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Clustering effects in ^{48}Cr composite nucleus produced via the reaction ^{24}Mg + ^{24}Mg at the excitation energy of 60 MeV

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Abstract. The reaction ^{24}Mg + ^{24}Mg was used to produce the composite nucleus ^{48}Cr at 60 MeV of excitation energy where a narrow resonance (170 KeV) has been found by measuring the elastic and inelastic channels. To determine the occurrence of deformation of this compound nucleus and its possible connection with the resonances and the hypothetical cluster structure, evaporative Light Charged Particles (LCP) were measured and compared to Statistical Model (SM) predictions. The experiment was performed at LNL using the 8πLP apparatus. The comparison of the evaporation residue-LCP coincidence angular distributions and LCP energy spectra with SM calculations supports the presence of a very large deformation of the composite nucleus ^{48}Cr that scales with the angular momentum.

1. Introduction

In many reactions involving light α-like reacting partners there is a consistent occurrence of narrow resonances in the elastic and inelastic channels [1]. Examples of such systems are ^{24}Mg + ^{24}Mg, ^{12}C + ^{12}C, ^{28}Si + ^{28}Si or ^{12}C + ^{28}Si. Furthermore, these resonances are linked to the formation of an intermediate highly deformed system with a lifetime comparable to the time scale of evaporation from compound nuclei at moderate excitation energy. The origin and characteristic features of these resonances and their connection with the cluster structure of the two reacting partners is a matter of discussion.

One recurring hypothesis is that the intermediate resonant states, with very large deformations, may act as doorway states to fusion. In this respect, entrance channel dynamics may contribute to the selective population of highly deformed configurations with a lifetime comparable to the evaporative time scale. The memory of the entrance channel asymmetry may therefore persist in the Light Charged Particles (LCP) evaporative angular distributions and energy spectra. Consequently, evaporative LCP can be a good probe to independently estimate the deformation of these states.

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In this framework, we have undertaken an exploratory study on the system ^{24}Mg + ^{24}Mg by using LCP evporative emission. A narrow resonance with J=36$\hbar$ at E_x=60 MeV was observed [2] for this system. Surprisingly, the resonance spin is higher than the grazing angular momentum in the entrance channel ($L_{graz} = 32\hbar$) by 4$\hbar$, raising many questions on this matter. Furthermore, the width of 170 KeV implies a lifetime of 4x10^{-21}s, ten times longer than a typical nuclear lifetime. A study [3] has been recently carried out on the J=36$\hbar$ resonance in order to investigate its decay into the inelastic and fusion-evaporation channels. The properties of the studied resonance are in agreement with the molecular model in [4] and the intermediate system's shape predicted is very close to a highly prolate deformed ^{48}Cr after a Jacobi shape transition as calculated by the Lublin-Strasbourg-Drop (LSD) model [5] between J=28$\hbar$ and 32$\hbar$ at E_x = 60 MeV. To estimate the extent of deformation of the excited intermediate system, evaporative LCP are measured in coincidence with Evaporation Residues (ER) and compared with the SM predictions which include a treatment of a spin-dependent compound nucleus shape.

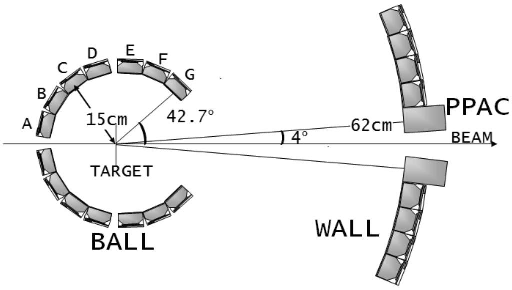

Figure 1. Schematic layout of the experimental apparatus. The letters from A to G label the 7 rings of the BALL section.

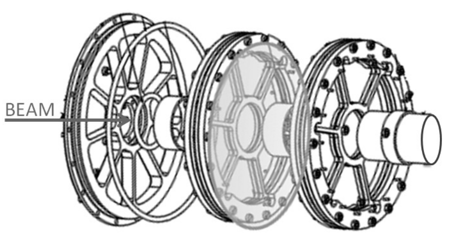

Figure 2. Scheme of the PPAC system.

2. Experimental procedure and observables

The experiment was performed at the Tandem accelerator of Laboratori Nazionali di Legnaro. A pulsed beam of ^{24}Mg of intensity of about 5-10 enA was used to bombard a ^{24}Mg target $60\mu g/cm^2$ thick on $15\mu g/cm^2$ C backing. The chosen beam energy of 91.4 MeV corresponds to the resonance $J^{\pi}=36\hbar^{+}$ at E_x=60 MeV in the ^{48}Cr compound nucleus (CN). The light charged particles emitted from the CN de-excitation were measured with the 8πLP apparatus [6].

The detector system, shown schematically in Fig. 1, is constituted by about 250 telescopes made by a ΔE stage of Si detectors followed by a second stage of CsI detectors, geometrically arranged in two sections: the BALL and the WALL. Particle identification is carried out by using the ΔE-E, Pulse Shape Discrimination and time of flight techniques. The BALL consists of 7 rings of detectors, labeled from A to G each containing 18 telescopes. ER were detected by a circular PPAC system (Fig. 2). The LCP and the ER events were collected by requiring the OR mode of singles and coincidence mode, including up to four-fold events between LCP. This triggering scheme was very effective for the evaluation of the multiplicities because it provided, in the same run, for the measurement of the singles and coincidence yields.

3. Experimental data and Statistical model simulations

SM calculations were performed with the code LILITA_N97 [7] which models the multistep evaporative decay of a compound nucleus by using the Hauser-Feshbach formulation of the SM. The program produces laboratory frame energy spectra and angular distributions for both ER and LCP, once the constraints imposed by the experimental apparatus are included. In this study we simulated the LCP decay from a normal and highly deformed ^{48}Cr composite system using two sets of deformability parameters δ_1 and δ_2 to modulate the deformation. These parameters are usually adopted in the statistical model to calculate the moment of inertia $\Im$ of the emitting nucleus as a function of the angular momentum J through the expression:

$$\Im = \Im_0 \cdot (1 + \delta_1 \mathrm{J}^2 + \delta_2 \mathrm{J}^4) \tag{1}$$

In the Rotating Liquid Drop Model (RLDM) calculation a set of deformability parameters corresponding to a deformation with an axis ratio b/a=1.51 for J=36 ħ were used. In the calculation indicated as Highly Deformed for the angular momenta in the window J=28ħ − 36ħ (around the angular momentum of the resonance) very large deformations were used (b/a= 3.0) whereas for lower angular momenta the RLDM deformation was assumed.

Our goal was to find an indication of the occurrence of a large deformation in this α-like system, and possibly its link with the observed resonances by studying the LCP evaporation at the excitation energy corresponding to a resonance. From Fig. 3 and 4 the experimental data are consistent with a deformation of the compound nucleus larger than the one predicted by the RLDM. The large deformation found for the nucleus ^{48}Cr at the resonance energy is, however, a common feature of non α-like system as well, where no resonances appear, though the deformation appears to be less pronounced. The cases of the reactions ^{28}Si + ^{28}Si [8] and ^{30}Si + ^{30}Si [9] are examples. This means that the large deformation of ^{48}Cr compound nucleus is not necessarily connected with the presence of resonances. Consequently, the resonances might be more strictly related to the α cluster composition of the projectile and target and to the mass symmetry of the entrance channel. To clearify on this point a measurement on the system ^{24}Mg + ^{24}Mg at an off-resonance energy would be very important.

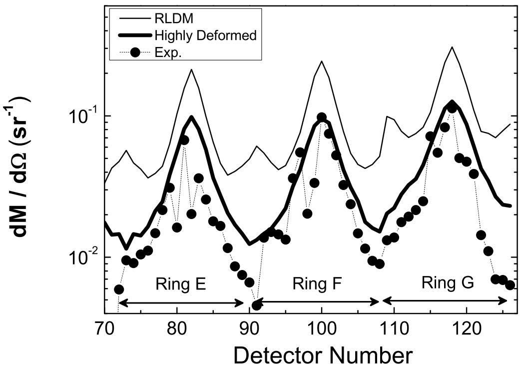

Figure 3. Experimental angular multiplicity distributions (full dots) of α particles in coincidence with ER versus the identification number of the BALL detectors in rings E, F and G compared to the simulations.

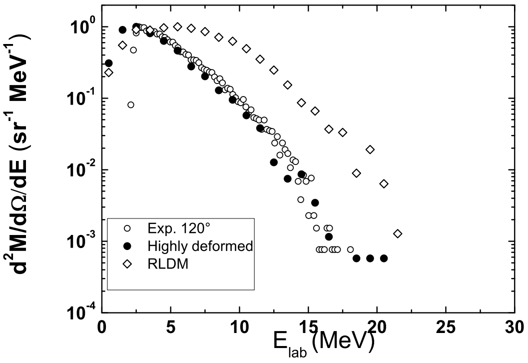

Figure 4. Laboratory energy spectrum of α particles at 120° in coincidence with ER compared to simulations

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