A systematic study of neutron magic nuclei with $N = 8$, 20, 28, 50, 82, and 126 in the relativistic mean field theory

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"Magic number" is a very important concept in many subjects of physics, such as atomic physics, nuclear physics and micro cluster physics. In nuclear physics, nuclei with magic numbers have been hot topics of nuclear research since the beginning of this subject. In recent experiments with radioactive nuclear beams (RNB), disappearance of traditional magic numbers and appearance of new magic numbers are observed in nuclei with exotic isospin ratios. Furthermore, nuclei with magic neutron numbers in the neutron-rich region are of special interest for the study of astrophysical r-process.

The unusual stability of nuclei with neutron (proton) numbers 2, 8, 20, 28, 50, 82, and 126, commonly referred to as "magic numbers", was traditionally explained in the nonrelativistic shell model approximately by the 3D Harmonic-Oscillator central potential together with a very strong spin-orbit interaction introduced by hand. On the other hand, in the models within the relativistic framework, say the relativistic mean field (RMF) theory, the strong spin-orbit interaction appears naturally as the interplay between the strong scalar and vector potentials, which are necessary for reproducing the saturation properties of nuclear matter. Due to the proper setting of the scalar and the vector potentials the shell structure is obtained without any additional parameters for the spin-orbit splittings. In this paper, we would like to apply the relativistic mean field (RMF) theory to study all the $N = 8, 20, 28, 50, 82$, and 126 isotones from the neutron drip line to the proton drip line [1].

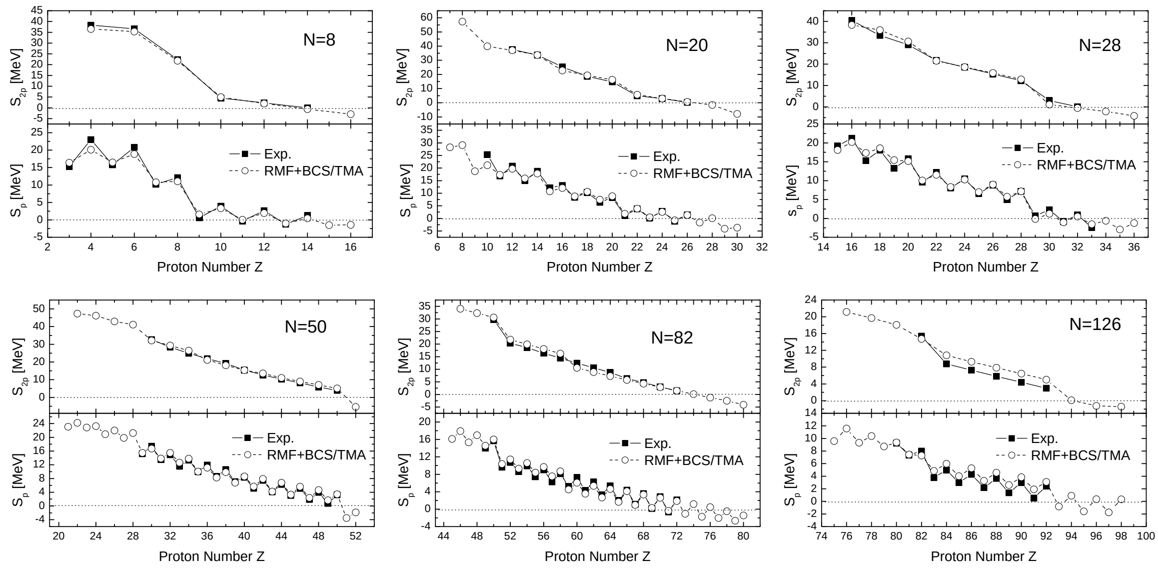

Figure 1: The two- and one-proton separation energies, S_{2p} and S_p, of the $N = 8$, 20, 28, 50, 82, and 126 isotones as a function of the proton number Z. The results obtained from the deformed RMF+BCS calculations with the TMA parameter set (open circle) are compared with available experimental data (solid square) [2].

The two- and one-proton separation energies are very important and sensitive quantities to identify the shell structures, and therefore to study the magicities of the corresponding proton numbers. In Fig. 1, we compare the two- and one-proton separation energies predicted by our RMF+BCS calculations with the experimental data [2]. It is quite clear that the theoretical predictions agree with the experimental data very well from the extremely light region to the heavy region. All traditional proton magic numbers are reproduced quite well. The calculations also show some extra (semi-)magic proton numbers, including $Z = 14$ in the $N = 8$ isotonic chain, and $Z = 58$ in the $N = 82$ isotonic chain.

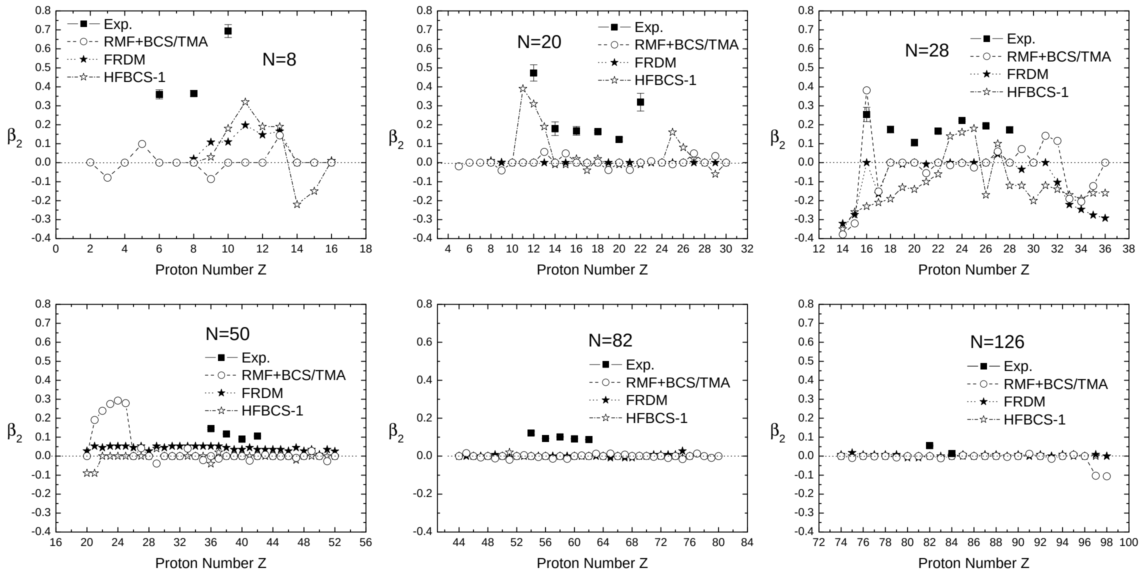

Figure 2: The mass quadrupole deformation parameters, β_2, of the $N = 8$, 20, 28, 50, 82, and 126 isotones as a function of the proton number Z. The results obtained from the deformed RMF+BCS calculations with the TMA parameter set (open circle) are compared with the predictions of the FRDM model (solid star) [3], those of the HFBCS-1 mass formula (open star) [4], and available experimental data (solid square with error bar) extracted from the $B(E2 : 0^+ \to 2^+)$ values [5].

The onset of nuclear deformation is another important signature of the magicity breaking of the corresponding neutron magic number. The predicted nuclear deformation parameter β_2 is plotted in Fig. 2 as a function of proton number Z, in comparison with the predictions of the FRDM [3] and the HFBCS-1 [4] mass formulas, and the empirical data [5]. The comparisons show that while all nuclei in the $N = 82$ and 126 isotonic chains are spherical, some nuclei in the other four isotonic chains are deformed, which indicates the magicity breaking of the corresponding neutron magic number. Further detailed discussions can be found in Ref. [1].

References

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