SHAPE COEXISTENCE IN THE LEAD ISOTOPES USING ALGEBRAIC MODELS: DESCRIPTION OF SPECTROSCOPIC AND GROUND-STATE RELATED PROPERTIES*

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A three-configuration mixing calculation is presented in the context of the Interacting Boson Model (IBM1), with the aim to describe recently observed collective bands built on low-lying 0^+ states in the neutron-deficient lead isotopes. Possible effects on the nuclear binding energy are addressed, caused by mixing of these low-lying 0^+ intruder states into the ground state, and a new method is described in order to provide a consistent description of both ground-state and excited-state properties.

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1. Three-shape coexistence in the neutron-deficient lead isotopes

Ample evidence has been accumulated for the presence of nuclear shape coexistence phenomena throughout the whole table of isotopes, especially at and near closed shells [1, 2]. The neutron-deficient lead isotopes in particular, with a closed proton shell at $Z = 82$, show very rich excitation spectra. Three "families" of excited states are observed, with different spectroscopic properties, and with a behaviour that strongly depends on the neutron number [3]. The low-lying excited 0^+ states have been interpreted within two different frameworks mainly: the mean field and the shell model.

In a mean-field approach [4], the spectrum is understood as reflecting several competing minima in the potential energy surface (PES), corresponding to spherical, oblate and prolate deformations. In a shell-model picture, the excited 0^+ states are generated by multi-particle multi-hole (mp-mh) proton excitations across the $Z = 82$ shell gap. The excitation energies of these

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intruder states are lowered by the residual proton–neutron interaction. The mp-mh excitations cannot be easily handled in full-scale shell model calculations, in particular for the large model space required for the description of heavy open-shell nuclei. They are, therefore, treated with the help of algebraic models, such as the Interacting Boson Models (IBM).

We propose an IBM1-mixing calculation, that describes the three different intrinsic "shape" configurations. In order to reduce the number of parameters that appear in such a configuration-mixing calculation, use is made of the concept of intruder-spin symmetry, relating configurations from neighbouring isotope series with different numbers of particle (N_p) and hole (N_h) bosons (*i.e.*, fermion pairs), but with a constant total number of bosons ($N = N_p + N_h$). In this way, experimental excitation energies in adjacent Pt and W nuclei are used to fix the essential IBM parameters [5]. The results of this three-configuration mixing calculation can be appreciated in figure 1 and in Ref. [5].

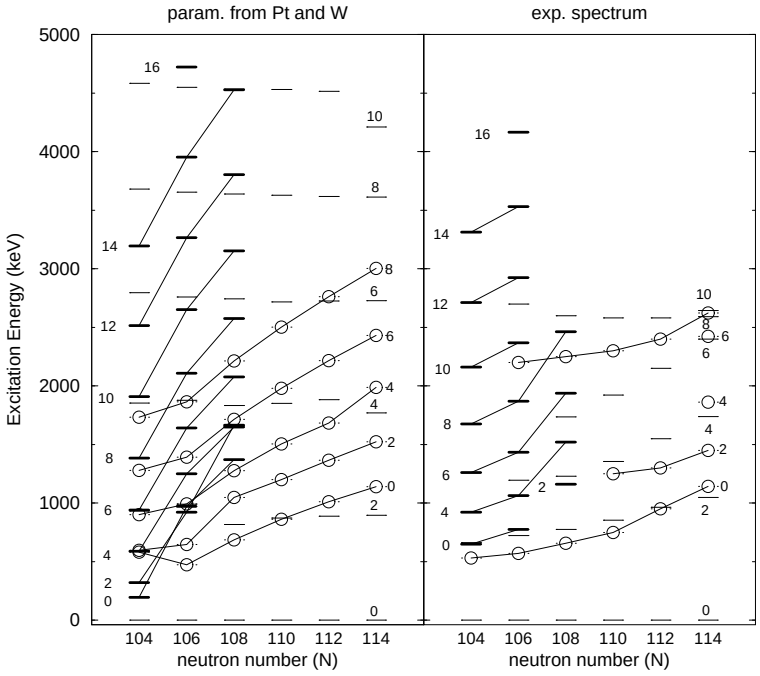

Fig. 1. Right panel: the experimental excitation spectrum of the Pb isotopes with $A = 186$ to 196, containing a regular ground-state spherical band (thin horizontal lines), a $2p$–$2h$ intruder band (open circles) and a $4p$–$4h$ intruder band (thick horizontal lines). Left panel: A 3-configuration mixing calculation within the IBM1 model, for the Pb isotopes in the same mass region [5].

Apart from the mean-field and the shell model, a third, purely phenomenological approach has also been used in order to interpret the experimental findings: the shape-mixing picture [6]. In this model, the physically observed states are the result of interactions between the several configurations. They result as a superposition of spherical, oblate and prolate configurations, the relative weights in the mixing being determined by a fit to the experimental data.

2. Local and global behaviour of mass-related ground-state properties

The possibility to study nuclear masses with the highest possible precision has become available over the last years, in particular at the ISOLTRAP and MISTRAL set-ups at ISOLDE/CERN. Here, precisions of the order of 30 keV on a total mass of a heavy Pb nucleus ($\approx$ 1600 MeV) are reached. Deviations from the global trend (liquid-drop behaviour) are showing up in the nuclear masses in various localised regions over the chart of isotopes. In

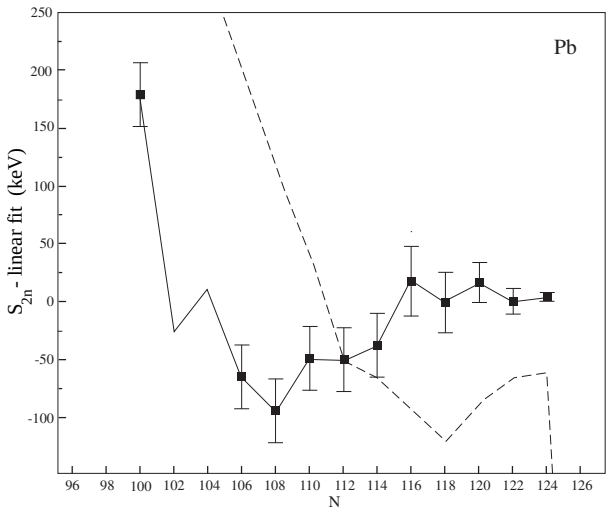

Fig. 2. Local variations in the S_{2n} values for the Pb isotopes, relative to the global and linear (liquid-drop like) behaviour. A comparison is made between the experimental data (full line connecting dots), and results from a calculation with Potential Energy Surfaces (PES), where the macroscopic part of the total energy is given by a Yukawa-plus-exponential mass formula and where the shell corrections are calculated using an axially-deformed single-particle Woods–Saxon potential. The two values ($N = 102, 104$) without data points are derived, containing at least one mass value obtained from mass systematics [8].

the Pb region, it is most probably the effect of mixing of low-lying intruder configurations (oblate and/or prolate shape configurations) in the ground state that turns out to be responsible for increased binding energies in the neutron-deficient region [7]. Figure 2 shows such local correlations in the two-neutron separation energies, S_{2n}, of the neutron-deficient lead isotopes. Using configuration mixing in the IBM1, detailed studies can be carried out, that give a consistent description of both the excited-state properties and the nuclear ground state (nuclear mass and nuclear binding energy) [8]. Moreover, it has been observed that in a consistent study of long chains of isotopes, one has to treat the ground state (through its binding energy) on equal footing with the excited states (relative energy spectrum). It turns out that parameters producing very similar energy spectra can still result in important differences in the ground-state binding energy (order of 1 MeV) [9].

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