Study of ground-state properties of neutron-rich Magnesium isotopes within covariant density functional theory

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Introduction

The covariant density functional theory (CDFT) is regarded as universal theory to study the structural properties of nuclei of the whole nuclear chart. These properties play a vital role in describing nuclear structure both experimentally as well as theoretically. Nakada et al. [1] studied the matter radii of $^{34\text{-}40}$Mg by employing semi-realistic interaction in axially-symmetric Hartree Fock Bogoliubov calculations and reproduced the neutron dependence of radii . Recently, the first spectroscopic study of ^{40}Mg is performed by Crawford et al. [2]. In their paper, they experimentally found two peaks at two different energies which they term as the energies of first and second excited states of ^{40}Mg. A careful study of nuclei in this region is of great interest as this region is connected to loss of magicity in these nuclei [3]. In this paper, by using density dependent point coupling (DD-PC1) interaction in the CDFT, ground state bulk properties like binding energy, root mean square radii, charge radii, two neutron separation energies and energies of first excited (2^+) states of $^{36\text{-}42}$Mg are studied and compared with the available experimental data [4].

Theoretical framework

In the present work, axially symmetric relativistic Hartree-Bogoliubov model (RHB) with DD-PC1 interaction is employed to study the deformation and ground state properties of the neutron rich even-even $^{36\text{-}42}$Mg isotopes. For the details of formalism see refs. [5,6]. The potential energy surface calculations are made by using RHB model for the energy as a function of quadrupole deformation parameter (β_2), by preserving axial symmetry. The β_2 is defined as

$$\beta_2 = \sqrt{\frac{4\pi}{5}}\frac{Q_{20}}{A\langle r^2\rangle}$$

where $\langle r^2\rangle$ is mean square radius and $Q_{20} = \langle Z^2 - \frac{1}{2}(x^2+y^2)\rangle$ is quadrupole moment. Both are computed by using HFB wavefunctions.

The charge radius is obtained by using

$$r_c = \sqrt{r_p^2 + 0.64} \text{ (fm)}$$

where, r_p is root mean square proton radius and factor 0.64 is correction due to finite size of the proton.

Results and discussion

In Fig. 1, potential energy curves (PECs) for neutron-rich $^{36\text{-}42}$Mg isotopes are displayed. The PECs show the variation of the binding energy (MeV) with quadrupole deformation parameter (β_2), obtained by preserving axial symmetry in self-consistent RHB calculations and with the inclusion of DD-PC1 effective interaction. The β_2 values obtained from these PECs give an evidence about the prolate shape in neutron-rich even-even $^{36\text{-}42}$Mg isotopes. As $\beta_2 > 0$ corresponds to prolate shape and $\beta_2 < 0$ corresponds to oblate shape. The values obtained for the β_2 from PECs for $^{36\text{-}42}$Mg isotopes are presented in table 1. From the values presented in table 1, one finds that a well-deformed prolate minimum is observed in $^{36\text{-}42}$Mg isotopes. Besides this, the PECs, indicate second minimum on the oblate side, in all these isotopes. The presence of second minimum, predicts the phenomenon of shape coexistence in neutron-rich magnesium isotopes.

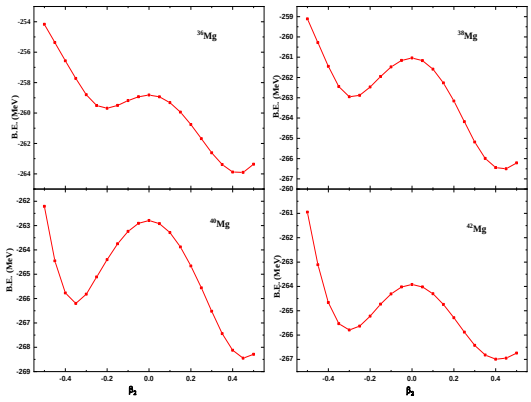

Fig.1 Potential energy curves of $^{36\text{-}42}$Mg isotopes as a function of quadrupole deformation parameter (β_2).

Table 1: Ground state properties of $^{36\text{-}42}$Mg calculated by DD-PC1 interaction.

A	Binding energy per nucleon (B.E./A) [MeV]		β_2	Root mean square radii [fm]		Charge Radii (R_c) [fm]
	Th.	Exp.		Th.	Exp.	
36	7.333	7.240	0.430	3.43	3.49	3.236
38	7.015	6.928	0.450	3.53	3.60	3.264
40	6.713	6.628	0.462	3.62		3.294
42	6.357		0.424	3.71		3.317

Table 2: Comparison of calculated first excited 2^+ energy ($E(2_1^+)$) with experimental data in $^{36\text{-}42}$Mg isotopes.

Mass Number (A)		36	38	40	42
$E(2_1^+)$ [KeV]	Th.	753.76	617.71	528.90	569.57
	Exp	662(6)	656(6)	500(14)	

In table 1, the calculated binding energies and root mean square radii for $^{36\text{-}42}$Mg isotopes are compared with the available experimental data [4]. The calculated results show good agreement with the available experimental data. The binding energy value for ^{42}Mg is predicted. Besides, the charge radii are also predicted for $^{36\text{-}42}$Mg. In table 2, the energies of first excited 2^+ state of $^{36\text{-}42}$Mg are obtained from the β_2 by using empirical relation [7] and compared with experimental data [2,8]. The calculated values of 2^+ energy reproduces the experimental data. The excitation energies of these isotopes will be studied by angular momentum projection techniques in future.

Two-neutron separation energies (S_{2n}) as a function of mass number (A) are displayed in fig. 2. The two neutron separation energies are calculated by the relation

$$S_{2n} = E(Z,N) - E(Z,N-2).$$

As the mass number increases the S_{2n} energy decreases and it is minimum at A=42. The calculated results are compared with the theoretical results and experimentally available data [4]. From fig. 2, one can conclude that the calculated results with DD-PC1 parameter set are in better agreement with the available experimental data.

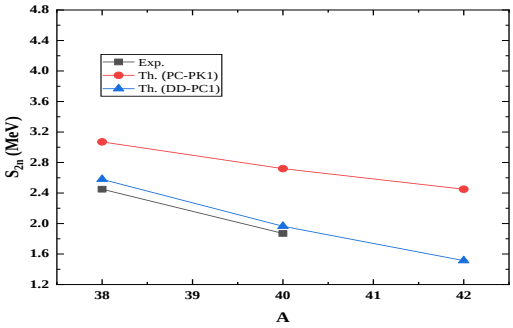

Fig.2 Comparison of experimental (Exp.) and calculated (Th.) S_{2n}.

References

[1] H. Nakada *et al.*, Phys. Rev. C**98**, 011301 (2018).
[2] H.L. Crawford *et al.*, Phys. Rev. lett.**122**, 052501 (2019).
[3] Y. Suzuki *et al.*, Phys. Rev. C**94**, 024343 (2016).
[4] M. Wang *et al.*, Chin. Phys. C**41**, 030003 (2017).
[5] T. Niksic *et al.*, Phys. Rev. C**78**, 034318 (2008).
[6] P.W. Zhao *et al.*, Phys. Rev. C**82**, 054319 (2010).
[7] S. Raman *et al.*, At. Data Nucl. Data Tables **78**, 1 (2001).
[8] P. Doornenbal *et al.*, Phys. Rev. lett. **111**, 212502 (2003).