Clustering effects and fragmentation of composite system $^{20}Ne^*$ formed in light heavy ion collisions

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Introduction

Clustering is a generic phenomenon, which exists in different domains extending from cosmic scale to sub-atomic scale. The speculations of cluster's existence within a nucleus were stimulated by observation of α-decay. Later, with availability of accelerated heavy ion (HI) projectiles, the clues about clustering were observed through selective population of particular nuclear states during nuclear reactions involving transfer of a cluster of nucleons between colliding nuclei. Specifically, for $^{12}C+^{12}C$ reaction the observation of resonance state, advocate the presence of even larger clusters [1]. Several studies on evolution of clustering in nuclei from stability line (N = Z) to drip line (N ≠ Z) have been carried out [2]. The nuclear reactions, particularly low energy reactions are the indispensable probes to explore the cluster structure within the nucleus. The cluster structures are studied experimentally via resonant elastic scattering, cluster knock out, capture reactions, electromagnetic interaction, etc. [3].

Apart from this, the decay of different composite systems with mass ~ 20-40 have been investigated to explore the reaction mechanisms [4]. These studies show the presence of competing modes of fusion-fission (FF) (of compound nucleus origin) and deep inelastic orbiting (DIO) (of non-compound nucleus origin), in the decay of nuclear systems formed in HI reactions. In this work, the evolution of cluster structure with increasing excitation energy has been presented in light mass alpha-conjugate system $^{20}Ne^*$, within the quantum mechanical fragmentation theory (QMFT)-based dynamical cluster-decay model (DCM), by taking into account the proper pairing strength in liquid drop part [5]. Furthermore, the decay analysis/ fragmentation studies has been made in reference to available Z-distribution data [4] and the possible role of clustering on the emission of different intermediate mass fragments/ clusters, with Z = 5, 6, 7, has been discussed.

Methodology

In QMFT, the fragmentation of compound nucleus is worked out in terms of the decoupled collective coordinates of mass asymmetry [$\eta = (A_1-A_2)/(A_1+A_2)$] and relative separation R. In terms of these coordinates, using l partial waves, the CN decay cross-section [5], in DCM, is

$$\sigma = \frac{\pi}{k^2}\sum_{\ell=0}^{\ell_{max}}(2\ell+1)P_0P; \qquad k=\sqrt{\frac{2\mu E_{c.m.}}{\hbar^2}} \tag{1}$$

where P_0 is preformation probability of cluster, given by

$$P_0(A_i)=|\psi(\eta(A_i))|^2(2/A)\sqrt{B_{\eta\eta}} \tag{2}$$

which is the solution of stationary Schrödinger equation in η coordinate at a fixed R, and P, the WKB penetrability, refers to R motion. Both P_0 and P carry the effects of T and angular momentum l of colliding nuclei at a given $E_{c.m.}$. It is important to note that a modified temperature dependence of the pairing energy coefficient δ(T) is essential in the temperature-dependent liquid drop energy (refer to Fig. 3 of Ref. [6]).

Calculations and Discussions

Firstly, the clustering prospects have been presented for ^{20}Ne nuclear system within QMFT. The clustering effects with rising temperature in alpha conjugate nuclear system are depicted in Fig. 1. In Fig. 1(a), it is observed that at T = 0 MeV only $^4He+^{16}O$ cluster configuration is robustly preformed while at higher T = 1.59 MeV (Fig. 1(b)) corresponding to Ikeda's threshold energy [2], $^8Be+^{12}C$ configuration is competing with $^4He+^{16}O$ cluster configu-

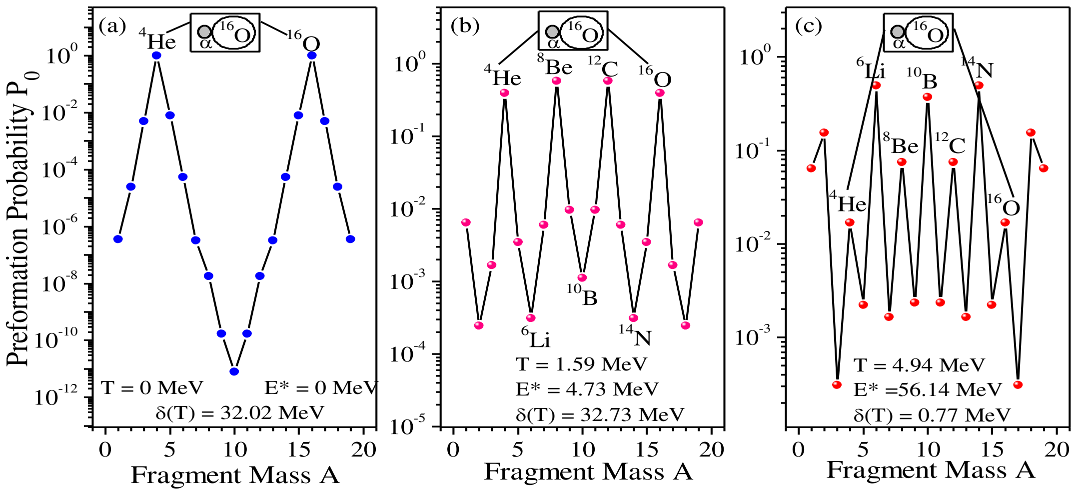

Fig. 1 The evolution of preformation probability, P_0 of different fragmented clusters in the decay of $^{20}Ne^*$ at different temperatures, i.e., at (a) T = 0 MeV, (b) T = 1.59 MeV and (c) T = 4.94 MeV.

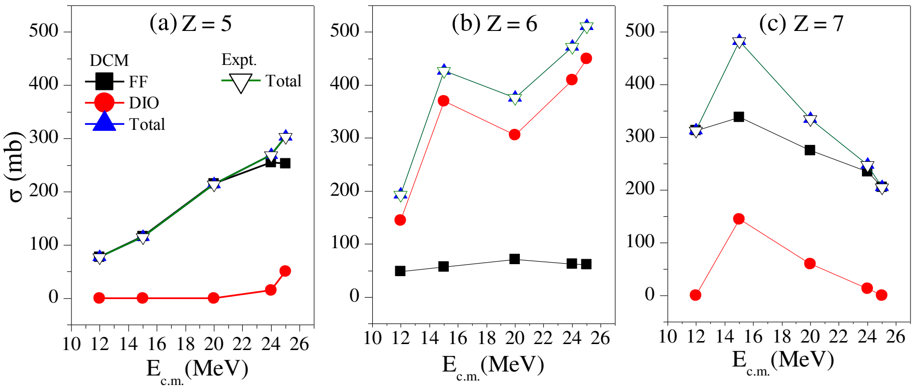

Fig. 2 The decay cross-section of Z = 5, 6, 7 clusters as a function of $E_{c.m.}$(MeV), in decay of $^{20}Ne^*$.

ration. Fig. 1(c) shows that at experimental excitation energy corresponding to T = 4.94 MeV, due to decreased pairing strength, (with δ(T) = 1.56 MeV), ^{6}Li, ^{10}B, ^{14}N clusters (i.e. np-xα type clusters) are more prominent than xα-type clusters.

The results in Fig. 2(a-c) show the existence of competing reaction modes of FF and DIO. Fig. 2(a) reveals that the yield for B fragments is mainly due to FF process and least contribution from DIO process as it is having very high value of P_0 (Fig. 1(c)), which is in contrast to C fragments (Fig. 2(b)). On the other hand, the results for N fragments are more or less like that of B fragments except that in this case the contribution of DIO process is more. The experimental verification of these results is called for.

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