Author(s): Grahn, Tuomas; Dewald, A.; Greenlees, Paul; Jakobsson, Ulrika; Jolie, J.; Jones, Peter; Julin, Rauno; Juutinen, Sakari; Ketelhut, Steffen; Kröll, T.; Krücken, R.; Leino, Matti; Maierbeck, P.; Melon, B.; Nyman, Markus; Page, Robert; Peura, Pauli; Pissulla, Th; Rahkila, Panu; Sarén, Jan; Scholey, Catherine; Sorri, Juha; Uusitalo, Juha

Title: Lifetime measurement in 195Po

Year: 2009

Version:

Please cite the original version:

Grahn, T., Dewald, A., Greenlees, P., Jakobsson, U., Jolie, J., Jones, P., Julin, R., Juutinen, S., Ketelhut, S., Kröll, T., Krücken, R., Leino, M., Maierbeck, P., Melon, B., Nyman, M., Page, R., Peura, P., Pissulla, T., Rahkila, P., . . . Uusitalo, J. (2009). Lifetime measurement in 195Po. Eur. Phys. J. A, (39), 291.

EPJ manuscript No.
(will be inserted by the editor)

Lifetime measurement in ^{195}Po

T. Grahn[1a], A. Dewald[2], P.T. Greenlees[3] U. Jakobsson[3], J. Jolie[2], P. Jones[3], R. Julin[3], S. Juutinen[3], S. Ketelhut[3], T. Kröll[4], R. Krücken[4], M. Leino[3], P. Maierbeck[4], B. Melon[2], M. Nyman[3], R.D. Page[1], P. Peura[3], Th. Pissulla[2], P. Rahkila[3], J. Sarén[3], C. Scholey[3], J. Sorri[3], and J. Uusitalo[3]

[1] Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, UK
[2] Institut für Kernphysik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany
[3] Department of Physics, University of Jyväskylä, P. O. Box 35, FI-40014 Jyväskylä, Finland
[4] Physik-Department E12, TU München, 85748 Garching, Germany

Received: date / Revised version: date

Abstract. The lifetime of the $17/2^+$ yrast state in ^{195}Po has been measured using the recoil distance Doppler-shift technique to be $\tau = 43(11)$ ps. The lifetime was extracted from the singles γ-ray spectra obtained by using the recoil-decay tagging method. The present work provides more information of the coupling schemes, shapes and configuration mixing in neutron-deficient odd-mass Po nuclei.

PACS. 21.10.Ky Electromagnetic moments – 21.10.Tg Lifetimes, widths – 23.20.-g Electromagnetic transitions – 27.80.+w $190 \leq A \leq 219$

1 Introduction

In neutron-deficient Po nuclei, two protons away from the $Z = 82$ shell closure, competing spherical and deformed structures have been found to coexist and mix at low spin [1]. When moving away from the $N = 126$ shell closure towards the neutron mid-shell at $N = 104$, the proton-neutron interaction within the expanding valence space gives rise to quadrupole collectivity and, consequently, particle-hole intruder states are lowered in energy. In the neutron-deficient even-mass Po nuclei such intruding 0^+ states have have been observed in α- and β-decay studies and associated with a $\pi(4p-2h)$ configuration [2] and an oblate minimum in the potential energy surface [3].

While shape coexistence in the light even-mass Po nuclei is rather well studied, information about the intruder states in corresponding odd-mass nuclei is somewhat scarce. Earlier in-beam and α-decay studies have revealed the low-lying level structure and bands built on the $I^\pi = 13/2^+$ α-decaying isomeric state in ^{193,195,197}Po [4–6]. The structure of these bands has been presumed to emerge from the decoupling of the odd $i_{13/2}$ neutron from the even-mass core and particularly in the case of ^{195}Po, from the ^{194}Po core. The weak coupling picture is demonstrated by the level spacings of the levels above the $13/2^+$ state in odd-mass Po nuclei being close to the yrast level spacings in their even-mass neighbours. Recent lifetime measurements have revealed the yrast band and the ground state in ^{194}Po to be predominantly of the oblate intruder character [8]. In ^{195}Po candidates for unfavoured states have been found. The fact that these states lie higher in energy than the favoured states further supports the decoupling picture and oblate deformation at low spin [4].

The structure of the $13/2^+$ state has been deduced to be an admixture of the spherical and oblate configurations in ^{193,195,197}Po [6], while in ^{191}Po shape staggering between the isomeric $13/2^+$ and the $3/2^-$ ground state has been observed [7]. This can be seen as a sign towards the pure intruder configuration of the $13/2^+$ state in light Po nuclei.

Alternatively, in Ref. [9], it has been suggested that the collectivity of the yrast levels in Po nuclei with $A < 199$ emerges from harmonic vibrational motion, which is manifested by the near equal level spacings. However, recent lifetime measurements and configuration mixing calculations of the angular momentum projected mean field states in ^{194}Po [10] and ^{196}Po [11] support the oblate deformed intruder interpretation of the yrast bands in those nuclei.

To provide further data concerning the low-energy structure of ^{195}Po, a Recoil Distance Doppler-Shift (RDDS) lifetime measurement has been carried out. The present study provides new data to aid the understanding of the evolution of collectivity in Po nuclei near the neutron mid-shell.

2 Experimental details

The present study was carried out at the Accelerator Laboratory of the University of Jyväskylä, where excited ^{195}Po nuclei were produced in the ^{113}Cd(^{86}Kr,4n)^{195}Po reaction at a beam energy of 382 MeV. In the present work experimental conditions were optimised for the study of ^{196}Po,

[a] *Electronic address:* tuomas.grahn@liverpool.ac.uk

which has been reported elsewhere [11]. The Köln plunger device was combined with the JUROGAM Ge-detector array and the gas-filled separator RITU [12]. With a stretched 1 mg/cm^2 ^{113}Cd target on a 1 mg/cm^2 Ta support facing the beam, an initial recoil velocity of $v/c = 3.5$ % was obtained. A 1 mg/cm^2 thick Mg foil replaced the standard stopper foil of the plunger device, thus allowing the fusion-evaporation residues to recoil into RITU. The JUROGAM Ge-detector array consisting of 43 Eurogam Phase I type Compton-suppressed Ge detectors [13] was used to detect prompt γ rays.

The gas-filled separator RITU was used to separate the recoils from the beam and other reaction products and transport them to the GREAT spectrometer [14] at the focal plane of the separator. At the entrance of GREAT recoiling nuclei passed through the MultiWire Proportional Counter (MWPC), which recorded their energy loss and timing information. After the MWPC the recoils were implanted into a pair of Double-sided Silicon Strip Detectors (DSSDs) providing the arrival time of the recoiling nucleus, and information of its subsequent radioactive decay. By using the timing and energy loss information of the MWPC and the timing information of the DSSDs, the selection of the recoils was made. Prompt γ rays were assigned to ^{195}Po according to principles of the Recoil-Decay Tagging (RDT) method [15]. The α decays originating from the isomeric $13/2^+$ state ($E_\alpha = 6699$ keV, $t_{1/2} = 1.92$ s [16]) were temporally and spatially correlated with the detected recoils. Thus, RDT singles γ-ray spectra of ^{195}Po were constructed. The data were collected using the triggerless Total Data Readout data acquisition system [17].

RDT singles γ-ray spectra were reconstructed using the GRAIN software package [18] from the data recorded with 13 different target-to-degrader distances (20 μm-6 mm). Due to their suitable efficiency and angular position, only ten of the JUROGAM Ge detectors, positioned at an angle of 134° with respect to the beam direction, could be used in the final RDDS analysis. The typical separation of the fully Doppler-shifted and degraded components in the final γ-ray spectra was on the order of 2 keV at 319 keV. Sample spectra are shown in Fig. 1.

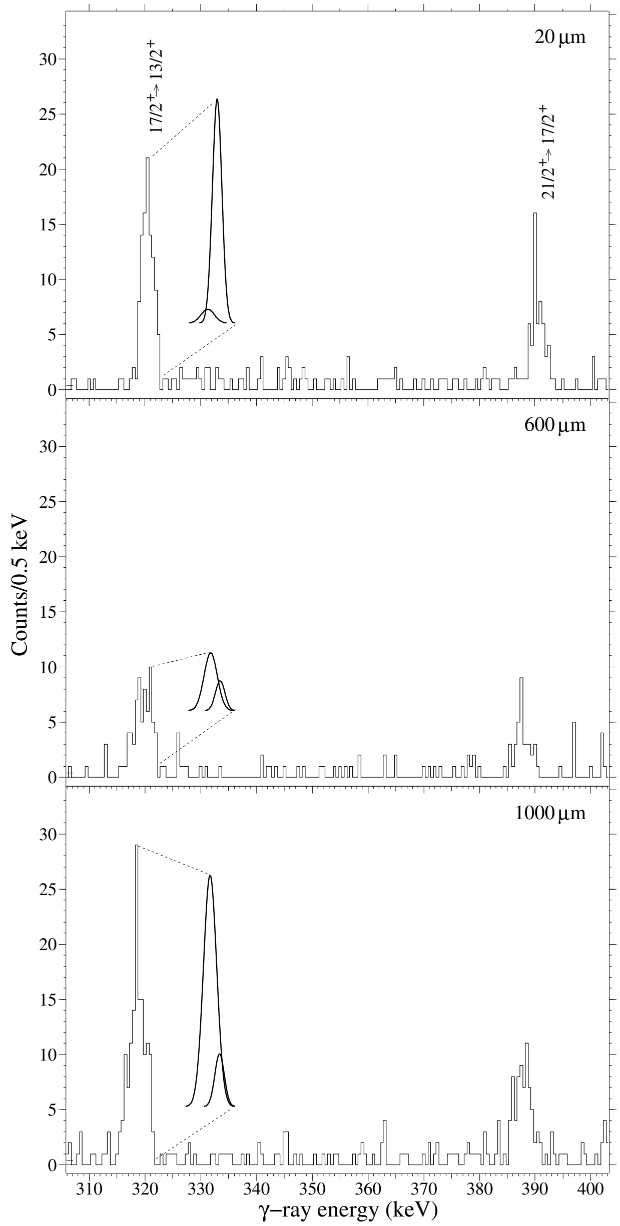

Fig. 1. Singles RDT γ-ray spectra recorded at the three target-to-degrader distances with ten JUROGAM detectors at 134°. Sample fits showing the fully Doppler-shifted (left) and degraded (right) components of the transitions under investigation are also drawn.

3 Results

The lifetime of the $17/2^+$ state, decaying by a 319-keV γ-ray transition to the α-decaying $13/2^+$ state in ^{195}Po [4] was extracted from the singles RDT γ-ray spectra using the Differential Decay Curve Method (DDCM) [19]. The intensity of the 319-keV γ-ray transition was normalised by the sum of the respective fully-shifted (I_s) and degraded components (I_d) and a decay curve $I_s/(I_d + I_s)$ was constructed. The $17/2^+$ state was fed up to $\sim 60\%$ from the $21/2^+$ state. As it has been discussed elsewhere [10,11], in certain cases it is reasonable to assume the similar time behaviour for the unobserved feeding than that for the observed one. For the present DDCM analysis, this is justified as the $17/2^+$ state is fed mainly by the intraband transitions from the $21/2^+$ state and the feeding time is not particularly long. With this feeding assumption, the final lifetime of $\tau = 43(11)$ ps was extracted, which corresponds to the reduced transition probability $B(E2)$ value of 80(20) W.u. The lifetime determination of this state is illustrated in Fig. 2.

By using the rotational model, the absolute values for the transition quadrupole moment Q_t and the transition quadrupole deformation parameter $\beta_2^{(t)}$ can be extracted from the measured $B(E2)$ value [10]. Assuming $K = 1/2$ for the yrast band of ^{195}Po, the values of $|Q_t| = 4.0(6)$ eb and $|\beta_2^{(t)}| = 0.13(2)$ are obtained. The measured magni-

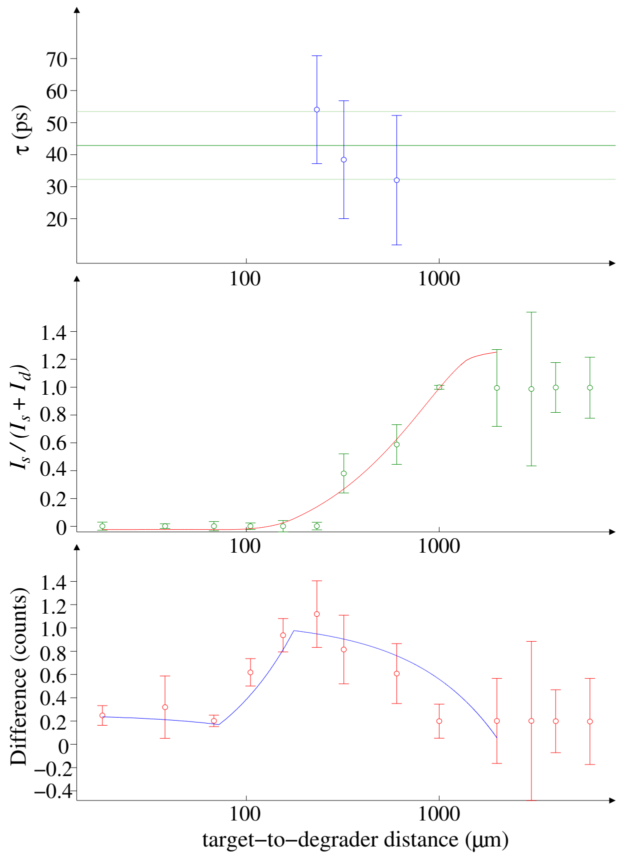

Fig. 2. Lifetime determination of the $17/2^+$ state in ^{195}Po. Lifetime values calculated for different distances within the region of sensitivity are presented in the top panel. The decay curve, recorded with ten Ge detectors at 134° is shown in the middle panel. The bottom panel shows the difference of the quantities $I_s/(I_s + I_d)$ for the depopulating and direct feeding transitions. The line drawn through the experimental points is the derivative of the decay curve multiplied by the lifetime value.

tude of the quadrupole deformation in the present work is within the error bars the same as for the oblate band in ^{194}Po ($|\beta_2^{(t)}| = 0.17(3)$ [8]).

4 Discussion

In the light Po nuclei, and in particular around ^{192,194}Po, the yrast level patterns of odd-mass nuclei are close to those of the adjacent even-mass ones. The level patterns built on top of the $13/2^+$ state in odd-mass Po nuclei have been interpreted either as a weak coupling of the odd $i_{13/2}$ neutron to the nearly spherical even-mass core [9] or, as a decoupling of the $i_{13/2}$ neutron hole from the even-mass oblate core [4]. The latter incorporates the particle-hole intruder states observed in neighbouring even-mass Po nuclei. Indeed, such behaviour has been observed and discussed in Ref. [6]. For the Po nuclei with $A > 198$ the level patterns can be successfully described by the weak coupling of the odd neutron to the near-spherical core. In

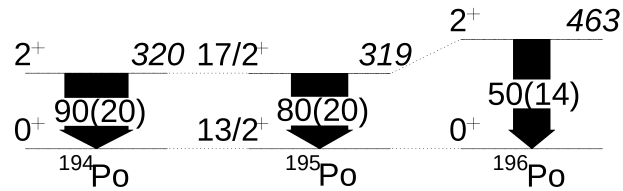

Fig. 3. $B(E2)$ values of the $2^+ \to 0^+$ transitions in ^{194}Po [8], and ^{196}Po [11] and that for the $17/2^+ \to 13/2^+$ transition in ^{195}Po measured in the present work. The width of the arrow is proportional to the $B(E2)$ value. Level energies and the $B(E2)$ values are given in keV and W.u., respectively.

the lighter Po nuclei ($A < 198$) unfavoured states have been observed [1,5]. In the odd-mass $^{191-197}$Po nuclei the unfavoured $15/2^+$ and $19/2^+$ states lie higher in energy than the corresponding favoured $17/2^+$ and $21/2^+$ states. This is consistent with the decoupling scheme. However, in ^{191}Po the unfavoured states have been observed at lower excitation energies than the favoured states. This can be seen as a sign of a change towards the strong-coupling scheme and prolate deformation in the light Po isotopes [1].

In Ref. [6], potential energy surface calculations have been carried out for the light Po nuclei predicting an oblate minimum for ^{195}Po, associated with the $\nu 1i_{13/2} \otimes \pi(4p - 2h)$ configuration. A spherical minimum ($\nu 3p_{3/2} \otimes \pi(2p - 0h)$) has been predicted to lie lower in energy, representing the $3/2^-$ ground state of ^{195}Po. However, based on the α-decay hindrance factors, both of these states are deduced to be an admixture of the spherical and oblate configurations.

In Fig. 3, the $B(E2)$ values of the $2^+ \to 0^+$ yrast transitions in ^{194}Po and ^{196}Po and that for the transition to the $13/2^+$ isomeric state in ^{195}Po have been illustrated. Similar level energies and the $B(E2)$ values of the 2^+ state in ^{194}Po and of the $17/2^+$ state in ^{195}Po support the decoupling scheme of the odd neutron from the even-mass ^{194}Po core. Hence, the data in Fig. 3 suggest similar structure for the isomeric $13/2^+$ state in ^{195}Po and the ground state in ^{194}Po, which has been found to be predominantly oblate, with a small admixture of near-spherical configuration [10].

5 Summary

In summary, the lifetime of the $17/2^+$ yrast state has been measured in ^{195}Po. The RDT method provided clean singles γ-ray spectra, thus allowing the extraction of the lifetime using the RDDS technique. A comparison of the $B(E2)$ value, measured in the present work, with the corresponding values in its even-mass neighbours further supports the decoupling of the odd neutron from the even-mass core.

This work has been supported through EURONS (European Commission contract no. RII3-CT-2004-506065), the Academy of Finland under the Finnish Centre of Excellence Programme 2006-2011 (Nuclear and Accelerator Based Physics contract 213503) and the UK STFC. The UK/France (STFC/IN2P3) Loan Pool and GAMMAPOOL network are acknowledged for the EUROGAM detectors of JUROGAM. CS and PTG acknowledge the support of the Academy of Finland, contract numbers 209430 and 111965, respectively. Discussions with A.N. Andreyev, P.-H. Heenen and M. Bender are gratefully acknowledged.

References

1. R. Julin, K. Helariutta, M. Muikku, J. Phys. G **27**, (2001) R109.
2. N. Bijnens *et al.*, Phys. Rev. Lett. **75**, (1995) 4571.
3. F.R. May, V.V. Paskevich and S. Frauendorf, Phys. Lett. **68B**, (1977) 113.
4. K. Helariutta *et al.*, Eur. Phys. J. **6**, (1999) 289.
5. D.R. Wiseman *et al.*, Eur. Phys. J. **34**, (2007) 275.
6. A.N. Andreyev *et al.*, Phys. Rev. C **66**, (2002) 014313.
7. A.N. Andreyev *et al.*, Phys. Rev. Lett. **82**, (1999) 1819.
8. T. Grahn *et al.*, Phys. Rev. Lett. **97**, (2006) 062501.
9. N. Fotiades *et al.*, Phys. Rev. C, **56**, (1997) 723.
10. T. Grahn *et al.*, Nucl. Phys. A **801**, (2008) 83.
11. T. Grahn *et al.*, Phys. Lett. B, submitted.
12. M. Leino *et al.*, Nucl. Instrum. Methods B, **99**, (1995) 653.
13. C.W. Beausang *et al.*, Nucl. Instrum. Methods A, **313**, (1992) 37.
14. R.D. Page *et al.*, Nucl. Instrum. Methods B, **204**, (2003) 634.
15. E.S. Paul *et al.*, Phys. Rev. C, **51**, (1995) 78.
16. J. Wauters *et al.*, Phys. Rev. C, **47**, (1993) 1447.
17. I.H. Lazarus *et al.*, IEEE Trans. Nucl. Sci., **48**, (2001) 567.
18. P. Rahkila, Nucl. Instrum. Methods A, **595**, (2008) 637.
19. A. Dewald, S. Harissopoulos, P. von Brentano, Z. Phys. A **334**, (1989) 163.
20. K. Van de Vel *et al.*, Phys. Rev. C **65**, (2002) 064301.