Spin-orbit interaction near the neutron drip line and shell effects at magic numbers near r-process path

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Relativistic mean-field theory based upon exchange of σ-ω-ρ mesons between nucleons in a relativistically covariant formalism has been successful in describing ground-state properties of nuclei along the line of β-stability and of nuclei far away from the stability line. The intrinsic spin-orbit interaction based upon Dirac-Lorentz covariance has proved to be distinctly advantageous in explaining the kink in isotopic shifts of Pb nuclei across the magic number N=126 as compared to non-relativistic density-dependent Skyrme and Gogny interactions [1]. This reflects a difference in shell effects in the RMF theory vis-à-vis non-relativistic approaches.

Based upon success of the RMF theory in shell effects in nuclei, the spin-orbit interaction in the Skyrme interaction was modified. Relinquishing the exchange component of the spin-orbit force in Skyrme force, the kink in isotope shifts in Pb nuclei could be explained [2]. Recently, experimental measurements on the neutron drip-line nucleus ^{34}Si have pointed towards a proton bubble structure in the interior of the nucleus [3]. The sizeable depleted density (bubble) was explained naturally within the RMF theory. The spin-orbit potential of the RMF theory seems to be greatly responsible for the bubble structure in contrast to the Skyrme interaction. However, a modified form of spin-orbit force in Skyrme functional was shown to facilitate formation of a bubble in nuclei [4].

In this work, we have explored the behavior of the spin-orbit interaction in the RMF theory across the magic numbers close to the r-process path and neutron drip-line. Magic numbers act as waiting-point nuclei in the sequence of r-process nucleosynthesis. In this study, we have employed a scalar-vector Lagrangian model SVI, where nonlinearities of σ and ω mesons have been removed [5], besides the conventional Lagrangian models based upon non-linearity of σ and ω mesons, The Lagrangian model SVI has been shown to predict the masses of the nuclei in the extreme region as compatible to the best mass formulas [6]. It is shown that spin-orbit interaction in the extreme region exhibits its strong shell character as exemplified by kinks in charge and neutron radii vis-à-vis a lack of kinks with Skyrme interactions [7]. This is reminiscent of the strong shell behavior of charge radii and the kink thereof in the experimental data [1]. The strong shell behavior of the spin-orbit interaction is expected to influence the properties of r-process nuclei in the vicinity of the major magic numbers.

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