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PROMPT DIPOLE γ-RAY EMISSION IN FUSION HEAVY-ION COLLISIONS: INCIDENT ENERGY DEPENDENCE*

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The evolution with beam energy of the prompt dipole radiation, related with entrance channel charge asymmetry effects, was studied in the fusion reactions: ^{36}Ar+^{96}Zr and ^{40}Ar+^{92}Zr at $E_{\rm lab} = 16$ and 15.1 MeV/u, respectively. Both reactions populate, through entrance channels having different charge asymmetries, the same compound nucleus at the same average excitation energy and with identical spin distribution. By studying the γ-ray energy spectra of the considered reactions, and by comparing the present result with previous ones obtained at lower energies, we deduce that the prompt dipole γ-ray emission presents a maximum value at 9 MeV/u and decreases toward lower and higher energies. Moreover, the centroid and the width of the preequilibrium dipole component were found to remain constant, within the errors, by increasing the beam energy.

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1. Introduction

The prompt dipole γ-ray emission, observed in charge asymmetric dissipative heavy-ion reactions [1–3], is related to the direct excitation of a Giant Dipole Resonance (GDR) in the dinuclear system. This is the so-called dynamical dipole mode, occurring because of a non vanishing dipole moment between the colliding ions. In recent theoretical works [5] it was suggested that this kind of preequilibrium γ-ray emission depends on the incident energy. A systematic study of such a dependence is of great interest because it could provide us information on the GDR damping width, on the symmetry energy of the nuclear matter at lower densities than the saturation one and it could be of aid in the formation of superheavy elements. Motivated by the above points we started in [3, 4] to study the evolution of the prompt dipole radiation with beam energy in fusion reactions by forming the ^{132}Ce compound nucleus at excitation energies of 117 MeV ($E_{\rm lab} = 6$ MeV/u) and 173.5 MeV ($E_{\rm lab} = 9$ MeV/u) through the reaction pair ^{32,36}S+^{100,96}Mo.

In this contribution we present the continuation of our investigation by forming a compound nucleus in the vicinity of $A = 132$ at an excitation energy of 304 MeV through the reaction pair ^{36}Ar+^{96}Zr and ^{40}Ar+^{92}Zr at $E_{\rm lab} = 16$ and 15.1 MeV/u, respectively. As in the previous measurements, all the parameters were kept identical between the two reactions except from the entrance channel charge asymmetry and thus, from the initial dipole moment. So any difference in the γ-ray emission between the two reactions can be safely ascribed to the difference in the entrance channel charge asymmetry. Moreover, we notice that the results of our new measurement can be compared with those of the previous ones as they refer to the same initial dipole moment difference and to a very similar initial mass asymmetry difference.

2. Experiments and results

The reactions ^{36,40}Ar+^{96,92}Zr were performed by using the ^{36,40}Ar pulsed beams provided by the Superconducting Cyclotron of the Laboratori Nazionali del Sud (Italy), impinging on a 450 μg/cm^2 thick ^{96}ZrO$_2$ target (enriched to 95.63% in ^{96}Zr) and on a 600 μg/cm^2 thick ^{92}ZrO$_2$ target (enriched to 95.36% in ^{92}Zr). The beam consisted of $\sim$1 ns wide bunches with a 150 ns separation. The γ-rays and the light charged particles were detected by using the 180 BaF$_2$ modules of the MEDEA experimental apparatus [6] covering 3.7π sr. The discrimination between γ-rays and light particles was performed by combining the time of flight information and the pulse shape analysis of the BaF$_2$ signal.

The fusionlike residues were detected by four position sensitive Parallel Plate Avalanche Counters (PPAC's) located symmetrically around the beam direction at 70 cm from the target. The total solid angle covered by the PPAC's was 0.089 sr. The fusionlike events were selected off-line in the bidimensional plot of the ΔE versus the TOF of the reaction products detected in each PPAC. Down-scaled single events together with coincidence events between a PPAC and at least one fired BaF_2 scintillator were collected during the experiment. The coincidence request eliminated any cosmic ray contamination of the γ-ray spectra.

In Fig. 1 the bremsstrahlung-subtracted linearized γ-ray energy spectra for the ^{40}Ar+^{92}Zr (circles) and the ^{36}Ar+^{96}Zr (squares) fusion-evaporation reactions are reported. The γ-ray spectra were linearized by dividing them by the same theoretical γ-ray spectrum, calculated with the CASCADE code, where a constant dipole strength and a level density parameter $a = A/10$ MeV^{-1} were considered and folded by the experimental setup response function (for more details see [3, 4]).

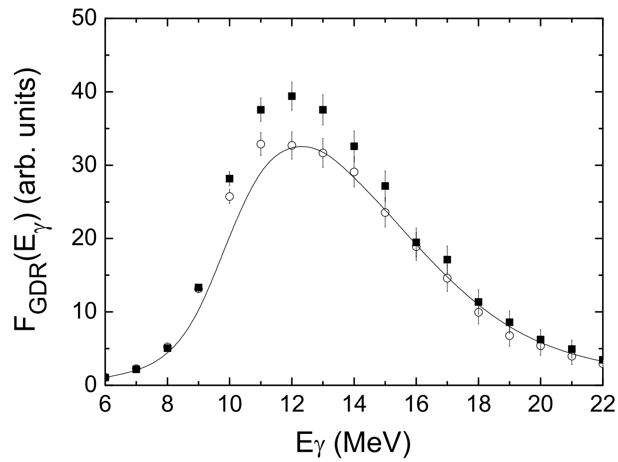

Fig. 1. Bremsstrahlung-subtracted linearized γ-ray energy spectra for fusion-evaporation events: ^{36}Ar+^{96}Zr (squares) and ^{40}Ar+^{92}Zr (circles) reaction at $E_{\mathrm{lab}} = 16$ and 15.1 MeV/u, respectively. The solid line is a linearized theoretical γ-ray spectrum calculated with the CASCADE code (for details see text).

The solid line in the same figure corresponds to a linearized theoretical γ-ray spectrum obtained with the CASCADE code and folded by the experimental setup response function. In this calculation the level density parameter was $a = A/10$ MeV^{-1}, while the dipole strength function was taken as a Lorentzian function with centroid $E_{\mathrm{GDR}} = 14$ MeV, width $\Gamma_{\mathrm{GDR}} = 13$ MeV and strength $S_{\mathrm{GDR}} = 1$ of the energy-weighted sum rule. We see in Fig. 1 that the data of the ^{36}Ar+^{96}Zr reaction present a larger yield in the compound nucleus GDR energy region which can be ascribed to the different initial dipole moment. By integrating these spectra between 8 and 21 MeV, an increase of the GDR γ-ray intensity of 14% was found by going towards the more charge asymmetric system. A comparison of the present result with the previous ones [3, 4] shows that the prompt dipole radiation intensity presents a maximum at a beam energy of 9 MeV/u and it decreases at lower and higher beam energies. This behavior is in good agreement with theoretical calculations, performed within the Boltzmann–Nordheim–Vlasov transport model framework and based upon a collective bremsstrahlung approach [5].

In Fig. 2 the differences between the bremsstrahlung-subtracted γ-ray energy spectra at 9 and $\sim$ 16 MeV/u are shown. In each picture the solid line is a fit of the data performed with a Lorentzian curve folded with the corresponding experimental set up response function by using the following values for the centroid and the width: $E_{\rm dyn\ dip} = (11.4 \pm 0.3)$ MeV and $\Gamma_{\rm dyn\ dip} = (3.0 \pm 0.5)$ MeV for $E_{\rm lab} = 9$ MeV/u and $E_{\rm dyn\ dip} = (12.0 \pm 0.6)$ MeV and $\Gamma_{\rm dyn\ dip} = (3.7 \pm 1.4)$ MeV for $E_{\rm lab} \sim 16$ MeV/u. We notice that the centroid energy and the width of the dynamical dipole mode were found to remain constant within errors when increasing the beam energy. Furthermore, the centroid energy was found to be lower than that ($E_0 =$ 15.1 MeV) of a GDR built on the ground state of a spherical nucleus with similar mass, in good agreement with theoretical predictions, suggesting that the oscillation occurs along the symmetry axis of a deformed dinuclear system.

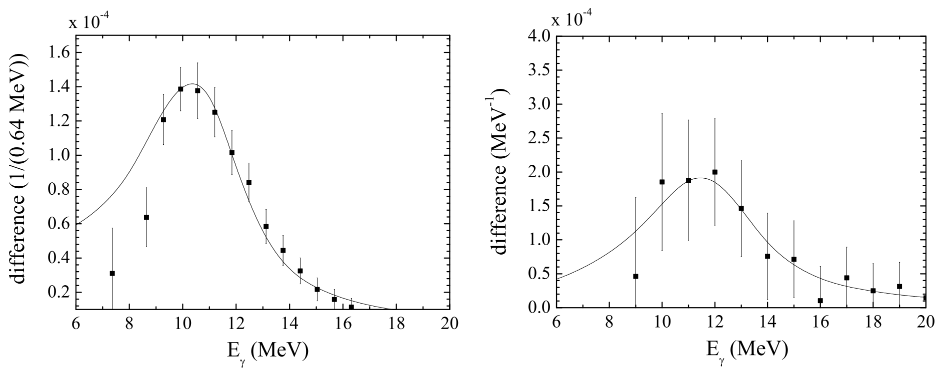

Fig. 2. Difference between the bremsstrahlung-subtracted γ-ray energy spectra at 9 (left) and $\sim$ 16 MeV/u (right). The solid lines are a fit of the data as described in the text.

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REFERENCES

[1] S. Flibotte *et al.*, *Phys. Rev. Lett.* **77**, 1448 (1996); M. Cinausero *et al.*, *Il Nuovo Cimento* **111**, 613(1998).

[2] D. Pierroutsakou *et al.*, *Eur. Phys. J.* **A16**, 423 (2003); *Nucl. Phys.* **A687**, 245c (2001).

[3] D. Pierroutsakou *et al.*, *Eur. Phys. J.* **A17**, 71 (2003).

[4] D. Pierroutsakou *et al.*, *Phys. Rev.* **C71**, 054605, (2005).

[5] V. Baran *et al.*, *Nucl. Phys.* **A679**, 373 (2001); *Phys. Rev. Lett.* **87**, 182501 (2001).

[6] E. Migneco *et al.*, *Nucl. Instrum Methods* **A314**, 31 (1992).