High-order effects on the incompressibility of isospin asymmetric nuclear matter

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We have derived the analytical expressions for the saturation density as well as the binding energy and incompressibility at the saturation density of asymmetric nuclear matter exactly up to 4th-order in the isospin asymmetry $\delta=(\rho_n-\rho_p)/(\rho_n+\rho_p)$ using 11 characteristic parameters defined at the normal nuclear density $\rho_0$ by the density derivatives of the binding energy per nucleon of symmetric nuclear matter, the symmetry energy $E_{\text{sym}}(\rho)$ and the 4th-order symmetry energy $E_{\text{sym,4}}(\rho)$ [1]. Using an isospin- and momentum-dependent modified Gogny (MDI) interaction and the Skyrme-Hartree-Fock (SHF) approach with 63 popular Skyrme interactions, we have systematically studied the isospin dependence of the saturation properties of asymmetric nuclear matter, particularly the incompressibility $K_{\text{sat}}(\delta)=K_0+K_{\text{sat},2}\delta^2+K_{\text{sat},4}\delta^4+O(\delta^6)$ at the saturation density. Our results show that the magnitude of the high-order $K_{\text{sat},4}$ parameter is generally small compared to that of the $K_{\text{sat},2}$ parameter. The latter essentially characterizes the isospin dependence of the incompressibility of asymmetry nuclear matter at the saturation density and can be expressed as $K_{\text{sat},2}=K_{\text{sym}}-6L-(J_0/K_0)L$, where $L$ and $K_{\text{sym}}$ represent, respectively, the slope and curvature parameters of the symmetry energy at $\rho_0$ while $J_0$ is the third-order derivative parameter of symmetric nuclear matter at $\rho_0$. Furthermore, we have constructed a phenomenological modified Skyrme-like (MSL) model which can reasonably describe the general properties of symmetric nuclear matter and the symmetry energy predicted by both the MDI model and the SHF approach. The results indicate that the high-order $J_0$ contribution to $K_{\text{sat},2}$ generally cannot be neglected. In addition, it is found that there exists a nicely linear correlation between $K_{\text{sym}}$ and $L$ as well as between $J_0/K_0$ and $K_0$. These correlations together with the empirical constraints on $K_0$, $L$, $E_{\text{sym}}(\rho_0)$ and the nucleon effective mass lead to an estimated value of $K_{\text{sat},2} = -370 \pm 120$ MeV.