REACTIONS WITH α-CONJUGATE NUCLEI — RESULTS AND PERSPECTIVES*

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In this paper, we report on some results for study of the decay of hot ^{28}Si in ^{28}Si+^{12}C and ^{40}Ca in ^{40}Ca+^{40}Ca reactions at 35 MeV/nucleon. The selection of projectile fragments and statistical test revealed that there are important dynamic effects in mid-peripheral and central reactions at 35 MeV/nucleon. Further investigation of the α-conjugate nuclei decay have been initiated, including the study of density and temperatures.

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1. Introduction

Atomic nuclei are commonly described as systems of strongly interacting fermions, namely neutrons and protons. However, in experiments we observe the existence of phenomena that can be explained by considering nuclei as systems composed of bosonic clusters, the most common being α (^{4}He) particles [1]. We call such nuclei α-conjugate. In the cooperation with the group from the Cyclotron Institute at Texas A&M University and with the use of NIMROD detecting array [2], we have pursued a study of the decay properties of α-conjugate composite states by using a combination of beams and targets of α-conjugate nuclei. Our experiments employed 10, 25, 35 MeV/u beams of ^{40}Ca and ^{28}Si incident on ^{40}Ca, ^{28}Si, ^{12}C and ^{180}Ta targets. It is important to note that in this energy region, we mostly detect projectile-like fragments from mid-peripheral events.

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2. Event selection and tests of statistical behaviour

Our previous analyses of near-Fermi-energy collisions [3, 4] indicate that significant proton emission occurs in the earliest stages of the collision as the nucleon momentum distributions are thermalizing, not in the later stage disassembly. In further analysis we focus on events for which the total mass $A_{\mathrm{TOT}} = 40$ (for ^{40}Ca $+ ^{40}$Ca reaction) or $A_{\mathrm{TOT}} = 28$ (for ^{28}Si $+ ^{12}$C reaction) and total charge $Z_{\mathrm{TOT}} = 20$ or 14. However, in this selection we have neglected both protons and neutrons. Horn and coworkers suggested that the ratio of average excitation energy to the average exit channel separation energy (Q value) could be used as a test for statistical emission from highly excited lighter nuclei [5–10]. They concluded that the ratio should be constant with a value near 2. They also concluded that the statistical variance of this ratio would be small enough to enable this ratio to be used as an identifier of statistical de-excitation on an event-by-event basis [10]. In figure 1, a plot of average excitation energy E^* *versus* exit channel separation energy $-Q$ for the decay of ^{40}Ca (left panel) and ^{28}Si (right panel) is presented. A linear fit to these data leads to slopes equal 2.39 and 2.17, for ^{40}Ca and ^{28}Si, respectively. For both decaying systems, the slope above 2

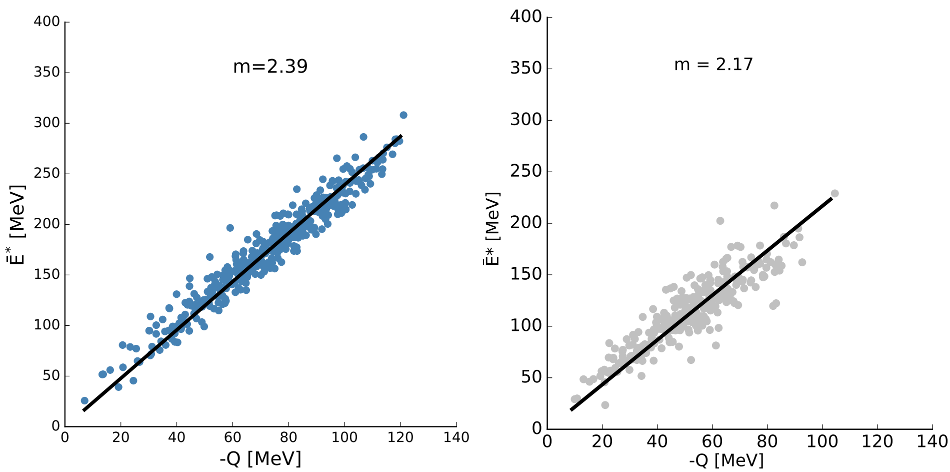

Fig. 1. Average excitation energy *versus* exit channel separation energy for the de-excitation channels of ^{40}Ca (left) and ^{28}Si (right) selected as described in the text.

(for ^{40}Ca well above 2) may be an indication of important, non-statistical or dynamical reaction mechanism for those decaying channels. A closer investigation of that problem is shown in figure 2, where the ratio of average excitation energy to the exit channel separation energy, $(\bar{E}^*/-Q)$, *versus* $-Q$ indicates that some prominent channels, particularly at lower separation energies, have ratios well above the average values. They have been identified as α-like exit channels by using open diamonds. It can be seen from figure 2 that α-conjugate channels of decaying ^{40}Ca are those with the largest values of $E^*/-Q$ from the systematics. Their ratios are well above the values for the other channels with similar separation energies.

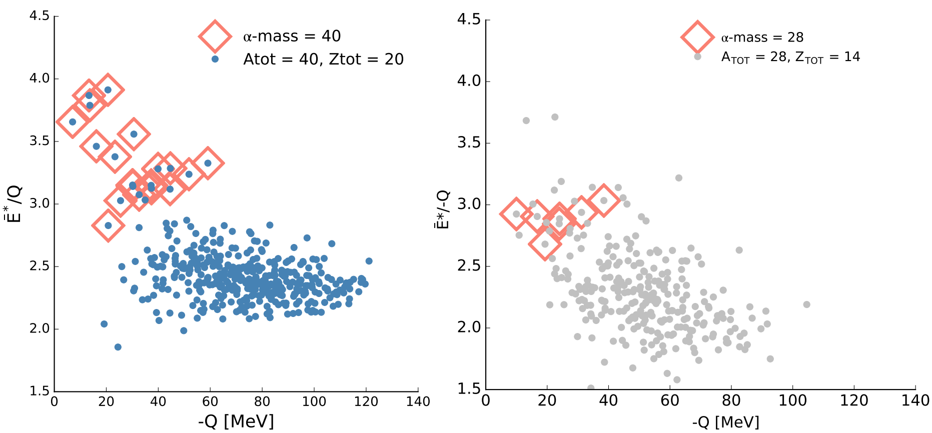

Fig. 2. Ratio of average excitation energy to the exit channel separation energy *versus* exit channel separation energy for the de-excitation channels of ^{40}Ca (left) and ^{28}Si (right) selected as described in the text.

3. α-conjugate exit channels

For further analyses, we have chosen to focus on those events for which α mass (α particles plus α-conjugate fragments) equals 40 (for ^{40}Ca + ^{40}Ca reaction) or 28 (for ^{28}Si + ^{12}C reaction) and compare the properties of all possible exit channels for the disassembly of the ^{40}Ca or ^{28}Si nuclei into α particles or α-conjugate nuclei. The results of the analyses for the ^{40}Ca nucleus may be found in [11]. The investigation of the ^{28}Si decay onto 7α led to a possible observation of resonance structures [12]. These structures may indicate the population of toroidal high-spin isomers (THSI) such as those predicted by a number of recent theoretical calculations [13–16]. The analogical investigation has been performed for the decay of ^{40}Ca nuclei onto 10α, however, the signature of THSI was not found. We strongly encourage further experimental work on collisions of light α-conjugate systems, both for the production of exotic clustered states and for the investigation of the dynamical evolution during such collisions. A higher granularity detector system and addition of γ-ray detection could offer significant improvements for such studies.

4. Temperature and density of hot decaying ^{28}Si and ^{40}Ca

The temperatures and mean partial densities of different portions of the colliding systems can be estimated by studying the measured particle quadrupole momentum and multiplicity fluctuations, as well as mean particle multiplicities, according to the method described in [17, 18]. The method takes into account the fermionic and bosonic nature of the particles (this implies specific event selection) and their mutual Coulomb repulsion [19]. For our analysis, we have selected the projectile-like sources consisting of only bosonic-like fragments (ground spin equals to 0), only fermionic-like fragments (partial ground spin), only even–even nuclei, only odd–odd nuclei, only even–odd nuclei and only α-conjugate nuclei respectively. For the last class of events (only α-conjugate nuclei) we employed the total α-mass 40 (for ^{40}Ca decay) or 28 (for ^{28}Si decay) to select the projectile-like sources. For the remaining class of events, the total mass $A_{\rm TOT}$ was set to 40 or 28, depending on the analysed system. Figure 3 shows preliminary results of local partial densities *versus* temperatures probed by bosons (d, α) for ^{40}Ca (top) and ^{28}Si (bottom) decaying into the type of matter for which the number of events was statistically significant. As it can be seen in the figure, we obtained similar results, regardless the event selection. It is thus necessary to perform the calculations for other types of matter (fermionic, odd–odd

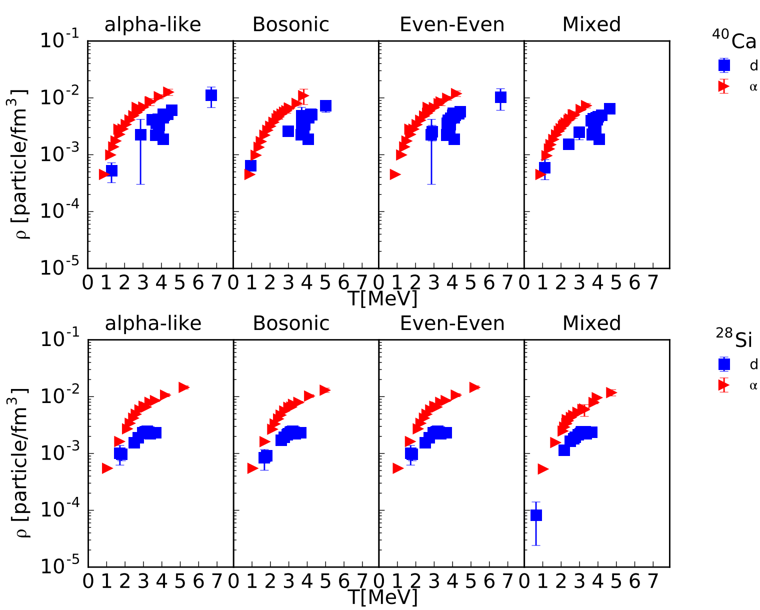

Fig. 3. Local partial densities *versus* temperatures probed by deuterons and αparticles for ^{40}Ca (top) and ^{28}Si (bottom) decaying into different type of matter.

etc.). The number of events decaying into those types of matter is large enough for such a calculation in the case of ^{28}Si decay, but makes the interpretation of results difficult for the ^{40}Ca decay. It is worth to notice different temperature and density experienced by deuterons in the decay of ^{40}Ca and ^{28}Si. These and other aspects of this research, as comparison with the results from theoretical calculations or examination of the secondary decay influence on the results, are ongoing.

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