Effect of temperature on the collective clusterization of non-alpha conjugate nuclei

Manpreet Kaur[1],* BirBikram Singh[1],† S.K. Patra[2], and R.K. Gupta[3]

[1]*Department of Physics, Sri Guru Granth Sahib World University, Fatehgarh Sahib- 140406, INDIA*
[2]*Institute of Physics, Sachivalaya Marg, Bhubaneswar-751005, INDIA and*
[3]*Department of Physics, Panjab University, Chandigarh-160014, INDIA*

Introduction

The assemblage of stars into galaxies and the conglomerate of nucleons in atomic nuclei are the extreme cases of clustering observed in nature. The study of clustering phenomenon, with longstanding history, still aims to understand the correlation between nucleons to aggregate in the form of α particles or heavier α-like particles. The fact that α like clusters does not appear in ground state rather they emerge with increase in excitation energy of nuclei, is encapsulated in Ikeda diagram for N = Z nuclei [1]. The extension of this work to the study of clustering features in neutron-rich light nuclei by Oertzen et al. [2] envisioned the covalent exchange between valence neutrons and α core in N $\neq$ Z nuclei.

The cluster structure of light nuclei has been explored through low energy reactions quite extensively [3]. During last decades, the decay of several light and medium mass nuclei with mass $\sim$ 20-40 have been studied to explore the reaction mechanisms [4–6]. It is interesting to explore the clustering effects in the decay of composite nuclei (CN) formed in heavy ion reactions. The decay of CN with the mass varying from light to heavy, and super heavy regions have been studied successfully within the collective clusterization process of dynamical cluster decay model (DCM) [6–9] based upon quantum mechanical fragmentation theory (QMFT). The QMFT based study supports the clustering in $^{18,20}O$ and $^{20,22}Ne$ systems with inclusion of modified temperature dependent pairing strength δ(T) in the

―――――

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

liquid drop energies [8, 9].

In the present work, we report on the role of temperature on the collective clusterization process in non-alpha conjugate systems $^{21,22}Ne$ (N $\neq$ Z) in the ground state and at the temperature equivalent to the excitation energy given by Ikeda diagram. Further, to study the impact of increasing temperature on the clustering, these effects are studied in the CN $^{21}Ne^*$ and $^{22}Ne^*$ formed in $^{10}B+^{11}B$ and $^{11}B+^{11}B$ reactions, respectively, with reference to experimental data [4].

Methodology

The QMFT based DCM is worked out in terms of collective coordinates of mass asymmetry $\eta = (A_T\text{-}A_P)/(A_T+A_P)$ and relative separation (R) with effects of temperature, deformation and orientation duly incorporated in it [6–9]. The cluster preformation probability P_0 is given by

$$P_0(A_i) =\mid \psi(\eta(A_i)) \mid^2 \frac{2}{A^*_{CN}} \sqrt{B_{\eta\eta}}, \qquad (1)$$

which is given by solution of stationary Schrodinger eq. in η co-ordinate. For clustering effects in nuclei we look for the maxima in P_0(A) (as shown in Fig.1) or the energetically favored potential-energy minima in the fragmentation potential $V_R(\eta,\text{T})$. It consists of temperature dependent Coulomb, proximity, centrifugal potentials along with temperature dependent liquid drop energies and shell effects. 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. [9]).

Calculations and Discussion

Fig.1 presents the relative P_0 of different clusters in non-alpha conjugate system (a) $^{21}Ne^*$ (b) $^{22}Ne^*$ at different temperatures. In
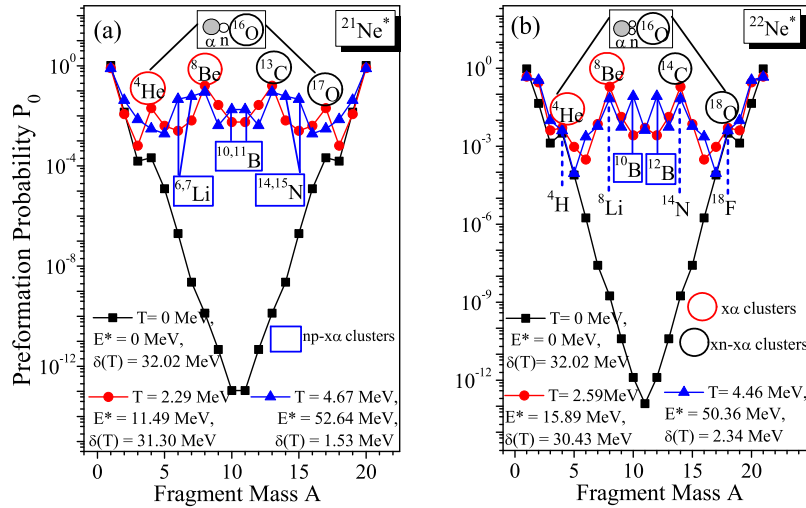
FIG. 1: The P_0 of clusters in the decay of a) $^{21}Ne^*$ at T = 0 MeV, 2.29 MeV (corresponding to Ikeda threshold energy [1]) and 4.67 MeV (corresponding to experimental energy [4]) b) same as (a) but for $^{21}Ne^*$ at corresponding T = 0 MeV, 2.59 MeV and 4.46 MeV values.

Fig.1(a) at ground state T = 0 MeV, the α and ^{17}O, which is n-xα (x is an integer) type cluster are predominant. But with rise in temperature, for $^{21}Ne^*$, $^8Be+^{13}C$ ($\equiv 2\alpha+n+^{12}C$) clusters are also observed. At still higher temperature T = 4.67 MeV, in addition to xα and xn-xα type clusters (shown by circle), the np-xα type clusters (shown by rectangle) are significantly preformed. Similar type of results we get for ^{22}Ne and $^{22}Ne^*$. But here we see that at T = 4.46 MeV in comparison to T = 2.59 MeV, the clusters (indicated by dotted lines) changes due to change in potential energy surface with increasing temperature.

It is to be noted that for both the cases change in cluster structure is due to decrease in pairing strength in liquid drop energies with increase in temperature. Within QMFT based DCM, this work clearly brings out the effect of temperature on the collective clusterization process in the decay of non-alpha conjugate nuclei. The full details of the calculations are given in Ref. [8].

Acknowledgements

References

[1] K. Ikeda et al., Prog. Theor. Phys. Suppl. E **68**, 464 (1968).

[2] W. Von Oertzen et al., EPJA **11**, 403 (2001); EPJA **43**, 17 (2010).

[3] F.D. Becchetti et al., NPA **339**, 132 (1980); M. Freer, Rep. Prog. Phys. **70**, 2149 (2007); G. V. Rogachev et al., Prog. Theor. Phys. Suppl. **196**, 184 (2012).

[4] A. Szanto de Toledo et al., PRL **62**, 1255 (1989); M. M. Coimbra et al., Nucl. Phys. A **535**, 161 (1991); S. Kundu et al., PRC **85**, 064607 (2012); Parmana **82**, 727 (2014).

[5] S.J. Sanders, PRC **44**, 2676 (1991); R.M. Anjos et al., PRC **48**, R2154 (1993); ibid PRC **49**, 2018 (1994).

[6] B.B. Singh et al., DAE Symp. on Nucl. Phys. **59**, 516 (2014); ibid **60**, 586 (2015); **60**, 592 (2015); EPJ Web Conf. **86**, 00048 (2015); JPS Conf. Proc **6**, 030001 (2015).

[7] R.K. Gupta et al., PRC **71**, 014601 (2005); PRC **77**, 054613 (2008).

[8] M. Kaur et al., PRC **95**, 014611 (2017).

[9] M. Bansal et al., J. Phys.: Conf. Ser. **321**, 012046 (2011).