New Islands of Inversion from the Latest Mass Predictions of the INM model

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Introduction

The Infinite Nuclear Matter (INM) model[1–5] of atomic nuclei in its latest development has predicted masses of about 7000 nuclei extending over the entire nuclear chart spanning up to and beyond the neutron- and proton-drip lines. Apart from predicting[2, 3] the usual nuclear saturation properties leading to resolution[2, 3] of the r_0-paradox[6] including extraction of the hitherto problematic nuclear incompressibility, it has the the characteristic local energy η carrying[7] signature of shell structure and many other important features (see Ref. [5] for details).

In the light of such significant features of the model it is worth reporting here about another interesting new phenomenon namely **Island of Inversion**[8, 9] using the latest mass prediction of the INM model. Such an Island of Inversion has been observed[8] experimentally in neutron-rich nuclei around neutron number N=20 region in the recent past , which manifests in enhanced binding of those nuclei centering around ^{31}Na. Extensive theoretical and experimental studies[10, 11] carried out over the years have concluded that the N=20 shell-closure in this region is broken by the intruder states from the pf-shell, thereby inducing strong collectivity and enhanced stability. Another such island of inversion centering around ^{62}Ti has also been reported[9] . Therefore it would be a challenge to see whether the latest INM mass predictions bear out existence of such islands apart from predicting more such islands in the heavy and very-heavy mass regions.

The INM model has been well-described elsewhere. Here for sake of completeness we just highlight few of its basic equations. In this model, the ground-state energy $E^{\mathrm{F}}(A, Z)$ of a nucleus is considered equivalent to the energy of a perfect sphere made up of infinite nuclear matter at ground-state plus the residual characteristic energy η. Thus a nucleus possess two categories of properties, namely the global one represented by the INM sphere and the individualistic one by η (A,Z). Consequently $E^{\mathrm{F}}(A, Z)$ can be written as the sum of three quantities:

$$E^{\mathrm{F}}(A, Z) = E(A, Z) + f(A, Z) + \eta(A, Z). \quad (1)$$

E being the property of nuclear matter at ground state, should satisfy the generalized HVH theorem[12]

$$E/A = [(1 + \beta)\epsilon_{\mathrm{n}} + (1 - \beta)\epsilon_{\mathrm{p}}]/2, \quad (2)$$

where $\epsilon_{\mathrm{n}} = (\partial E/\partial N)_Z$ and $\epsilon_{\mathrm{p}} = (\partial E/\partial Z)_N$ are the neutron and proton Fermi energies respectively for nuclear matter. Its solution is given by

$$E = -a_{\mathrm{v}}^{\mathrm{I}} A + a_{\beta}^{\mathrm{I}} \beta^2 A, \quad (3)$$

where $a_{\mathrm{v}}^{\mathrm{I}}$ and a_{β}^{I} are the usual global volume and asymmetry parameters pertaining to INM liquid. Here the suffix I is used to denote the INM character of the respective quantities. The term f(A,Z) denoting the finite-size effects is given by

$$f(A, Z) = a_s^I A^{\frac{2}{3}} + a_C^I [Z^2 - 5(\frac{3}{16\pi})^{\frac{2}{3}} Z^{\frac{4}{3}}] A^{-1/3} - \delta(A, Z) \quad (4)$$

where a_s^I, a_c^I are the usual universal parameters characterizing the surface and coulomb

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terms of the INM sphere and $\delta(A,Z)$ is the usual pairing term.

Using Eqs. (1-3), we arrive at three essential equations of the model

$$f - N(\partial f/\partial N)_Z - Z(\partial f/\partial Z)_N = E^{\rm F} - \left[N\epsilon_{\rm n}^{\rm F} + Z\epsilon_{\rm p}^{\rm F}\right], \qquad (5)$$

$$-a_{\rm v}^{\rm I} + a_{\beta}^{\rm I}\beta^2 = \frac{1}{2}\left[(1+\beta)\,\epsilon_{\rm n}^{\rm F} + (1-\beta)\,\epsilon_{\rm p}^{\rm F}\right] - \left[\frac{N}{A}\left(\frac{\partial f}{\partial N}\right)_Z + \frac{Z}{A}\left(\frac{\partial f}{\partial Z}\right)_N\right], \qquad (6)$$

$$\eta(A,Z) = \left[N\left(\frac{\partial \eta}{\partial N}\right)_Z + Z\left(\frac{\partial \eta}{\partial Z}\right)_N\right], \qquad (7)$$

defining the INM model completely. Eq. (6) determines the finite-size coefficients a_s^I and a_c^I etc. of the INM sphere, Eq. (7) determines the global parameters a_v^I and a_β^I while appropriate solution of Eq. (8)(see Ref. [5] for details) exclusively determines the local energy η. Thus once the three functions $E(A,Z)$, $f(A,Z)$ and $\eta(A,Z)$ are determined, energy of the nucleus (A,Z) is obtained using Eq. (1) leading to construction of the latest Mass Table[5].

For studying Islands of Inversion we have calculated two-neutron separation energies S_{2n} using predicted nuclear masses and plotted them (not shown here due to lack of space) as isolines as a function of neutron number N throughout the nuclear chart. The typical sharp fall of S_{2n} at the shell-closures clearly reproduce the well-known magic numbers 8, 20, 50, 82 and 126 in conformity with experiment. However the monotonic decrease with increase of neutron numbers N in the β-stable valley gets arrested in the neutron-rich region for Z=10 and 11, agreeing with the observed[8] island of inversion around ^{31}Na.

We also find that there is a region spanned by Z=17 to 23 and N=38 to 42, where S_{2n} isolines exhibit the same feature of enhanced stability suggesting the existence of another island of inversion. This may be due to breaking of N=40 shell by the intruder states from the *sdg* shell and thereby inducing strong deformation around ^{62}Ti in agreement with experimental[9] observation. Thus the agreement of INM mass predictions for detecting these two islands with experimental findings shows the goodness of the model.

These finding of these two islands of inversion do suggest that these two may not be the isolated cases, and this phenomenon may be a general feature of nuclear dynamics especially in the exotic neutron-rich regions close to n-drip line, where breaking of shell- closures by intruder states from higher shells are quite plausible. In fact our extensive S_{2n} systematics in the high-mass region reveal two more islands in the heavy-mass region delineated by Z=37-40, N= 70-74; and Z=60-64, N= 110-116, where these may be due to breaking of N=70 and N=112 shells by the intruder states from the *pfh* and *sdgi* shells respectively.

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