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Feasibility study to investigate deformations and the onset of octupole correlations in ^{140}Ba

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Abstract

We propose to perform a test measurement to investigate the population of excited states in ^{140}Ba by means of a two neutron-transfer reaction induced by an ^{18}O beam on a ^{138}Ba target, at energies below the Coulomb barrier, namely at 65 MeV. The γ-transitions will be measured using the Bucharest ROSPHERE array, consisting of 15 Ge detectors and 10 $LaBr_3(Ce)$ scintillators.

An additional aim of the test is to check the target performance, since barium target manufacturing presents difficulties. Depending on the results of the proposed test on the population of the excited states in ^{140}Ba and on how well we can identify low branching rate transitions, a follow-up proposal will be prepared taking into account the tested experimental conditions.

The lifetime of the 3^- and of the first two 2^+ states in ^{140}Ba is an important information to be used if one wants to learn on the onset of octupole correlations in the neutron-rich chain of Ba isotopes. For the ^{144}Ba nucleus the B(E3) information has been obtained by Coulomb excitation and thus to have data on lifetime of 3^- in ^{140}Ba will give the trend of the octupole collectivity evolution with neutron number.

***We request 3 days of beam time**: they will be used to find the best conditions for populating the states of interest.*

Physics motivation

The structure of ^{140}Ba has particular interest, since the nucleus is located, within the long chain of Ba isotopes, at the onset of deformation. A dedicated study of ^{140}Ba can possibly reveal information on octupole correlations, which are expected for several isotopes in the neutron-rich region. This is the case of ^{144}Ba nucleus, which was found to have an unexpectedly large value of the octupole deformation parameter β_3 (see Ref. [1]).

While several of the ^{140}Ba energy levels have been identified using different population reactions [2], the corresponding lifetimes are largely unknown, with the sole exception of the first excited 2^+ state. The lifetime of this 2^+ state was found approximately equal to 10 ps in an experiment performed at ISOLDE using Coulomb excitation [4].

Another 2^+ state at higher excitation (1993.7 keV, see figure 1) was recently studied with an experiment with AGATA at LNL to understand its nature as mixed symmetry state (as reported in Ref. [3]). The presence of mixed-symmetry states suggests the existence of "exotic" excitation modes in this nucleus.

Part of the level scheme of ^{140}Ba of interest for this study is shown in Fig. 1. The energies and transitions from the 2^+_2, 3^- and 0^+_2 states are shown. However no corresponding lifetimes are known and this provides a strong motivation to measure their values.

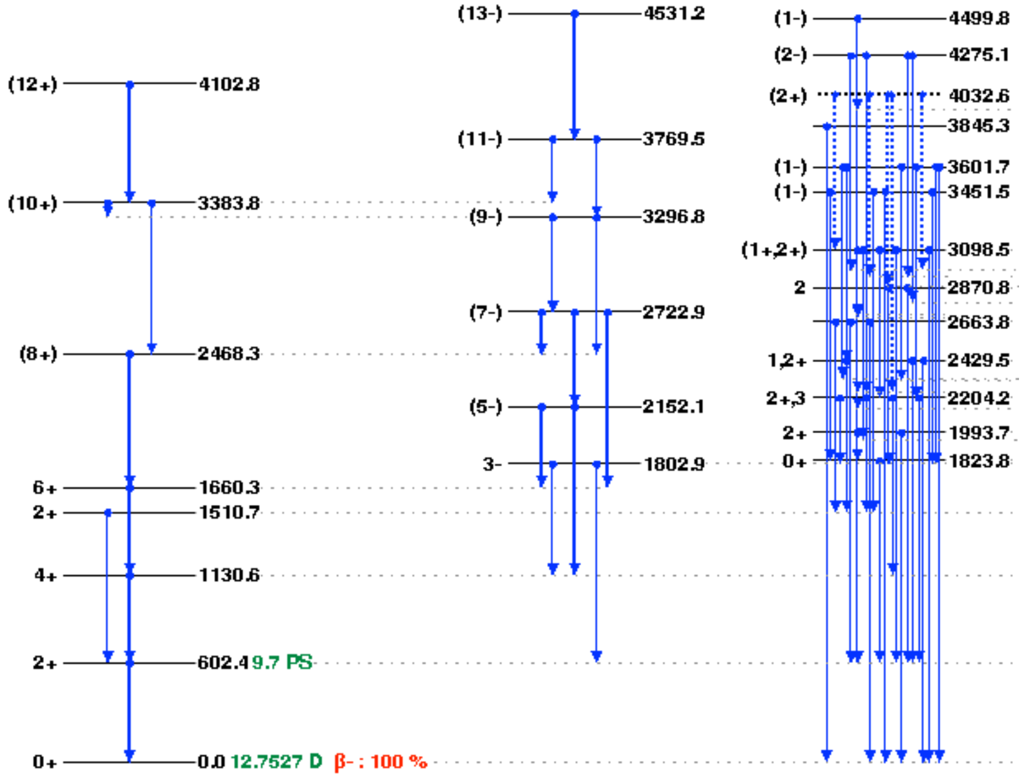

Fig. 1. *A part of the known level scheme of the nucleus ^{140}Ba. The energies of the transitions of interest from the 3- and 2+ states are indicated.*

The existing spectroscopic information on the lifetime of the first 2^+ allows for inferring that the measured deformation of this nucleus in this state is very similar to that of ^{142}Ba in the ground state.

The lifetime measurement has been well reproduced by Monte Carlo shell-model calculations and state-of-the-art energy density functional methods. Both theoretical approaches reproduce the experimentally deduced deformation of ^{140}Ba.

It has been pointed out that the choice of axial or non-axial symmetry in the Monte Carlo shell-model calculations has only little impact on the calculated Q moments of ^{138}Ba and ^{140}Ba. However, a triaxial deformation has to be included in the Energy Density Function calculations in order to reproduce the correct ordering of the 2^+_2 and 0^+_2 states. In addition, this model suggests an increasing prolate deformation with increasing spin number for the ground-state band, i.e., considerable centrifugal stretching, but oblate-triaxial configurations for the 0^+_2 , 2^+_2, and 4^+_2 states. These suggestions can also be tested in terms of the recently developed proxy-SU(3) model [5] that provides predictions for the β and γ collective variables.

In light of all the above, the measurement of lifetimes for the different states in ^{140}Ba becomes particularly important. Such measurements will provide information on deformations that are expected from theory.

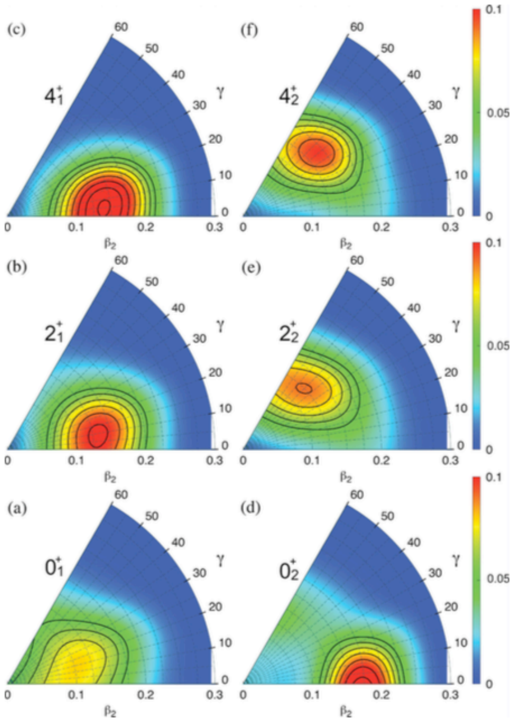

Fig. 2 Distribution of probability in the triaxial (β_2,γ) plane (γ in degrees) for the states belonging to the first two bands calculated with the Gogny D1S density functional including beyond-mean-field effects (from ref. [4])

The 3$^-$ octupole excitation in ^{140}Ba

The investigation of 3$^-$ octupole excitations in this nucleus is particularly interesting to establish the onset of octupole correlations. The strength of this excitation is needed to assess the degree of collectivity. Therefore lifetime measurements should be performed to infer collectivity and to provide a test to theory. Lifetimes measurements are particularly scarce for 3$^-$ states despite these states are great probes to study the phenomenon of particle vibration couplings in which the 3$^-$ vibrational phonons, and not just the 2$^+$ ones, also play a role.

Moreover, very recently, calculations for the ground state deformation of neutron-rich Ba isotopes have been performed [6] showing that the ^{142}Ba wave function is characterized by the presence of a pear shape type. Similar calculations will be performed for ^{140}Ba in the near future.

It is also important to note that the value of the octupole deformation β_3 in ^{144}Ba deduced from measurements in Ref. [1] is larger than that of the existing predictions. Therefore, based on this finding, an unexpected rather large value in β_3 in ^{140}Ba cannot be excluded.

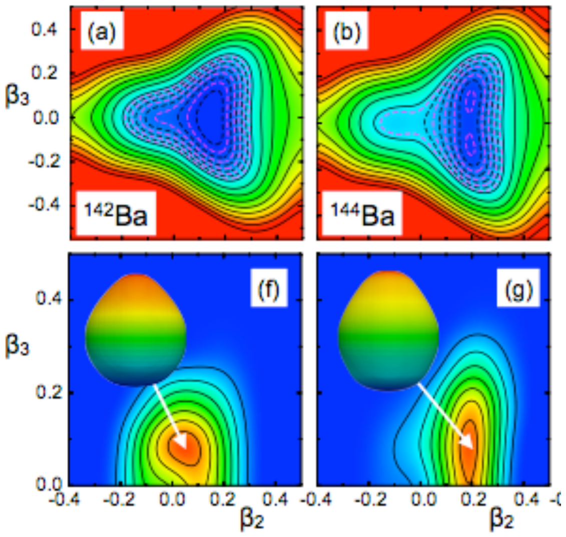

Fig. 3 *Top panels*: Potential energy surfaces for the two ^{142,144}Ba isotopes. Deformed minima are seen. *Bottom panels*: Calculated collective wave functions of the ground states (0+) are represented for the HFB wave functions that correspond to the maximum of each collective wave function (see the arrows). Pear-shapes are clearly seen (figure from Ref. [6]).

Experimental details

We propose to populate ^{140}Ba using the reaction ^{138}Ba(^{18}O,^{16}O)^{140}Ba at 65 MeV, which corresponds to a transfer of two neutrons at energies 1 MeV below the Coulomb barrier. A target thickness of ~5 mg/cm^2 will be needed to fully stop the ^{140}Ba nuclei inside the target.

The subsequent γ decay of ^{140}Ba will be detected by the ROSPHERE array, consisting of 15 HPGe detectors and 10 LaBr$_3$ scintillators, with absolute detection efficiency at 1.33 MeV of ~1.5% and ~1%, respectively.

This 2n reaction, below the Coulomb barrier, has proven to be very successful in the study of ^{66}Ni in populating low-lying spin states and excited 0$^+$ states (see Ref. [7]).

Since this is a test run and the target quality, in particular, cannot be foreseen at this time, a precise estimate of count rate cannot be given. However, we expect that 3 days of beam time are needed and should be appropriate for our purpose.

In conclusion **the beam time request is for 3 days.**

References

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