Complementary Mechanisms in Nuclear Structure: Isomers, Highly excited states and Giant Resonances

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Let us begin a short statement of a comment about the formulation of the title which at first glance could be misleading: Since isomers may appear at high energies, so may the Giant Resonances (after Brink hypothesis) one may be tempted to think the this formulation carries a trivial message. In fact, for a nuclear structure physicist the above elements combine into the link with nuclear symmetries, spontaneous symmetry breaking, nuclear phase transitions, critical points and critical phenomena, cf. the most recent dedicated conferences, e.g. ref. [1].

Indeed, the isomers addressed in the presented discussion correspond to two sub-families: the well known K-isomers, which appear in axially symmetric nuclei, both prolate and oblate and the isomers generated by the so called high-rank symmetries, tetrahedral and octahedral ones which represent the new class of phenomena of interest. The latter ones gain particularly in actuality in view of the first announcement of their experimental evidence in ref. [2].

The physics of K-isomers provokes several challenges related to spontaneous symmetry breaking via non-axial shape oscillations around axially-symmetric potential energy minima resulting in the axial symmetry breaking, the so-called K-mixing and oblate-prolate shape competition. Such studies necessarily involve the lifetime measurements related to the electromagnetic radiation de-exciting such states what implies in turn the necessity of programming the corresponding equipment in terms of the future nuclear physics investments in Poland.

The physics of high-rank symmetry isomers imposes alternative detection methods given the fact that the isomers in question essentially do not involve electromagnetic radiation, neither in terms of population nor in terms of de-excitation. The corresponding instrumentation would involve high-resolution mass spectrometry tools.

Population of both types of isomers necessitates employing nuclear reactions preferably involving heavy ions with the energies sufficient for production of compound nuclei at sufficiently high-spins.

The highly excited states addressed in the present discussion correspond to a simultaneous increase of the nuclear temperature and angular momentum. Under these two conditions satisfied simultaneously, atomic nuclei manifest forms of behaviour analogous to those known in the physics of astronomical objects under the names of Jacobi and Poincare transitions. The Jacobi transitions are induced by increasing spin leading first to an increase of the oblate deformation, whereas the angular momentum remains aligned with the symmetry axis. At a certain critical value of angular momentum the system looses stability against axial geometrical forms, the nucleus becomes tri-axil and quickly elongates with a further increase of spin. The Poincare transitions correspond to a further loss of stability, this time against the left-right asymmetry. Both types of transitions can be qualified as spontaneous symmetry breaking phenomena leading to shape-phase transitions, ref. [1] is just a small example.

As it turns out, in the vicinity of the critical spin values the nuclear shapes change dramatically accompanied by the dramatic changes in the occupancy of the underlying single particle orbitals at the negligible changes in the potential energy, typically of the order of a couple of keV, the properties accompanying critical phenomena. At the same time one finds special singular states or sequences of states (e.g. super-deformed bands) at zero temperature coexisting with / embedded among the huge density of states just mentioned – another exotic mechanism worth considering in our future plans.

The importance of the studies of the giant dipole resonances in the present context consists in the fact that profile of the GDR radiation distribution function allows to determine experimentally the most probable nuclear shapes, including the non-axial nuclear forms, cf. ref. [3] for the first manifestation of the so-called Coriolis splitting of the giant-dipole resonance. These measurements provide important by-product information: the population probability distributions indicating the most likely deformation fed. With this, and only with this information one will be able to address the physics of nuclear hyper-deformed configurations, the mechanism remaining elusive despite years devoted to its discovery.

Thus investing in the studies of the giant-dipole resonance population and decay properties, especially in connection with the Jacobi shape transitions, involves as a natural consequence the issue of population and detection of the super- and hyper-deformed bands. Instrumental needs for such studies would involve multi-detector systems (calorimeter type or Germanium arrays) and a possibility of inviting PARIS and / or AGATA collaborations to place their detection systems in conjunction with the future accelerator of appropriate parameters would certainly offer unique opportunities.

Bibliography

[1] 9th International Conference on Quantum Phase Transitions in Nuclei and Many-Body Systems, Padua, 2018
8th International Conference on Quantum Phase Transitions in Nuclei and Many-Body Systems, Prague, 2016
7th Conference on Shape-Phase Transitions and Critical-Point Phenomena in Nuclei, Seville, 2014
[2] J. Dudek *et al.*, Phys. Rev. C **97**, 021302(R) (2018)
[3] A. Maj *et al.*, Nucl. Phys. A **731**, 319 (2004), especially Fig. 4