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ScienceDirect
Nuclear Physics A 789 (2007) 125–141
NUCLEAR PHYSICS A

IBM-1 description of the fission products ^{108,110,112}Ru

I. Stefanescu [a,g,*], A. Gelberg [b], J. Jolie [b], P. Van Isacker [c], P. von Brentano [b], Y.X. Luo [d,e], S.J. Zhu [f,d], J.O. Rasmussen [e], J.H. Hamilton [d], A.V. Ramayya [d], X.L. Che [f]

[a] *Instituut voor Kern- en Stralingsfysica, K.U. Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium*
[b] *Institut für Kernphysik der Universität zu Köln, 50937 Köln, Germany*
[c] *Grand Accélérateur National d'Ions Lourds, CEA/DSM–CNRS/IN2P3, BP 55027 F-14076 Caen Cedex 5, France*
[d] *Physics Department, Vanderbilt University, Nashville, TN 37235, USA*
[e] *Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA*
[f] *Department of Physics, Tsinghua University, Beijing 100084, PR China*
[g] *Horia-Hulubei National Institute for Physics and Nuclear Engineering, PO Box MG-6, Bucharest, Romania*

Received 12 December 2006; received in revised form 13 March 2007; accepted 16 March 2007

Available online 30 March 2007

Abstract

IBM-1 calculations for the fission products ^{108,110,112}Ru have been carried out. The even–even isotopes of Ru can be described as transitional nuclei situated between the U(5) (spherical vibrator) and SO(6) (γ-unstable rotor) symmetries of the interacting Boson Model. At first, a Hamiltonian with only one- and two-body terms has been used. Excitation energies and B(E2) ratios of gamma transitions have been calculated. A satisfactory agreement has been obtained, with the exception of the odd–even staggering in the quasi-γ bands of ^{110,112}Ru. The observed pattern is rather similar to the one for a rigid triaxial rotor. A calculation based on a Hamiltonian with three-body terms was able to remove this discrepancy. The relation between the IBM and the triaxial rotor model was also examined.

PACS: 21.10.Ky; 21.10.Re; 21.60.Ew; 21.60.Fw

Keywords: Interacting boson model, ^{108,110,112}Ru; Energies, E2 branching ratios

* Corresponding author at: Instituut voor Kern- en Stralingsfysica, K.U. Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium.
E-mail address: irina.stefanescu@fys.kuleuven.be (I. Stefanescu).

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2007.03.007

1. Introduction

In recent years neutron-rich even–even isotopes of Ru have been studied by gamma-ray spectroscopy. In this work we will concentrate our attention on the heavy fission products ^{108,110,112}Ru, for which new data are available. In most cases, such nuclei were produced by spontaneous fission, and the gamma-rays were studied by using large Ge-detector arrays [1–3]. Recently, fission products with masses between about 100 and 112 were produced by a ^{252}Cf source, and studied with the Gammasphere array [4–6]. In the most recent publication from the latter collaboration, Zhu et al. [7], several new excited states and transitions have been reported. Some neutron-rich even–even Ru isotopes were also produced by the β-decay of Tc [8–11]. Recently, ^{104}Ru was re-investigated by Coulomb excitation [12].

The impressive accumulation of experimental data during the last 5–6 years has created improved conditions for revisiting the description of ^{108,110,112}Ru by means of nuclear models. In the paper by Stachel et al. [13] the authors proposed to consider the isotopes between ^{98}Ru and ^{110}Ru as belonging to a transition from the U(5) to the SO(6) limit of the Interacting Boson Model (IBM) [14]. In geometrical terms this would be equivalent to a transition between a spherical vibrator [15] and a γ-unstable rotor [16]. The authors of [13] used a schematic Hamiltonian, which can describe the main features of the U(5) to SO(6) transition in even–even Ru isotopes. In their conclusion they viewed this simplified treatment only as a guideline. A more detailed approach is necessary for a comparison of the data with the model for each nucleus. Even–even Ru isotopes were studied in [17,18], where the IBM-2 was used. In this variant of the model, separate proton and neutron bosons are considered. The authors focussed their attention on mixed-symmetry states [19–21].

More recently a search for a possible phase transition in these nuclei was carried out in [22]. Again, a schematic Hamiltonian was used to describe the U(5) to SO(6) transition. The use of coherent states [23,24] allowed the authors to keep track of the dependence on deformation of the total energy surface. The authors came to the conclusion that a phase transition takes place at ^{104}Ru, which can be considered as an example of the E(5) critical symmetry proposed by Iachello [25].

Other models have also been used for the calculation of excitation energies and transition strengths. The rotation–vibration model [4,26] and the generalized collective model [27,28] were applied to $^{108–112}$Ru. A microscopically based quadrupole Bohr Hamiltonian was applied to ^{104}Ru [12].

Recently excited states in $^{109–112}$Ru were populated in a ^{238}U(α, f) fusion–fission reaction [29]. The bands above the backbending were interpreted with the cranked shell model.

The main aim of this work is to describe the most important observables of the heavy ^{108,110,112}Ru isotopes such as excitation energies, E2 branching ratios and the odd–even staggering in the quasi-γ bands by using the interacting boson model. We will use both the standard IBM-1 Hamiltonian and an extended one, which also comprises a three-body term. We will also discuss the relation between the IBM-1 and the Rigid Triaxial Rotor Model (RTRM). The calculations will be compared to the latest experimental information presented in [7] which includes revisited γ-ray intensities and, for ^{110,112}Ru, a newly observed band-like structure built on the proposed (4_3^+) state.