Role of shell corrections in the decay of light mass nucleus

Taranjeet Kaur, Manpreet Kaur,* and BirBikram Singh†
Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib- 140406, INDIA

Introduction

The liquid drop generalization of atomic nucleus provide the base upon which the semi-empirical mass formula of liquid drop energies was built by Weizsäcker. It successfully explained the experimental variation of binding energy with mass number over the range of periodic table and fission process in heavy nuclei. The unresolved mysteries of peaks in binding energy curve for magic nuclei were later on explained on the basis of shell model. Later on studies show that experimental binding energy contains the shell corrections in addition to liquid drop energies, which are defined within Strutinsky's renormalization procedure [1]. The empirical shell corrections were calculated by Myers and Swiatecki [2].

Recently, the role of shell corrections on the cluster radioactivity has been investigated within quantum mechanical fragmentation theory (QMFT). It shows that shell corrections play a crucial role in the collective clusterization process for the cluster radioactive decay [3]. Also, it has been shown that shell corrections play an important role in the stability of beta decay stable isobars [4]. In the present work, the role of shell corrections on the fragmentation potential or collective potential energy surface in the decay of ^{20}Ne nucleus is studied at the ground state, at the threshold energy given by Ikeda diagram [5] and the experimental energy [6], within the dynamical cluster-decay model (DCM) [7]. We find that the shell corrections do play a significant role in light mass region and investigation of their role in medium and heavy mass region along with few more lighter nuclei at T $\leq$ 1.5 MeV will be of interest in further studies.

*Electronic address: manpreet13phd@sggswu.edu.in
†Electronic address: birbikramsingh@sggswu.edu.in

Methodology

The fragmentation potential ($V_R(\eta$,T)) within DCM is given as

$$V_R(\eta, T) = B_i + V_c + +V_p + +V_l \quad (1)$$

i.e. it is sum of Coulomb (V_c), proximity (V_p), centrifugal potential (V_l) all being temperature dependent and B_i are the temperature dependent binding energies of two nuclei and defined as below

$$B_i(T) = V_{LDM}(T) + \delta U \exp(\frac{-T^2}{T_0^2}) \quad (2)$$

where V_{LDM} is the liquid drop energy, i.e., macroscopic part and δU are the "empirical" shell corrections, i.e., microscopic part [2], of the binding energies. The temperature dependent macroscopic part V_{LDM} is calculated as suggested by Davidson et al. [8], based upon the semi-empirical mass formula of Seeger et al. [9], and given as

$$V_{LDM}(A, Z) = \alpha A + \beta A^{\frac{2}{3}} + \left(\gamma - \frac{\eta}{A^{\frac{1}{3}}}\right) \left(\frac{I^2 + 2 \mid I \mid}{A}\right) + \frac{Z^2}{R_0 A^{\frac{1}{3}}} \left(1 - \frac{0.7636}{Z^{\frac{2}{3}}} - \frac{2.29}{[R_0 A^{\frac{1}{3}}]^2}\right) + \delta \frac{f(Z, A)}{A^{\frac{3}{4}}} \quad (3)$$

where above terms represent volume, surface, asymmetry, Coulomb and pairing energies, respectively and I = a_a(Z - N). Also, f(Z, A) = (-1,0,1) for even-even, even-odd and odd-odd nuclei, respectively. In the present work, the role of shell corrections on the fragmentation potential (given by eq. 1) is studied by taking

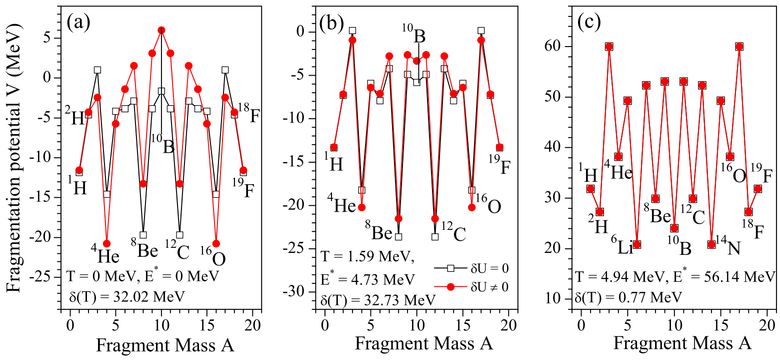

FIG. 1: Fragmentation potential V (MeV) for the decay of ^{20}Ne at (a) T = 0 MeV (b)T = 1.59 MeV (c)T = 4.94 MeV corresponding to ground state, threshold energy [5] and experimental energy [6], respectively with and without inclusion of shell corrections.

δU $\neq$ 0 and δU = 0 in eq.(2). It is relevant to mention here that when these coefficients were fitted the data available was only for few hundred nuclei. So in the wake of available data (experimental as well as theoretical) for thousands of nuclei, these coefficients need to be refitted. However, the aim of the work [10] was not to fit the constants but to include temperature dependence of the recent binding energies. So only the bulk (α) and neutron proton asymmetry (a_a) constants of Seeger's formula at T = 0 were refitted.

Calculations and Discussions

The Fig. 1(a,b) shows the calculated fragmentation potential V (MeV) for the decay of ^{20}Ne in ground as well in intrinsic excited state given by Ikeda diagram for inclusion (δU $\neq$ 0) and non-inclusion (δU = 0) of shell corrections. From this Fig. 1(a) we note that at T = 0 MeV for δU = 0, ^{8}Be and ^{12}C are more stable than neighboring fragments but with inclusion of shell corrections the ^{4}He and ^{16}O become more stable than ^{8}Be and ^{12}C. The binary symmetric fragment ^{10}B is out of favor being unstable for both the cases. At temperature corresponding to Ikeda threshold energy for ^{20}Ne, the shell corrections suggest the competition between different α fragments (^{4}He, ^{8}Be, ^{12}C and ^{16}O) (Fig. 1(b)). For binary symmetric fragment ^{10}B instability is decreased slightly in comparison to at T = 0 MeV.

At still higher temperature corresponding to experimental available data [6], it is clear from Fig. 1(c) that potential energy surface changes drastically at higher T, the binary symmetric fragment becomes favorable having competition with ^{6}Li, ^{14}N fragments. However, it is noted that role of shell corrections vanishes at higher temperature, as evident from eq. 2 also.

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