LIGHT CHARGED PARTICLE EMISSION AND THE GIANT DIPOLE RESONANCE IN Ce NUCLEUS*

F. Gramegna[a], S. Barlini[a], V.L. Kravchuk[a], A.L. Lanchais[a]
O. Wieland[b], A. Bracco[b], A. Moroni[b], G. Casini[f], G. Benzoni[b]
N. Blasi[b], S. Brambilla[b], M. Brekiesz[c], M. Bruno[d], F. Camera[b]
M. Chiari[f], F. Crespi[b], E. Geraci[d], B. Guiot[d], M. Kmiecik[c]
S. Leoni[b], A. Maj[c], P.F. Mastinu[a], P. Mason[b], B. Million[b]
A. Nannini[f], A. Ordine[e], and G. Vannini[d]

[a]Laboratori Nazionali di Legnaro, I.N.F.N., Legnaro (Padova), Italy
[b]I.N.F.N. and Dipartimento di Fisica dell'Universitá di Milano, Milano, Italy
[c]The H. Niewodniczański Institute of Nuclear Physics, PAN, Kraków, Poland
[d]I.N.F.N. and Dipartimento di Fisica dell'Universitá di Bologna, Bologna, Italy
[e]I.N.F.N. Sezione di Napoli, Napoli, Italy
[f]I.N.F.N. Sezione di Firenze, Firenze, Italy

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The ^{132}Ce compound nucleus was formed in fusion reactions ^{64}Ni + ^{68}Zn and ^{16}O + ^{116}Sn at different excitation energies. High energy γ-rays have been measured in coincidence with Evaporation Residues (ER) in these reactions. At the same time Light Charged Particles (LCP) were measured with the same gate on ER for all the reactions in order to verify and compare the amount of pre-equilibrium emission using mass-symmetric and mass-asymmetric entrance channels. Results on α-particle spectra will be presented together with a moving source fit analysis.

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1. Introduction

The Giant Dipole Resonance (GDR) in nuclei is the best known collective mode, which is built both on the ground state and on the excited state of the hot rotating nuclei. While at low incident energies the studies performed generally by using fusion reactions between two nuclei bring to quite unambiguous results, at high excitation energy the situation is more

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complex. One of the outstanding problems is, in fact, the behavior of the width of the GDR built on excited states at high excitation energy corresponding to temperatures greater than 2 MeV [1]. Under this limit the width is increasing rapidly with bombarding energy due to the increasing spin induced deformation and increasing thermal shape fluctuations. In this regime, therefore, the global systematics is reasonably well described by the shape fluctuation calculation in which the quadrupole deformation of the nucleus is assumed to couple adiabatically to the GDR vibration [2–4]. But beyond the bombarding energy, where the angular momentum saturates (that is the maximum angular momentum the nucleus can sustain), it has been argued that the width should grow much more slowly. Many experiments have been interpreted in terms of a saturating width and at a higher energy a saturating GDR γ-ray multiplicity. It is, however, very difficult to reliably reconstruct the excitation energy in this bombarding energy range, because different phenomena start to compete with the complete fusion process. Recently measurements have been performed using the GARFIELD and HECTOR detection systems [5], in which both high energy gamma rays and charged particles emitted in coincidence with ER have been measured. In order to evaluate the role of the pre-equilibrium emission at higher energies we have chosen a system formed through the two different entrance channel mass asymmetries with the different bombarding energies.

2. Experimental set-up

The experiment was performed in the III experimental Hall of the Legnaro National Laboratory using the GARFIELD [6, 7] apparatus combined with the 8 large BaF_2 detectors of the HECTOR set-up [9]. The large scattering chamber was equipped with one of the two GARFIELD drift chambers (gaseous micro-strip coupled with CsI(Tl) crystals) which covers the angular range from $\theta = 30°$ to $90°$, while the BaF_2 were positioned at backward angles. In the forward direction, between $\theta = 4°$ and $12°$, two couples of Position Sensitive Parallel Plate Avalanche Counters (PSPPAC) were positioned symmetrically with respect to the beam direction. At larger angles, where radiation damage could be relatively small, some lithium drift silicon detectors were positioned between each PSPPAC couple. A pulsed beam (1 ns) was provided by the TANDEM–ALPI accelerator system of LNL.

3. Measurements and preliminary results

The problem of the damping mechanism of the GDR, built on excited states, in the high excitation energy (high temperature) region has been recently connected to the poor determination of the excitation energy of the emitting system. Therefore, exclusive measurements are necessary to get better information on the reaction mechanisms. In this framework some experiments have been recently performed by Kelly *et al.*, [8], who studied the reaction $^{18}O+^{100}Mo$ with the projectile energy varied from 122 to 214 MeV. The light charged particles were measured tagged on high energy γ-rays ($E_\gamma > 10$ MeV). A moving source fit method was used, where both a fast and an evaporative components of the light charged particle emission were assumed. The first component is derived from a fast source, moving with velocity which is in between the velocity of the projectile and the one of the compound nucleus, while the second equilibrated source is, in fact, moving with the CM velocity. This method was leading to an estimation of the pre-equilibrium effect of about 30% for the mass-asymmetric system studied at the higher energy. On this basis the authors of Ref. [8] proposed to correct all the existing data on the GDR width: the excitation energies of the systems were lowered by an amount of energy the pre-equilibrium particles were supposed to have taken away. This conclusion might have been correct for the studied system in a mass-asymmetric reaction, but it is rather unjustified to assume without proving that it is valid for all possible systems for which GDR measurements have been performed. Following the idea that more information was really necessary we performed some very exclusive measurements using two different reactions with different mass asymmetry in the entrance channel: under the same experimental conditions on the ER trigger the coincidence between the ER and the high energy gamma rays was collected together with the one between the ER and the charged particles emitted in the reaction. The measured reactions were the mass-symmetric $^{64}Ni + ^{68}Zn$ at 300, 400 and 500 MeV bombarding energies (corresponding to nominal excitation energies of the ^{132}Ce compound nucleus of 100, 150 and 200 MeV, respectively) and the mass-asymmetric $^{16}O + ^{116}Sn$ at 130 and 250 MeV (with 100 and 200 MeV nominal excitation energies, respectively).

3.1. Preliminary results

The preliminary results of the present work suggest that very interesting information can be derived. The γ-ray spectra for the studied reactions are shown in Ref. [10]. Comparing the two γ-ray yields derived from the reactions at higher bombarding energies of the Ni beam, the difference in the high energy part of the γ-ray spectra results compatible with the simulation prediction. The low energy (statistical) part of the γ-ray spectra is very much the same. On the contrary, comparing the two reactions leading to the same compound nucleus at the same nominal excitation energy, reached through the Ni or O entrance channel, even the statistical part appears to be different. Possible interpretation of this result is linked to the nonequilibrium effects in γ-ray emission when the system is formed through the mass-asymmetric channels [12, 13]. Analysis is still in progress.

The experimental spectra were obtained for α-particle and $Z > 2$ charged particles for the two reactions at the higher energies. Analysis on proton spectra and the lower energies is still in progress.

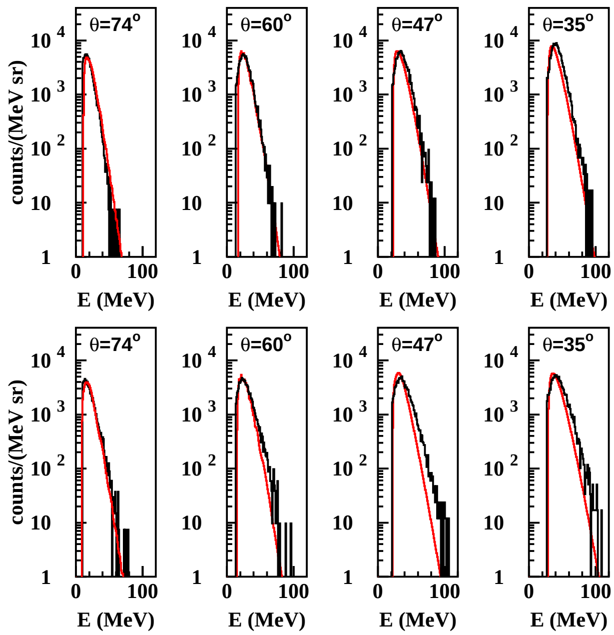

Fig. 1. Upper row — global (simultaneous for different detection angles) moving source fit for the experimental α-particle spectra at four different angles for the Ni + Zn at 400 MeV. Lower row — the same as in upper row, but for the Ni + Zn at 500 MeV.

The analysis of α-particle spectra through a moving source fit analysis (see Fig. 1), clearly shows that at low energy (up to 400 MeV incident energy for the Ni induced reactions) the whole part of the measured cross section gated on ER presents an evaporative behavior from a source with expected emission parameters. In fact, from the moving source fit a value of temperature $T = 4.2$ MeV, an average Coulomb barrier $E_{\mathrm{c}} = 13.2$ MeV and a source velocity $V_{\mathrm{s}} = 1.7$ cm/ns have been obtained in agreement with the statistical model calculations (PACE4 [11]). For the Ni case at 500 MeV bombarding energy the situation is very similar: the fit parameters (in this case $T = 4.5$ MeV, $E_{\mathrm{c}} = 12.4$ MeV and $V_{\mathrm{s}} = 1.9$ cm/ns) are still very close to the predicted. This shows that in the mass-symmetric case almost no pre-equilibrium emission is present at these energies. Therefore, the GDR data obtained in measurements performed through mass-symmetric entrance channels should correspond to the decay of an equilibrated nucleus. The analysis of the oxygen induced reaction is still in progress: preliminary investigation in the 250 MeV bombarding energy case shows that a large part of the cross section cannot be described by only evaporative component. An excess yield due to pre-equilibrium (fast) emission seems to be present. This is partly in agreement with the previous work by Kelly *et al.*, even though we want to stress that further analysis is in progress to quantify better such effects.

4. Conclusions

Interesting results have been obtained from the very exclusive measurements of the high energy γ-rays from GDR and LCP in coincidence with ER emitted in the de-excitation of the compound system ^{132}Ce. The measurements were performed for the different projectile energies and for the different mass asymmetries in the entrance channel. For the system formed through the mass-symmetric channels no pre-equilibrium emission is observed up to the higher energy. It means that the excitation energy of the compound nucleus can be confirmed at the nominal value of 250 MeV corresponding to complete fusion and the decay is dominantly statistical. When more mass-asymmetric projectile-target combination is used and, therefore, the entrance energy per nucleon increases, pre-equilibrium emission starts to be evident in the higher energy range confirming, at least qualitatively, the results by Kelly *et al.* Analyses are in progress and we expect to achieve a consistent picture of such phenomena.

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