A comparative study: Clustering within microscopic and macroscopic approaches

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]*Physics Department, Panjab University, Chandigarh-160014, INDIA*

Introduction

The tendency of nucleons to conglomerate within the nucleus leading to an increase in stability is still a topic of much interest. The discovery of α decay in the heavy nuclei prompted the idea that nucleus can be visualized as being composed of α-particles as building block. Since then it has captured a central attention in the nuclear structure and nuclear reaction studies for last many decades. The famous 'Hoyle state' of ^{12}C consisting of 3α particles was predicted theoretically in 1953 which was confirmed experimentally in 1957 [1, 2]. Furhter, Ikeda suggested that these alpha cluster states are not predominant in the ground state but manifest near the cluster decay threshold energies [3].

Experimentally, cluster structures of various light mass alpha conjugate and non-alpha conjugate systems ^{16}O to ^{40}Ca have been investigated using quasi elastic scattering, cluster transfer or knock out reactions [4]. On theoretical front, the clustering prospect in the ground and intrinsic excited states have been studied successfully within the relativistic mean field theory (RMFT) calculations for neutron-rich light stable nuclei as well as heavy mass nuclei [5]. Clustering in light mass ^{20}Ne has been studied within density dependent functional approach [6]. Recent work within quantum mechanical fragmentation theory (QMFT)-based Dynamical Cluster-decay model (DCM) explores the clustering effects in light mass alpha and non-alpha conjugate systems [7]. In this work, we investigate clustering aspects in ^{20}Ne nucleus using microscopic and macroscopic approaches of RMFT and QMFT, comparatively.

Methodology

The RMFT Lagrangian with the NL3 parameter set [5] is used in present work, which is reasonably useful for both β-stable and drip lines nuclei. The Lagrangian contains the terms of interaction between mesons and nucleons and also self-interaction of isoscalar scalar sigma meson. From the relativistic Lagrangian the field equations for the nucleons and mesons are obtained. These equations are solved by expanding the Dirac spinors and the boson fields in a deformed harmonic oscillator basis with an initial deformation. The set of coupled equations is solved numerically by a self-consistent iteration method to obtain the nuclear matter density.

The QMFT is worked out in terms of collective coordinates of mass asymmetry η and relative separation (R) including the effects of temperature, deformations and orientations [7]. 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 Schr'odinger eqn. in η co-ordinate. For clustering effects in nuclei we look for the maxima in P_0(A) [see Fig. 1 (b) and (d)].

Calculations and Discussion

The RMFT calculated contour plots of nuclear density distribution for ground state (g.s.) of ^{20}Ne depicts trigonal bipyramid configuration, as shown in Fig.1(a) [5]. Within QMFT, most probable cluster configurations

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

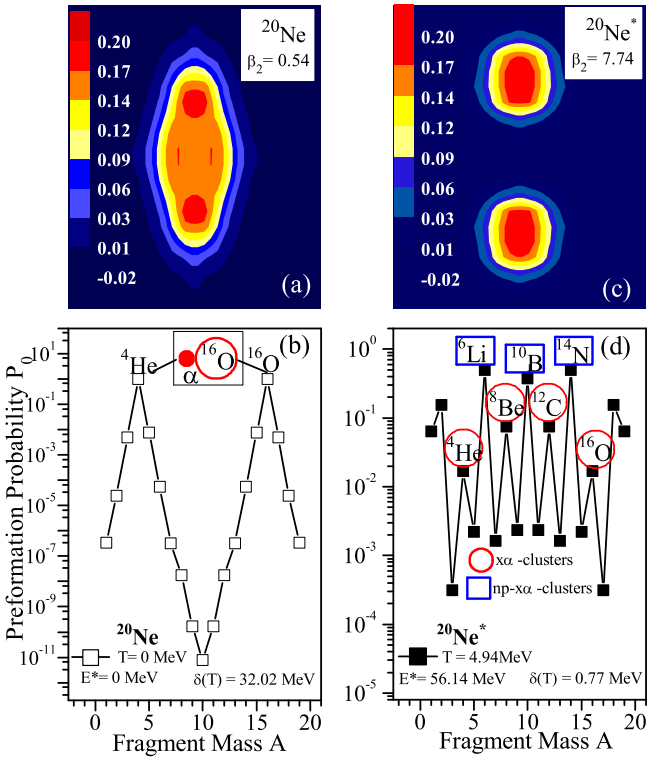

FIG. 1: For the g.s. of ^{20}Ne, a) the RMFT calculated matter density distribution and, b) within QMFT, the calculated preformation profile P_0 of different clusters, and the c) and d) same as (a) and (b), respectively, but for the excited state, are plotted.

is α+^{16}O or equivalently 5α configuration (Fig.1(b)). The RMFT calculations for intrinsic excited state at higher deformation corresponds to a configuration of two completely separated fragments of equal size, possibly ^{10}B+^{10}B configuration are presented in Fig. 1(c) [5].

Quite interestingly, the clustering profile changes drastically with an increase in energy within framework of QMFT as shown in Fig.1(d). In addition to α+^{16}O another xα-type configurations alongwith ^{10}B cluster is preformed which is in consonance with the microscopic theory results shown in Fig.1 (c) as well as with results of density functional formalism [6]. These results are in agreement with Ikeda diagram revealing that more number of α cluster structures appear with increase in threshold energy [3]. Moreover, np-xα type clusters are more probable than xα-type clusters (shown by boxes), further details are given in the Ref. [7].

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