The platinum nuclei: concealed configuration mixing and shape coexistence

J.E. GARCÍA-RAMOS

Departamento de Física Aplicada, Universidad de Huelva, 21071 Huelva, Spain
E-mail: enrique.ramos@dfaie.uhu.es

V. HELLEMANS

Université Libre de Bruxelles, Physique Nucléaire Théorique et Physique Mathématique, CP229, B-1050 Brussels, Belgium

University of Notre Dame, Department of Physics, 225 Nieuwland Science Hall, Notre Dame IN 46556, USA

K. HEYDE

Department of Physics and Astronomy, Proeftuinstraat, 86 B-9000 Ghent, Belgium

The role of configuration mixing in the Pt region is investigated. For this chain of isotopes, 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 gyromagnetic factors and isotope shifts. The necessity of incorporating intruder configurations to obtain an accurate description of the latter properties becomes evident.

Keywords: Pt isotopes; Shape coexistence; Intruder states.

1. 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 lost for the Pt nuclei. Focussing on the systematics of the energy spectra in these Pt nuclei, as a function of the neutron number, one observes a rather sudden drop in the excitation energy of the 0_2^+, 4_1^+, 2_3^+ and 6_1^+ states between $N = 110$ ($A = 188$) and $N = 108$ ($A = 186$), 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 $N = 100$ ($A = 178$). This suggests the crossing and the strong mixing of two different families of states.

In a previous article,[2] we studied the Pt nuclei extensively within the Interacting Boson Model (IBM)[3] formalism and carried out a detailed comparison of calculations incorporating proton 2p-2h excitations with calculations that only consider the smaller model space of the [N] configurations. It turned out that the results for the energy spectra and absolute $B(E2)$ values were very similar up to an excitation energy of ~ 1.5 MeV, even though the corresponding wave functions have to be very different. As such, it was concluded that these similarities point towards a picture where the configuration mixing and the larger model space are somehow "concealed".[4] It is the goal of this contribution to present the calculation of observables that will be sensitive to the mixing of $[N]$ and $[N+2]$ configurations, in particular, gyromagnetic factors and isotopic shifts.

2. Configuration mixing formalism

In this section, we present an abridged introduction to the IBM configuration mixing formalism (or IBM-CM). For an in-depth discussion, we refer to.[2]

The IBM-CM allows the simultaneous treatment and mixing of several boson configurations which correspond to different particle–hole (p–h) 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, and $\hat{H}_{\rm ecqf}^i$ is the extended consistent-Q Hamiltonian (ECQF)[6] with $i = N, N+2$ (see[3]).

The parameter Δ^{N+2} can be associated with the energy needed to excite two particles across the $Z = 82$ shell gap, corrected for the pairing interaction energy gain and including monopole effects. The operator $\hat{V}^{N,N+2}_{\rm mix}$ describes the mixing between the N and the $N+2$ configurations.

The $E2$ transition operator in the case of two-configuration mixing is defined as $\hat{T}(E2)_\mu = \sum_{i=N,N+2} e_i \hat{P}_i^\dagger \hat{Q}_\mu(\chi_i)\hat{P}_i$, where the e_i $(i = N, N+2)$ are the effective boson charges and $\hat{Q}_\mu(\chi_i)$ is the same quadrupole operator appearing in the ECQF Hamiltonian.

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 and the $E2$ transition operator. The results from the fitting procedure are summarized in Table 3 or Ref.[2] and will be used in the calculations presented in next section.

3. Study of observables sensitive to configuration mixing

The detailed IBM-CM calculations carried out in Ref.[2] show a strongly changing character of the wave function in the $[N]$ and $[N+2]$ space along the Pt isotope chain. The lightest (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 a number of observables. Indeed, charge radii, gyromagnetic factors, and α-decay hindrance factors are highly sensitive to the $[N]$ and $[N+2]$ composition of the wave functions. Therefore, we will focus on these experimental quantities as they allow to probe precisely those components of the nuclear wave functions and the importance of configuration mixing.

3.1. *Gyromagnetic factors*

A particularly interesting set of data are the g-factor measurements for the 2_1^+ state in the mid-shell ^{184,186,188}Pt nuclei.[7] The data display a rather flat behavior as a function of the neutron number in the vicinity of mid-shell.

Within the IBM context, magnetic moments can be calculated using the IBM-2,[3] which differentiates between proton (π) and neutron bosons (ν). The M1 operator can then be written as

$$\hat{T}(M1) = \sqrt{\frac{3}{4\pi}}\Big(\hat{P}_N^\dagger(g_N^\pi \hat{L}_\pi + g_N^\nu \hat{L}_\nu)\hat{P}_N + \hat{P}_{N+2}^\dagger(g_{N+2}^\pi \hat{L}_\pi + g_{N+2}^\nu \hat{L}_\nu)\hat{P}_{N+2}\Big). \quad (2)$$

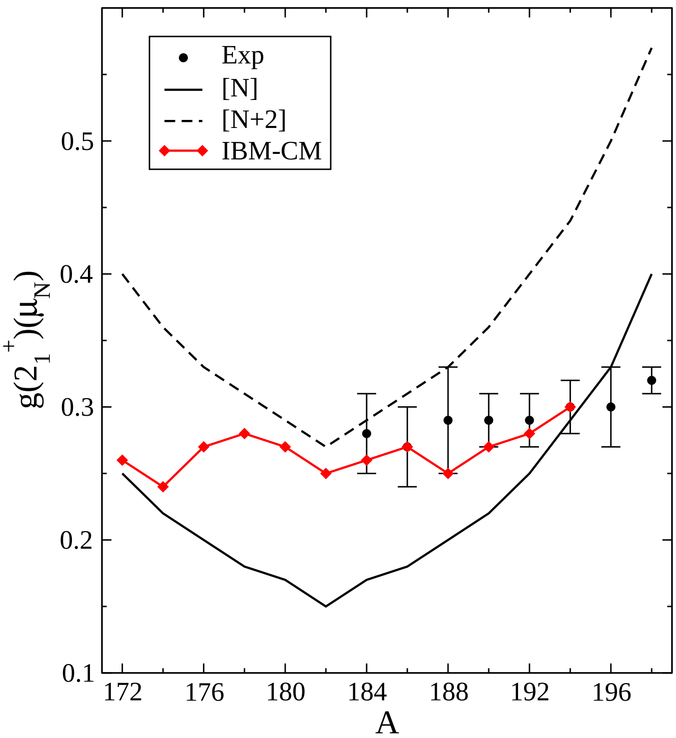

Fig. 1. Gyromagnetic factor for the even-even Pt isotopes (experimental data from[8]). Full circles for the experimental data, full and dashed lines for $[N]$ and $[N+2]$ unperturbed results, respectively, and red full diamonds with full line for the IBM-CM calculations.

Using the standard microscopic values for the g factors, i.e. $g_N^\nu = g_{N+2}^\nu = 0\ \mu_N$ and $g_N^\pi = g_{N+2}^\pi = 1\ \mu_N$, assuming F-spin symmetry for the IBM-2 Hamiltonian,[3] it can be readily shown that the gyromagnetic factor can be written as,

$$\frac{g(2_1^+)}{\mu_N} = \frac{1}{2\mu_N}\mu(2_1^+) = \frac{N_\pi}{N}\omega^1(2,N) + \frac{N_\pi+2}{N+2}(1-\omega^1(2,N)), \qquad (3)$$

where N_π is the number of protons out of the closed shell divided by two and $\omega^1(2,N)$ is that part of the wave function of the 2_1^+ state within the $[N]$-boson (regular) space. In Fig. 1, we present the calculated g-factors and the experimental values. Note that this calculation is parameter free once the regular components are determined from the diagonalization of the Hamiltonian. As a reference, we also plotted the limits corresponding to wave function with either fully regular $[N]$ character or intruder $[N+2]$. The theoretical results obtained after the mixing calculation should be situated between both lines. Note that, according to the IBM, this flat behavior of the g-factors is necessarily explained by a strong mixing between the regular and intruder 2p-2h configurations. For more details see Ref.[4]

3.2. *Isotopic shifts*

Experimental information about ground-state charge radii is also available for both the even-even and odd-mass Pt nuclei. In particular, detailed studies by Hilberath *et al.*[9] for the $^{183-198}$Pt nuclei and by Le Blanc *et al.*[10] have extended the charge radii measurements down to ^{178}Pt. 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 $A = 184$.

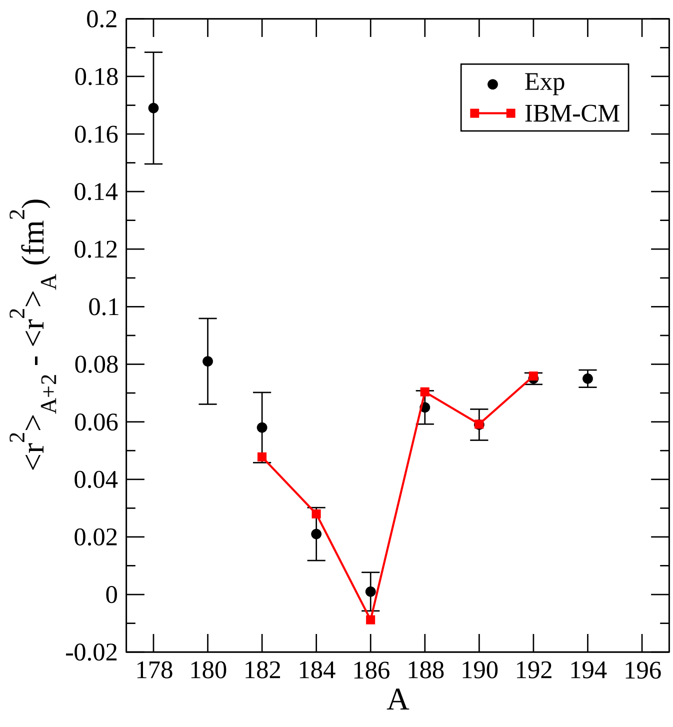

Fig. 2. Experimental data and theoretical values for the isotope shifts $\Delta\langle r^2\rangle_A = \langle r^2\rangle_{A+2} - \langle r^2\rangle_A$ for the even-even Pt isotopes (from[9] and[10]).

To calculate the isotope shifts, we have used the standard IBM-CM expression for the nuclear radius

$$r^2 = r_c^2 + \hat{P}_N^\dagger(\gamma_N \hat{N} + \beta_N \hat{n}_d)\hat{P}_N + \hat{P}_{N+2}^\dagger(\gamma_{N+2}\hat{N} + \beta_{N+2}\hat{n}_d)\hat{P}_{N+2}. \quad (4)$$

The four parameters appearing in this expression are adjusted to the experimental data (see Ref.[4] for details). The comparison with the experimental data show a very good quantitative agreement, which confirms the appropriate balance between $[N]$ and $[N+2]$ configurations in the wave function along the whole chain of Pt isotopes.

4. Conclusions

In this contribution, we have studied observables that are sensitive to the presence of intruder configurations in the wave function, such as gyromagnetic factors and isotope shifts, for a chain of Pt isotopes. For this purpose, we used an IBM-CM Hamiltonian whose parametrization was adjusted to the excitation energies and the $B(E2)$ transition rates of these isotopes in a preceding work.[2] The g-factor very clearly indicates the need for rather strong mixing in the wave functions. Similarly, the isotopic shifts constitute a direct measure of the ground-state wave function and as such is an observable that is sensitive to its precise decomposition.

In summary, we have seem that although some observables, such as excitation energies and $B(E2)$ transition rates, are rather insensitive to the mixed character of the wave functions, for others, e.g. radii and g-factors, one needs a strong mixing to explain the experimental systematics.

References

1. K. Heyde and J.L. Wood, to be published in Rev. Mod. Phys.
2. J.E. García-Ramos and K. Heyde, Nucl. Phys. A **825**, 39 (2009).
3. F. Iachello and A. Arima, *The Interacting Boson Model*, Cambridge University Press (1987).
4. J.E. García-Ramos, V. Hellemans, and K. Heyde, Phys. Rev. C **84**, 014331 (2011).
5. P.D. Duval and B.R. Barrett, Nucl. Phys. A **376**, 213 (1982).
6. D.D. Warner and R.F. Casten, Phys. Rev. C **28**, 1798 (1983).
7. A.E. Stuchbery, S.S. Anderssen, A.P. Byrne, P.M. Davidson, G.D. Dracoulis, and G.J. Lane, Phys. Rev. Lett. **76**, 2246 (1996).
8. Bao-An Bian, Yao-Min Di, Gui-Lu Long, Yang Sun, Jing-ye Zhang, and J.A. Sheikh, Phys. Rev. C **75**, 014312 (2007).
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).
10. F. Le Blanc *et al.*, Phys. Rev. C **60**, 054310 (1999).