Bound-state Beta Decay of Bare ^{187}Re ◇

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The radionuclide ^{187}Re with a halflife of 45 Gyr can be used [1] to estimate the age of our galaxy. Compared to other cosmochronometers like ^{235}U, ^{238}U or ^{232}Th, the ^{187}Re-^{187}Os pair has the advantage, that the abundance ratio of mother and daughter nuclei can be directly measured. However one uncertainty in its calibration has been pointed out by Yokoi et al. [2]: ^{187}Re may become highly ionized in the hot plasma of a star, and bound-state beta-decay (β_b-decay) - where the beta-particle remains bound in an atomic orbit - may decrease the halflife by more than nine orders of magnitude. This is due to the fact, that the Q-value for β_b-decay of bare ^{187}Re to the K-shell is 73.1 keV compared to 2.6 keV for the atom and that the first excited state of ^{187}Os can be fed with Q=63.3 keV. If one knows the halflife e.g. for fully ionized ^{187}Re one can calculate the halflives for other charge states. We now succeeded to measure the halflife of fully ionized ^{187}Re nuclei circulating in a storage ring. After ^{163}Dy [3] this is the second case, where β_b-decay has been observed.

^{187}Re ions were accelerated in the GSI accelerator complex to a final energy of 347·A MeV, fully ionized and accumulated in the experimental storage ring ESR. Electron cooling lead to an excellent beam quality and brightness, which, together with a residual gas pressure of 10^{-11} mbar, allowed to store the beam with an effective halflife of 4.3 hours. With about 10^8 stored ^{187}Re^{75+} ions several hundred ^{187}Os^{75+} ions were produced during storage times of up to 4 hours by β_b-decay of ^{187}Re^{75+} and were circulating with nearly the same frequency as the main beam (same charge, velocity and - within 0.4 ppm - same mass). Their number is proportional to the decay constant for β_b-decay, which we want to determine, the number of ^{187}Re^{75+} ions in the storage ring, and the storage time, which is very small compared with the halflife.

In order to separate the ^{187}Os^{75+} ions from the ^{187}Re^{75+} mother nuclei, the bound decay electron was stripped by turning on an Ar gas jet target, which crossed the beam and produced ^{187}Os^{76+} ions, with detectable, different mass/charge ratio.

We used the dipole magnet after the gas stripper as a magnetic spectrometer and measured with particle detectors the number of ions as a function of magnetic rigidity: The position was measured with a microstrip gas chamber (MSGC) [4]. Information on the nuclear charge was obtained from an ionization chamber (IC). Both detectors were operated in the same gas mixture of argon/isobutane at a pressure of 1 bar. A position spectrum after accumulating ^{187}Os^{75+} from the decay of bare ^{187}Re for four hours is shown in fig.1. For this spectrum a condition on the energy loss signal has been requested. Because of space limitations the IC had only an effective thickness of 17 mm and the energy loss resolution was 4.3 %. Therefore a unique Z determination was not possible. Background from ^{187}Re ions, elastically scattered from Ar atoms in the gas target, and from nuclear fragmentation reactions could nevertheless be drastically reduced. The shape and ratio of the background contributions was determined in runs, where we did not wait for the ^{187}Re to decay. Since in nuclear reactions a large momentum spread is imparted on the ejectiles, the position distribution is correspondingly wider. From Schottky frequency spectra, measured in the same beam time and yielding a consistent result for the decay rate, we know, that the "nuclear background" we see near the position of ^{187}Os^{76+} is mostly due to ^{182}W^{74+}. But the narrow peak on top has the correct position and width to originate from bare ^{187}Os nuclei after stripping in the gas jet.

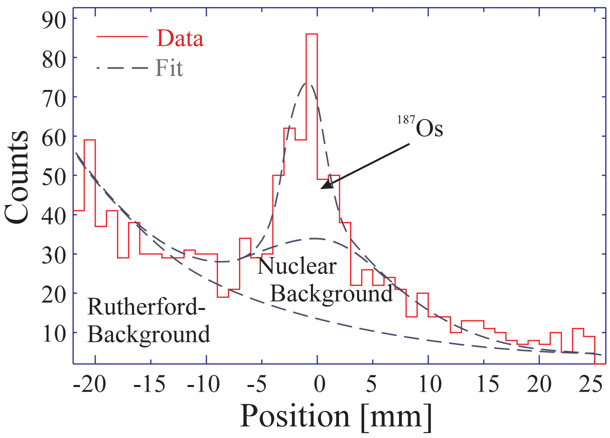

Fig. 1: Position spectrum of ions deflected by the first dipole magnet behind the gas target after collecting ^{187}Os^{75+} ions for about 2 hours.

A total of 14 such spectra were recorded for different breeding times. From the number of ^{187}Os nuclei produced by an initial number of ^{187}Re after a certain breeding time, we obtain - after proper corrections - ten consistent values for the decay constant λ_{β_b} in the lab system. The average value, converted to the ions rest frame is

$$\lambda_{\beta_b} = 6.8^{+1.1}_{-0.9} \cdot 10^{-10}\,\mathrm{s}^{-1} \ .$$

This corresponds to a halflife of $T_{1/2} = 32^{+5}_{-4}\,\mathrm{yr}$ of bare ^{187}Re. Thus the measurement confirms the nine order of magnitude enhancement of the decay rate for bare ^{187}Re^{75+} as predicted by Yokoi et al. [2] .

References

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