Probing the Shell Structures of $^{250\text{-}339}Hs_{108}$ Isotopes

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Introduction

The experimental synthesis of super heavy elements (SHE) [1] provides the fuel to the theoretical nuclear physicist for a detailed investigation of the stability and structural properties of SHEs. The closed nucleon shells provide a major contribution to the stability of a nucleus. Especially in the super heavy region, the shell effects play a very important role both in their formation and existence. The main purpose of our work is to find out the possible neutron shell closure of $^{250\text{-}339}Hs_{108}$ isotopes. So, to get a clearer picture of the possible neutron shell closure we calculate binding energy per nucleon (B.E/A), matter radius (r_{matter}), two neutron separation energy (S_{2n}), differential variation of S_{2n} (dS_{2n}), the energy gap (ΔE), and also three-point differences of charge radii ($\Delta_{1n}^{(3)} r_{ch}$). Where r_{ch} is the charge radius. Charge radii act as a mirror that reflects different nuclear phenomena such as halo structures, shape coexistence, pairing correlation, neutron skins [2] etc. ΔE shows a clear local maximum and $\Delta_{1n}^{(3)} r_{ch}$ shows a local minimum at magic numbers [2]. We use NL3* [3] force parameter in the axially deformed relativistic mean field model (RMF) while studying the above said properties of Hs isotopes.

Formulation

The starting point of our calculation is the Lagrangian density [4].

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

Where the symbols have their usual meaning. 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.

$$S_{2n}(Z,N) = E_{bind}(Z,N) - E_{bind}(Z,N-2)$$

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

$$\Delta E = 2[\Delta_{1n}^{(3)} B.E(N,Z) - \Delta_{1n}^{(3)} B.E(N+1,Z)]$$

Where

$$\Delta_{1n}^{(3)} B.E(N,Z) = \frac{1}{2}(-1)^N[B.E(N+1,Z) - 2B.E(N,Z) + B.E(N-1,Z)]$$

and

$$\Delta_{1n}^{(3)} r(N,Z) = \frac{1}{2}(-1)^{N+1}[r(N+1,Z) - 2r(N,Z) + r(N-1,Z)]$$

Result and discussion

Fig-1 shows the variation of B.E/A as a function of neutron number. We compare our calculated results with the available experimental [5] results. Both the curves show a very good match with a maximum B.E/A value at N=156.

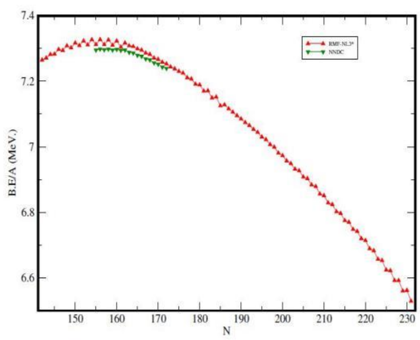

Fig. 1 The variation of B.E/A as a function of neutron number of Hs

In Fig-2 we see an unusual increase in the value of matter radius r_m in the range $186 \leq N \leq 201$. This unusual behavior can be thought of as due to shape transitions. Except this, we see small peaks at odd neutron numbers.

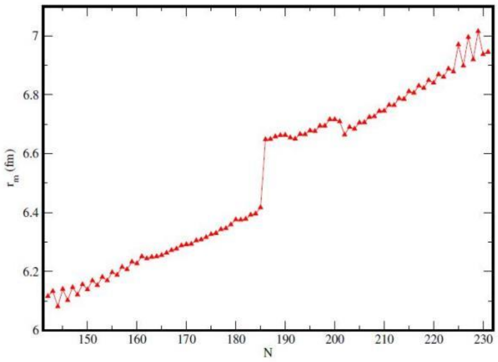

Fig. 2 The variation of r_m as a function of neutron number of Hs

The structural study remains incomplete without separation energies. So, we calculate $S_{2n.}$ In Fig-3 we can see clear peaks at N= 162, 176, 182, 184, 192, 204, 220 for S_{2n} curve. These peaks indicate more stability against neutron decay. These results are well supported by the dS_{2n} results. Where we can see clear deep at N=162, 176, 184, 208, 220. Experimentally ^{270}Hs is the first even-even nucleus to be observed on the predicted N=162 neutron shell [6]. Hence we can say that our enhanced calculated stability at N=162 is well supported by the experimental data. This extra stability against neutron decay for the particular isotopes is thought to be due to the shell or subshell closure of the neutron.

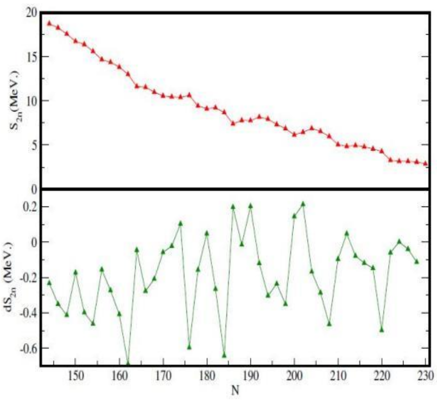

Fig. 3 The variation of S_{2n} and dS_{2n} as a function of neutron number of Hs

To estimate the odd-even staggering of charge radii and binding energy we calculate three-point differences both for binding energy and charge radius. The energy gap is calculated from the three point difference in B.E. The variation of ΔE and $\Delta^{(3)}_{1n} r_{ch}$as a function of neutron number is shown in Fig-4. Both the above-said parameters along with the neutron separation energies provide us with a clear picture of the shell and sub-shell closure. At well-known shell gaps$\Delta^{(3)}_{1n} r_{ch}$ parameter is locally inverted [2]. In fig-4 we see the deep at N=176, 184, 202. On the other hand, the local increase in ΔE at N= 175, 183, 202, 219 indicates subshell closure around these neutron numbers.

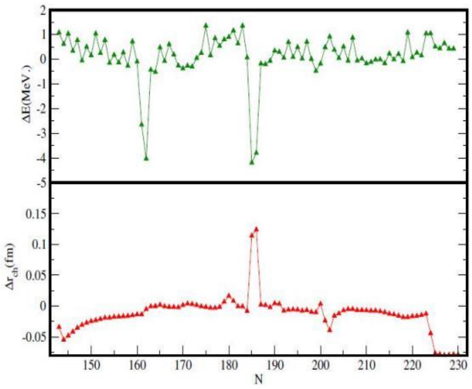

Fig. 4 The variation of ΔE and $\Delta^{(3)}_{1n} r_{ch}$ as a function of neutron number of Hs.

Conclusion

The calculated S_{2n} and dS_{2n} values describe the possible sub-shell closure at N=162, 176, 184, and 220 indicating extra stability against neutron decay. These results are well supported by $\Delta^{(3)}_{1n} r_{ch}$and ΔE providing a good contribution towards the structural properties of Hs isotopes.

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