CALCULATION OF DECAY PROPERTIES OF VERY NEUTRON-RICH NUCLEI WITH A MODIFIED NILSSON POTENTIAL*

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Nuclei with extreme neutron to proton ratios, which are in most cases not accessible to experimental investigations, play an important role in astrophysics. For such nuclei near the particle drip-lines new structure effects are expected. Hartree–Fock–Bogoliubov (HFB) calculations with the SkP interaction show modified nuclear potential wells which may be simulated by a Nilsson potential with vanishing ℓ^2-term. The influence of this modification on the β-decay properties of very neutron-rich nuclei is studied within the framework of the QRPA.

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1. Introduction

Nuclear structure data, such as masses and β-decay properties, are requested by various disciplines; *e.g.* by astrophysics [1]. Properties of nuclei needed for these applications are in most cases not known experimentally; hence, they have to be taken from theoretical models. Until recently, internally consistent data on a large number of nuclei (several thousand) could only be obtained from global macroscopic–microscopic models, such as the FRDM [2] and the ETFSI [3] approaches for nuclear masses or the quasiparticle random phase approximation (QRPA) [4] for β-decay properties. In the QRPA are used nuclear input parameters (such as decay energies (Q_β, S_n) and nuclear shapes (ϵ_2)) which were derived from the mass models. As the parameters of these models are fitted mainly to stable nuclei,

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unprecedented extrapolations are required to predict the structure of nuclei far from stability. A good test for such extrapolations is provided by calculations which aim at reproducing the nucleosynthesis by the rapid neutron capture process, which involves mostly unknown neutron-rich nuclei. Within the standard nuclear models, FRDM or ETFSI, the general features are well reproduced, but there remain some deviations which can be attributed to an overestimation of the shell strengths near the magic neutron numbers $N = 82$ and $N = 126$ [5, 6].

2. Nuclear masses from mean field models

Quenching of the spherical shells at $N = 20$, 28 and 50 has been shown experimentally and has also been indicated by the HFB calculations with the SkP force within a selfconsistent treatment of the pairing (see discussion in Ref. [7]). Since the centrifugal barrier pushes up states of high angular momentum j, the low-energy continuum contains mainly the low-j states. In light and medium-heavy nuclei, these low-j continuum states, which are located right above the shell gaps, enter these gaps and effectively lead to quenched shell effects [8].

Therefore, new insights into drip-line effects may be obtained from masses derived from state-of-the-art mean-field models applying various density-dependent nuclear effective forces. Due to the enormous computing time needed for the calculation of thousands of nuclei, until now only the less demanding, spherical-shape calculations are available for neutron-rich isotopes. By substituting the FRDM masses by the HFB ones for $N \simeq 82$, the r-process calculations could, indeed, be improved considerably in the $A \simeq 120$ mass region [7]. A further essential breakthrough is expected, if also β-decay properties ($T_{1/2}$, P_n) will be calculated with the HFB wavefunctions. Following a suggestion of Dobaczewski *et al.* [8], a first estimate of these effects can be obtained by simulating the HFB potential in terms of a modified Nilsson potential.

3. Neutron–skin formation in extremely neutron–rich isotopes simulated by a modified Nilsson potential

In the case of nuclei near the neutron drip-line, the high neutron to proton number ratio would have led to unrealistic high central neutron densities, if the spatial extensions for neutron and proton distributions were identical. Therefore, the neutron distribution should extend further out than the proton one, forming a neutron skin [9, 10]. To a first approximation, this leads to a more diffused neutron potential well, which can be simulated by a Nilsson potential with vanishing ℓ^2-term [8]. In the present study, we calculate the single-particle energies using *(i)* the parameter set of Ragnarsson–Sheline [11] and *(ii)* a modified set obtained by reducing the strength of the ℓ^2-term to 10% of its original value. An expected feature of this modified potential is, for example, a change in the level ordering (in analogy to the HFB calculations mentioned above), see Fig. 1. To get an idea about the effect of these modified single-particle energies on β-decay properties, the half-lives $T_{1/2}$ and neutron emission probabilities P_n for nuclei in the r-process path have been calculated with the QRPA applying masses from the HFB and wave functions derived from the two Nilsson potentials. In Fig. 2, these β-decay properties are compared with the standard values derived from the FRDM. The nuclei up to mass 114 with $N \leq 72$ have deformed nuclear ground-states, so that they cannot be adequately described by the spherical calculations presently available. The predicted trend of longer half-lives in the mass range $115 \leq A \leq 130$ seems to be in accordance with recent experimental values for neutron-rich Ag isotopes [12].

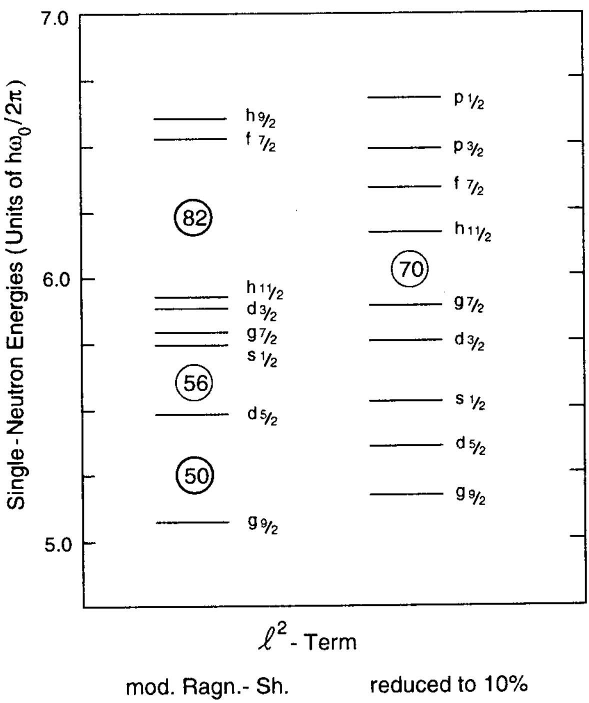

Fig. 1. Single-particle energies for neutrons in a "classical" Nilsson potential (left part) and in a well where the ℓ^2-term (the parameters μ_n) is reduced to one tenth of the standard value.

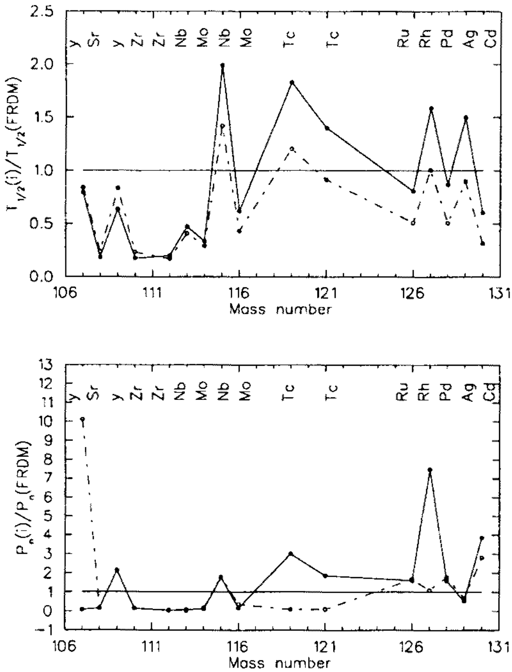

Fig. 2. Ratios of β-decay properties of very neutron-rich nuclei around the magic $N = 82$ gap (upper part $T_{1/2}$, lower part P_n). Values obtained with masses and Nilsson-model wave functions from the FRDM are applied as reference. For these nuclei around the magic $N = 82$ gap, the FRDM masses were replaced by the spherical masses from the HFB. The use of the Nilsson potential with reduced ℓ^2-term leads in most cases to longer half-lives $T_{1/2}$ and higher neutron emission probabilities P_n close to $N = 82$ (filled circles), as compared to those obtained with standard Nilsson potential (open circles).

4. Summary

The nuclear-structure signatures near the neutron drip line, which had been inferred from astrophysical requests [5], are substantiated by the HFB calculations. In the present study we have attempted to analyze the influence of changing shell structure on the β-decay properties of neutron-rich nuclei. By decreasing the magnitude of the ℓ^2-term in the Nilsson single-particle Hamiltonian we have obtained an increase of the half-lives as compared to the results obtained using standard single-particle spectra.

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