Evidence of shell structures in the isotopic chain of Th-element

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Introduction:

Nuclear physics makes a reliable prediction about the ground state properties of all the nuclei with the help of several theoretical models which are later classified into three categories. The first one is, Macroscopic model based on Bethe-Weizscker mass formula, the second is, the Macro-Microscopic model such as the Finite Range Droplet model (FRDM), and finally the Microscopic model Hartree-Fock method. The study of ground state properties is one of the fundamental requirements in theoretical nuclear physics. As the nucleons, mesons, and their interactions through spin play important contributions in mean field theory we use here relativistic mean model (RMF) to calculate the masses of Th nuclei. Again, the limits of the nuclear mass and charge in the valley of heavy nuclei are still unexplored. Recent theoretical and experimental studies on exotic nuclei with unbalanced *Z* and *N* cast challenge these expected thoughts in the nuclear chart. As we know the shell effect can stabilize this instability giving rise to a new magic number and shell or sub-shell closures in the vicinity of neutron drip-line motivated us to study the structural properties of Th-isotopes.
Recent theoretical and experimental work has confirmed the existence of different shell structures in the neutron deficient Th-isotopes around the mass region A= 218-228 [1-5].

Theory Formalism:

The relativistic Lagrangian density is given as:

$$\mathcal{L} = \overline{\psi_i}\,(i\gamma^{\mu}\partial_{\mu} - M)\psi_i + \frac{1}{2}\partial^{\mu}\sigma\partial_{\mu} - \frac{1}{2}m_{\sigma}^{2}\sigma^{2} - \frac{1}{3}g_2\sigma^3 - \frac{1}{4}g_3\sigma^4 - g_s\overline{\psi_i}\,\psi_i\,\sigma - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_{\omega}^{2}V^{\mu}V_{\mu} + \frac{1}{4}c_3\left(V^{\mu}V_{\mu}\right)^2 - g_{\omega}\overline{\psi_i}\,\gamma^{\mu}\,\psi_i\,V_{\mu} - \frac{1}{4}\overrightarrow{B^{\mu\nu}}.\overrightarrow{B_{\mu\nu}} + \frac{1}{2}m_{\rho}^{2}\overrightarrow{R^{\mu}}.\overrightarrow{R_{\mu}} - g_{\rho}\overline{\psi_i}\,\gamma^{\mu}\vec{\tau}\,\psi_i.\overrightarrow{R^{\mu}} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} - e\,\overline{\psi_i}\,\gamma^{\mu}\frac{(1-\tau_{3i})}{2}\psi_i\,A_{\mu} \quad\text{......................(1)}$$

All the quantities have their usual well-known meanings. From the above Lagrangian, we obtained the field equations for 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 factor β_0 . The set of coupled equations is solved numerically by self-consistent iteration method. We use well-known NL3* and NL-SH parameter sets[4-8]. The static solutions of the field equations give us the ground state properties such as the binding energies (B.E), nuclear radii, etc. Using the B.E. values we obtain the following quantities [8].

$$S_{2n}(N,Z) = B.E(N,Z) - B.E(N-2,Z) \quad\text{...........(2)}$$

$$dS_{2n}(N,Z) = \frac{S_{2n}(N+2,Z) - S_{2n}(N,Z)}{2} \quad\text{...............(3)}$$

Results and Discussion:

We have studied the ground state properties like binding energy (B.E.), two-neutron separation energies(S_{2n}) and differential variation of two neutron separation energies (dS_{2n}), and other bulk properties using RMF-formalism with NL3* and NL-SH force parameter set for the isotopic chain of Z=90. The results that we obtained are compared with the Finite Range Droplet Model (FRDM) [9] and are shown in Fig-1, 2, and 3. From the Fig-1, it shows that the B.E./A increases with the increase of neutron number and reaches a peak value at N~126 (A=216, Z=90) and decreases gradually towards the higher mass region. This gives that ${}^{216}_{90}Z$ is the most stable element from binding energy analysis. All the parameter sets i.e NL3* and NL-SH shows well agreed with FRDM results.

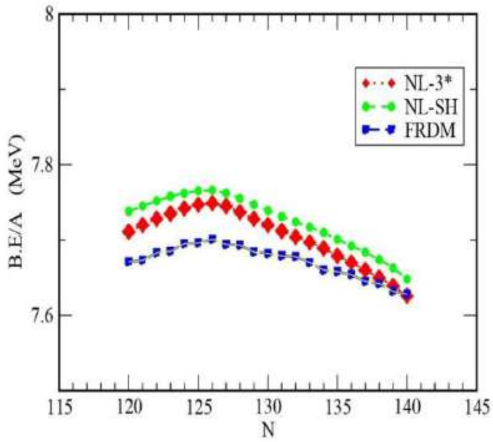

Fig.1 (color line) The binding energy per particle(B.E/A) calculated with NL3* (Red line with diamond) and NL-SH (Green line with circles) are compared with FRDM [9] (Blue line squares) values for Th-isotopes.

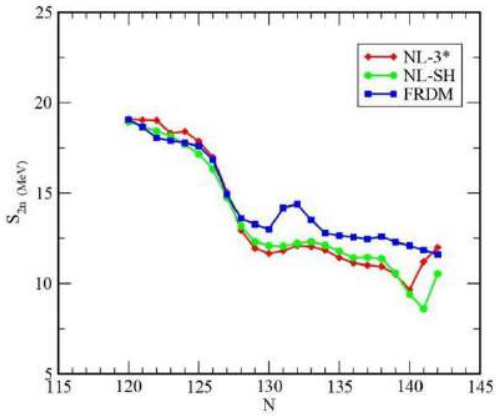

Fig.2 The two neutron separation energy S_{2n} ~ N with NL-3*(diamond) NL-SH (circles) sets are compared with FRDM [9] (squares) for the isotopic chain of Z=90.

The differential variation of the two neutron separation energy (dS_{2n}) clearly shows a drop at N=126 which shows the major shell closure at N=126 and the applicability of RMF theory. In addition to this, dS_{2n} shows non-linear behavior at N=134/138. It may convey a possible shell or sub-shell closure.

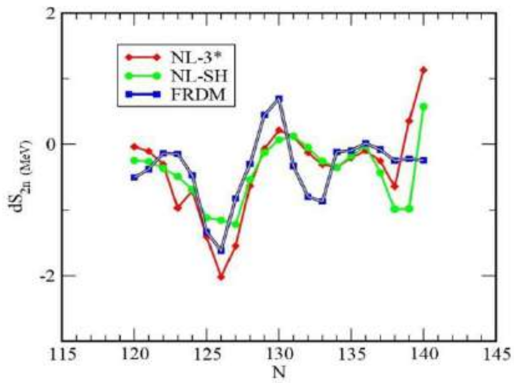

Fig.3 The calculated differential variation of two-neutron separation energy (dS_{2n})with NL3* (diamond), NL-SH (circles) compared with FRDM [9] (squares) for the isotopes of Z=90.

These results are well supported by $\Delta^{(3)}_{1n} r_{ch}$ ΔE providing a good contribution to the structural properties of Th-isotopes.

Conclusion:

From the present study of Th-isotopes, it is found that $^{216}_{90}Z$ is the most stable element with N=126. We also estimated the two neutron separation energy S_{2n} and its differential variation (dS_{2n}) which shows a possible major shell closure at N=126, 134, and 138.

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