Vol. 40 (2009) ACTA PHYSICA POLONICA B No 3

LIFETIME MEASUREMENTS OF EXCITED STATES IN NEUTRON-RICH NUCLEI AROUND ^{48}Ca*

D. Mengoni[a], J.J. Valiente-Dobón[b], A. Gadea[c], E. Farnea[d]
S.M. Lenzi[a], S. Lunardi[a], A. Dewald[e], T. Pissulla[e], S. Szilner[f]
A.M. Stefanini[b], R. Broda[g], F. Recchia[b], A. Algora[c], L. Angus[h]
S. Aydin[b], D. Bazzacco[b], G. Benzoni[i], P.G. Bizzeti[j]
A.M. Bizzeti-Sona[j], P. Boutachkov[k], L. Corradi[b], F. Crespi[i]
G. de Angelis[b], E. Fioretto[b], A. Görgen[l], M. Gorska[k]
A. Gottardo[b], E. Grodner[b], A. Howard[m], W. Królas[g]
S. Leoni[i], P. Mason[b], R. Menegazzo[b], D. Montanari[i]
G. Montagnoli[a], D.R. Napoli[b], A. Obertelli[l], T. Pawłat[g]
B. Rubio[c], E. Şahin[b], F. Scarlassara[a], J.F. Smith[h]
D. Steppenbeck[m], C.A. Ur[b], P.T. Wady[h], J. Wrzesiński[g]

[a]Dipartimento di Fisica dell'Universitá and INFN Sezione di Padova, Pd, Italy
[b]Istituto Nazionale di Fisica Nucleare, LNL, Legnaro, Italy
[c]Instituto de Física Corpuscular, CSIC-Universidad de Valencia, Valencia, Spain
[d]Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Pd, Italy
[e]Institut für Kernphysik der Universität zu Köln, Köln, Germany
[f]Ruđer Bošković Institute, Zagreb, Croatia
[g]Institute of Nuclear Physics, Polish Academy of Sciences, Kraków, Poland
[h]School of Engineering and Science, University of Paisley, Paisley, Scotland, U.K.
[i]Dipartimento di Fisica dell'Universitá and INFN Sezione di Milano, Mi, Italy
[j]Dipartimento di Fisica dell'Universitá and INFN Sezione di Firenze, Fi, Italy
[k]Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany
[l]CEA Saclay, IRFU/Service de Physique Nucléaire, Gif-sur-Yvette Cedex, France
[m]Schuster Laboratory, University of Manchester, Manchester, U.K.

(Received November 7, 2008; revised version received December 14, 2008)

The lifetimes of the first excited states of the $N = 30$ isotones ^{50}Ca and ^{51}Sc and the $Z = 18$ isotopes $^{44-46}$Ar isotopes have been determined using a novel technique that combines the Recoil Distance Doppler Shift method with the CLARA-PRISMA spectrometers in multinucleon transfer reactions. The results allow determinination of the effective charges above ^{48}Ca and test the strength of the $N = 28$ magic number when moving away from the stability line.

PACS numbers: 27.40.+z, 21.10.Tg, 23.20.–g, 21.60.Cs

* Presented at the Zakopane Conference on Nuclear Physics, September 1–7, 2008, Zakopane, Poland.

1. Introduction

Spectroscopy of the moderately neutron-rich nuclei around the doubly-magic ^{48}Ca has been possible only recently by means of deep inelastic stable beam reactions and the use of radioactive beams.

That region offers the unique opportunity to study the evolution of the nuclear properties when adding few nucleons to a doubly-closed configuration. Structural changes have been verified in the magic character of the $N = 32$ in Ca, Ti and Cr isotopes [1] and in the possible quenching of the $N = 28$ shell closure.

Spectroscopic information are nevertheless limited and data on electromagnetic transition probabilities are scarce or missing completely due to the difficulty in populating such neutron-rich nuclei. Therefore an experiment has been performed at Laboratori Nazionali di Legnaro, using the CLARA-PRISMA set-up [2, 3] in combination with the novel RDDS method [4]. In this contribution we report about the results obtained during such experiment.

2. Experimental details and results

A ^{48}Ca beam at a bombarding energy of 310 MeV was delivered by the LNL Tandem-ALPI accelerator complex on a target consisting of 1.0 mg/cm^2 of enriched ^{208}Pb evaporated onto a 1.0 mg/cm^2 Ta support to accomplish the stretching of the target. A thick 4 mg/cm^2 Mg foil was used as an energy degrader. Different target-degrader distances, ranging from 20 μm to 3000 μm were employed during the experiment by arranging stack of various metallic rings. The target-degrader combination, which constitutes the plunger system, was placed at the centre of the reaction chamber of the CLARA array in order to measure the lifetimes of the excited states in the projectile-like nuclei. More experimental details and a schematic view of the apparatus setup can be found in [5].

Several nuclear species, ranging from Ti to Cl, have been populated. In this contribution we concentrate on Ca, Sc and Ar isotopes, which are isotopes abundantly populated and give the possibility to extract lifetimes for the low lying excited states.

In Fig. 1 (left) the 1027 keV $2^+ \rightarrow 0^+$ gamma transition in the ^{50}Ca nucleus as a function of the target-to-degrader distance is shown. A lifetime of 96 ± 3 ps has been extracted by fitting the intensity ratio over the various distances. The lifetime of the state can be deduced when the recoil velocity before the degrader is provided and the intensity from the upper feeders properly taken into account. The recoil velocity is calculated considering that the Doppler shift, between the shifted and unshifted peaks, is, for each angle, a function of the velocity [5]. The feeding is taken into account using the total kinetic energy loss as described in [6]. The Q-value of the reaction is used to select an entry-point in the excitation mechanism.

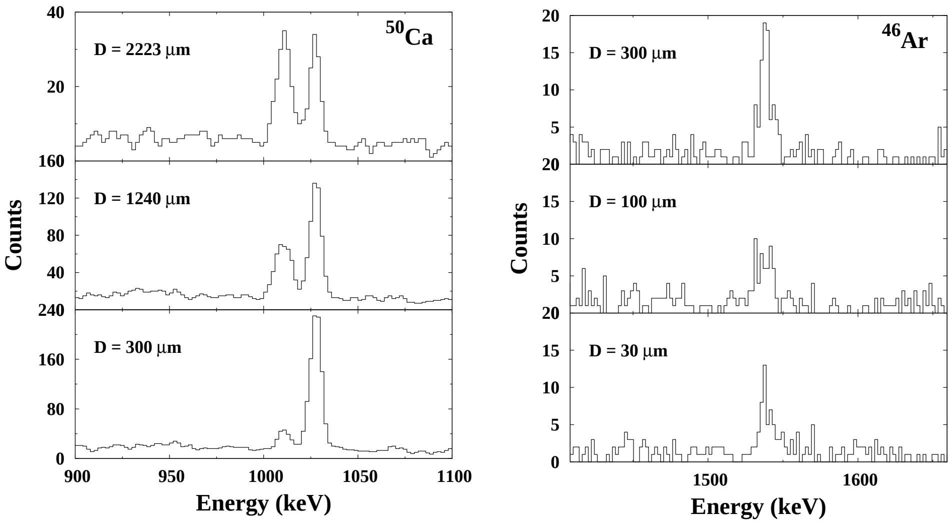

Fig. 1. Left part: 1027 keV $2^+ \to 0^+$ gamma transition in the ^{50}Ca nucleus. The two components, the shifted and unshifted one, are clearly distinguished along the various distances, due to the long lifetime of the state. Right part: 1553 keV $2^+ \to 0^+$ gamma transition in the ^{46}Ar nucleus. Only the shifted component is visible due to the short lifetime of the level. For the distances, whose time of flight is comparable with the time needed to overtake the degrader, the energy of the shifted peak continuously degrades into the unshifted one, as can be seen in the bottom panel on the right.

The $B(\mathrm{E2}\downarrow)$ reduced transition probability, which is 7.5 ± 0.2 $e^2\mathrm{fm}^4$, has been derived from the lifetime and it is smaller than the corresponding value in ^{48}Ca. The energy and $B(\mathrm{E2}\downarrow)$ of the 2^+ state in ^{50}Ca are well reproduced by these calculations. The excited level shows a single particle character, consisting of a quasi-pure ($\approx$86%) $\nu \left(f^8_{7/2} p^2_{3/2}\right)$ configuration. The comparison with shell-model calculations allows to extract the effective charge of the neutron in the *fp* shell. The result seems to indicate a solely isoscalar excitation of the core, Ref. [7].

Concerning the Sc isotopic chain, a lifetime of 34 ± 7 ps been derived for the 1065 keV $11/2^- \to 7/2^-$ transition in ^{51}Sc. The $B(\mathrm{E2})$ value derived from the measurement is in agreement with the absence of isovector term in the effective charges.

For lifetimes shorter than few ps, as it is the case for the 2^+ state in ^{46}Ar, it is important to consider the slow-down of the recoils into the degrader. This leads to a continuous degradation of the shifted component into the unshifted one, which makes impossible to distinguish the two peaks, as can be seen in Fig. 1 (right) for the 30 μm distance. To recover the degraded information, a realistic Monte Carlo simulation, which takes into account the energy and angular dispersion of the recoils in the degrader, has been performed. A detailed study of the simulation can be found in [8]. The result seems to confirm the weakening of the $N = 28$ magic number south of ^{48}Ca.

3. Summary and conclusions

The analysis we performed on the RDDS data provided the lifetime of the ^{50}Ca, ^{51}Sc nuclei and $^{44-46}$Ar nuclei. It has been possible to derive from our results, the neutron effective charges in the *fp* shell and extend the knowledge on the shell evolution, through the $B(\mathrm{E2}\downarrow)$ extraction, along the Ca and Sc isotopic chain beyond the previous limits. Moreover the deduced effective charges seem to indicate a pure isoscalar excitation of the core. The lifetime for $^{44-46}$Ar, as deduced from the simulations and models, seems to indicate a weakening of the $N = 28$ below ^{48}Ca. In conclusion this experimental technique, which uses the differential plunger in combination with a gamma and a magnetic spectrometer in multi-nucleon transfer reaction, has revealed as a reliable and promising method for lifetime measurements in view of the AGATA demonstrator experimental campaign.

This work has been partially supported by the European Commission within the sixth Framework Programme through I3-EURONS (contract No RII3-CT-2004-506065) and the DGF (Germany under contract No DE1516/-1).

REFERENCES

[1] B. Fornal *et al.*, *Phys. Rev.* **C77**, 014304 (2008).
[2] A. Gadea *et al.*, *Eur. Phys. J.* **A20**, 193 (2004).
[3] A. Stefanini *et al.*, *Nucl. Phys.* **A701**, 217c (2002).
[4] A. Dewald *et al.*, to be published.
[5] D. Mengoni *et al.*, LNL Annual Report 2007.
[6] J.J. Valiente-Dobón, LNL Annual Report 2007.
[7] J.J. Valiente-Dobón *et al.*, submitted to *Phys. Rev.* **C**.
[8] D. Mengoni *et al.*, *Eur. Phys. J.* **A**, to be published.