Observation of Bound-State $\beta^-$ Decay of Fully Ionized $^{207}$Tl at the FRS-ESR

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The bound state $\beta^-$ decay ($\beta^-_b$ decay) is a particular decay mode of the weak interaction in which the decay electron remains in a bound atomic state rather than being emitted into the continuum.

In the present work, we observed $\beta^-_b$ decay of bare $^{207}\text{Tl}^{81+}$ in the FRS-ESR facility at GSI. Those ions were produced through the projectile fragmentation of primary 833 MeV/u $^{208}\text{Pb}$ beam impinged on a $^9\text{Be}$ target. It was the first time to use a secondary beam in this mass region for the measurement of $\beta^-_b$ decay in the experimental storage ring ESR. $^{207}\text{Tl}^{81+}$ were successfully separated from its neighbor of H-like $^{207}\text{Pb}^{81+}$ by the $B\rho\Delta E-B\rho$ method in the fragment separator FRS. We succeeded to reduce the number of $^{207}\text{Pb}^{81+}$ ions down to roughly of $\sim1\%$ as the contamination ratio. They are finally injected into the ESR and electron-cooled with stochastic pre-cooling. It was also the first time to apply stochastic pre-cooling to $\beta^-_b$ decay measurement in the ESR. We could reduce the beam cooling time by about 90% compared to those at the previous experiments [1], where only the electron cooling was applied.

As shown in Fig. 1, the numbers of both the $^{207}\text{Tl}^{81+}$ parent ions and their $\beta^-_b$ decay daughters were recorded as a function of the storage time by the Schottky mass spectrometry [2] in the ESR. The $\beta^-_b$ decay as well as the continuous $\beta^-$ decay probability ($\lambda_{\beta^-_b}$ and $\lambda_{\beta^-_c}$) and, hence, the bound-to-continuum branching ratio has been analyzed (see Fig. 2). The obtained branching ratio is in good agreement with theoretical calculations [3], within an, experimental uncertainty. The comparison of $\lambda_{\beta^-_b}$ and of $\lambda_{\beta^-_c}$ with the theoretical values seems to be systematically small. However the ratio agrees with the theoretical value within an error. This fact suggests that some theoretical assumptions are not good enough, to calculate individual value of $\lambda_{\beta^-_b}$ or $\lambda_{\beta^-_c}$.

It was hesitated to accelerate $^{205}\text{Tl}$ ions at the SIS facility so far due to possible contamination in the ion source, since $^{205}\text{Tl}$ as well as $^{207}\text{Tl}$ is known to be exceedingly-poisonous. However, as this work demonstrates, $^{207}\text{Tl}$ can be produced and separated using a technique of the fragmentation, the postponed experiment at the ESR using $^{205}\text{Tl}$, is now feasible. $^{205}\text{Tl}$ is expected to be available as an experimental probe for the study on the s-process nucleosynthesis and/or solar neutrino problem [4,5].

References