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INVESTIGATION OF THE DYNAMICAL DIPOLE MODE IN THE ^{192}Pb MASS REGION*

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The dynamical dipole mode was investigated in the mass region of the ^{192}Pb compound nucleus, by using the ^{40}Ca + ^{152}Sm and ^{48}Ca + ^{144}Sm reactions at $E_{\rm lab} = 11$ and 10.1 MeV/nucleon, respectively. Both fusion–evaporation and fission events were studied simultaneously for the first time. Preliminary results obtained with a part of the collected statistics show that the dynamical dipole mode survives in reactions involving heavier mass reaction partners than those investigated in our previous works. As it represents a fast cooling mechanism on the fusion path, it could be used to favor the synthesis of super heavy elements through "hot" fusion reactions.

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1. Introduction

In charge asymmetric heavy-ion reactions, a large amplitude collective dipole oscillation develops along the symmetry axis of the dinuclear system due to the presence of a non vanishing dipole moment between the interacting ions [1]. This oscillation is the so-called dynamical dipole mode that decays emitting prompt photons, in addition to the photons originating from the Giant Dipole Resonance (GDR) thermally excited in the hot compound nucleus (CN). The dynamical dipole radiation is concentrated at a lower centroid energy than that of a statistical GDR built in a spherical nucleus of similar mass due to the high deformation of the emitting source and it has an anisotropic angular distribution around 90° with respect to the beam direction. Moreover, its intensity depends on the reaction dynamics and thus, on the incident energy [2].

In our previous works [3, 4] we performed a systematic study of the dynamical dipole features dependence on the incident energy, by employing the reaction pairs: ^{32,36}S+^{100,96}Mo at $E_{\rm lab}$ = 6 and 9 MeV/nucleon and ^{36,40}Ar+^{96,92}Zr at $E_{\rm lab}$ = 16 MeV/nucleon to form, through entrance channels having different charge asymmetries, the ^{132}Ce compound nucleus at different excitation energies with identical spin distribution. The experimental evidence of the dynamical dipole was the observation of an extra yield in the γ-ray energy spectrum of the charge asymmetric system with respect to the charge symmetric one of each reaction pair, at a centroid energy lower than that of the GDR and with an highly anisotropic angular distribution [3, 4]. The extracted centroid energy and width did not change within error bars with increasing energy in agreement with BNV predictions. The extra γ yield integrated over energy and over solid angle presented a pronounced maximum intensity at $\sim$ 9 MeV/nucleon while BNV calculations showed a smoother evolution with incident energy. Recently, new results [5] appeared on the dynamical dipole mode excited in the same compound nucleus employing the ^{16}O+^{116}Sn charge asymmetric reaction at $E_{\rm lab}$ = 8 and 15.6 MeV/nucleon. The comparison of the two data sets with each other and with the theoretical models indicates that more efforts should be done from both an experimental and a theoretical point of view in order to clarify the interplay between the different parameters influencing the dynamical dipole mode.

2. The dynamical dipole mode in the mass region of the ^{192}Pb: experimental results

Because of its prompt nature, the dynamical dipole mode could be an interesting cooling mechanism of the composite system, facilitating the formation of super heavy elements. Its decay with emission of pre-equilibrium dipole photons in charge asymmetric "hot" fusion reactions would produce a lowering of the composite system excitation energy, increasing therefore its survival probability against fission and thus, the evaporation residue cross-section. However, it is predicted in [6] that the dynamical dipole γ yield should decrease in collisions involving heavier mass partners due to the fact that the reactions with small nuclei are less damped than those involving more nucleons. In order to examine the possibility to take advantage of the dynamical dipole mode γ decay in the formation of super-heavy elements and to verify experimentally if this pre-equilibrium effect survives in heavier systems than those studied up to now, we extended our investigation of the dynamical dipole mode in the mass region of the ^{192}Pb compound nucleus, formed at an excitation energy of 236 MeV, employing the ^{40}Ca+^{152}Sm and ^{48}Ca+^{144}Sm reactions at $E_{lab} = 440$ MeV and 485 MeV, respectively.

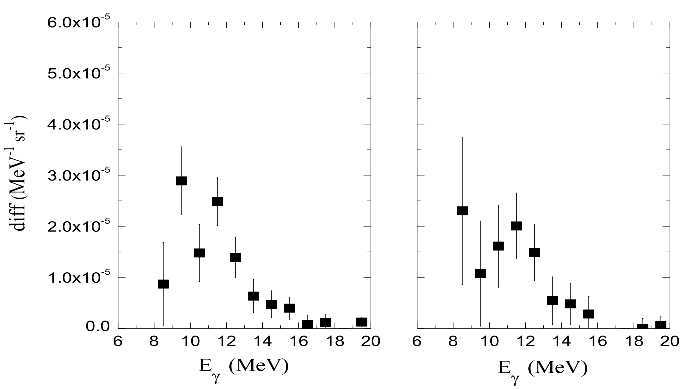

Fig. 1. γ-ray spectra difference of the ^{40,48}Ca+^{152,144}Sm reactions in fusion–evaporation (left) and fission events (right).

The experiment was performed by using the ^{40}Ca (^{48}Ca) pulsed beam provided by the Superconducting Cyclotron of the Laboratori Nazionali del Sud (LNS, Italy), impinging on a 1 mg/cm^2 thick ^{152}Sm (^{144}Sm) target. The compound nucleus ^{192}Pb was formed in the two reactions with identical spin distribution ($L_{max} = 74\hbar$) at the same excitation energy of 236 MeV, evaluated with the empirical formula of [7]. The entrance channel mass asymmetry was 0.22 and 0.18 for the ^{40}Ca+^{152}Sm and ^{48}Ca+^{144}Sm reaction, respectively, while the initial dipole moment was quite different for the two systems, namely 30.6 fm for the more charge asymmetric one and 5.3 fm for the charge symmetric one. Therefore, in this experiment all the reaction parameters were kept identical except for the initial dipole moment (as in our previous experiments). The γ-rays and the light charged particles were detected by using the MEDEA experimental apparatus [8], consisting of

180 BaF_2 scintillators. The fusion–evaporation residues were detected by four position sensitive Parallel Plate Avalanche Counters (PPACs) located symmetrically around the beam direction at 70 cm from the target and covering the angular range from $\theta = 3°$ to $10.5°$. The fission events were selected by detecting the two kinematically coincident fission fragments with four position sensitive PPACs, centered at $\theta = 52.5°$ symmetrically around the beam axis at 16 cm from the target, placed such that one pair defined a mid-plane perpendicular to the two BaF_2 modules (placed at $\theta = 90°$ and $\phi = 0°$, $180°$) and the other a collinear one. This configuration allowed the measurement of photons emitted parallel (0°) or perpendicular (90°) to the spin axis of the composite system.

More than half of the collected statistics has been analyzed for scintillators in the rings located at $\theta_{\rm lab} = 82°$, $97°$ and $112°$ with respect to the beam direction. In Fig. 1 the difference between the γ-ray spectra of the two reactions for fusion–evaporation and fission events is presented. The observed dynamical dipole γ-ray yield is concentrated at a centroid energy $E_\gamma \sim 10$–11 MeV, lower than that of the GDR, $E_{\rm GDR} = 13$ MeV, confirming the high deformation of the emitting source. Therefore, in this work we found that the dynamical dipole mode survives in composite systems of mass $A = 192$ at an incident energy of 11 MeV/nucleon. However, the associated γ yield is comparable with that obtained for reactions leading to $A \sim 130$ composite systems despite the smaller initial dipole moment of the S + Mo and Ar + Zr systems. This observation supports the theoretical predictions of a decrease of the dynamical dipole yield with increasing the mass of the reaction partners [6].

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