Determination of α -decay branching ratios for $^{178,179}\text{Hg}$

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Abstract. The neutron-deficient nuclides $^{182,183}\text{Pb}$ were produced at the Accelerator Laboratory of the University of Jyväskylä by bombarding a ^{107}Ag target with ^{78}Kr ions. The nuclei of interest were separated using the RITU gas-filled separator and their radioactive decays investigated using the GREAT spectrometer. Correlating the α decays of these Pb isotopes with those of their respective Hg daughters allowed α -decay branching ratios of $b_\alpha(^{178}\text{Hg}) = 89(4)\%$ and $b_\alpha(^{179}\text{Hg}) = 75(4)\%$ to be deduced.

1 Introduction

In the present work the α -decay branching ratios of ^{178}Hg ($E_\alpha = 6429(3)$ keV, $T_{1/2} = 266.5(24)$ ms [1]) and ^{179}Hg ($E_\alpha = 6288(5)$ keV, $T_{1/2} = 1.05(3)$ s [1]) have been determined. Only an approximate value of $b_\alpha = 55(25)\%$ has been reported previously for ^{179}Hg [2], while the value of $b_\alpha = 70\%$ for ^{178}Hg , tabulated in *Evaluated Nuclear Structure Data File* (ENSDF) [3], was based only on systematics [4]. The motivation for the present study is that a precise branching ratio for ^{178}Hg is needed for determining the probability of β -delayed fission of ^{178}Tl , which was recently observed in a separate study [5]. The present data result from the experiment described in detail in [6], where the reader can find a full description of the experimental equipment and the analysis techniques used.

2 Experimental details

The experiment was performed at the Accelerator Laboratory of the University of Jyväskylä. The α -decay chains

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of $^{182,183}\text{Pb}$ nuclei, produced via the pn and $p2n$ evaporation channels of the $^{78}\text{Kr} + ^{107}\text{Ag} \rightarrow ^{185}\text{Bi}^*$ reaction, were used to determine the values of α -decay branching ratios for $^{178,179}\text{Hg}$. A beam of $^{78}\text{Kr}^{15+}$ ions with an average intensity of approximately 90 particle nA was delivered by the K-130 cyclotron and impinged on a target inducing fusion-evaporation reactions. Four bombarding energies of 338, 343, 347 and 352 MeV at the centre of the target were used. Self-supporting metallic targets with a thickness of 0.7 mg/cm^2 were prepared from isotopically enriched material of ^{107}Ag (98.8% enrichment). Targets were mounted on a rotating wheel to minimize their deterioration under the relatively high beam intensity.

The evaporation residues (ERs) were separated from the primary beam and fission products by the gas-filled recoil separator RITU [7]. Nuclei transported into a focal plane of the separator were implanted into the double-sided silicon strip detector (DSSD) of the spectrometer GREAT [8]. A transmission multiwire proportional counter (MWPC) was positioned upstream of the DSSD. The MWPC was used to discriminate between ER implantations and radioactive decays that occur in the DSSD and also to measure the energy loss of ions passing through it. Combining a measurement of the ion velocities (as a time of flight between the MWPC and DSSD) with the energy loss measurement allowed ERs to be distinguished from other particles. The average implantation rate was approximately 50 ERs per second. Standard correlation

Fig. 1. Energy spectra of α particles measured in the $^{78}\text{Kr} + ^{107}\text{Ag}$ reaction, summed over four beam energies, see the text for details. a) Spectrum of ER- α events with the time condition of $\Delta t(\text{ER}-\alpha) \leq 1.5$ s. Some peaks are marked with the isotope they belong to and the measured α -decay energies. b) Two-dimensional energy spectrum of the ER- α_1 - α_2 correlated events with the time conditions of $\Delta t(\text{ER}-\alpha_1) \leq 1.5$ s and $\Delta t(\alpha_1-\alpha_2) \leq 3.0$ s.

techniques between ER implantations and subsequent α decays were employed. X-rays and γ -rays were detected by a segmented planar HPGe detector, which was positioned behind the DSSDs inside the vacuum chamber and by a large-volume clover HPGe detector outside the chamber. The data were collected by a triggerless Total Data Read-out acquisition system [9] and analysed using the GRAIN software package [10].

3 Experimental results

Figure 1a shows a part of the energy spectrum of α particles correlated with ER implantations within the time interval of $\Delta t(\text{ER}-\alpha_1) \leq 1.5$ s. The spectrum is dominated by the 6921(7) keV and 6706(7) keV peaks, which are known α decays of ^{182}Pb ($T_{1/2} = 55(5)$ ms [1]) and ^{183}Pb ($T_{1/2} = 415(20)$ ms [11]). Three other α decays of ^{183}Pb are known [11]. However, they are either weak or were dominated by stronger activities in the present experiment and therefore were not used in the data analysis. Figure 1b depicts a two-dimensional energy spectrum of ER- α_1 - α_2 correlated events with time constraints of $\Delta t(\text{ER}-\alpha_1) \leq 1.5$ s and $\Delta t(\alpha_1-\alpha_2) \leq 3.0$ s. The ER- α_1 ($^{182,183}\text{Pb}$)- α_2 ($^{178,179}\text{Hg}$) correlations of interest are indicated by the rectangles. The influence of random correlations was investigated thoroughly and was found to be negligible. By comparing the number of ER- α_1 - α_2 correlations from fig. 1b with that of ER- α_1 correlations from fig. 1a, after correction for the efficiency of α - α correlations, which was determined by the dedicated GEANT4 code, α -decay branching ratios of $b_\alpha(^{178}\text{Hg}) = 89(4)\%$ and $b_\alpha(^{179}\text{Hg}) = 75(4)\%$ were determined. The number of ER- α_1 - α_2 events was corrected to account for the fact that the time interval $\Delta t(\alpha_1-\alpha_2) \leq 3.0$ s covers only 86% of the decay curve of ^{179}Hg . No correction was necessary for ^{178}Hg due to its significantly shorter half-life.

Fig. 2. (Colour on-line) Ratio of measured β -decay partial half-lives for the ground states of neutron-deficient Hg isotopes from ^{185}Hg ($N = 105$) to ^{176}Hg ($N = 96$) to values calculated using the QRPA approach [13]. The experimental values deduced in present work are indicated by the red symbols. The data for the other isotopes were taken from ENSDF [3] and the experimental uncertainties are often smaller than the plotted symbols and therefore are not shown. The value of $b_\alpha = 94(12)\%$ for ^{176}Hg reported in [16] allows within the experimental uncertainty an infinite partial β -decay half-life, so only a lower limit can be calculated, as indicated in the figure.

Fig. 3. (Colour on-line) Reduced α -decay widths of neutron-deficient even-even Pb, Hg and Pt isotopes calculated using Rasmussen prescription [14]. The input data for the calculations were taken from ENSDF [3]. The experimental value deduced in present work is indicated by the red symbol.

4 Discussion

Partial β -decay half-lives of $T_{1/2}^\beta(^{178}\text{Hg}) = 2.4(9)$ s and $T_{1/2}^\beta(^{179}\text{Hg}) = 4.2(7)$ s were deduced from the present data. Theoretically, a partial β -decay half-life of $T_{1/2}^\beta = 5$ s was calculated [12] using the gross theory of β decay for ^{178}Hg . Another calculation [13] based on the QRPA approach for Gamow-Teller decays predicted $T_{1/2}^\beta = 1.16$ s. Both calculations reproduce the experimental values presented here reasonably well.

The comparison of measured partial β -decay half-lives of ground states of neutron-deficient Hg isotopes with QRPA predictions from [13] is given in fig. 2. These calculations do not reflect the complicated structure of neutron-deficient Au isotopes, the daughters of Hg β decays [6]. Nevertheless, in general they provide reasonable agreement with the experimental data.

Reduced α -decay widths of $\delta_\alpha^2(^{178}\text{Hg}) = 86(7)$ keV and $\delta_\alpha^2(^{179}\text{Hg}) = 62(5)$ keV were calculated for $^{178,179}\text{Hg}$ decays using the Rasmussen prescription [14] with an assumption of $\Delta L = 0$ decays. The systematics of reduced α -decay widths of neutron-deficient even-even Pb, Hg and Pt isotopes are presented in fig. 3. The systematic behaviour of reduced α -decay widths of isotopes in vicinity of $Z = 82$ has been discussed in [15]. With the more recent data available that are included in fig. 3, the reduced α -decay widths are currently under intensive theoretical investigation. While the general picture can be settled, more precise data on both half-lives and branching ratios for many isotopes are still needed.

The hindrance factor of 1.4(2) for the α decay of ^{179}Hg , calculated relative to the $0^+ \rightarrow 0^+$ decay of the adjacent isotope ^{178}Hg , indicates an unhindered decay. This corroborates the interpretation that the ground states of both ^{179}Hg and ^{175}Pt have the same spin and parity. In the literature, $(7/2^-)$ assignments for the ground states of ^{179}Hg and ^{175}Pt are suggested [11, 17].

5 Summary

Alpha-decay branching ratios of 89(4)% and 75(4)% have been deduced for ^{178}Hg and ^{179}Hg , respectively, using correlated α -decay chains. The partial β -decay half-lives and reduced α -decay widths calculated on the basis of these new values agree well with both theoretical predications and the experimental systematics.

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