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

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The most serious problem of the cosmochronometric pair ^{187}Re/^{187}Os, is due to bound–state β^- decay (β_b decay) – where the beta–particle remains bound in an atomic orbit – of ^{187}Re, when it is highly ionized in a stellar environment [1]. For neutral ^{187}Re^{0+}, only the unique, first forbidden transition to the ^{187}Os ground state is energetically allowed. Because the inner orbits are occupied, β_b decay contributes less than 1% [2]. For fully ionized ^{187}Re^{75+} – as it occurs in high temperature regimes in stellar interiors – β decay is forbidden because the electronic cloud in Os is stronger bound by 15.31 keV [3] than in Re. However, β_b decay with the electron bound in the K– (Q_{β_b} = 72.97 keV) or L–shell (Q_{β_b} = 9.07 keV [4]) is still possible. Concerning the β_b decay to the K–shell, Yokoi *et al.* [5] realized that also the first excited state at 9.75 keV can be fed in a non–unique first forbidden transition with a substantially larger matrix element. Their estimated half–life for bare ^{187}Re of $T_{1/2}$ = 14 yr is a billion times shorter than that for neutral ^{187}Re ($T_{1/2}$ = 42 Gyr). The experiment to measure the β_b decay of ^{187}Re was performed at the heavy ion facility GSI. ^{187}Re ions were accelerated in the SIS to a final energy of $347 \times A$ MeV, fully stripped and injected into the experimental storage ring ESR. With about 10^8 stored ^{187}Re^{75+} ions, several hundred ^{187}Os^{75+} ions were produced during storage times of up to 5 hours, circulating with nearly the same revolution frequency as the main beam. Their number grows in proportion to the storage time, provided that it is small with respect to the half–life. In order to separate the hydrogen–like ^{187}Os^{75+} ions from the ^{187}Re^{75+} mother nuclei, the bound decay electron was stripped by turning on an argon gas jet target which crossed the beam and produced ^{187}Os^{76+} ions, with a detectable, different mass/charge ratio. The number of bare ^{187}Os ions originating from the ^{187}Re^{75+} decay was determined with two independent methods [6]. In the first one we used the dipole magnet after the gas stripper as a magnetic spectrometer, and measured with a microstrip gas counter the number of ^{187}Os–ions as a function of their magnetic rigidity. In an independent experiment we used the Schottky–noise frequency analysis, which is based on the fact that each circulating ion induces a signal whenever it passes a pair of capacitive pickup plates. These periodic signals reveal, when Fourier–transformed, the corresponding revolution frequency (or harmonics) of each species of stored ions. This frequency is a unique function of the mass/charge ratio since all ions have the same velocity enforced by the electron cooler. The final results of ten individual measurements with either method for the decay rate are shown in fig. 1 in form of ideograms [7]. Adding statistical and systematical errors algebraically and taking the average of both results, we finally get

$$\lambda_{\beta_b} = (6.7 \pm 0.4) \times 10^{-10}\mathrm{s}^{-1} \longrightarrow T_{1/2} = (32.9 \pm 2.0)\,\mathrm{yr}\,.$$

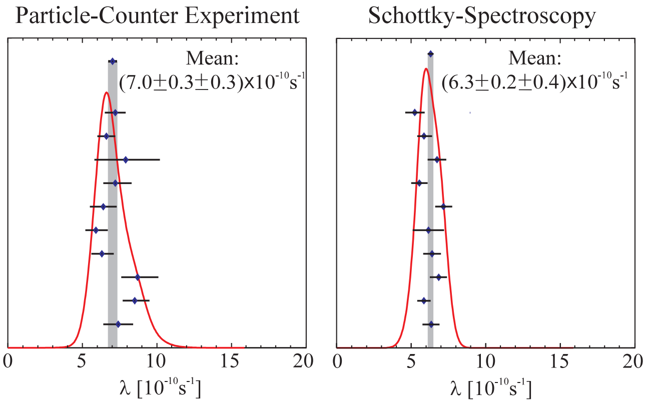

Fig. 1: Ideograms of ten individual measurements with the particle counter and the Schottky spectroscopy. The weighted mean value is shown as the uppermost datum. The first error is due to statistical, the second is due to systematical uncertainties. The fulldrawn curve, the sum of Gaussians for each measurement, serves to judge the consistency of the data.

The measured λ_{β_b} is practically equal to the β_b decay probability into the K shell of ^{187}Os, because the decay into the L shell is about 7 orders of magnitude less probable. From the measured λ_{β_b} we can deduce the nuclear transition matrix element M, which we express as usual in terms of $ft \propto M^{-2}$:

$$\log ft = 7.87 \pm 0.03\,.$$

With this measured ft–value the decay rate of ^{187}Re in any charge state, and hence at any temperature, can be reliably calculated. The measured value is very close to $\log ft = 7.5$, assumed by Yokoi *et al.* [5] in their study of the ^{187}Re/^{187}Os cosmochronometry. They overestimated the ^{187}Re decay rate only by a factor of about 2.3. As this factor also applies to the reverse transition, the electron capture decay of ^{187}Os from the thermally excited 9.75 keV state, the net effect of the measured value for the transition rate would be small. The Galactic age, estimated to be between 11 and 15 Gyr, would increase by less than 1 Gyr. On the other hand, the work of Yokoi *et al.* adopted a simple model of stellar evolution. In the past decade many systematic studies of stellar evolution have been made. Therefore it seems timely to improve the estimates on the astration effects.

References

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