targets to catch ^{212}Fr atoms that recoiled out of the targets. Each stack was irradiated for 10 min with a 100.9-MeV ^{11}B beam supplied from the RIKEN AVF cyclotron. The incident beam energy was determined by time-of-flight measurement.[3)] The average beam current was measured with a Faraday cup and found to be 48.6, 48.8, and 50.0 pnA for the ^{206}Pb, ^{207}Pb, and ^{208}Pb stacks, respectively. After the irradiation, each foil was subjected to γ-ray spectrometry with Ge detectors.

The radioactivity of ^{212}Fr was determined from its 227.72-keV (γ-ray intensity $I_\gamma = 42.6\%$) γ line. Figure 1 shows the excitation functions measured for the first time for the ^{206}Pb(^{11}B, 5n)^{212}Fr, ^{207}Pb(^{11}B,6n)^{212}Fr, and ^{208}Pb(^{11}B,7n)^{212}Fr reactions. The maximum cross section for the production of ^{212}Fr is available in the ^{206}Pb(^{11}B, 5n)^{212}Fr reaction around 73.6 MeV.

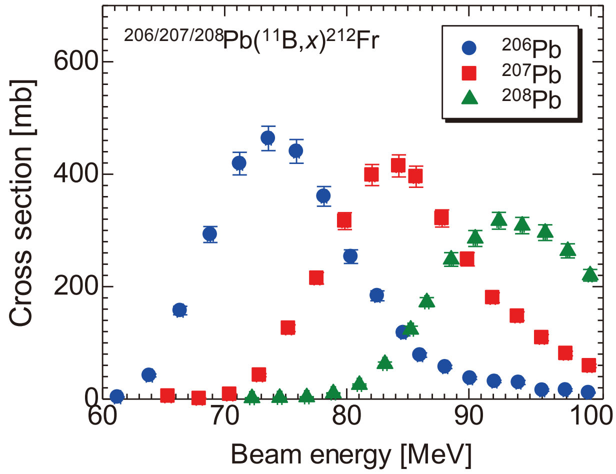

Fig. 1. Excitation functions of the $^{206/207/208}$Pb(^{11}B, x)^{212}Fr reactions.

Based on the measured excitation functions, we will optimize the production condition of ^{212}Fr in the ^{206}Pb(^{11}B, 5n)^{212}Fr reaction for future chemistry studies of Fr using the multitarget He/KCl-jet transport system.[4)] In this system, 4 sets of an 864-μg/cm^2 ^{206}Pb target on a 10-μm Be foil are placed in 12-mm-spacing in 129-kPa He and are irradiated with a ^{11}B beam at an energy of 86 MeV. The beam energies on the four ^{206}Pb targets are calculated to be in the range of 70–79 MeV, which covers the peak region of the excitation function of the ^{206}Pb(^{11}B, 5n)^{212}Fr reaction. The ^{212}Fr atoms that recoiled out of the ^{206}Pb target are thermalized in the He gas, attached to KCl aerosol particles, and transported through a Teflon capillary to a chemistry laboratory, where the solvent extraction of ^{212}Fr will be performed. 60 kBq ^{212}Fr, which is sufficient radioactivity to study its solvent extraction behavior, is available after the 1-min aerosol collection by assuming a beam intensity of 300 particle nA, recoil efficiency of 48%, and gas-jet efficiency of 50%.

References

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