POINCARÉ SHAPE TRANSITIONS IN HOT ROTATING NUCLEI*

K. Mazurek[a,b], J. Dudek[c], M. Kmiecik[a], A. Maj[a]
J.P. Wieleczko[b], D. Rouvel[c]

[a]The H. Niewodniczański Institute of Nuclear Physics PAN
Radzikowskiego 152, 31-342 Kraków, Poland
[b]Grand Accélérateur National d'Ions Lourds, CEA/DSM-CNRS/IN2P3
Caen, France
[c]Institut Pluridisciplinaire Hubert Curien and Université de Strasbourg
67037 Strasbourg Cedex 2, France

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Poincaré shape transitions in hot, fast rotating Barium nuclei have been investigated using a realistic, the so-called Lublin–Strasbourg Drop (LSD) model. In this contribution we present typical forms of the shape evolution of the total energy landscapes in function of spin and isospin selecting for illustration ^{116}Ba, ^{128}Ba, ^{142}Ba and ^{152}Ba isotopes, as representative for the medium-mass $A \sim 130$ nuclei.

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1. Introduction

Shape transitions in hot nuclei have analogies with those in rotating stars and more generally, turning liquid systems. In astronomy, processes of this type were considered by Jacobi [1] who introduced shape transitions that preserve the left–right symmetry. Another class of shapes which break the left–right symmetry was introduced also in the context of rotating stars by Poincaré, [2]. The existence of the nuclear Jacobi shape transition was demonstrated experimentally through the measurements of the Giant Dipole Resonance strength function with increasing angular momentum [3].

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2. Potential energy surfaces

Nuclear energy of hot rotating nuclei has been approximated using the Lublin–Strasbourg Drop (LSD) macroscopic model, *cf.* Refs. [4, 5]; the LSD expression has been improved by adding the congruence and average pairing energy. The total energy has been calculated in a rich space of multipole deformation parameters $\alpha \equiv \{\alpha_{\lambda\mu}\}$ with $\lambda \in [2, 16]$. Equilibrium nuclear shapes for each given spin have been found through the energy minimisation including the rotational energy term $I(I+1)/\mathcal{J}(\alpha)$, where $\mathcal{J}(\alpha)$ denotes a rigid-body moment of inertia at the deformation α. For low and generally not too high spins the equilibrium shape evolves from spherical to more and more oblate configurations. At high angular momenta, however, one of the two above mentioned shape transitions occur that precede rotation-induced fission. Although we focus on the Poincaré-type shape evolution we also perform tests by minimising the total energy using the α_{20} and α_{22} deformations together with α_{40} and α_{42} as well as α_{60} and α_{62} representing similar 'tri-planar' symmetry. Calculations show that the extra degrees of freedom do not lower the total energy below the result obtained using α_{22} in the nuclei studied but these results will not be discussed here in detail.

The Poincaré transitions imply a gradual increase in the mass-asymmetry with increasing spin and offer a possibility of combining the theory predictions related to the masses of the fission fragments within appropriately chosen spin-windows — a characteristic which is in principle observable.

In the following we project the total energy on the $(\alpha_{20}, \alpha_{30})$-plane minimising over $\alpha_{\lambda,0}$ deformations with $4 \leq \lambda \leq 16$. Figure 1 illustrates the results for ^{116}Ba and ^{128}Ba for a selection of spins. The plots show the evolution of the equilibrium shapes with increasing spin and isospin. For ^{116}Ba the octupole deformation begins playing a significant role for spins in excess of $60\,\hbar$. At those spins the predicted fission barrier is of about 3 MeV only, it is therefore clear that the left–right asymmetry can be manifested by the mass-asymmetric fission fragment distributions only at the highest spins (if at all). The Poincaré transition in this case is very fast but takes place very close to the fission limit. The nucleus ^{128}Ba, in contrast, can be viewed as a much better candidate to observe the Poincaré shape transition, given the fact that the onset of the transition takes place at spins for which the fission barrier is 5–6 MeV high — and — importantly, because it will be possible to produce it in laboratory. According to our prediction the fission-fragment mass-asymmetry should quickly take over for spins larger than $72\,\hbar$ or so.

Illustration of trends in evolution of the Poincaré shape transitions with *increasing isospin* continues in Fig. 2, where the shape transitions with an *increasing spin* are shown for ^{148}Ba and, in the extreme case of ^{152}Ba. Since the stability against fission increases with the increasing neutron number the cor-

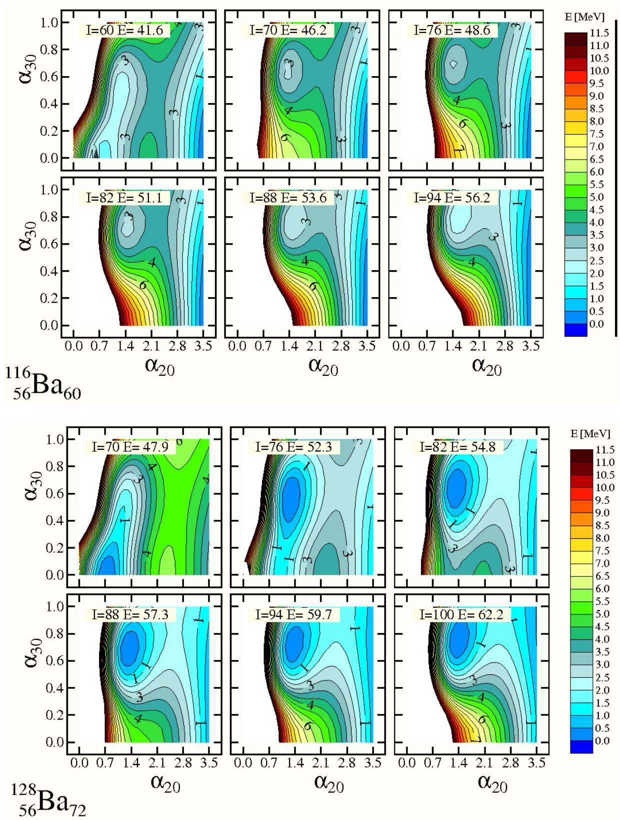

Fig. 1. Potential energy surfaces of the rotating ^{116,128}Ba in the Poincaré shape transition region; the spins and the energies at the minima relative to the spherical configurations at spin zero are also given.

responding onset spin-values increase as well and, importantly, with slightly increasing barrier heights. At the transition-onset spin-values the barrier heights are between 5–6 MeV and the mass-asymmetric fission-fragment distributions are predicted for spins in excess of $I \approx 82\,\hbar$ and $I \approx 86\,\hbar$ for ^{148}Ba and ^{152}Ba, respectively. Whereas ^{152}Ba is an extremely exotic proton–neutron combination, producing ^{142}Ba is possible with soon available instruments — together with many Barium nuclei in the mass range roughly between ^{128}Ba and ^{142}Ba.

Figure 3 illustrates the nuclear susceptibility to develop deformations — in terms of various multipole degrees of freedom — with increasing spin. Multipolarities $\lambda = 2, 4$ and 6 seem to be strongly correlated for all isospins. Indeed an overall increase in all the three deformations preserve the same proportions, the main difference being the onset of the strong-deformation effect which begins at lower spins for lower nuclear isospin.

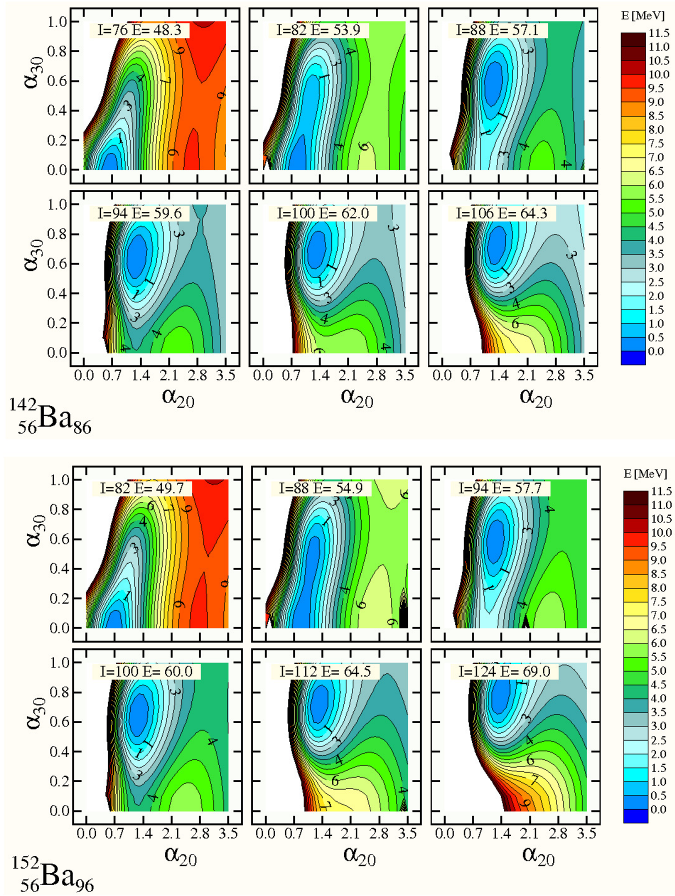

Fig. 2. Similar to Fig. 1 but for ^{142,152}Ba.

Let us observe that the onset of the left–right (mass-) asymmetry corresponding to $\lambda = 3$ and higher λ-odd components is correlated with the onset of the even multipole components with $\lambda = 4$ or higher as the bottom part of Fig. 3 demonstrates. It is worth emphasising that the main effect of the left–right asymmetry is described by two lowest components, *viz.* $\lambda = 3$ and 5; these variables are clearly correlated at least within the LSD model.

Dramatic shape transitions discussed so far are accompanied by the strong and quickly growing elongation of the nuclear system which implies an extremely rapid increase in the moment of inertia. The classical estimates of the spin of the rotating nucleus give $I = \mathcal{J}(\alpha) \cdot \omega$, where $\mathcal{J}$ denotes the effective moment of inertia and ω the associated classical rotational frequency. It then follows that increasing spin by $2\,\hbar$ corresponds to such a strong increase in the moment of inertia that $\omega(I) < \omega(I-2)$ *i.e.* de-

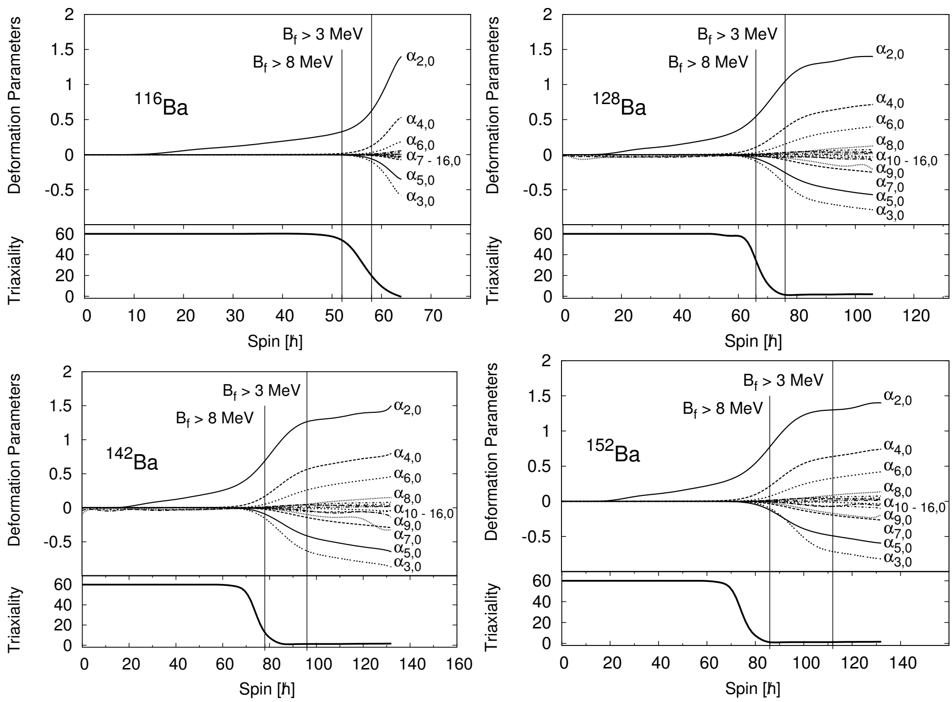

Fig. 3. Illustration of an increase in the multipole deformations of the order of λ with increasing spin. Deformations with odd-λ are plotted as negative. Tri-axiality is represented in terms of Bohr's γ-parameter in degrees. For spins corresponding to $B_{\mathrm{f}} > 8\,\mathrm{MeV}$, one may expect the neutron and charged particles emission as a dominating cooling channel, for $3 < B_{\mathrm{f}} < 8\,\mathrm{MeV}$ evaporation competes with fission, otherwise fission prevails. Inserts at the bottoms of each figure represent the Bohr triaxiality parameter γ in degrees; $\gamma = 60$ corresponds to the oblate, axially-symmetric shapes, spin aligned with the symmetry axis.

crease rather than an increase. This mechanism, referred to as a *gigantic back-bending*, is illustrated in Fig. 4 in the form of spin *versus* ω dependence (left). The energy-spin dependence, $E_I = \hbar^2 I(I+1)/2\mathcal{J}(\alpha)$, immediately allows to estimate the associated transition energies $E_\gamma[I \rightarrow (I-2)]$ illustrated in the right-hand side of Fig. 4. From the experimental point of view it is expected that at the configurations for spins corresponding to $B_{\mathrm{f}} > 3$ MeV we will be able to measure essentially electromagnetic signals such as the decay of the Giant Dipole Resonance, dipole and quadrupole feeding of the rotational bands and more generally a continuum gamma radiation. For spins such that $B_{\mathrm{f}} < 3\,\mathrm{MeV}$ it is expected that the main experimental signal will involve the measurements of the fragment-mass distribution.

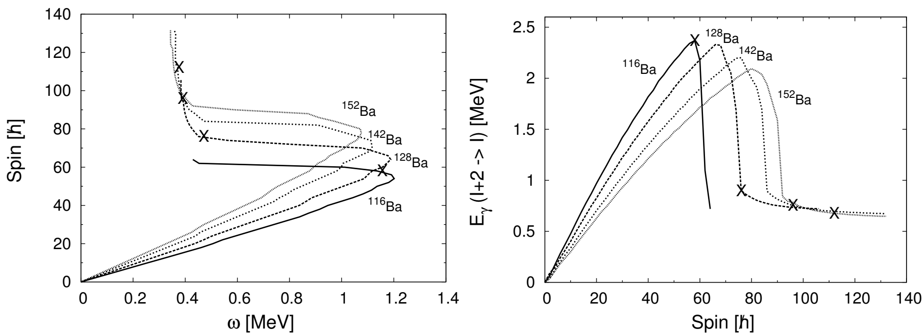

Fig. 4. Gigantic back-bending illustrated for isotopes indicated, is represented as the spin *versus* rotational frequency dependence (left) and equivalently in terms of stretched quadrupole transition energies $E_\gamma[I \rightarrow (I-2)]$ *versus* spin (right). Crosses denote the spin-position at which the fission barrier reaches the value $B_{\rm f} = 3\,{\rm MeV}$.

3. Summary and conclusions

The Poincaré shape transitions are predicted in all Barium isotopes studied, but the stability against fission increases strongly with increasing neutron number, so that the Poincaré phenomena will strongly be visible in neutron-rich Ba isotopes. We believe that it will be important to systematically investigate through experiments the fission-fragment mass-distributions correlated with the nuclear spin and continuum γ-radiation in order to examine the Poincaré transitions in sub-atomic physics. We predict an expected shape of the Gigantic Back-bending mechanism which can be used for a semi-quantitative comparison with the experimental data.

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