Latest Mass-Table Based on The INM Model:Nuclear Masses and Exotic Features

* R. C. Nayak*
Dept. of Physics, Berhampur University, Berhampur-760007, INDIA

Introduction

The Infinite Nuclear Matter (INM) model[1–3] of atomic nuclei developed over the recent years has been found to be successful both in predicting nuclear masses far away from the β-stable valley[3] as well as the nuclear saturation properties[4, 5]. The previous mass table based on the INM model was last prepared in 1999[3] using known mass-data of Audi-Wapstra published in 1993[6]. Hence it is desirable to generate a new mass-table by including hundreds of new mass measurements that has taken place after 1993 and that too more and more towards drip-lines. In the present work we use the model to obtain the final mass table using the latest mass-data of 2003[7] apart from comparing with the new mass measurements that are available in literature after 2003.

Secondly the model apart from predicting nuclear masses also provides the so-called local energy η of a given nucleus, which has been conjectured to carry signature of shell structure as it embodies mainly shell and deformation energies. Although this was shown[8] to be the case qualitatively, quantitative proof has been lacking till now. In the present work we highlight such calculations in this connection by comparing the local energies with the Shell-Correction and Deformation energies obtained from microscopic calculations involving Relativistic mean-field (RMF)[9] and Extended Thomas-Fermi (ETHF)[10] approach. We also present results on shell-quenching feature alongwith the possible existence of new islands of stability based on the local energy systematics.

*Electronic address: rcnayak00@yahoo.com

THE INM MODEL

As per the main presumption of the model the energy of a finite nucleus can be written as the sum of three characteristically different 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, satisfy the generalized HVH theorem[11]

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

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. 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 global parameters, which can be termed as volume and asymmetry coefficients pertaining to INM liquid. The second term $f(A,Z)$ denoting the finite-size effects is given by

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

where a_s^I, a_c^I are the usual universal parameters characterizing the surface and coulomb terms of the INM sphere and $\delta(A,Z)$ is the usual pairing energy given by

$$\delta(A,Z) = \begin{cases} +\Delta\, A^{-1/2} & : \; even-even\; nuclei, \\ 0 & : \; odd-A\; nuclei, \\ -\Delta\, A^{-1/2} & : \; odd-odd\; nuclei. \end{cases}$$

Eqs. (1) and (2) together with the nature of local and global terms lead to two separate INM equations

$$S(A,Z) = \frac{E^{\mathrm{F}}}{A} - \frac{1}{2}\left[(1+\beta)\epsilon_{\mathrm{n}}^{\mathrm{F}} + (1-\beta)\epsilon_{\mathrm{p}}^{\mathrm{F}}\right], \tag{5}$$

and

$$\frac{\eta(A,Z)}{A} = \frac{1}{2}\left[(1+\beta)(\frac{\partial\eta}{\partial N})_Z + (1-\beta)(\frac{\partial\eta}{\partial Z})_N\right]. \tag{6}$$

Here, $S(A,Z)$ given by $f/A - (N/A)(\partial f/\partial N)_Z - (Z/A)(\partial f/\partial Z)_N$ is a function exclusively of finite-size coefficients and hence has been used to determine the model parameters a_s^I, a_c^I first and consequently the other model parameters $a_{\mathrm{v}}^{\mathrm{I}}$ and a_β^{I} as described elsewhere [3–5]. Eq. (6) is used to obtain the local energies both for known and unknown nuclei by solving it in an Interactive Local Area Network[3] followed by Ensemble Averaging Procedure[8].

In principle $f(A,Z)$ may include terms like proton form factor $\sim Z^2/A$, Nolen-Schiffer charge anomaly $\sim (N-Z)$ and surface-Symmetry $\sim \beta^2 A^{2/3}$. Since these terms get canceled[4, 5] in the Eq. (5), these are ignored in the model. As a result the INM model has only five free parameters. Consequently these are determined as accurately as possible and free from any possible correlations of other possible macroscopic correction terms. For generating the Mass Table, we use the latest known mass-data[7] to obtain the local energies for both known and unknown nuclei adopting the procedure stated above.

Results and Discussion

The local energy η of a given nucleus is expected more or less to consist of energy arising exclusively from the shell structure, because of the fact that energy due to deformation for a given nucleus is considered shell-driven. Accordingly it should reveal the shell-structure of a given nucleus. This was shown[8] to be the case when the local energies are plotted in the form of isolines. However for a quantitative definition of this quantity as the shell and deformation energies, microscopic calculations are being carried out in the framework of RMF[9] and ETHF[10] formalism. Preliminary results show their close proximity with the shell and deformation energies obtained from RMF and ETHF calculations thereby justifying our previous contention.

One of the crucial features of the INM model is its agreement with the shell-quenching behaviour of the n-magic shell-gaps in the exotic n-rich regions of the nuclear chart. This is also borne out in the present mass-predictions. For instance shell-gaps given by $S_n(N_m-1) - S_n(N_m+1)$ for a given n-magic number N_m support vanishing magicity towards n-drip regions in agreement with the r-process nuclidic abundance calculations[12].

Apart from these features, local-energy systematics from the present calculations also provide possible occurrence of new islands of stability. Some of the significant regions are around Z & N equal to (62,100)and (78,150).

References

[1] L. Satpathy, J.Phys.**G13**, 761 (1987)

[2] L. Satpathy and R. C. Nayak , At. Data and Nucl. Data Tables **39**, 213 (1988)

[3] R. C. Nayak and L. Satpathy, At. Data and Nucl. Data Tables **73**,213(1999)

[4] R.C.Nayak, V. S. Uma Maheswari and L. Satpathy, Phys. Rev. C **52**, 711 (1995)

[5] L. Satpathy, V. S. Uma Maheswari and R.C. Nayak, Phys. Rep. 319,85(1999)

[6] G.Audi and A.H.Wapstra, Nucl. Phys.**A565**, 1(1993)

[7] G.Audi, A.H.Wapstra and C.Thibault, Nucl. Phys. **A729**, 337 (2003)

[8] R. C. Nayak, Phys. Rev. C **60**,064305 (1999)

[9] G. A. Lalazissis et al, Phys. Rev. C **55**, 540 (1997)

[10] J. M. Pearson et al, Nucl. Phys. **A528**, 1 (1991)

[11] L.Satpathy and R. C. Nayak, Phys. Rev. Lett. **51**, 1243 (1983)

[12] B. Chen et al, Phys. Lett.**B 355**, 37(1995)