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Lifetime measurements in the Yrast magnetic band in ^{193}Pb

K A Gladnishki[1], **D L Balabanski**[1,2,3], **P Petkov**[2,4], **A Dewald**[4], **D Tonev**[4], **M Axiotis**[5], **A Fitzler**[4], **M Danchev**[3], **S Harissopulos**[6], **S Lalkovski**[3], **N Marginean**[5], **T Martinez**[5], **O Moeller**[4], **G Neyens**[7], **A Spyrou**[6], **E A Stefanova**[2] **and C Ur**[5]

[1] Dipartimento di Fisica, Universitá di Camerino, 62032 Camerino, Italy
[2] INRNE, Bulgarian Academy of Sciences, BG-1784, Sofia, Bulgaria
[3] University of Sofia 'St. Kl. Ohridski', 1164-Sofia, Bulgaria
[4] Institut für Kernphysik, Universität zu Köln, D-50937 Köln, Germany
[5] INFN, Laboratori Nazionali di Legnaro, 35020 Legnaro, Italy
[6] INP, NCSR Demokritos, GR-15310 Aghia Paraskevi, Athens, Greece
[7] Instituut voor Kern en Stralingsfysica, KU Leuven, Celestijnenlaan 200 D, B-3001 Leuven, Belgium

E-mail: kalin.gladnishki@unicam.it

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Abstract
Lifetimes of states in the $\nu i_{13/2}^{-1} \bigotimes \pi(i_{13/2}h_{9/2})_{11^-}$ magnetic band in ^{193}Pb have been measured with the recoil-distance Doppler-shift (RDDS) method. This band is built on the $I^\pi = 29/2^-$ isomer ($E_{ex} = 2584$ keV, $T_{1/2} = 9.4$ ns). High-spin states in ^{193}Pb were populated in the ^{170}Er (^{28}Si, 5n) reaction at 149 MeV. The nuclear γ-decay was detected with the GASP spectrometer in combination with the Köln plunger device. These results provide for the first time a complete set of experimental observables for such an excitation in atomic nuclei.

1. Introduction

Regular bands of magnetic dipole transitions have been systematically observed in the Pb isotopes between ^{191}Pb and ^{202}Pb. The energy spacings of the states in these bands follow a rotational-like pattern. These structures, characterized by strong M1 γ-ray transitions, very small E2 transition probabilities and rather large dynamical moments of inertia, were assigned to a new rotational mode, the magnetic rotation, and arise from the anisotropy of the currents of valence particles in the nucleus, which induces a large magnetic moment. For a recent review, see [1, 2].

The M1 bands in Pb isotopes are based on proton excitations across the $Z = 82$ shell gap coupled to neutron–hole excitations in the $\nu i_{13/2}$ shell, e.g, near the bandhead a perpendicular coupling of the proton and neutron spins is energetically favoured, forming a shears state, while along the band the angular momentum increases by a step-by-step alignment of the proton and neutron spins [3].

In this paper, we report a study of the lifetimes in ^{193}Pb. This nucleus is close to the neutron mid-shell, and in this region shape coexistence is a well-known effect. The isomeric states based on neutron excitation in the Pb nuclei $13/2^+$ (one hole in the $\nu i_{13/2}$ shell), 12^+ (two holes) and $33/2^+$(three holes) are spherical, while the 11^- isomers (2p–2h proton excitations) are characterized by an oblate shape [4]. In ^{193}Pb the coupling of these states results in a $I^\pi = 29/2^-$ isomer ($E_{\rm ex} = 2584$ keV, $T_{1/2} = 9.4$ ns). The spin and configuration assignment, $\nu i_{13/2}^{-1} \bigotimes \pi(i_{13/2}h_{9/2})_{11^-}$, have been unambiguously fixed for this state from spectroscopic studies [5, 6] and a g-factor measurement [7], respectively, and quadrupole moment $|Q_s| = 2.84(24)$ eb, also has been measured [8]. It is well reproduced by tilted-axis cranking (TAC) calculations, Q_s (TAC) $= -2.85$ eb [9]. The calculation yields an oblate deformation $\beta_2 = -0.13$ for this state which is the bandhead of a magnetic rotational band (denoted further as A11). Here we report the first results for lifetimes in this band.

2. Experiment

The experiment was performed at the XTU tandem accelerator at the INFN Laboratori Nazionali di Legnaro, Italy. Excited states in ^{193}Pb were populated in the ^{170}Er (^{28}Si, 5n) reaction at a beam energy of 149 MeV. The nuclear γ-decay was detected by the 4π γ-ray spectrometer GASP [10] which consists of 40 Compton-suppressed Ge detectors, grouped in seven rings covering backward and forward angles. During the experiment two measurements were done: a recoil-distance method (RDDM) measurement (in order to approach the lifetimes at the bottom of the A11 band) and a Doppler-shift attenuation method (DSAM) measurement (in order to obtain information for short lifetimes).

Further, we discuss the results of the RDDM measurements. In the experiment, the Köln plunger device was used. Spectra were recorded for nine different distances, in the range from 0.1 μm to 257.1 μm. Triple $\gamma\gamma\gamma$-coincidence events have been collected during the experiment. For each distance, the events were sorted offline into $\gamma\gamma$-coincidence matrices with γ-rays detected in one given detector ring placed along one axis and γ-rays detected elsewhere in the array along the second axis of the matrix. The analysis of the same transition for different distances requires a normalization of its intensity due to fluctuations of the beam current or differences in the measuring times. The 882 and 520 keV γ-rays in ^{193}Pb were used for normalization. Gates were set on the 213 keV $27/2^+ \rightarrow 25/2^+ \gamma$-ray transition below the isomer. In order to extract the lifetimes of interest the DDCM method [11] was used. The results are presented in table 1.

3. Results and discussion

At this stage of analysis, we have determined the lifetime of the $33/2^-$ level depopulated by the 252 keV transition and an upper limit for the $35/2^-$ level depopulated by the 381 keV transition. The latter allows an estimate of the E2 transition strength of the 633 keV γ-ray (see table 1).

Prior to our measurement, lifetimes in the A11 band in ^{197}Pb have been measured [12], which can be used for comparison. We should note that Fotiades *et al* did a systematic study of the A11 bands in the Pb nuclei [13] and concluded that there is a disagreement of 1$\hbar$ between the spin assignment in ^{193}Pb and all the other isotopes. As already mentioned, the

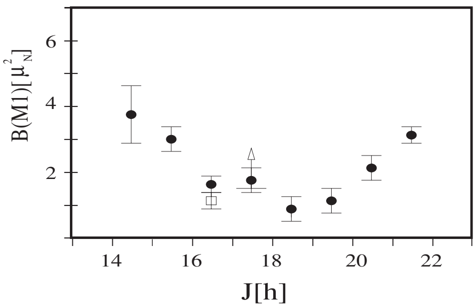

Figure 1. Comparison between B(M1) values as a function of level spin for shears bands A11 in ^{197}Pb [12] (full circles) and ^{193}Pb (open square and arrow). The spin values for ^{197}Pb were increased by $1\hbar$.

Table 1. Lifetimes deduced from the present experiment.

E_{lev} (keV)	E_γ (keV)	I_i^π	I_f^π	σL	$B\,(\sigma L)$	τ (ps)
2939	252.3	$33/2^-$	$31/2^-$	M1	$1.1(2)\ \mu_N^2$	3.2 (8)
3320	381.2	$35/2^-$	$33/2^-$	M1	$\geqslant 1.4\ \mu_N^2$	$\leqslant 1$
3320	633.2	$35/2^-$	$31/2^-$	E2	$\geqslant 0.1$ (eb)^2	

spin of the $T_{1/2} = 9.4$ ns isomer has been fixed to $I^\pi = 29/2^-$ after a DCO analysis of the isomeric decay [5]. Therefore, in order to do the comparison we increase the spin by $1\hbar$ for ^{197}Pb, relative to the published values [14]. The results are presented in figure 1 and are in reasonable agreement. From the deduced E2 strength we can extract an upper limit for the intrinsic quadrupole moment $Q_0 \geqslant 1.69$ b, which in turn provides a limit for the deformation $\beta_2 \geqslant 0.056$.

4. Summary

The measured lifetimes in the A11 magnetic band in ^{193}Pb together with the previously measured DCO and branching ratios for the transitions in the band, as well as the g-factor and the quadrupole moment for the bandhead, provide a complete set of experimental observables for such an excitation in atomic nuclei which can be used for a stringent test of the theoretical models aiming at the description of magnetic rotation. The results from TAC calculations for the B(M1) strength are in a reasonable agreement with the experimental data. In this case, the model parameters have been adjusted to the measured quadrupole moments in the Pb nuclei. However, the $B(\mathrm{M1})/B(\mathrm{E2})$ ratios cannot be reproduced well with this parametrization [9].

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