Horia Hulubei National Institute for Physics and Nuclear Engineering
University of Bucharest

Coexistence Phenomena in Medium Mass Nuclei

Oana Radu (Andrei)

Ph.D. thesis

Supervisor
Prof. Dr. Alexandrina Petrovici

March 2009

Abstract

The investigation of the structure and dynamics of exotic nuclei in the A=60-90 mass region is one of the most exciting challenges in low-energy nuclear physics. Intense theoretical and experimental studies revealed that the structure and dynamics of exotic nuclei in this region are dominated by shape coexistence. For nuclei close to the N = Z line, the problem is complicated by the competition between the neutron-proton and like-nucleon pairing correlations, which is expected to influence significantly the behavior of these nuclei. Also the isospin mixing is expected to play an important rol in isospin related phenomena, like the superallowed Fermi β decay procces.

Consequently, the realistic description of coexistence phenomena in proton-rich A∼70 nuclei requires beyond-mean-field approaches. The variational approaches of the Vampir model family, developed by us in collaboration with Tuebingen University, Germany, has been successfully applied for the investigation of a variety of coexistence phenomena in medium mass nuclei. The beyond-mean-field complex Excited Vampir model allows for a unified description of low and high spin states including in the projected mean fields neutron-proton correlations in both T=1 and T=0 channels. The coexistence phenomena have been described based on chains of variational calculations for symmetry-projected essentially complex Hartree-Fock-Bogoliubov (HFB) vacua which include neutron-proton pairing and general unnatural-parity correlations. The Vampir approaches allow using rather large single particle basis as well as general two-body interactions and thus providing the possibility to accomplish really large-scale nuclear structure studies going far beyond the possibilities of the shell-model configuration-mixing approach. The effective two-body interaction is constructed from a nuclear matter G-matrix based on the Bonn one-boson-exchange potentials Bonn A and Bonn CD.

Specific issues which are considered within this thesis are related with the studies concerning the microscopic description of coexistence phenomena manifested by the structure and dynamics of exotic A~70 nuclei.

Oblate–prolate coexistence and mixing is found to be responsible for the characteristic features identified at low excitation energy for low and intermediate as well as high spins. Our investigations indicate the essential role played by particular neutron–proton matrix elements of the effective interaction on the oblate–prolate coexistence and mixing in the ^{78}Kr nucleus. Their properties agree nicely with the available experimental data [1, 2].

We proposed a new mechanism for the population of magnetic cascades of negative-parity states in the A ≃ 80 mass region based on the shape coexistence dominating the structure of the nuclei using the

beyond-mean-field complex Excited Vampir approach [3].

We studied the influence of Coulomb-induced isospin-mixing on the superallowed Fermi β decay using the complex Excited Vampir variational approach for the description of the lowest few 0^+ states in the two isovector triplets of nuclei A=70 and A=74. Special effort has been made to study the isospin impurity induced by the truncation of the many-nucleon configuration space and/or some missing correlations in the configurations themselves. It was shown that these effects are definitely smaller than the isospin-mixing effects induced by the Coulomb interaction. Since it turned out that a large fraction of the depleted strength of the ground to ground transition can be attributed to particular non-analog decay branches at least in some cases ($^{74}Sr \rightarrow ^{74}Rb$ and $^{70}Kr \rightarrow ^{70}Br$), there is some hope for experimental detection [4].

In A=82 analogs we estimated for the first time the isospin-symmetry-breaking correction taking into account both the Coulomb interaction and the isospin-symmetry breaking in the strong force as it is considered by the Bonn CD potential. We presented the first results on the effect of isospin mixing on superallowed Fermi β decay of the odd-odd ^{82}Nb nucleus to ^{82}Zr calculating the lowest 30 0^+ states in these nuclei. The first theoretical estimation of the strengths of the significant nonanalog branches was presented. Using the same effective interaction and model space we investigated the structure of the low-, intermediate- and high-spin yrast states which revealed to be similar for the two investigated nuclei. The comparison with the available data indicates good agreement for the yrast states [5].

The properties of proton-rich nuclei in the A = 60–90 mass region are important to understand the rapid proton capture (rp) process, because their weak decay determines details of nucleosynthesis. Relevant for the Gamow-Teller (GT) β decay of the waiting point nuclei could be the GT strength distributions for the low-lying excited states whose thermal population may result in a significant reduction of the effective lifetime at the high temperatures of X-ray bursts. The description of the GT strength distributions for the β decay of nuclei close to the proton drip line in the A∼70 region meets the difficulty of treating self-consistently the shape coexistence and mixing that dominate the structure of both even-even parent and odd-odd daughter nucleus.

We studied the effect of shape mixing on the Gamow–Teller β decay of ^{74}Kr within the complex Excited Vampir approach. The results, which are the first self-consistent approach to this subject at all, indicate that the GT strength distribution is indeed influenced considerably by the shape-mixing [6].

In ^{72}Kr waiting point nucleus we studied for the first time the strength distributions not only for the ground state but also for the decay of low lying excited states. The GT strength distributions for the β decay of ^{72}Kr to ^{72}Br are significantly influenced by the shape mixing as it was illustrated using Bonn A and Bonn CD potentials with the same renormalization of the G matrix. The results on the GT β decay of ^{72}Kr waiting point nucleus indicate agreement with the available data [7].

References

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