Shape and Structure of N~Z nuclei in A~80 mass region

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Introduction

Nuclei having equal or almost equal number of neutrons and protons (N ~ Z) are of particular interest due to their significance in understanding the proton drip line, the occupation of identical orbits by neutrons and protons and role of iso-scalar and iso-vector pairing. These nuclear phenomenons have vital role to play in the study of nuclear structure in general and astrophysics, weak interaction in particular. The experimental progress in the field has been tremendous and with the use of exotic beams of radioactive ions at GSI, RIKEN, RIA and other such labs, extensive data has been accumulated. Hence, the subject needs a high theoretical focus so as to analyze the accumulated data as well as to guide the future experimental facilities/efforts.

Mathematical Details

In the present work, we have used axially deformed relativistic mean field theory to study the ground state properties (such as binding energies, quadrupole deformations, one/two-nucleon separation energies, root-mean-square (rms) radii of charge and neutron, occupations numbers and shell gaps) and structure of N~Z nuclei from Z=30 to Z=50.

The RMF theory is well established now, and we refer [1] for details, however for sake of completeness, we sketch the mathematical details here, in brief. The basic ingredient is the relativistic Lagrangian density for a nucleon–meson many-body system [1, 2]:

$$\mathcal{L} = \overline{\psi_i}\{i\gamma^\mu\partial_\mu - M\}\psi_i + \frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma - \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi_i}\psi_i\sigma$$
$$-\frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_w^2V^\mu V_\mu + \frac{1}{4}c_3(V_\mu V^\mu)^2 - g_w\overline{\psi}_i\gamma^\mu\psi_i V_\mu - \frac{1}{4}\vec{B}^{\mu\nu}.\vec{B}_{\mu\nu}$$
$$+\frac{1}{2}m_\rho^2\vec{R}^\mu.\vec{R}_\mu - g_\rho\overline{\psi}_i\gamma^\mu\vec{\tau}\psi_i.\vec{R}^\mu - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\overline{\psi}_i\gamma^\mu\frac{(1-\tau_{3i})}{2}\psi_i A_\mu.$$

The field for the σ-meson is denoted by σ, that for the ω-meson by V_μ and for the isovector ρ-meson by R_μ. A_μ denotes the electromagnetic field. The ψ_i are the Dirac spinors for the nucleons whose third component of isospin is denoted by τ_{3i} . Here, g_s, g_w, g_ρ and $e^2/4\pi = 1/137$ are the coupling constants for σ-, ω- and ρ-mesons and photons, respectively. g_2, g_3 and c_3 are the parameters for the nonlinear terms of σ- and ω-mesons. M is the mass of the nucleon and m_σ , m_ω and m_ρ are the masses of the σ-, ω- and ρ-mesons, respectively. $\Omega_{\mu\nu}$, $B_{\mu\nu}$ and $F_{\mu\nu}$ are the field tensors for the V_μ, $R\mu$ and the photon fields, respectively [1]. There exist a number of parameter sets for solving the standard RMF Lagrangians. In this work, we have used the NL–SH, NL3* and PK1 parameter set. These have been successfully used for many other studies in different mass regions, for RMF calculations.

Pairing is a very crucial quantity for open shell nuclei in determining the nuclear properties and in order to take care of the pairing effects in this work, we have used the constant gap for the proton and neutron, as given in [3]: $\Delta_p = RB_s e^{sI-tI2}/Z^{1/3}$ and $\Delta_n = RB_s e^{-sI-t\,2}/A^{1/3}$, with $R = 5.72$, $s = 0.118$, $t = 8.12$, B_s=1 and $I = (N-Z)/(N+Z)$. This type of prescription for pairing effects, both in the RMF and Skyrme-based approaches, has already been used by us and many other authors [4]. For this pairing approach, it is shown that the results for binding energies and quadrupole deformations are almost identical with the predictions of the Relativistic Hartree–Bogoliubov (RHB) approach.

Result and Discussion

The obtained results suggest that all the 3 force parameter set reproduce nuclear masses

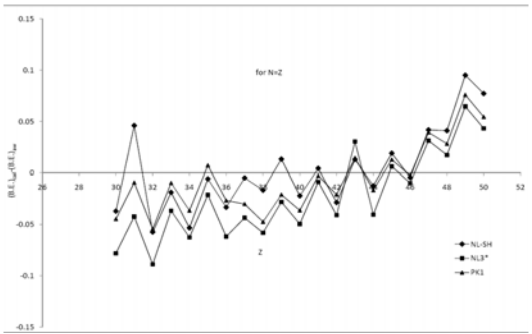

Fig. 1a. Plot for N=Z nuclei for difference in Binding energy (B.E $_{calculated}$ – B.E$_{Audi\ \&\ Wapstra}$).

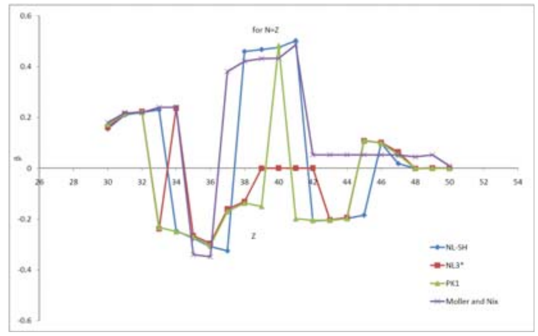

Fig. 2a. Plot for quadrupole deformation for N= Z nuclei.

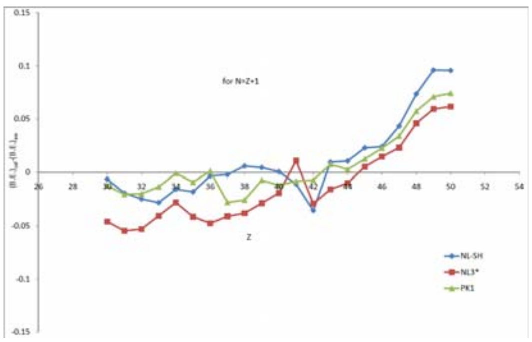

Fig. 1b. Same as Fig. 1a, but for N=Z+1 nuclei.

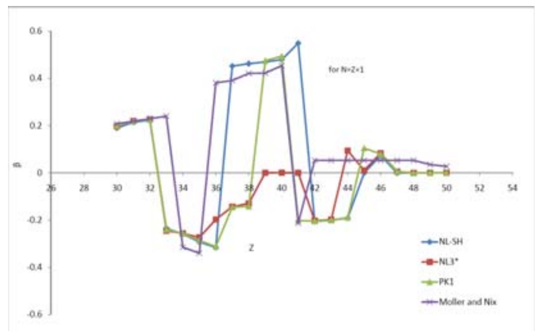

Fig. 2b. Same as Fig. 2a, but for N=Z+1 nuclei.

with reasonable accuracy for all the nuclei under consideration, see Fig. 1. Also, the results are quite similar for nuclear matter radii as well as neutron radii and proton radii. However, the calculated deformation vary quite a bit in the 3 set of calculations (Fig. 2). It is important to note that large deformations can be found in medium-heavy nuclei with N=Z=30-50. The charge and neutron rms radii increase rapidly beyond the magic number N=Z=28 until Z=40 with increasing nucleon number. This observation is consistent with similar other observation made in other RMF study [5], with reasonable accuracy for all the nuclei under consideration.

Conclusion

A number of exciting new results are presented in this paper for N~Z nuclei, which deal with a rapidly developing research field. Further, the detailed analysis with other realistic interactions in Shell Model may provide crucial insight to such study.

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