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Measurements of ^{110}Xe and ^{106}Te decay half-lives

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Abstract. The α-decays of ^{110}Xe and ^{106}Te were studied at the GSI on-line mass separator. By using the grow-in and decay of the α activity, observed in pulsed-beam measurement, the half-life of ^{110}Xe was found to be $T_{1/2} = 105^{+35}_{-25}$ ms. The lifetime of ^{106}Te was determined to be $T_{1/2} = 70^{+20}_{-10}\,\mu$s by measuring the time between two successive ^{110}Xe → ^{106}Te → ^{102}Sn α-decays. The newly determined half-lives were used to calculate reduced α-decay widths for ^{106}Te and ^{110}Xe. Universal systematics of reduced α widths are proposed to search for the evidence of enhancement of the α formation amplitude in the emitters above ^{100}Sn.

PACS. 21.10.Tg Lifetimes – 23.60.+e α decay – 27.60.+j $90 \leq A \leq 149$

1 Introduction

The island of α emitters above ^{100}Sn was explored in several experiments giving insight into the nuclear structure of nuclei in this region [1]. It was found, for instance, that the measured α-decay energies of trans-tin emitters increase along the decay chains as a result of particularly strong binding of nuclei close to the ^{100}Sn. This observation provides a direct proof of the $N = Z = 50$ shell closure. What remains to be proven, however, is the suggestion that nuclei above ^{100}Sn undergo superallowed α-decay as a result of enhanced correlations of valence protons and neutrons occupying the same single-particle orbitals in $N \approx Z$ nuclei [2].

In a simple Gamow picture α-decay is treated as a two-step process in which an α-particle preformed at the nuclear surface penetrates through the Coulomb and centrifugal barrier. The probability of quantum tunnelling can be calculated in the WKB approximation using experimental Q_α values. Then, the information on the α-preformation probability can be obtained from the ratio of the measured transition probability and the calculated barrier penetrability. The α-formation amplitude contains information on the structure of the states connected by the α transitions and provides insight into the nature of α-clustering correlations in nuclei. The influence of shell closures is clearly visible already in the global systematics of the α-decay widths of even-even nuclei [1]. The theoretical models predicting the amplitude of α-cluster formation point to the importance of the n-n and p-p pairing correlations [3], configuration mixing [4] and the influence of continuum states [5]. It is also expected that p-n correlations become significantly important in the α-decay of the $N \approx Z$ nuclei because valence neutrons and protons occupy the same orbitals and have large overlaps of wave functions [6]. Therefore, studies of α-decays in the ^{100}Sn region provide a unique possibility to investigate the role of p-n correlations in the α-cluster formation process.

So far, the ^{114}Ba → ^{110}Xe → ^{106}Te → ^{102}Sn α-decay chain connecting $N = Z + 2$ nuclei represents the closest experimental approach to the $N = Z$ line. In our recent work [7] we reported on the first observation of the α-decay of ^{114}Ba. The Q_α value for ^{114}Ba, the half-life of ^{110}Xe and the α-decay branching ratios for these two isotopes were measured for the first time. In this work we report on the

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reinvestigation of the ^{110}Xe and ^{106}Te α-decays performed at the GSI on-line mass separator.

2 Experimental method

The ^{110}Xe nuclei were produced in reactions of a 5.0 MeV/u ^{58}Ni beam and 3 mg/cm^2 thick ^{58}Ni targets. The reaction products were stopped and ionized in the FEBIAD-B2C ion source [8] of the on-line mass separator. The ions, extracted from the source, were accelerated to 55 keV and separated according to their mass number. Two different detection set-ups were used to study the α-decays in the ^{110}Xe $\rightarrow$ ^{106}Te $\rightarrow$ ^{102}Sn chain:

A) The mass-separated $A = 110$ beam was periodically implanted (1 s beam-on / 1 s beam-off) in a thin carbon foil placed in front of a silicon surface-barrier detector telescope. It consisted of a 20 μm, 450 mm^2 ΔE detector and a 500 μm, 2000 mm^2 E detector. The latter counter was used to reject signals triggered by positrons, β-delayed protons and high-energy β-delayed α-particles passing through the ΔE detector. The solid angle covered by the telescope amounted to about 34%. The observed grow-in and decay of the collected activity was used to determine the decay half-life. Signals from the detectors were processed by analog electronics and recorded in event-by-event mode by a standard data acquisition system. Together with the energy and fast timing information the time of occurrence of each event within the collection cycle was stored.

B) Since ^{106}Te nuclei are too short-lived ($< 100\,\mu$s) to be extracted directly from the ion source of the separator, they were produced as α-decay products of mass-separated ^{110}Xe ions. The $A = 110$ beam was continuously implanted at an angle of 45 degrees on a thin carbon foil placed between two silicon detectors, whose dimensions were 100 μm, 200 mm^2 and 300 μm, 900 mm^2, respectively. This detector configuration minimized the efficiency loss due to the ^{106}Te recoil escape and enabled registration of ^{110}Xe-^{106}Te α-α correlations with a total efficiency of about 16%. This value is 5 times higher than the efficiency for α-α correlation registration in set-up A). The short lifetime of ^{106}Te requested a data-taking system capable to register α-decay events occurring in less than 100 μs after each other. Since this time interval is critical for the standard acquisition system with a typical dead-time of about 100 μs, a DGF-4C module [9] was used to register signals from the detector's preamplifiers. In this module the input signals were digitized and analyzed by the on-board signal processor. The amplitude and the time stamp of each processed signal were stored in the internal memory buffer and transferred on request to the host computer. The system based on the DGF-4C module enabled practically dead-time–free registration of the correlated events.

3 Results

3.1 Measurements of ^{110}Xe half-life

Figure 1 shows the energy spectrum of α-particles measured in the ΔE detector in anticoincidence with signals from the E detector of the telescope during 10 hours of mass-110 measurement. The 3737 keV and 4160 keV α lines assigned by Schardt *et al.* [10] to the decays of ^{110}Xe and ^{106}Te, respectively, are clearly visible. The ^{106}Te is produced exclusively as α-decay product of ^{110}Xe and since its half-life is very short compared to the ^{110}Xe decay time scale, both lines follow the same time dependence, characteristic of the ^{110}Xe decay. The inset in fig. 1 shows the time distribution of the ^{110}Xe + ^{106}Te lines during the 1 s collection and 1 s deflection of the $A = 110$ beam. A least-square fit of the theoretical time distribution to the experimental data yielded $T_{1/2} = 110^{+30}_{-20}$ ms for the half-life of ^{110}Xe. This result agrees with the value of 100^{+30}_{-20} ms obtained by using the ratio of events observed during the grow-in and decay period for the half-life determination. For further discussion we adopt $T_{1/2} = 105^{+35}_{-25}$ ms for the half-life of ^{110}Xe. This value is consistent with the previous estimate of 160^{+290}_{-60} ms [7].

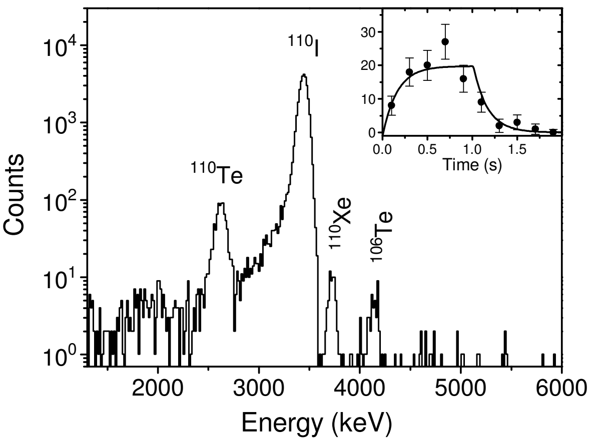

Fig. 1. Energy spectrum of α-particles registered in the ΔE detector in anticoincidence with the E detector of the telescope. The inset shows the time distribution of the sum of the 3737 keV ^{110}Xe and 4160 keV ^{106}Te α lines. The solid curve represents the best fit of the theoretical distribution to the experimental data.

3.2 Measurement of ^{106}Te half-life

The half-life of ^{106}Te was determined through the analysis of time correlations between the ^{110}Xe and ^{106}Te α-decay events. The detection set-up B) was used to i) increase the efficiency of detection α-α correlation and ii) to circumvent the problem of the dead-time of the standard data acquisition system. Figure 2 shows the energy spectrum of particles registered in one of the detectors within 1 ms after the detection of a signal corresponding to the energy of ^{110}Xe α-particles registered in the opposite counter. Most of the correlated events group around 4160 keV, *i.e.* the energy of ^{106}Te α-particles. Three events at the energy of the ^{110}I α line are due to random correlations and represent about 0.02% of the intensity of ^{110}I α line in the single spectrum. The contribution of randomly correlated

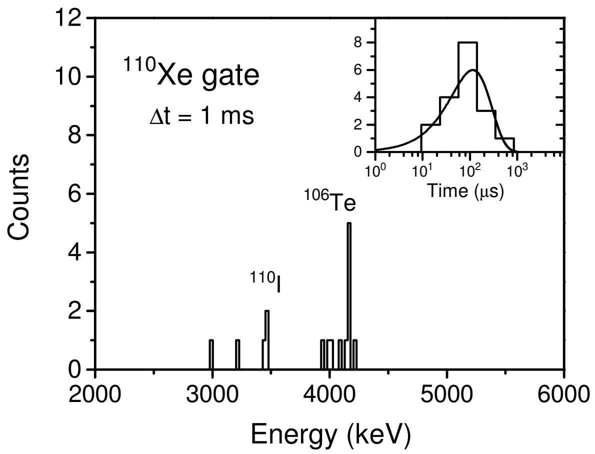

Fig. 2. Energy spectrum of particles registered within 1 ms after detection of a signal corresponding to the α-decay of ^{110}Xe. The inset shows the distribution of the logarithm of the time difference between the detection of ^{110}Xe and ^{106}Te α-decay. The solid curve represents the best fit of the theoretical distribution to the experimental data.

events to the ^{106}Te peak is smaller than 0.2 counts and can thus be neglected. The inset in fig. 2 shows, in logarithmic time scale, the observed distribution of the time difference between the detection of ^{110}Xe and ^{106}Te α-decay. A statistical procedure proposed by Schmidt [11] was applied to verify that the measured time distribution is consistent with the assumption of a single-decay half-life. The test is based on a comparison of the standard deviation of the measured logarithmic distribution with the theoretical expectation. The analysis of the measured correlation times gives 0.83 for the standard deviation of the logarithmic time distribution. This value falls between the limits (0.79 and 1.73) defined by a significance level of 90% for 18 correlated events. Thus, the result of the test supports the assumption of a single exponential decay character of the measured time distribution and indicates that there was no cut-off in the time range covered in the measurement. The half-life of ^{106}Te determined by applying the maximum-likelihood method [12] to the 18 data points amounts to $80^{+25}_{-15}\,\mu$s. This value is in agreement with the ^{106}Te half-life of $60^{+30}_{-10}\,\mu$s reported by Schardt *et al.* [10]. For further discussion we adopt the average value of these two measurements which yields $70^{+20}_{-10}\,\mu$s for the decay half-life of ^{106}Te.

4 Discussion

Table 1 lists the experimentally determined α-decay properties of ^{110}Xe and ^{106}Te. The last column of the table shows the reduced α-decay widths (W_α) defined as a ratio between the measured transition probability and the calculated s-wave barrier penetrability [13], normalized to the decay width for the ground-state α-decay of ^{212}Po [14]. The screening correction applied in the calculations was determined from the tables of Huang *et al.* [15].

Table 1. Experimentally determined α-decay properties of ^{110}Xe and ^{106}Te.

Isotope	Q_α(keV)	$T_{1/2}$ (ms)	b_α(%)	W_α
^{110}Xe	3885 ± 14 [16]	105^{+35}_{-25}	64 ± 35 [7]	$2.4^{+1.5}_{-1.6}$
^{106}Te	4290 ± 9 [16]	$0.070^{+20\,(a)}_{-10}$	100	$4.6^{+0.7}_{-1.3}$

(^{a}) Average value of $T_{1/2}$ from ref. [10] and this work.

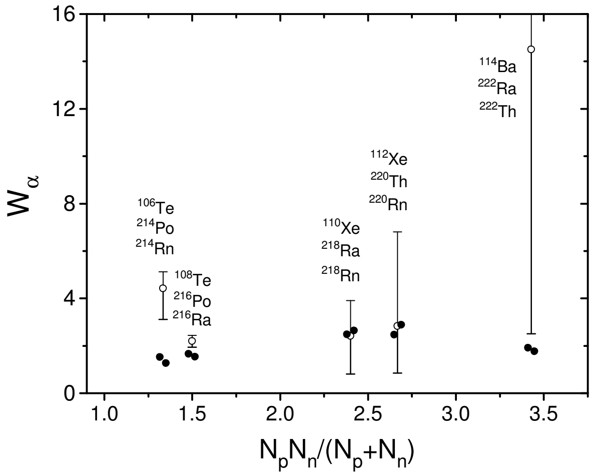

Fig. 3. Experimental reduced α-decay widths for even-even emitters plotted as a function of parameter $P = N_pN_n/(N_p + N_n)$. Data points for trans-tin and trans-lead isotopes are marked by open and full circles, respectively. Error bars for trans-lead α emitters are too small to be shown in scale. Experimental data for ^{108}Te, ^{112}Xe and trans-lead isotopes were taken from [14] whereas those for ^{114}Ba, ^{106}Te and ^{110}Xe stem from [7] and from the present work.

The more accurate data on the decay half-lives, obtained in this work, substantially reduced the uncertainties of the W_α values reported in our previous work [7]. In the case of ^{110}Xe, the main contribution to the uncertainty W_α comes from the uncertainty of the α-branching ratio, whereas for the case of ^{106}Te the half-life uncertainty is dominant.

Figure 3 shows the systematics of the reduced α-decay widths for the even-even α emitters in the trans-tin and trans-lead region plotted as a function of the factor $P = N_pN_n/(N_p + N_n)$ [17], N_p and N_n denoting the number of valence protons and neutrons above the ^{100}Sn and ^{208}Pb cores, respectively. The P-factor describes the average number of interactions of each valence nucleon with those of the other type. Such a parametrization of the W_α systematics seems to be relevant in order to identify the expected enhancement of the α-particle formation amplitude in the $N \approx Z$ nuclei due to the particularly strong p-n interaction in such systems. The remarkable general agreement of the W_α of trans-lead isotopes with the same P values supports the usefulness of the applied parametrization. While the reduced α-widths for the ^{110}Xe and ^{112}Xe agree with the benchmarks set by the respective trans-lead isotopes, the α-decay widths for ^{106}Te, ^{108}Te and ^{114}Ba lie above the W_α values for the heavy P-partners. However, the largest deviation of W_α values for these isotopes is below the 2σ level. Therefore, at this stage no firm conclusion can be drawn on a possible enhancement of the α-formation amplitude due to the strong p-n correlations in $N \approx Z$ nuclei.

Further α-decay studies in the ^{100}Sn region should concentrate on the accurate measurements of decay branching ratios for the ^{110}Te, ^{110}Xe, ^{112}Xe and ^{114}Ba (in the latter case also the accuracy of the $T_{1/2}$ measurement has to be improved), where α-particle emission competes with the β-decay. These measurements can be performed *e.g.* at inflight separators where the energetic (fragmentation) reaction products can be identified and counted ion by ion before being implanted in the α-particle detector. Studies of the $^{112}\mathrm{Ba} \to {}^{108}\mathrm{Xe} \to {}^{104}\mathrm{Te} \to {}^{100}\mathrm{Sn}$ α-decay chain connecting $N = Z$ nuclei would be of prime interest in order to clarify the influence of the p-n interaction on the α cluster formation probability. However, these measurements represent a major experimental challenge due to the extremely low production cross-sections and/or very short half-lives of isotopes in the ^{112}Ba-^{100}Sn α-decay sequence.

In summary, α-decays of ^{110}Xe and ^{106}Te were investigated at the GSI on-line separator. The half-life of ^{110}Xe was determined from the observed grow-in and decay of the collected activity. The new $T_{1/2}$ value for ^{110}Xe, obtained in this work, replaces the previous estimate of the half-life based on only two observed events. The half-life of ^{106}Te was measured by using versatile digital signal processing electronics to register correlation time between the subsequent ^{110}Xe and ^{106}Te α-decays. The newly determined half-lives improved the accuracy of the reduced α-decay widths for ^{110}Xe and ^{106}Te. In general, however, the α-decay widths of even-even emitters in ^{100}Sn region are still known with insufficient accuracy to enable firm conclusions on the expected enhancement of the α-formation amplitude due to the p-n interaction.

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References

1. E. Roeckl, *Alpha decay*, in *Nuclear Decay Modes*, edited by D.N. Poenaru (Institute of Physics Publishing, 1996) p. 237.
2. R.D. Macfarlane, A. Siivola, Phys. Rev. Lett. **14**, 114 (1965).
3. V.G. Soloviev, Phys. Lett. **1**, 202 (1962).
4. G. Dodig-Crnkovic, F.A. Janouch, R.J. Liotta, Nucl. Phys. A **501**, 533 (1989).
5. A. Insolia, R.J. Liotta, E. Maglione, Europhys. Lett. **7**, 209 (1988).
6. D.S. Delion, A. Insolia, R.J. Liotta, Nucl. Phys. A **549**, 407 (1992).
7. C. Mazzocchi *et al.*, Phys. Lett. B **532**, 29 (2002).
8. R. Kirchner, Nucl. Instrum. Methods Phys. Res. B **204**, 179 (2003).
9. B. Hubbard-Nelson, M. Momayezi, W.K. Warburton, Nucl. Instrum. Methods Phys. Res. A **422**, 411 (1999).
10. D. Schardt *et al.*, Nucl. Phys. A **368**, 153 (1981).
11. K.-H. Schmidt, Eur. Phys. J. A **8**, 141 (2000).
12. K.-H. Schmidt *et al.*, Z. Phys. A **316**, 19 (1984).
13. J.O. Rasmussen, Phys. Rev. **113**, 1593 (1959).
14. Y.A. Akovali, At. Data Nucl. Data Tables **84**, 1 (1998).
15. K.-N. Huang *et al.*, At. Data Nucl. Data Tables **18**, 243 (1976).
16. G. Audi, A.H. Wapstra, C. Thibault, Nucl. Phys. A **729**, 337 (2003).
17. R.F. Casten, D.S. Brenner, P.E. Haustein, Phys. Rev. Lett. **58**, 658 (1987).