Study of the effect of temperature on binding energies of nuclei

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Introduction

To understand the fundamental nature of the atom, number of theories and models were developed. Nuclear masses were assumed to be sum of masses of their constituent nucleon i.e., protons and neutrons. But mass spectrograph studies show that, there is a difference between mass of nucleus and sum of nucleon masses. The binding energy per nucleon curve throws light on the properties of the atomic nucleus. In present study, using liquid drop model approach [1], we intend to explore the effect of temperature on the binding energy per nucleon (B.E./A) using semi-empirical mass formula (SEMF) [2], for $T \leq 4$ MeV. The different energy terms as well as shell corrections contributing to B.E. of nuclei are investigated for understanding their behavior with rise in the temperature. The behavior of B.E./A curve at different values of temperature has been investigated. The effect of temperature dependent binding energies has been analyzed by using the temperature dependence of various energy terms of liquid drop model provided by Davidson et. al. [3], which is based on Seeger's SEMF (at T=0 MeV) [4].

Methodology

Within the Strutinsky renormalization procedure [5], the binding energy consists of the two parts first is macroscopic part (liquid drop energy) and second is microscopic part (shell corrections). It allows us to define temperature T-dependent binding energy of a nucleus as sum of the liquid drop energy V_{LDM} (T) [3] and shell corrections $\delta U(T)$ [6]

$$B(A,Z,T)=V_{LDM}(A,Z,T) + \delta U \exp - (T)^2/(T_0)^2 \qquad (1)$$

where V_{LDM} is the based upon semi empirical mass formula of Seeger (at T=0 MeV) and temperature dependence introduced by Davidson et al. as

$$V_{LDM}(A,Z,T)=\alpha(T)A+\beta(T)A^{2/3}+(\gamma(T)-\eta(T)/A^{1/3})[(I^2+2|I|/A)]+Z^2/R_0(T)A^{1/3}(1-0.7636/Z^{2/3}-2.29/[R_0(T)A^{1/3}]^2)+f(Z,A)/A^{3/4} \qquad (2)$$

Where above terms represent volume, surface, asymmetry, coulomb and pairing energies, respectively. Here $I = a_a (Z-N)$, $a_a=1.0$ and f (Z, A) = (-1,0,1) for even-even, even-odd and odd-even nuclei, odd-odd, respectively.

The shell corrections in accordance with Myers and Swiatecki formula [6] are given by

$$\delta U=C\left[\frac{F(N)+F(Z)}{(A/2)^{2/3}}-cA^{1/3}\right] \qquad (3)$$

here, $F(X)=\frac{3}{5}\left(\frac{M_i^{\frac{5}{3}}-M_{i-1}^{\frac{5}{3}}}{M_i-M_{i-1}}\right)(X-M_{i-1})-\frac{3}{5}\{X^{\frac{5}{3}}-M_{i-1}^{\frac{5}{3}}\}$

where X=N or Z, $M_{i-1}<X<M_i$ and M_i as the magic numbers 2, 8, 20, 28, 50, 82, 126 and 184 for both neutrons and protons.

Results and Discussions

Fig. 1. represents the values of the B.E./A at different temperatures, the value of the total B.E./A (MeV) decreases with increase in the temperature. However, there is little rise in the values at smaller temperature values around T ~ 1 MeV, as almost all the coefficients show little rise in their respective values around smaller temperature, and then permanent fall at the higher temperatures. This trend is also reflected in the B.E./A curve at different temperature.

As the main contributors in the binding energy are volume energy, surface energy and coulomb energy terms. Volume energy is the most dominant term and it contributes positively in binding energy whereas surface energy and coulomb energy reduce it. The change in magnitude of surface energy from 0 MeV to 1 MeV is more in order to compensate the small

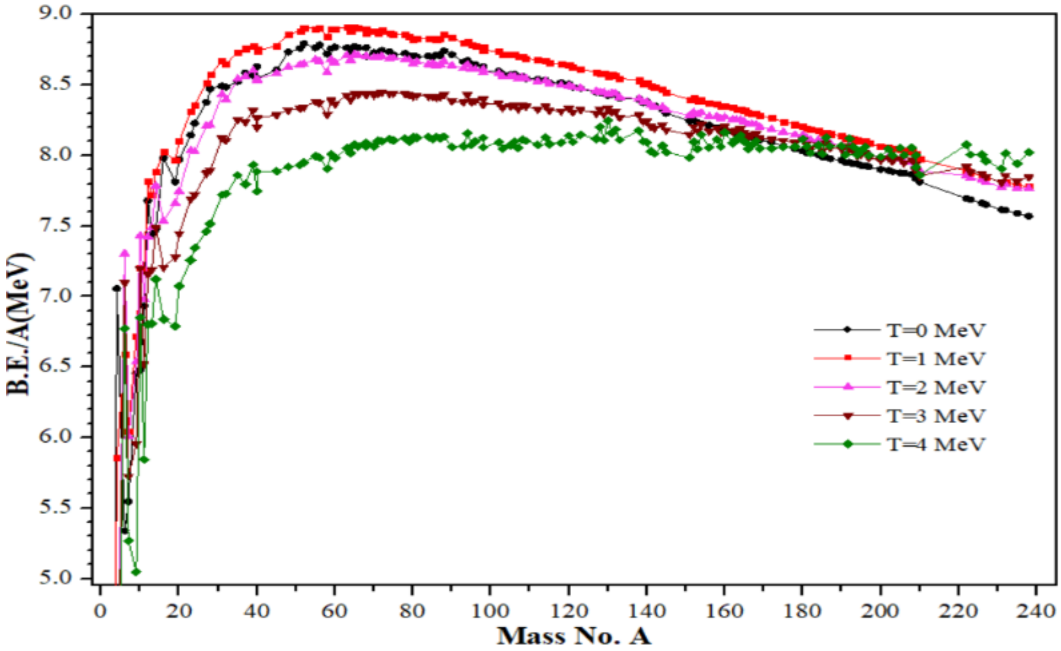

FIGURE 1. *The variation of B.E./A (MeV) with mass no. A at different temperatures.*

change in magnitude of volume energy in this temperature range. The magnitude of all the energy terms of binding energy decreases with temperature after a little rise at smaller temperature. Thus, the overall effect of these terms results in increased values of binding energies at 1 MeV. So, for the mass region A~10-240, the total B.E/A increases from 0 MeV to reach a peak value at approximately 1MeV and after that it decrease with rise in temperature, as after 1 MeV the magnitude of change (decrease) in the volume energy term increases with temperature and it is more than the change in the magnitude of all other terms. The significance of asymmetry energy increases for heavier nuclei with increase in temperature. The trend of B.E./A curve is almost reverse in this region due to rise of the change in the values of asymmetry energy, which is more pronounced at T=4 MeV.

We have explored the temperature dependence of the binding energy per nucleon curve, and different terms contributing to it in the semi-empirical mass formula, for temperatures ≤4 MeV. The values of different energy terms of SEMF at different values of temperature 0, 1, 2, 3, 4 MeV have been calculated. It is observed that with increase in temperature the B.E./A (MeV) has mixed trends. The above-mentioned results and calculations clearly establish the effect of temperature on the B.E./A curve. It shows the different variations and trends with increase in temperature. It enhances the knowledge about the temperature dependence of B.E./A curve as well as the effect on the different energy terms. For the mass number A~10-250, there is rise in the values up to smaller temperature values around T ~ 1 MeV, attributed to the behavior of surface energy term.

References

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