Direct observation of bound beta decay of bare ^{206,207}Tl at FRS-ESR

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Bound beta decay (β_b decay), the time-mirrored orbital electron capture, is a special form of β^- decay, where the electron becomes bound in an inner atomic shell (predominantly the 1s-shell) of the daughter atom. For neutral atoms the capture of an electron into an unoccupied shell has a small probabiliy because of the small overlap of the wavefunction with the nucleus. Therefore, β_b decay remains there a spurious effect only. However, when atoms get highly ionized, as, e. g., in a stellar plasma, β_b decay can become a significant decay branch. Then β^- lifetimes may alter by many orders of magnitude with respect to those of the corresponding neutral atoms, as has been proven by several experiments performed at the ESR over the last years [1,2]. The exploration of β_b decay is important for a comprehensive understanding of the creation of matter in hot stellar plasmas.

An experiment was carried out at the FRS-ESR facilities, where the β_b decay of ^{206}Tl and ^{207}Tl was *directly* observed for the first time. The mass difference between mother- and β_b daughter-atom amounts in either case to about 1.6 MeV, and the β_b decay-branch to 10-20%[3]. The ^{206}Tl and ^{207}Tl-atoms were produced by fragmentation of a ^{208}Pb primary beam in a Be target at the FRS and separated using the Bρ-ΔE-Bρ method. This technique ensured that bare Tl ions, but no hydrogen-like Pb ions were injected into the ESR. In the ESR, the ions were stored, electron-cooled, and detected via time-resolved Schottky spectroscopy. The beam noise, which is induced in pick-up electrodes, is recorded and frequency-analyzed. At the revolution frequency of each stored ion species the frequency spectrum shows lines with an area being proportional to the ion number.

Figure 1 presents the first direct observation of β_b decay. It shows time-resolved frequency spectra of the Schottky lines of stored and cooled bare ^{207}Tl^{81+} ions, together with their β_b-daughters ^{207}Pb^{81+}. The mass resolving power $m/\Delta m$ exceeds $7*10^5$, which is by far sufficient to resolve both peaks clearly. The spectra have been determined from summing-up one hundred subsequent, 64.8 milliseconds lasting measurements and covered an observation time of up to 40 minutes after injection.

Figure 2 shows the number of ions in both peaks as a function of observation time. The initial number of bare ^{207}Tl ions in the ESR was about 2000. After the cooling phase of approximately 100 seconds the intensity of the ^{207}Tl^{81+} mother nuclei decreases exponentially due to beta decay to the continuum (^{207}Pb^{82+}, not shown here), β_b decay to ^{207}Pb^{81+}, and due to charge-changing processes in the residual gas and in the electron cooler of the ESR. These unavoidable 'storage ring losses' also lead, finally, to a slow decrease of the stable ^{207}Pb^{81+} ions, whose intensity increases at the beginning due to the feeding from the decaying ^{207}Tl^{81+}.

From those spectra, together with the measured β^- decay to the continuum (β_c), a wealth of unique information will result: total and partial β_b lifetimes, the β_b Q-value and, moreover, the ratio of bound- and continuum electron wave function, which yields the 'Fermi function'. For β^- decay, the latter has never before been probed by experiments (in contrast to β^+- and orbital electron-capture decay).

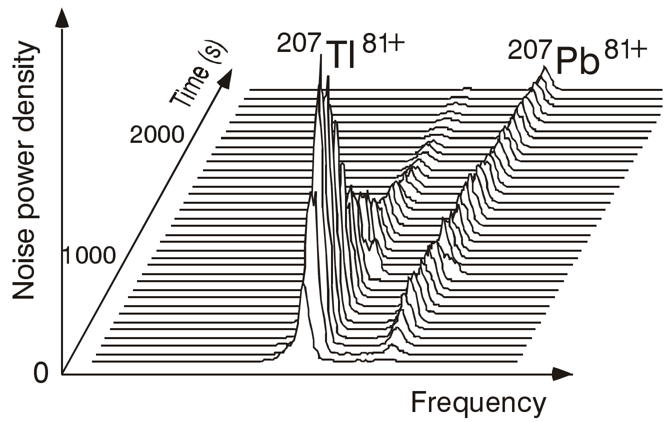

Figure 1: Time-resolved frequency spectra of bare ^{207}Tl^{81+} mother and hydrogen-like ^{207}Pb^{81+} β_b-daughter ions. The noise-power is a direct measure for the number of ions.

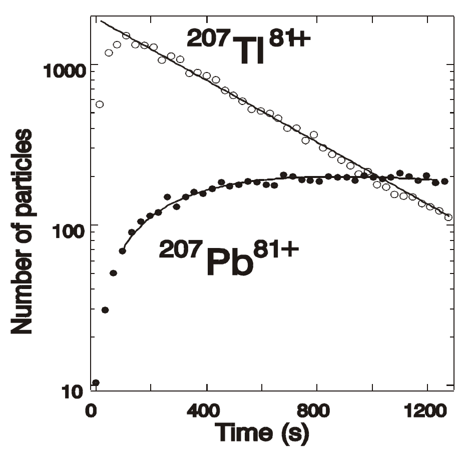

Figure 2: Number of mother (^{207}Tl^{81+}) and β_b-daughter ions (^{207}Pb^{81+}) as a function of time after injection. The first 100 seconds are needed for electron cooling of the hot fragment beams (first three data points, which have been excluded from the fit). Each data point is obtained from 32.4 seconds of observation time.

References

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