Vol. 39 (2008) *ACTA PHYSICA POLONICA B* No 2

NEW γ–PARTICLE DETECTION SET-UP FOR COULOMB EXCITATION EXPERIMENTS — TOWARDS DETERMINATION OF TRIAXIALITY OF ^{100}Mo*

K. Wrzosek[a,b], M. Zielińska[a,c], T. Czosnyka[a], J. Choiński[a]
K. Hadyńska[a,d], J. Iwanicki[a], M. Kisieliński[a,e], M. Kowalczyk[a,b]
J. Kownacki[a], P. Napiorkowski[a], D. Piętak[f], J. Srebrny[a]
K. Zając[g]

[a]Heavy Ion Laboratory, University of Warsaw, Warsaw, Poland
[b]Faculty of Physics, University of Warsaw, Warsaw, Poland
[c]CEA Saclay, DAPNIA/SPhN, Gif-sur-Yvette, France
[d]Faculty of Physics, A. Mickiewicz University, Poznań, Poland
[e]The A. Sołtan Institute for Nuclear Studies, Świerk, Poland
[f]Department of Electronics and Information Technology
Warsaw University of Technology, Warsaw, Poland
[g]Department of Theoretical Physics, Institute of Physics
M. Curie-Skłodowska University, Lublin, Poland

(Received January 15, 2008)

Low-lying 0^+ states, close in energy to the first excited 2^+ state, have been observed in even–even molybdenum isotopes, indicating shape coexistence in these nuclei. Results of our previous Coulomb excitation measurements of ^{96}Mo and ^{98}Mo supported the shape coexistence scenario. A series of Coulomb excitation experiments to study the neighboring stable ^{100}Mo isotope was performed on beams of the Warsaw Cyclotron. During the recent experiment with ^{100}Mo target the new dedicated set-up for Coulomb excitation measurements was used at HIL. First results are presented. The performance of the new detection system opens promising possibilities for future Coulomb excitation experiments.

PACS numbers: 25.70.De, 21.10.Ky

1. Introduction

The competition of single-particle and collective excitation modes, characteristic for transitional nuclei ($A \approx 100$), results in a variety of phenomena, making this region of nuclear chart an ideal testing ground for modern

* Presented by K. Wrzosek at the XXX Mazurian Lakes Conference on Physics, Piaski, Poland, September 2–9, 2007.

nuclear structure theories. For the Sr and Zr isotopes a dramatic change of the ground state structure is observed at $N = 58, 60$ [1]. This effect is less pronounced in molybdenum isotopes, but still the rapidity of shape change gives rise to shape coexistence in these nuclei.

Isotopes of molybdenum with neutron number close to 50 have spherical shape and their properties can be well described by the shell model [2]. As the number of neutrons increases from $N = 54$ for ^{96}Mo to $N = 58$ for ^{100}Mo, the influence of collective motion on the electromagnetic structure gets stronger, resulting in unusual features of these nuclei.

An experimental indication of shape coexistence in an even–even nucleus is observation of an excited 0^+ state at energy close to the first excited 2^+ state. Such low-lying 0^+ states have been observed for all the molybdenum isotopes in question. In ^{98}Mo the energy of the 0_2^+ state is even so low that it becomes the first excited state. Such a peculiar feature is observed only for four stable even–even nuclei with $Z > 20$.

Multiple Coulomb excitation is one of the most important experimental methods to study nuclear shape in excited states. While lifetime measurments allow to determine reduced transition probabilities, Coulomb excitation experiments can also bring information on the static quadrupole moments (in both ground and excited states) as well as relative signs of the matrix elements, which are essential to determine the nuclear shape using the Quadrupole Sum Rules method [3, 4].

2. Shape coexistence in molybdenum isotopes

A series of experiments [5–7] was performed to investigate the electromagnetic structure of ^{96}Mo, ^{98}Mo and ^{100}Mo both at the Heavy Ion Laboratory (HIL) in Warsaw and at the Japan Atomic Energy Agency (JAEA) in Tokai. Large number of electromagnetic matrix elements for the low-spin states in even–even molybdenum isotopes was found by a global fit of calculated to measured (or previously known) observables: γ-ray yields, level lifetimes, branching ratios and mixing ratios. The fit and the error calculation were performed using the Coulomb Excitation Least Squares Fitting code GOSIA [3,8]. The Quadrupole Sum Rules method was used to express parameters of charge distribution in a model-independent way. Quadrupole deformation parameters were deduced for the ground and the first excited 0^+ states in ^{96,98,100}Mo using E2 matrix elements extracted from data collected in previous experiments [5–7]. Fig. 1 shows the deformation parameter $\langle Q^2 \rangle$ calculated for both states in ^{96,98,100}Mo, compared to available data from selected Ge isotopes, which also have low-lying 0_2^+ levels. The Q parameter is a measure of an overall deformation and is analogous to Bohr's β parameter, but related rather to the charge than to the mass distribution.

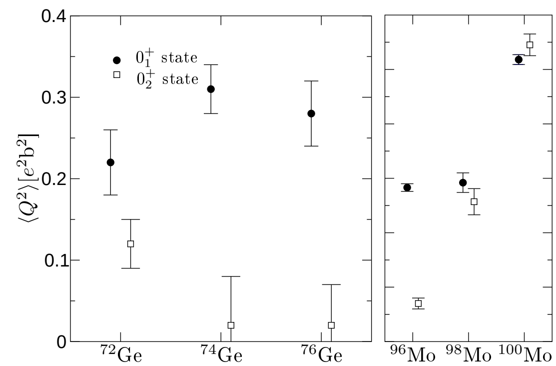

Fig. 1. Mean values of the quadrupole deformation parameter $\langle Q^2\rangle$ found for the two first 0^+ states in ^{96,98,100}Mo and ^{72,74,76}Ge.

Cases of ^{96}Mo and Ge isotopes are similar — their ground states are deformed and the first excited states are almost spherical. For ^{98}Mo its overall deformation is equal within uncertainty limits for both 0^+ states. A similar trend is observed also in the ^{100}Mo isotope with the expectation value of $\langle Q^2\rangle$ being almost the same for both 0^+ states. On the other hand, their deformation is larger as compared to the other Mo isotopes.

It was possible to determine the triaxiality parameter δ (equivalent to Bohr's γ) for ^{96}Mo and ^{98}Mo nuclei. Expectation values of $\langle\cos(3\delta)\rangle$ calculated for both 0^+ states in molybdenum and germanium isotopes are presented in Fig. 2.

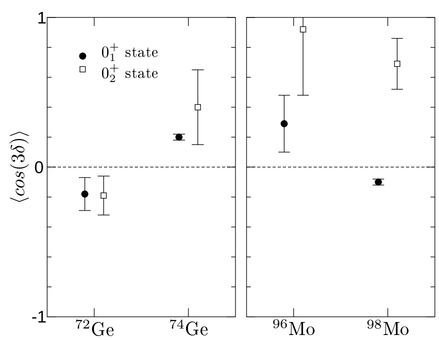

Fig. 2. Mean values of the triaxiality parameter $\langle\cos(3\delta)\rangle$ found for the two first 0^+ states in ^{96,98}Mo and ^{72,74}Ge.

The 0^+ ground state of ^{98}Mo is triaxial, while the first excited 0^+ state has a prolate shape [5, 6]. On the contrary, the triaxiality remains the same for each of the Ge isotopes. For ^{96}Mo both ground and excited state have prolate shapes. However, since the $\langle Q^2\rangle$ value is quite low for 0_2^+ state, the triaxiality parameter for this level was deduced with a large uncertainty, making it difficult to draw further conclusions.

In the case of ^{100}Mo the data collected so far are not sufficient to extract the triaxiality parameters for the low-lying 0^+ states. Further measurements using the upgraded γ-particle detection array are needed.

3. New dedicated set-up for Coulomb excitation experiments

The ^{32}S + ^{100}Mo on-beam test run, performed in January 2006, was the third one in the series of measurements of Coulomb excitation of ^{100}Mo and the first one to use the new γ-particle detection set-up dedicated for Coulomb excitation experiments at HIL in Warsaw. The γ rays depopulating Coulomb-excited states were detected in the OSIRIS-II array in coincidence with scattered particles. OSIRIS-II is a multi-detector system intended for γ spectroscopy with heavy ion beams. It consists of 12 HPGe detectors equipped with anti-compton BGO shields. The scattered projectiles were detected by silicon PiN-diodes, placed inside a spherical chamber of 5 cm radius. The active area of a single PiN-diode is $0.5 \times 0.5\,\mathrm{cm}^2$. Each diode can be placed in any of 110 different positions inside the chamber. Scattering angle coverage extends from 110° to 170° with respect to the beam direction. Particle detector system was constructed in LMU Munich by the German–Polish collaboration and successfully used with NORDBALL set-up at Tandem Accelerator Laboratory of Niels Bohr Institute, University of Copenhagen, Risø, Denmark [9–11].

The results of the test run, as well as of several tests using calibration sources, are encouraging. The new particle detection system was succesfully integrated into the OSIRIS-II set-up, allowing for a coincidence γ-particle measurement. The quality of the collected data improved significantly in comparison to measurements performed with the previous Coulomb excitation set-up CUDAC (Coulex Universal Detector Array Chamber) [12], where three HPGe detectors without anti-compton BGO shields were used. Fig. 3 presents a part of the background subtracted γ-ray spectrum of the Coulomb-excited ^{100}Mo collected by a single germanium detector of the OSIRIS-II array compared to a similar spectrum measured by a HPGe detector used previously with the CUDAC set-up.

Although during the test run the time of measurement was 1.5 times shorter compared to the experiment performed using the CUDAC set-up, the collected statistics are of the same order. Future Coulomb excitation experiments at HIL will profit from the higher γ-ray detection efficiency of the OSIRIS-II set-up, as well as from the better peak-to-total ratio in collected spectra. A remarkable improvement of coincidence time measurements was observed as well. New set-up timing performance allows to achieve higher true-to-random coincidence ratio (see Fig. 4).

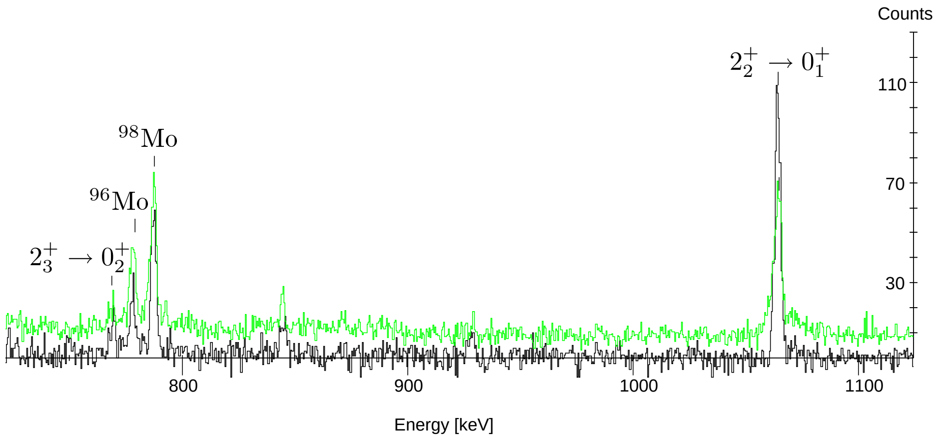

Fig. 3. Gray: γ rays detected in coincidence with ^{20}Ne ions scattered on a ^{100}Mo target, collected by a single HPGe detector coupled to the CUDAC particle detection set-up. Black: γ rays detected in coincidence with ^{32}S ions backscattered on a ^{100}Mo target, collected by a single BGO-shielded HPGe detector of the OSIRIS-II set-up.

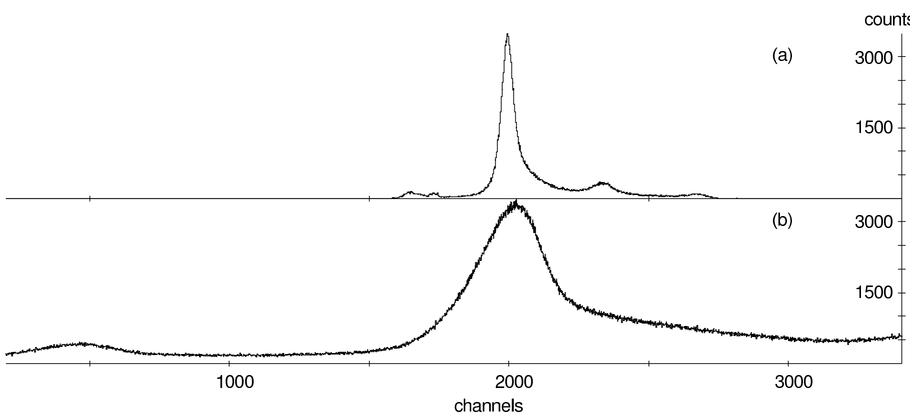

Fig. 4. (a) γ–particle coincidence time spectrum measured by a single Ge detector of the OSIRIS-II array during the ^{32}S + ^{100}Mo test run. (b) γ–particle coincidence time spectrum measured by a single Ge detector coupled to the CUDAC array during the ^{20}Ne + ^{100}Mo experiment.

4. Summary

Our previous Coulomb excitation experiments allowed to deduce the quadrupole deformation parameters $\langle Q^2 \rangle$ for both low-lying 0^+ states in ^{96,98,100}Mo. In the case of ^{100}Mo the data collected so far were not sufficient to extract the triaxiality parameter, pointing out the necessity of upgrading the existing COULEX set-up at HIL. The results of the on-beam test run with new scattering chamber coupled with the OSIRIS-II set-up are encouraging. The Coulomb excitation experiment with ^{100}Mo target and ^{32}S beam using the new γ and particle detection array is scheduled at HIL UW for December 2007.

The authors would like to thank L. Pieńkowski for stimulating discussions. This work was partly supported by the Polish State Committee for Scientific Research (KBN) under the contract No. 2 P03B 007 25.

REFERENCES

[1] J.L. Wood *et al.*, *Nucl. Phys.* **A651**, 323 (1999).
[2] P. Singh *et al.*, *Phys. Rev.* **C45**, 2161 (1992).
[3] D. Cline, *Annu. Rev. Nucl. Part. Sci.* **36**, 683 (1986).
[4] K. Kumar *et al.*, *The Electromagnetic Interaction in Nuclear Physics*, North Holland, 1974.
[5] M. Zielińska, *et al.*, *Acta Phys. Pol. B* **33**, 515 (2002).
[6] M. Zielińska *et al.*, *Nucl. Phys.* **A712**, 3 (2002).
[7] K. Wrzosek *et al.*, *Int. J. Mod. Phys.* **E15**, 374 (2006).
[8] T. Czosnyka, D. Cline, C.Y. Wu, *Bull. Amer. Phys. Soc.* **28**, 745 (1983); GOSIA User's Manual, available at `http://www.pas.rochester.edu/cline/Research/2006manual.pdf`
[9] M. Würkner *et al., Nucl. Phys.* **A725**, 3 (2003).
[10] M. Loewe *et al., Phys. Lett.* **551**, 71 (2003)
[11] P. Napiorkowski *et al., Annu. Rep. HIL 1995* (1996).
[12] J. Iwanicki *et al.*, *Acta Phys. Pol. B* **28**, 153 (1997).