The clustering in Magnesium isotopes

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Introduction

The internal configuration or structure of a nucleus plays an important role on the stability, which is connected to their radioactivity. In 1984, the cluster radioactivity was discovered [1] and the consequent excitement led to several experiments at different places all over the world. The confirmed identification of nuclear clustering motivate us to answer few questions such as: (i) are they initially present inside the parent nucleus (ii) how they look like and (iii) what are the constituent of these clusters. There are several techniques existed in literature to understand the clustering structure of the nuclear system. Here, we have used RMF theory with the recently developed *NL3** [2] and *NL075* [3] parameter sets to study the clustering phenomena. The present work directed to a particular case for Mg isotopes is taken up to examine the preformed clusters and their constituents.

The RMF theory is applied successfully to study the structural properties of nuclei throughout the nuclear landscape [4, 5] starting from proton to neutron drip-lines. A well documentation of this theory is given in Refs. [4, 5]. From the Lagrangian, we obtained the field equations for the nucleons and mesons. These equations are solved by expanding the upper and lower components of the Dirac spinors and the boson fields in an axially deformed harmonic oscillator basis with an initial deformation β_0. The set of non-linear coupled equations is solved numerically by a self-consistent iteration method [4, 5]. The center-of-mass motion energy correction is estimated by the usual harmonic oscillator formula $E_{c.m.} = \frac{3}{4}(41A^{-1/3})$. The quadrupole deformation parameter β_2, the root mean square (rms) matter radius, the total binding energy and other observables are also obtained by using the standard relations, given in [4, 5]. To deal with the open shell nuclei, we have adopted BCS-pairing method in a constant gap approximation [4].

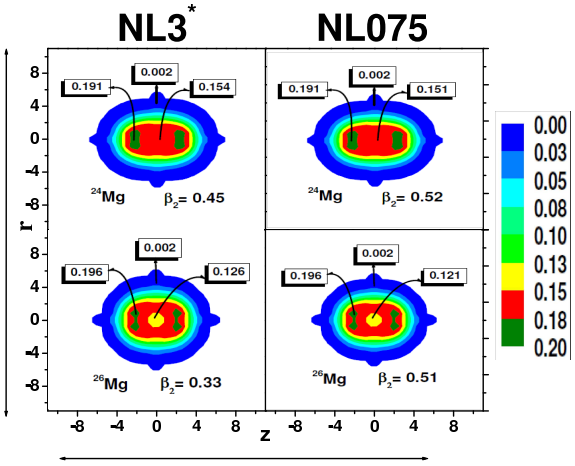

FIG. 1: The internal sub-structure of ^{24,26}Mg in the ground state configuration.

Calculations and Discussions

We have carried out the numerical solutions using maximum oscillator quanta $N_F = N_B = 10$ for Fermion and boson. The number of mesh points for Gauss-Hermite and Gauss-Lagurre integration are 20 and 24, respectively. For a given nucleus, the maximum binding energy corresponds to the ground state and other solutions are obtained at various excited intrinsic states. In our calculations, we obtained different nucleonic potentials, densities, single-particle energy levels, root-mean-square (rms) radii, deforma-

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TABLE I: The RMF (NL3* and NL075) results for binding energy, β_2, and r_{ch} for Mg-isotopes are compared with the experimental data. .

Nucleus	RMF (NL3*)			RMF (NL075)			Experiment		
	BE	β_2	r_{ch}	BE	β_2	r_{ch}	BE	β_2	r_{ch}
^{24}Mg	193.5	0.45	3.125	190.1	0.52	3.210	198.2 (0.0002)	0.60 (0.008)	3.057 (0.002)
^{26}Mg	212.5	0.33	3.061	209.9	0.51	3.185	215.1 (0.0003)	0.48 (0.010)	3.033 (0.002)
^{28}Mg	228.1	0.26	3.061	224.7	0.40	3.159	231.6 (0.002)	0.49 (0.035)	
^{30}Mg	240.5	0.56	3.072	236.8	0.23	3.110	241.1 (0.008)	0.43 (0.019)	

tions and binding energies. These observables explain the structure and sub-structure for a nucleus in a given state. The calculated bulk properties like binding energy (BE), nuclear charge radii (r_{ch}) and the quadrupole deformation parameter (β_2) for the ground state of $^{20-34}$Mg from NL3* and NL075 are compared with the experimental data [4] are given in Table 1.

The internal structure of a nucleus depends on the density distributions of the proton, neutron and matter for a given state. Here, the densities are obtained from RMF in the positive quadrant of the plane parallel to the symmetry $z-$axis. These are evaluated in the ρz plane. The complete picture of a nucleus in the ρz plane can be obtained by reflecting the first quadrant to other quadrants. The contour plotting of density along with the color code for the ground state of $^{24-26}$Mg are shown in Fig. 1. From the color code, one can identify the clustering structures in Mg nuclei. For example, the color code with deep green corresponds to maximum density $\rho \sim 0.18\ fm^{-3}$ and the deep blue bearing the minimum value of $\rho \sim 0.001\ fm^{-3}$. A careful inspection of the figures show the formation of various clusters inside the nuclei. This region has a very high probability of preformation and decaying from its interior. Again, the constituents inside the cluster is estimated by using the simple formula [4]:

$$n = \int_{z_1}^{z_2} \int_{r_1}^{r_2} \rho(z, r_\perp) d\tau, \qquad (1)$$

where, n is the number of neutrons N or protons Z or mass A and z (z_1, z_2), $r_\perp$ (r_1 , r_2) are the ranges are taken from the counter plot. From the obtained clusters for ground state of Mg-isotopes, we found ^{16}O as a central core surrounded by clouds of neutrons which can be obtained from Ref. [4].

Summary and Conclusions

We have presented the gross nuclear properties like binding energy, deformation parameter β_2, charge radii r_{ch} and the nucleonic density distributions for the isotopic chain $^{20-34}$Mg using an axially deformed relativistic mean field formalism with $NL3^*$ and $NL075$ parameter sets. We found deformed prolate ground states solution for Mg isotopes, which are consistent with the experimental data. Analyzing the nuclear density distributions, the clusters of Mg isotopes are identified. We found sub-structure like ^{16}O or $4{\cdot}\alpha$ condensate types along with few more neutrons inside Mg isotopes. It is interesting to see these evaporation residues like ^{16}O and ^{4}He for Mg-isotopes in laboratory.

The author thanks to Dr. S. K. Patra for fruitful discussion as well as careful reading of the manuscript.

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