Direct Observation of Bound-State β^- Decay of Fully Ionized ^{205}Hg

J. Kurcewicz[1], F. Bosch[1], H. Geissel[1,2], Yu. A. Litvinov[1,2], K. Beckert[1], P. Beller[1], D. Boutin[1,2], C. Brandau[1], L. Chen[1,2], T. Faestermann[3], B. Franzke[1], M. Hausmann[4], P. Kienle[3,5], O. Klepper[1], R. Knöbel[1,2], C. Kozhuharov[1], S. A. Litvinov[1,2], L. Maier[3], M. Mazzocco[1], F. Montes[1], A. Musumarra[6], C. Nociforo[1], F. Nolden[1], W. R. Plaß[1,2], C. Scheidenberger[1,2], M. Steck[1], B. Sun[1], K. Takahashi[7], H. Weick[1], N. Winckler[1,2], and M. Winkler[1]

[1]GSI, Darmstadt, Germany; [2]JUL, Gießen, Germany; [3]TUM, Mnchen, Germany; [4]MSU, East Lansing, U.S.A.; [5]SMIsP, Vienna, Austria; [6]LNS, Catania, Italy; [7]ULB, Brussels, Belgium

The β^- decay to an electronic bound state in the daughter atom, accompanied by the emission of a monoenergetic neutrino was first observed at GSI in 1992 [1], more than 40 years after its theoretical prediction[2]. This phenomenon of minor importance for neutral atoms, might become a strong decay channel for highly ionized atoms in stellar environements. Thus the heavily altered nuclear half-lives might have a large impact on the path of the nucleosynthesis proces. Here we report on the direct observation of the bound-state β^- decay of fully ionized ^{205}Hg.

The experiment was performed at the SIS synchrotron of GSI Darmstadt, which delivered a 750 A GeV ^{208}Pb beam with an intensity of the order of 10^9 ions/spill. The ions of interest ^{205}Hg^{80+} were produced in the projectile fragmentation. The 4 g/cm^2 thick beryllium target was placed at the entrance to the projectile Fragment Separator (FRS). After passing the magnetic sections of the separator the selected ions were injected into the ESR storage ring, where they could remain for extended periods of time circulating with a revolution frequency of the order of 2 MHz. Both, stochastic and electron cooling were applied in an attempt to decrease the velocity spread of the circulating ions.

The beamline of the ESR is equipped with a set of Schottky noise probes which collect the mirror charge of each passing ion, thus providing the information about its revolution frequency. The 30th harmonic of the noise signal generated in the Schottky pick-up electrodes was amplified and mixed down with a local oscillator providing a reference frequency. The difference signal in the frequency range of 0-300 kHz was digitized by using a 16-bit ADC and a Fast Fourier Transformation was applied to the data yielding revolution frequency spectra of the coasting ions. Analyzing the frequency peaks present in the subsequently accumulated Schottky spectra, a time distribution of the number of the bare Hg and the β_b-decay daughter Tl ions stored in the ESR was constructed. In general the time evolution of the number of mother activity ions can be described by the following expression

$$N_m(t) = N_m(0)e^{-\lambda t}, \quad (1)$$

where $N_m(0)$ is the number of stored mother ions at the beginning of the measurement and $\lambda = \lambda_{\beta_b} + \lambda_{\beta_c} + \lambda_{\text{loss}}$ is the decay constant consisting of components responsible for continuum-state, bound-state β^--decay and non-radioactive losses in the ring, respectively. In case of the daughter activity the number of stored ions is given by

$$N_d(t) = N_m(0)\frac{\lambda_{\beta_b}}{\lambda - \lambda_{\text{loss}}}\left(e^{-\lambda_{\text{loss}}t} - e^{-\lambda t}\right) + N_d(0)e^{-\lambda_{\text{loss}}t}, \quad (2)$$

where $N_d(0)$ is the number of daughter ions at the beginning of the measurement. Several measurements of the decay constant have been performed showing overall consistent results. The results of the analysis of the Schottky power noise spectra are shown in Fig. 1. The obtained time distribution of registered decay events was fitted separately for each of performed measurements using Eq.(1) and (2).

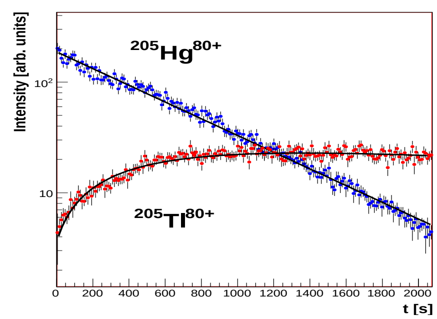

Figure 1: Time distribution of the peak intensity corresponding to number of stored ^{205}Hg^{80+} and ^{205}Tl^{80+} ions. The continuous line shows the fitted theoretical dependence given by Eqs. (1) and (2).

The average decay rates for bound and continuum state β^- decay are $\lambda_{\beta_b} = 3.7(3) \cdot 10^{-4}$ s^{-1} and $\lambda_{\beta_c} = 1.69(14) \cdot 10^{-3}$s^{-1}, respectively. The experimental values of the decay constant indicate an overall good agreement with the theoretical prediction $\lambda^{th}_{\beta_b} = 3.21 \cdot 10^{-4}$ s^{-1}, $\lambda^{th}_{\beta_c} = 2.21 \cdot 10^{-3}$ s^{-1} [4], however, showing a lower λ_{β_c} value. This is confirmed by a recent theoretical work which provides for bare ^{205}Hg^{80+} the continuous β^--decay rate value of $\lambda_{\beta_c} = 2.34 \cdot 10^{-3}$ s [5].

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