Concealed configuration mixing and shape coexistence in the platinum nuclei

J.E. García-Ramos*, V. Hellemans† and K. Heyde**

*Departamento de Física Aplicada, Universidad de Huelva, 21071 Huelva, Spain
†Université Libre de Bruxelles, Physique Nucléaire Théorique et Physique Mathématique, CP229, B-1050 Brussels, Belgium
**Department of Physics and Astronomy, Ghent University, Proeftuinstraat 86, B-9000 Gent, Belgium

Abstract. The role of configuration mixing in the Pt region is investigated. The nature of the ground state changes smoothly, being spherical around mass $A \sim 174$ and $A \sim 192$ and deformed around the mid-shell $N = 104$ region. Interacting Boson Model with configuration mixing calculations are presented for deformations and isotope shifts. The assumption of the existence of two configurations with very different deformation provides a simple framework to explain the observed isotope shifts systematics.

Keywords: Pt isotopes, shape coexistence, intruder states
PACS: 21.10.-k, 21.60.-n, 21.60.Fw.

INTRODUCTION

Shape coexistence has been observed in many mass regions throughout the nuclear chart and turns out to be realized in more nuclei than anticipated a few decades ago [1].

Recently, a lot of new results have become available for the even-even Po, Hg and Pt nuclei, for which experimental information was highly needed. In this mass region the intruder bands are easily singled out for the Pb and Hg nuclei and the excitation energies display the characteristic parabolic pattern with minimal excitation energy around the $N = 104$ neutron mid-shell nucleus. However, this structure seems absent in the Pt nuclei. Indeed, the energy systematics in these Pt nuclei display a rather sudden drop in the excitation energy of the 0_2^+, 4_1^+, 2_3^+ and 6_1^+ states between $N = 110$ and $N = 108$, followed by a particularly flat behavior as a function of N until the energies of those states start to move up again around neutron number $N = 100$. This suggests the crossing and the strong mixing of two different families of states.

In two previous articles [2, 3], we studied the Pt nuclei extensively with the Interacting Boson Model (IBM) [4] incorporating proton 2p–2h excitations (IBM-CM) [5]. The conclusion of these studies was that configuration mixing in the Pt nuclei is somehow "concealed".

The IBM-CM allows the simultaneous treatment and mixing of several boson configurations which correspond to different particle–hole shell-model excitations [5]. Hence, the model space corresponds to a $[N] \oplus [N+2]$ boson space. The boson number N is obtained as the sum of the number of active protons (counting both proton particles and holes) and the number of valence neutrons, divided by two. Thus, the Hamiltonian for

two-configuration mixing is written

$$\hat{H} = \hat{P}_N^{\dagger}\hat{H}_{\rm ecqf}^{N}\hat{P}_N + \hat{P}_{N+2}^{\dagger}\left(\hat{H}_{\rm ecqf}^{N+2} + \Delta^{N+2}\right)\hat{P}_{N+2} + \hat{V}_{\rm mix}^{N,N+2}\,, \qquad (1)$$

where $\hat{P}_N$ and $\hat{P}_{N+2}$ are projection operators onto the $[N]$ and the $[N+2]$ boson spaces respectively, $\hat{V}_{\rm mix}^{N,N+2}$ describes the mixing between the $[N]$ and the $[N+2]$ boson subspaces, $\hat{H}_{\rm ecqf}^{i}$ is the extended consistent-Q Hamiltonian (ECQF) with $i = N, N+2$ (see [4]), and Δ^{N+2} can be associated with the energy needed to excite two particles across the $Z = 82$ shell gap.

Within this formalism we have performed a fit to the excitation energies and $B(E2)$ transition rates of $^{172-194}$Pt in order to fix the parameters for the IBM-CM Hamiltonian. The results from the fitting procedure are summarized in Table 3 of Ref. [2] and they will be used in the calculations showed in the presented contribution.

This contribution aims to describe the observed isotopic shift systematics, which is very sensitive to configuration mixing, in terms of the mixing of two configurations with very different deformation.

EVOLUTION OF THE DEFORMATION AND OF THE ISOTOPIC SHIFTS AS A FINGERPRINT OF CONFIGURATION MIXING

The detailed IBM-CM calculations carried out in Ref. [2] display a strongly evolving character of the wave function in the $[N]$ and $[N+2]$ space along the Pt isotope chain. The lightest and the heaviest Pt isotopes show a rather pure $[N]$ composition, while the isotopes near the mid-shell, $^{176-188}$Pt, present a mixed character (see Fig. 11 of Ref.[2]). These changes in the wave function are expected to strongly affect the deformation of the nucleus which is reflected in the evolution of the charge radii.

A geometric interpretation of the IBM is obtained within the intrinsic state formalism, proposed by Ginocchio *et al.* [6]. In this approach one derives the equilibrium value of the shape variables β (deformation) and γ (degree of triaxiality) be means of a variational procedure. These variables can be connected with the standard Hill-Wheeler variables [6]. To study the geometry of the IBM-CM, Frank *et al.* [7] proposed a new method which takes into account the existence of two families of states.

We have calculated the energy surface for the Pt chain of isotopes and the corresponding equilibrium value of the deformation parameter β. In the upper part of Fig. 1 we present the value of β for the unperturbed configurations (omitting the mixing term in the Hamiltonian) and the full IBM-CM result. It is clear that the unperturbed configurations have a very different value of β (around 0.5 for the regular and 1.0 for the intruder one) and that the full IBM-CM varies between the regular value at the beginning and the end of the shell, and the intruder one at the mid shell. This is explained invoking the crossing of both configurations, as can be observed in the bottom part of Fig. 1, where the unperturbed and full IBM-CM energies of the ground state are depicted. The equilibrium value of γ for the whole chain has also been calculated, giving rise to a prolate shape up to ^{188}Pt and a gamma-unstable form for the heaviest isotopes. The obtained

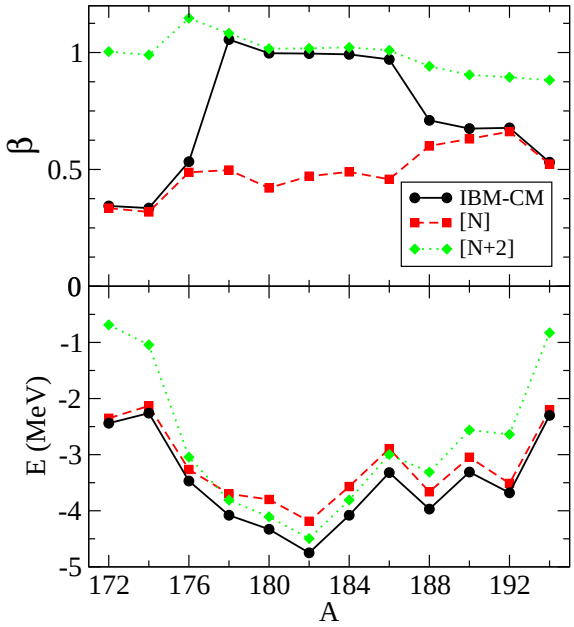

FIGURE 1. Upper panel: value of β for the unperturbed configurations (red dashed line for [N] and green dotted line for [N+2]), and black full line for the IBM-CM calculation. Bottom panel: ground state energy for the unperturbed configurations and for the IBM-CM calculation.

values for (β,γ) are in qualitative agreement with recent mean-field results using Gogny interactions (see Fig. 6 of Ref. [8])

The change in the deformation parameter should have a strong influence in the value of the radius. Experimental information about ground-state charge radii is available for both the even-even and odd-mass Pt nuclei [9]. We illustrate the relative changes of the radius defined as $\Delta\langle r^2\rangle_A \equiv \langle r^2\rangle_{A+2}$ -$\langle r^2\rangle_A$ in Fig. 2. Here one observes a pronounced dip in the relative difference of charge radii for mass $A = 186$ and $A = 184$.

The isotope shifts were calculated using the standard IBM-CM expression for the nuclear radius

$$r^2 = r_c^2 + \hat{P}_N^\dagger(\gamma_N\hat{N} + \beta_N\hat{n}_d)\hat{P}_N + \hat{P}_{N+2}^\dagger(\gamma_{N+2}\hat{N} + \beta_{N+2}\hat{n}_d)\hat{P}_{N+2}. \qquad (2)$$

The four parameters appearing in this expression are adjusted to the experimental data (see Ref. [3] for details). A very good agreement with experimental data is obtained, which confirms the appropriate balance between $[N]$ and $[N+2]$ configurations in the wave function along the whole chain of Pt isotopes.

CONCLUSIONS AND ACKNOWLEDGMENTS

In this contribution, we have studied the evolution of the deformation parameter β and of the isotope shifts for a chain of Pt isotopes with the IBM-CM approach. The parameters in the Hamiltonian were adjusted to the excitation energies and the $B(E2)$ transition rates of these isotopes in a preceding work [2].

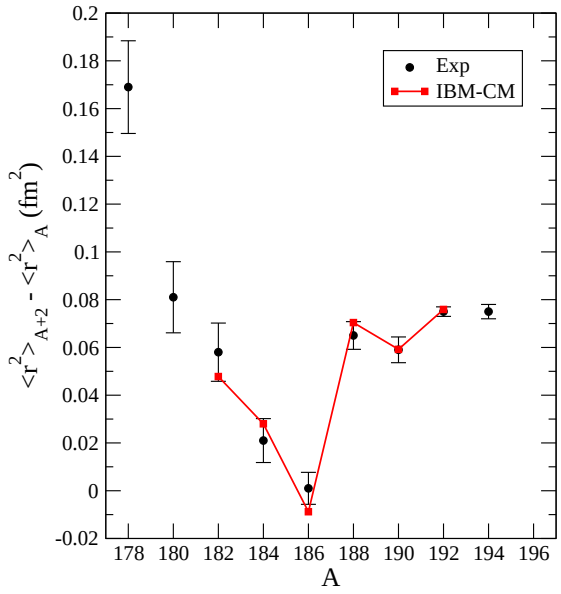

FIGURE 2. Experimental data and theoretical values for the isotope shifts $\Delta\langle r^2\rangle_A = \langle r^2\rangle_{A+2} - \langle r^2\rangle_A$ for the even-even Pt isotopes (from [9]).

The calculations clearly demonstrate the presence of two configurations with very different deformations that cross around the mid shell. At the beginning and the end of the shell, the isotopes are slightly deformed while being well-deformed at the mid shell. This behavior is reflected in the experimental systematics of the isotope shifts (Fig. 2), which is nicely reproduced by our calculations.

This work has been supported by the Spanish MINECO and the European funds "FEDER" under project number FIS2011-28738-C02-02, by Junta de Andalucía under project P07-FQM-02962, and by Spanish Consolider-Ingenio 2010 (CPAN CSD2007-00042). VH gratefully acknowledges a postdoctoral felloship from the FRS-FNRS (Belgium). KH thanks the "FWO-Vlaanderen" for financial support. This research was performed in the framework of the BRIX network (P6/23) funded by the "IAP Program-Belgian State-BSP".

REFERENCES

1. K. Heyde and J.L. Wood, Rev. Mod. Phys. **83**, 1467 (2011).
2. J.E. García-Ramos and K. Heyde, Nucl. Phys. A **825**, 39 (2009).
3. J.E. García-Ramos, V. Hellemans, and K. Heyde, Phys. Rev. C **84**, 014331 (2011).
4. F. Iachello and A. Arima, *The Interacting Boson Model*, Cambridge University Press (1987).
5. P.D. Duval and B.R. Barrett, Nucl. Phys. A **376**, 213 (1982).
6. J.N. Ginocchio and M.W. Kirson, Nucl. Phys. **A 350**, 31, (1980).
7. A. Frank, P. Van Isacker, and C.E. Vargas, Phys. Rev. **C69**, 034323 (2006).
8. R.R. Rodríguez-Guzmán, P. Sarriguren, L.M. Robledo, and J.E. García-Ramos, Phys. Rev. C **81**, 024310 (2010).
9. Th. Hilberath, St. Becker, G. Bollen, H.-J. Kluge, U. Krönert, G. Passler, J. Rikovska, R. Wysse, and the ISOLDE Collaboration, Z. Phys. A **342**, 1 (1992); F. Le Blanc *et al.*, Phys. Rev. C **60**, 054310 (1999).