A relativistic self-consistent mean-field framework for Sm isotopes

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Introduction

Atomic nuclei among the finite many body systems are the prime examples for deformed quantum systems. Dynamical symmetries related to atomic nuclei provide elegant and analytic frame of reference to understand their behaviour.Most nuclei, however, do not actually remain within the stable limits of structure but rather are in shape transition region where their dynamical symmetries breaks around the critical point to a deformed shape as the number of valence nucleons increases. The investigation of shape fluctuations and critical point behaviour in transitional nuclei as a function of nucleon number is one of the most exciting hot topics in the present nuclear structure physics[1], though the concept of phase transition is only approximate for finite systems. Interpretation of evolution of the structure of such nuclei in the phase transition region has traditionally been the most difficult task since they exhibit a complicated interplay of competing degrees of freedom. Particularly it is more challenging to understand and predict the properties of such nuclei at the critical point of a phase transition where structure is changing most dramatically. But understanding such nuclei, in many respect, is very important, as their structure defines the nature of the transition region itself.

The present paper aims for a better and systematic understanding of the phase transitional region and critical point concept in transitional nuclei using the microscopic and self-consistent relativistic mean-field models, which will show that $^{144-158}$Sm are excellent empirical manifestation of the critical point structure concept. Even-Even Samarium (Sm) isotopes have been the focal point of large number of experimental studies in the past. The study of Samarium nuclei has been a challenging theoretical problem too, since they lie in the range from near spherical to well deformed shapes. ^{148}Sm is believed to be basically spherical while ^{154}Sm is thought to be well deformed nucleus and $^{150-152}$Sm are transitional nuclei.

Method of the calculations and Discussions

In our present work, ground state properties of the neutron rich even-even $^{144-158}$Sm nuclei (Z=62) are studied using the new improved self-consistent relativistic mean-field models, namely, a constrained relativistic mean-field (RMF) model[2] using the nonlinear meson-nucleon interaction (NL3*) with BCS pairing, and the covariant density functional models[3]: the density- dependent meson-exchange model (DD-ME), and a density dependent point-coupling model (DD-PC). These calculations are done in axially symmetric configuration. Treatment of the pairing correlations have been taken care of as given in Refs.[2, 3] for respective models.

The binding energy for the ground state are listed in Table I. For the binding energy the data is well reproduced within 0.2%.Particularly, excellent agreement (within 1 MeV) is obtained for binding energy in $^{146-158}Sm$ with DD-ME1, DD-PC1 and NL3* except in case of DD-ME2, where it is 0.2%.Even for neutron magic nuclei ^{144}Sm , the difference between the calculated results and the experimental data[4]is less than 3 MeV, i.e., less than 0.3% relatively.

We have presented the quadrouple deforma-

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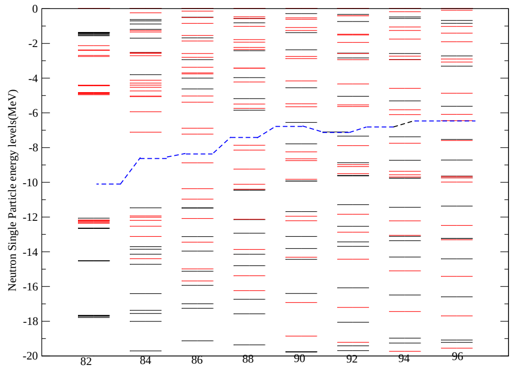

FIG. 1: Neutron Single Particle Energy Levels

tion parameter(β_2) of Sm isotopes in Table II.Our calculated results are compared with FRDM and Experimental results.The spherical shapes in ^{144,146}Sm and the weakly deformed ^{148}Sm are well reproduced. The deformations in $^{150-154}Sm$ show good agreement with available experimental data[5]. Noticeably, the quadrupole deformation values for higher mass nuclei show an almost constant nature in the case of different model calculations.

In Fig.1,we plot the single neutron levels for $^{144-164}Sm$ using DD-ME2 interaction.Other interactions give similar structure are not presented here.Both Even and odd parity levels have been shown by black and red colors, respectively. The Fermi level are presented here by dashed line.One can figure out the shape transition behaviour in Sm isotopes. Here,^{144}Sm shows spherical symmetry with large single-neutron gap in neutron Fermi surface. The deformation in ^{146}Sm is still small and the energy gap can be clearly seen from the single-particle spectra. The critical-point nuclei $^{148-152}Sm$ belongs to a transition area in which the energy gap still exist but are much smaller than that in $^{144,146}Sm$.In general, we can say that the Fermi level slowly increases. A good deformation seems to be reached at A=148 or A=150 with a rather constant level density, from that moment the Fermi levels stays roughly constant up to ^{158}Sm. These characteristics in microscopic shell structure can be viewed as the signature of the critical-point symmetry. Other numerical results calculated will be presented.

TABLE I: The Total Binding Energy.

E(MeV)	EXP[4]	DD-ME1	DD-ME2	DD-PC1	NL3*
^{144}Sm	1195.74	1198.79	1197.30	1198.70	1199.05
^{146}Sm	1210.91	1210.99	1209.47	1210.79	1212.17
^{148}Sm	1225.40	1224.79	1223.34	1224.72	1225.75
^{150}Sm	1239.25	1239.01	1237.67	1239.23	1239.57
^{152}Sm	1253.11	1252.55	1251.55	1253.37	1253.70
^{154}Sm	1266.94	1266.13	1265.42	1267.46	1267.59
^{156}Sm	1279.99	1278.42	1277.64	1280.16	1279.98
^{158}Sm	1291.98	1290.11	1289.40	1292.37	1291.65

TABLE II: The quadrouple deformation parameter (β_2).

β_2	EXP[5]	DD-ME1	DD-ME2	DD-PC1	NL3*
^{144}Sm	0.09	-0.00	-0.00	-0.00	-0.00
^{146}Sm	-	-0.08	-0.08	-0.07	0.00
^{148}Sm	0.14	0.15	0.15	0.16	0.13
^{150}Sm	0.19	0.21	0.22	0.22	0.20
^{152}Sm	0.31	0.29	0.29	0.29	0.28
^{154}Sm	0.34	0.33	0.33	0.33	0.32
^{156}Sm	-	0.33	0.33	0.33	0.34
^{158}Sm	-	0.34	0.34	0.34	0.35

References

[1] J. M. Arias, Phys. Rev. C **63**, 034308 (2001).
[2] B.D.Serot and J.D.Walecka, Adv.Nucl.Phys.**16**,1(1986).
[3] T.Niksic*et al.*,Comp.Phys.Comm.**185**,1808(2014).
[4] G. Audi*et al.*, Nucl. Phys. A **624**, 1(1997).
[5] S. Raman *et al.*, At. Data Nucl. Data Tables **78**, 1(2001).