RMF model based Investigation of Two Neutron Separation Energies for Middle Weight Nuclides near Drip Lines

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Introduction

The production of more and more new isotopes has revived the interest in nuclear structure models in recent years. Understanding the structure of the atomic nucleus is one of the central challenges in nuclear physics. The study of nuclei lying far from the line of β-stability play an important role in our understanding of nuclear physics. Far away from stability line, the limits of nuclear existence are reached, where one or more nucleons are no longer bound. Near nuclear driplines, the physics is very interesting and has fascinated the researchers to work on it. The purpose of present work to investigate theoretically the two neutron separation energy (S_{2n}) which reflects the magicity of Shell Structure in the isotopic chains of Germanium, Selenium, Strontium and Krypton. Our results are complimented by the close agreement with the recent available experimental data [4].

Theoretical Framework

We have employed relativistic self-consistent mean field models to construct the Nuclear Density Functionals from Lagrangian densities based on mesons exchange and point coupling models. The pairing correlations of nucleons are considered by the relativistic Hartree-Bogoliubov functional based on quasi-particle operators of Bogoliubov transformations. The nuclear energy density functionals are constructed by using meson coupling model with DD-ME2 parameterizations [1] and point coupling model with DD-PC1 parameterizations [2] with a separable pairing interaction parameter, G = 728 MeVfm^3 and pairing width, a = 0.644 fm in the p-p channel. The Lagrangian density for mesons exchange approximation is given as [1],

$$\begin{aligned}
\mathcal{L} \;=\; & \sum_i \overline{\psi}_i (i\gamma_\mu \partial^\mu - m)\psi_i + \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma - \frac{1}{2} m_\sigma^2 \sigma^2 \\
& - \frac{1}{2}\Omega_{\mu\nu}\Omega^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu - \frac{1}{4}\vec{R}_{\mu\nu}\vec{R}^{\mu\nu} + \frac{1}{2} m_\rho^2 \vec{\rho}_\mu . \vec{\rho}^\mu \\
& - \frac{1}{4} F_{\mu\nu}F^{\mu\nu} - g_\sigma \overline{\psi}\psi\sigma - g_\omega \overline{\psi}\gamma^\mu \psi \omega_\mu - g_\rho \overline{\psi}\vec{\tau}\gamma^\mu \psi . \vec{\rho}_\mu \\
& - e\overline{\psi}\gamma^\mu \psi A_\mu . \qquad (1)
\end{aligned}$$

And the total Lagrangian density for point-coupling models is [2],

$$\begin{aligned}
\mathcal{L} \;=\; & \overline{\psi}(i\gamma.\partial - m)\psi - \frac{1}{2}\alpha_S(\rho)(\overline{\psi}\psi)(\overline{\psi}\psi) \\
& - \frac{1}{2}\alpha_V(\rho)(\overline{\psi}\gamma^\mu\psi)(\overline{\psi}\gamma_\mu\psi) - \frac{1}{2}\alpha_{TV}(\rho)(\overline{\psi}\vec{\tau}\gamma^\mu\psi)(\overline{\psi}\vec{\tau}\gamma_\mu\psi) \\
& - \frac{1}{2}\delta_S(\partial_\nu\overline{\psi}\psi)(\partial^\nu\overline{\psi}\psi) - e\overline{\psi}\gamma.A\frac{1-\tau_3}{2}\psi . \qquad (2)
\end{aligned}$$

The Hamiltonian densities can be calculated from Eqs.(1,2) and hence the nuclear energy density functional for DD-ME2, DD-PC1 respectively.

Results and Discussions

The two neutron separation energy is defined as the energy required to remove two neutrons from a nucleus. The two neutron separation energy is calculated using the formula,

$$S_{2n}(Z,N) = [B(Z,N) - B(Z,N-2)], \qquad (3)$$

where S$_{2n}$(Z,N) defines the two neutron separation energy for the nuclei with atomic number Z and neutron number N. We have theoretically calculated S$_{2n}$(Z,N) results for even-even isotopes of Ge, Se, Kr and Sr with the

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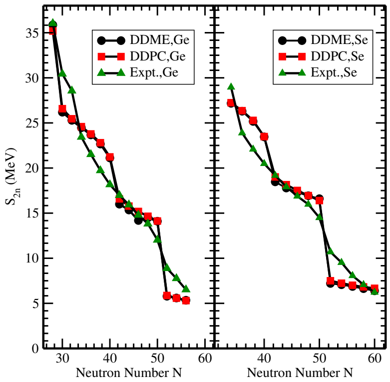

FIG. 1: (color online) Variation in experimental and theoretical two neutron separation energy (S_{2n}) in MeV plotted as a function of neutron number N, for the exotic nuclei of Germanium and Selenium. Experimental Data is taken from [4]

help of binding energies B(Z,N) and B(Z,N-2), and then compared these theoretical results with the experimental data [4]. In the Fig.(1), we compared the theoretical and experimental results for two neutron separation energy S_{2n}(Z,N) as a function of neutron number N for the isotopes of Germanium left panel and Selenium right panel. In left panel of Fig.(1), we observed a significant drop in S_{2n}(Z,N) values at ${}^{60}_{32}$Ge, ${}^{72}_{32}$Ge of about 5 MeV and ${}^{82}_{32}$Ge of about 10 MeV illustrating the N = 28, 40 and 50 shell effect respectively in isotopes of Germanium. In right panel of Fig.(1) for the isotopes of Selenium, we observed three such declines at ${}^{74}_{34}$Se of about 5 MeV and ${}^{84}_{34}$Se of about 10 MeV to representing N = 40 and N = 50 shell gaps. In Fig. (2), we present the results for S_{2n}(Z,N) for isotopes of Krypton in left panel and Strontium in right panel. In left panel of Fig.(2), we observed an abrupt decrease in S_{2n}(Z,N) at ${}^{76}_{36}$Kr of about 5 MeV and ${}^{82}_{36}$Kr of about 10 MeV illustrating the N = 40 and N = 50 shell effect respectively in isotopes of Krypton. However in case of Strontium also N = 40 and 50 shell structure effects are observed at ${}^{74}_{38}$Sr (of about 5 MeV) and ${}^{84}_{38}$Sr (of about 10 MeV) respectively. These abrupt decrease in S_{2n}(Z,N) values in Figs.(1 and 2) indicate that the energy necessary to remove two neutrons from (Z, N + 2) nucleus is much smaller than the energy required to remove two neutrons from (Z, N) nucleus, where N are the number of neutrons at nuclear magic numbers. Our theoretical results confirm the presence of N = 28, 40 and 50 sub-shell gap in Ge isotopes. Also the confirmation of N = 40 and 50 sub-shell gap in Se, Kr and Sr nuclei.

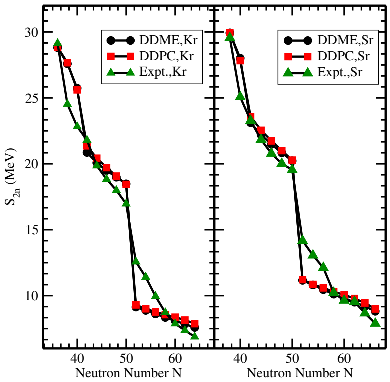

FIG. 2: (color online) Variation in experimental and theoretical two neutron separation energy (S_{2n}) in MeV plotted as a function of neutron number N, for the exotic nuclei of Krypton and Strontium. Experimental data is taken from [4]

References

[1] G. A. Lalazissis, T. Nikšić, D. Vretenar and P. Ring, Phys. Rev. C **71** 024312 (2005).

[2] T. Nikšić, D. Vretenar and P. Ring, Phys. Rev. C **78** 034318 (2008).

[3] T. Nikžić, P. Ring, D. Vretenar, Y. Tian and Z. Y. Ma, Phys. Rev. C **81** 054318 (2010).

[4] W.J. Huang, G. Audi, Meng Wang, F.G. Kondev, S. Naimi and Xing Xu, Chinese Physics C **41** 030002 (2017).