LIFETIME MEASUREMENTS FOR ^{46}Ti AND ^{50}Cr USING THE AGATA SPECTROMETER*

J. Pellumaj[a,b], R. Escudeiro[c,d], F. Recchia[c,d], S.M. Lenzi[c,d]

on behalf of the AGATA Collaboration

[a]Dipartimento di Fisica e Scienze della Terra
Università degli Studi di Ferrara, Ferrara, Italy
[b]INFN, Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy
[c]Dipartimento di Fisica e Astronomia, Università degli Studi di Padova
Padova, Italy
[d]INFN, Sezione di Padova, Padova, Italy

Received 29 November 2022, accepted 12 January 2023,
published online 22 March 2023

Lifetimes of nuclear-excited states of the cross-conjugate pair of nuclei ^{46}Ti and ^{50}Cr were measured by using the Doppler Shift Attenuation Method (DSAM). High-spin states of these two nuclei were populated by a fusion–evaporation reaction, ^{16}O(^{36}Ar, αn). The reduced transition probabilities obtained from the experimental lifetimes are discussed in the framework of theoretical calculations obtained from the shell model using the KB3G and GXPF interaction. Rotational collectivity decreasing by the termination of the yrast band has been confirmed in both nuclei.

DOI:10.5506/APhysPolBSupp.16.4-A13

1. Introduction

Very interesting phenomena of the nuclear structure appear in nuclei in the $1f_{7/2}$ shell (nuclei between ^{40}Ca and ^{56}Ni), such as shape co-existence, backbending, and transitions from collective to single-particle behavior. These features motivated theoretical and experimental research work aiming to understand the nuclear structure in this region [1]. Typically, nuclei in the $1f_{7/2}$ shell show a large prolate deformation in the low-energy excited states that decreases soon at high angular momentum, particularly towards the band termination. Theoretical calculations based on the shell model predict high B(E2) values for low-energy excited states, translated into high collectivity and short lifetimes [2]. The experimental investigation of such a phenomenon in ^{46}Ti and ^{50}Cr has been carried out in this work.

* Presented at the Zakopane Conference on Nuclear Physics, *Extremes of the Nuclear Landscape*, Zakopane, Poland, 28 August–4 September, 2022.

2. Experimental setup

To populate excited states of nuclei of interest, a fusion–evaporation reaction was used. A stable beam of ^{36}Ar with energy of 115 MeV and intensity 5 *pn*A, accelerated at the Ganil laboratory, was impinged on a thin foil of CaO (550 μg/cm^2 thick) evaporated on a gold backing 10 mg/cm^2 thick.

The state-of-the-art of γ spectroscopy, the Advanced GAmma Tracking Array (AGATA) [3], was placed in the close-up configuration at backward angles with reference to the beam direction. The AGATA array was coupled to NEDA (NEutron Detector Array) [4] and Diamant (light-charged particles detector array) [5]. NEDA, used in this experiment as a neutron-tagging instrument, is an array of liquid-scintillator detectors with high-detection efficiency and excellent neutron-γ discrimination capabilities at high counting rates. Diamant is an array of 84 CsI(Ti) crystals arranged in a spherical shape. In this setup, Diamant is placed inside the reaction chamber surrounding the target, and is used to detect and discriminate between light-charged particles such as protons and alpha particles. AGATA coupled with the ancillary devices, NEDA and Diamant, makes the perfect setup to obtain the needed channel selectivity event by event. The trigger condition in the acquisition is set in γ–γ or γ–neutron coincidences, suppressing non-neutron channels.

This work investigates the evolution of collectivity along the yrast states for nuclei in the $1f_{7/2}$ region via lifetime measurements, focusing on ^{46}Ti and ^{50}Cr. Other reaction channels populated in this experiment are being studied [6]. For measuring the lifetimes of the nuclear-excited states, the DSAM technique was employed [7], a Doppler-effect-based technique for measuring lifetimes ranging from 10^{-12} to 10^{-15} seconds.

3. Results and discussion

To determine the lifetimes of the levels of interest, the experimental data are compared with spectra obtained from realistic Geant4 simulations that consider the geometry of the setup, the response function of the detectors, the reaction mechanism, and the decay of the nucleus of interest following complex γ level schemes [8]. Several parameters had to be adjusted in the simulations, the intensities of the γ rays, the lifetimes of the states of interest, and the background level. A series of simulations were performed until the simulated spectrum fitted the experimental data.

The γ-ray spectrum of ^{46}Ti (measured in coincidence with two protons and one alpha emitted from the compound nucleus) and ^{50}Cr (measured in coincidence with two protons), both gated in the corresponding $2^+ \rightarrow 0^+$ transition, are compared with the simulated spectra in Fig. 1. For both nuclei, simulations are performed for the $10^+ \rightarrow 8^+ \rightarrow 6^+ \rightarrow 4^+$ cascade, fitting simultaneously the γ intensities and the lifetimes of the nuclear-exited states. This allows one to consider the direct feeding of the energy levels.

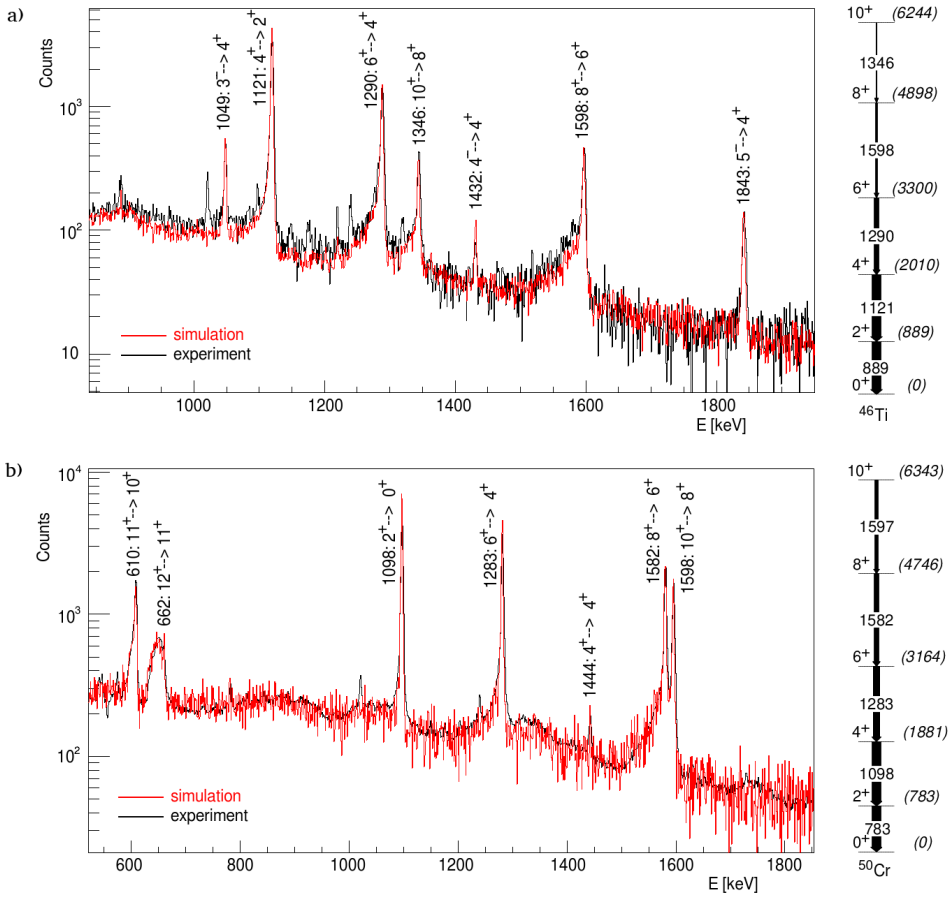

Fig. 1. Comparison of the experimental data with the simulated spectra, (a) ^{46}Ti and (b) ^{50}Cr.

The lifetimes of the yrast states measured in this experiment are shown and compared with literature data [1, 9–11, 15] in Table 1. The lifetimes of the yrast states of ^{50}Cr agree with previous measurements. In the case of ^{46}Ti, slightly shorter lifetimes are measured in this work compared with previously reported values.

The B(E2) values extracted from the experimental lifetimes are compared with the ones obtained from shell model calculations performed with the ANTOINE code [12] using the KB3G [13] and GXPF [14] interactions. For ^{46}Ti, the reduced transition probabilities show large discrepancies compared with the calculated ones. This is probably because the calculations for both interactions consider a closed core of ^{40}Ca, thus not allowing cross-shell excitations, which may be a strong assumption for ^{46}Ti with only six nucleons in the valence space contributing to the wave function of the nuclear states. In the case of ^{50}Cr, the decreasing trend of the B(E2) values along the yrast line is very well reproduced from both interactions. A reduction of the rotational collectivity along the yrast line is confirmed for both nuclei. This is due to the alignment of the valence nucleon spins with the rotational angular momentum, reducing the deformation of the nucleus.

Table 1. The measured lifetimes of the energy levels of ^{46}Ti and ^{50}Cr, and the reduced transition probabilities obtained from experimental data are compared with shell model calculations performed with the KB3G and GXPF interaction.

Nucl.	J^π	τ_{exp} [ps]	τ_{lit} [ps]	$B(\text{E2})_{\text{exp}}$ [$e^2\text{fm}^4$]	$B(\text{E2})_{\text{KB3G}}$ [$e^2\text{fm}^4$]	$B(\text{E2})_{\text{GXPF}}$ [$e^2\text{fm}^4$]
^{46}Ti	4+	1.44(43)	2.01(23)[9]	320(96)	169	158
			2.00(15)[10]			
	6+	0.97(23)	1.34(13)[9]	237(56)	172	158
	8+	0.36(10)	1.33(33)[1]	218(61)	157	145
			0.51(5) [9]			
	10+	1.21(7)	2.5(6)[1]	153(9)	115	108
			1.68(15)[9]			
			1.3(3)[15]			
^{50}Cr	4+	2.4(3)	2.5(7)[11]	213(27)	308	307
	6+	1.00(25)	1.0(2)[11]	235(59)	263	265
	8+	0.4(1)	0.4(11)[11]	206(52)	227	228
	10+	1.05(17)	1.1(2)[11]	75(12)	75	77

REFERENCES

[1] J.A. Cameron *et al.*, *Phys. Rev. C* **58**, 808 (1998).
[2] F. Brandolini, C.A. Ur, *Phys. Rev. C* **71**, 054316 (2005).
[3] S. Akkoyun *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **668**, 26 (2012).

[4] J.J. Valiente-Dobon *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **927**, 81 (2019).
[5] J.N. Scheurer *et al.*, *Nucl. Instrum. Methods Phys. Res. A* **385**, 501 (1997).
[6] R. Escudeiro *et al.*, in preparation.
[7] O. Möller A. Dewald, P. Petkov, *Prog. Part. Nucl. Phys.* **67**, 786 (2012).
[8] AGATA Collaboration (E. Farnea *et al.*), *Nucl. Instrum. Methods Phys. Res. A* **621**, 331 (2010).
[9] F. Brandolini *et al.*, *Phys. Rev. C* **70**, 034302 (2004).
[10] O. Möller *et al.*, *Phys. Rev. C* **67**, 011301 (2003).
[11] F. Brandolini *et al.*, *Nucl. Phys. A* **642**, 387 (1998).
[12] E. Caurier *et al.*, *Rev. Mod. Phys.* **77**, 427 (2005).
[13] A. Poves *et al.*, *Nucl. Phys. A* **694**, 157 (2001).
[14] M. Honma *et al.*, *Eur. Phys. J. A* **25**, 499 (2005).
[15] A.R. Poletti *et al.*, *Phys. Rev. C* **23**, 1550 (1981).