Characterization of a complete set of double-octupole bands in ^{150}Sm

A. Ionescu[1,2], (Spokesperson), N. Mărginean[1], O. Sima[2], S. Pascu[1], M. Boromiza[1,2], D. Bucurescu[1], I. Căta-Danil[1], C. Clisu[1], C. Costache[1], D. Filipescu[1,3], N. Florea[1], I. Gheorghe[3], T. Glodariu[1], R. Lică[1], R. Mărginean[1], C. Mihai[1], R. Mihai[1], A. Mitu[1], A. Negreţ[1], C. Niţă[1], A. Olăcel[1], A. Oprea[1], P. Petkov[1], T. Sava[1], C. Sotty[1], L. Stan[1], L. Stroe[1], A. Șerban[1], I. Știru[1], R. Șuvăilă[1], S. Toma[1], A. Turturică[1], S. Ujeniuc[1], N. V. Zamfir[1]

[1]"Horia Hulubei" National Institute for Physics and Nuclear Engineering, RO-077125, Bucharest-Măgurele, Romania

[2]University of Bucharest, Faculty of Physics, Atomiștilor 405, Bucharest-Măgurele, Romania

[3]ELI-NP, Bucharest-Măgurele, Romania

October 10th, 2017

1. Experiment Summary

We propose to characterize for the first time a complete set of double-octupole bands in ^{150}Sm. This proposal is part of a project which aims to identify for the first time the negative-parity components in the structure of positive-parity states in atomic nuclei. The first part of the work on the project was performed at the 14 MV Tandem Accelerator from TUM (Munich) which consisted in measuring complete angular distributions for states up to 4 MeV, with good energy resolution (with the Q3D spectrometer) for the direct two-neutron transfer reaction ^{152}Sm(p, t) ^{150}Sm at an incident energy of 22 MeV. The experiment has revealed a large number of new states in ^{150}Sm, especially 0^+ states. The second part of the project will be carried out at the 9 MV Tandem Accelerator from IFIN-HH (Bucharest), using the transfer reaction ^{150}Nd(p, n) ^{150}Pm with the detection of the gamma rays in the ROSPHERE spectrometer. The aim of this experiment is to identify and measure the gamma rays de-exciting the newly found states populated in the beta decay of ^{150}Pm.

Beam time request: 14 days of beam time.

2. Introduction

The presence of negative-parity states in the low-lying structure of atomic nuclei has been observed in the early days of nuclear physics [1]. These characteristics have been associated with the presence of octupole degrees of freedom, some of the lowest collective modes observed. The octupole deformation has been revealed experimentally only recently in the case of actinides [2]. Since the vibrational spectra are usually interpreted in terms of phonons, these observations led to a search of double-octupole phonon states, similar to the well-known two-phonon states in the case of quadrupole states. The presence of an increased number of 0^+ states in several nuclei has been interpreted with the Interacting Boson Model (IBM) using *spdf* bosons as having mainly *2pf* bosons in their structure [3,4,5,6]. At the same time, the calculations with the Quasiparticle Phonon Model (QPM) show in most of the cases a complete different picture: the octupole phonons are predicted to play a relative modest role especially at lower excitation energies, indicating that the structure of the lowest excited 0^+ states is described as originating from pairing vibrations [3,4,6,7] (see Fig. 1, for the case of ^{232}U. A similar situation can be found also for the rare-earth region).

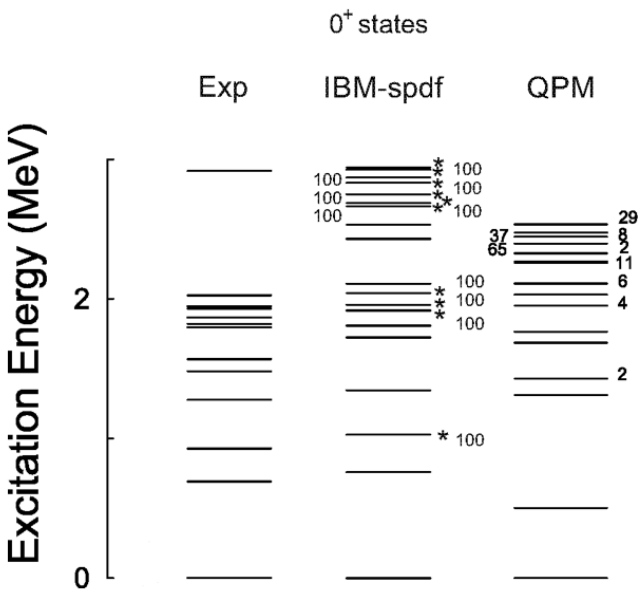

Fig.1: Experimental (left), IBM-spdf (middle), and QPM (right) 0^+ energy states in ^{232}U up to 3 MeV. The numbers to the left and right of the states represent the amplitude of the double-octupole phonon component in the wavefunctions of each state. The states, which are not marked, are having a vanishing octupole component.

It can be observed that the IBM model predicts many double-octupole phonon states while the QPM predicts small octupole contributions as the amplitudes indicate in Fig.1. However, the QPM somehow fails to describe the B(E1)/B(E2) ratio connecting positive and negative parity states in these nuclei. This debate can only be solved if the appropriate states are measured with great accuracy. One of the best place to search for such examples is the region of N=88 (^{144}Ba-^{146}Ce-^{148}Nd-^{150}Sm-^{152}Gd-^{154}Dy), which is one of the so-called “octupole-driving numbers” where octupole correlations are estimated to be strong.

This implies performing two different type of measurements in order to have a more complete characterization for the level scheme of ^{150}Sm. The first step was to identify the complete set of states up to 4 MeV in ^{150}Sm by performing a (p, t) transfer reaction on ^{152}Sm and to establish their energy positions in the level scheme as well as to arrange them in bands based on a linear moment of inertia. Possible candidates for the first excited 0^+ states can be observed in Fig.2. The (p, t) reaction, as shown in Fig.2, allowed to populate many such 0^+ excited states in ^{150}Sm. We based our assumptions of assigning the spin and parity to these states as being $J^{\pi}=0^+$ on the cross section behavior for two angles we performed the measurement: at 5^o and 17^o, respectively (see Fig.2). Many of the excited 0^+ excited states in ^{150}Sm are seen for the first time thus making a more complete picture of the structure of this nucleus. We propose in this experiment to perform gamma ray spectroscopy of ^{150}Sm following the beta decay of ^{150}Pm.

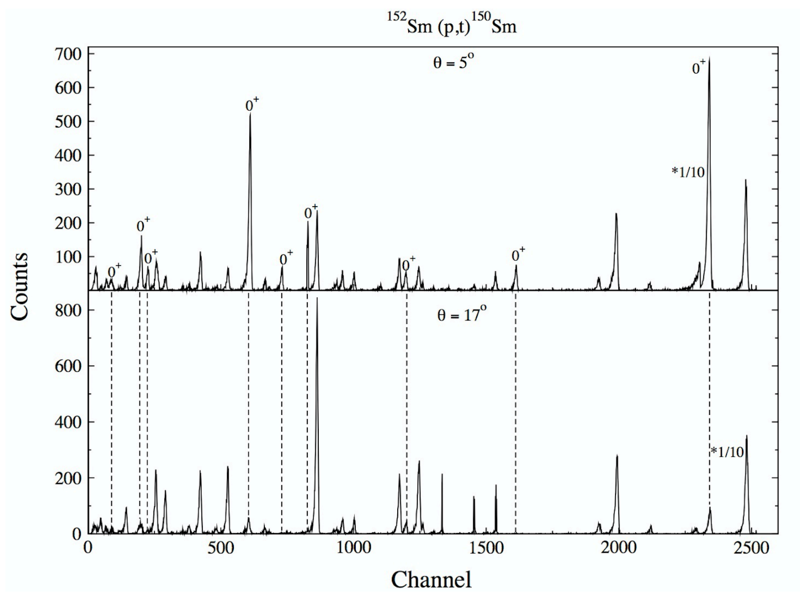

Fig.2: Spectra at 5^o and 17^o for ^{152}Sm(p,t)^{150}Sm. Candidates for the 0^+ excited states are proposed based on their cross section comparison at two angles, 5^o and 17^o, and marked on the figure, most of them seen for the first time.

The study of transfer strength was shown to be an important part in order to identify the nature of the 0^+ states. In ^{150}Sm (N=88), relative strong *E1* transitions have been observed between the 0_2^+ band and the octupole band, pointing towards important octupole correlations in this nucleus [8]. Because only two excited 0^+ states are known at the present time [9], it is very interesting to investigate the distribution of energy and intensity also at higher excitation energy.

3. Experiment Description

Excited states in ^{150}Sm will be populated via beta decay of ^{150}Pm ($T_{1/2}$=2.7 h), which will be produced in the ^{150}Nd(p, nγ) reaction [10]. According to CASCADE calculations, the cross section for the n channel is about 200 mb from the total predicted cross section of about 240 mb for the incident energy of 8 MeV. The (p, n) reaction will be performed with a proton beam delivered by the 9 MV Tandem Accelerator. We will use an incident energy of 8 MeV because we want that the contribution of the (p, 2n) channel to be negligible. The target for this experiment will be ^{150}Nd with a thickness of about 5 mg/cm^2 deposited on a backing of about 5 mg/cm^2 gold.

The expected production rate during this experiment, assuming the following experimental condition: a 5 mg/cm^2 ^{150}Nd target, a 30 pnA proton beam and an estimated cross section of 200 mb, will be of about 8×10^4 ^{150}Pm nuclei per second. Considering a detection efficiency of 1% for the HPGe detectors, we expect to observe about 3 counts per hour for a gamma ray of intensity 0.01% (relative to 100 for the first 2^+) seen in coincidence with the first 2^+ gamma ray decay. Therefore, in order to have a reasonable number of counts for such a weak peak transition (~1000 events), we request 14 days of beam time.

References:

[1] F. Asaro, F. Stephens Jr., and I. Perlman, Phys. Rev. **92**, 1495 (1953).
[2] L. P. Gaffney *et al.*, Nature **497**, 199 (2013).
[3] A. I. Levon *et al.*, Phys. Rev. C **79**, 014318 (2009).
[4] A. I. Levon *et al.*, Phys. Rev. C **88**, 014310 (2013).
[5] M. Spieker *et al.*, Phys. Rev. C **88**, 041303(R) (2013).
[6] A. I. Levon *et al.*, Phys. Rev. C **92**, 064319 (2015).
[7] N. Lo Iudice, A. V. Sushkov, and N. Yu. Shirikova, Phys. Rev. C **72**, 034303 (2005).
[8] S. P. Bvumbi *et al.*, Phys. Rev. C **87**, 044333 (2013).
[9] J. Barrette, M. Barrette, and S. Monaro, Can. J. Phys., **48,** 1161 (1970).
[10] D. Bucurescu *et al.*, Phys. Rev. C **85**, 017304 (2012).