Spin-Isospin Resonances and the Neutron Skin of Nuclei

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Charge distributions in nuclei have been measured with extremely high precision since many years and they provide an essential tools for our understanding of atomic nuclei. It is much more difficult to measure the distribution of neutrons. Therefore this quantity is at present in the center of many theoretical and experimental investigations. It places important additional constraints on effective interactions used in nuclear models. Various experimental methods have been used, or suggested, for the determination of this quantity, but no existing measurement of neutron densities or radii has an established accuracy of one percent.

We suggest a new method for determining the difference between the radii of the neutron and proton density distributions along an isotopic chain, based on measurement of the excitation energies of the Gamow-Teller resonances relative to the isobaric analog states.

Collective spin and isospin excitations in atomic nuclei have been the subject of many experimental and theoretical studies. Nucleons with spin up and spin down can oscillate either in phase (spin scalar S=0 mode) or out of phase (spin vector S=1 mode). The spin vector, or spin-flip excitations can be of isoscalar (S=1, T=0) or isovector (S=1, T=1) nature. These collective modes provide direct information on the spin and spin-isospin dependence of the effective nuclear interaction. Especially interesting is the collective spin-isospin oscillation with the excess neutrons coherently changing the direction of their spins and isospins without changing their orbital motion – the Gamow-Teller resonance (GTR) $J^\pi = 1^+$. The simplest charge-exchange excitation mode, however, does not require the spin-flip (i.e. S=0) and corresponds to the well known isobaric analog state (IAS) $J^\pi = 0^+$. The spin-isospin characteristics of the GTR and the IAS are related through the Wigner super multiplet scheme, which implies the degeneracy of the GTR and IAS. The Wigner SU(4) symmetry is, however, broken by the spin-orbit term of the effective nuclear potential.

It is implicit, therefore, that the energy difference between the GTR and the IAS reflects the magnitude of the effective spin-orbit potential. In Ref. [1] the framework of relativistic mean field theory was employed in an analysis of the isospin dependence of the spin-orbit term of the effective single-nucleon potential for light neutron-rich nuclei. It was shown that the magnitude of the spin-orbit potential is considerably reduced in neutron-rich nuclei.

We found a direct connection between the increase of the neutron-skin thickness in neutron-rich nuclei, and the decrease of the energy difference between the GTR and the IAS [2]. The calculation is performed in the framework of the fully self-consistent RHB plus proton-neutron relativistic QRPA model. The RHB model represents a relativistic extension of the Hartree-Fock-Bogoliubov framework, and it provides a unified description of particle-hole (ph) and particle-particle (pp) correlations, that is essential for a quantitative analysis of ground-state properties and multipole response of unstable, weakly-bound nuclei far from the line of β-stability [3].

In Fig. 1 the calculated and experimental energy spacings between the GTR and IAS are plotted as a function of the calculated differences between the rms radii of the neutron and proton density distributions of even-even Sn isotopes. The calculated radii correspond to the RHB NL3+D1S self-consistent ground-state solutions, on which the proton-neutron RQRPA calculations are performed. We notice a remarkable uniform dependence of the energy spacings between the GTR and IAS on the size of the neutron-skin. In principle, therefore, the value of $r_n - r_p$ can be directly determined from the theoretical curve for a given value of $E_{\mathrm{GT}} - E_{\mathrm{IAS}}$. This method is, of course, not completely model independent, but it does not require additional assumptions. Since the neutron-skin thickness is determined in an indirect way from the measurement of the GTR and IAS excitation energies in a sequence of isotopes, in practical applications at least one point on the theoretical curve should be checked against independent data on $r_n - r_p$.

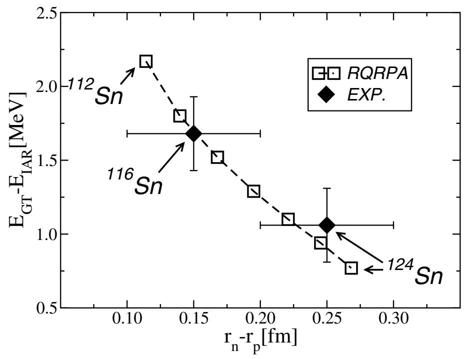

Figure 1: The proton-neutron RQRPA(NL3) differences between the excitation energies of the GTR and IAS as a function of neutron skin in Sn isotopes. Exp. data are from Refs. [4, 5]

References

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