Structure of unstable nuclei in the sd-pf shell region by shell model with proper tensor force

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The structure of unstable nuclei around $N = 20$ has drawn much theoretical and experimental interest associated with various exotic structures seen there such the disappearance/appearance of the magic number. Based on our extensive shell-model studies with the Monte Carlo shell model (MCSM) calculation [1], we have pointed out that the so-called shell evolution [2] ranging from stable to unstable nuclei plays an important role in the description of the exotic structures. In the case of the $N \sim 20$ region, the shell evolution emerges as the shift of the magic number from $N = 20$ to $N = 16$ dominated by strongly attractive $T = 0$ monopole interaction between $0d_{3/2}$ and $0d_{5/2}$ [1], which can be generalized into any strong $T = 0$ $j_<$-$j_>$ monopole interactions [2].

As for the underlying microscopic origin of the shell evolution, it has been recently argued that the above mentioned property can be accounted for by the tensor force in a quantitative way with the $\pi + \rho$ exchange potential [3]. Since its effect works also between $j_<$ and $j'_>$ orbits with different orbital angular momenta, it motivates us to reconstruct a new effective interaction with high predictive power for the sd-pf shell, particularly for its cross-shell part. Comparing the $T = 0$ tensor part among various interactions, we find that that of the "realistic" GXPF1 interaction [4] for the pf shell is very close to $\pi + \rho$ while that of Millener-Kurath (MK) [5], which is often used as the cross-shell interaction, is much weaker. Together with [3], the shell evolution is expected to be quantitatively described by the shell model with an interaction with tensor force close to $\pi + \rho$. Indeed, we show, for instance, that the proton $0d_{3/2}$-$1s_{1/2}$ shell gap narrowing from $N = 20$ to 28 is well described by such an interaction in a natural way without introducing any arbitrary shift of the monopole interaction. The tensor-induced shell evolution causes a certain narrowing of the proton $1s_{1/2}$-$0d_{5/2}$ shell gap at the same time, having large influence on the structure of ^{42}Si which has recently attracted attention in the context of the possibility of a new magic nucleus [6]. In the present shell-model calculation, the ^{42}Si nucleus is predicted to be no magic nucleus but to contain large deformed wave component driven by that effect, contrary to shell-model predictions with the MK interaction and [7].

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