

The γ -decay of the GDR in highly excited Ce nuclei

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Received 21 March 2005

Published 12 September 2005

Online at stacks.iop.org/JPhysG/31/S1973

Abstract

The γ -decay of the GDR in the ^{132}Ce compound nuclei produced by the reaction $^{64}\text{Ni}+^{68}\text{Zn}$ at $E_{\text{beam}} = 300\text{ MeV}, 400\text{ MeV}, 500\text{ MeV}$ (E^* of 100 MeV, 150 MeV and 200 MeV) has been measured. We have detected heavy recoil nuclei, light charged particles and γ -rays. The data obtained with the symmetric reaction $^{64}\text{Ni}+^{68}\text{Zn}$ indicate emission from a fully equilibrated compound nucleus as deduced from the analysis of charged particle spectra. The GDR parameters are found to be consistent with the predictions of the thermal fluctuation model.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The damping mechanisms of the GDR in the high temperature region (high excitation energy) are still not well understood [1]. The two main mechanisms giving rise to the spreading of the width which have been identified so far are the collisional damping and the thermal large-amplitude fluctuations of the nuclear shape. The phenomenon of collisional damping is essentially connected with the coupling of the giant modes with the quantal fluctuations of the nuclear surface. Some of the existing models for the collisional damping width predict a constant behaviour with temperature [2–4], in contrast with [5] which predicts an increase with temperature. The second important mechanism at work in the breaking of the strength of the GDR is the coupling of the vibration to the temperature-induced large-amplitude fluctuations (shape fluctuations) of the nuclear surface [6, 7]. In fusion-evaporation reactions

at low excitation energies corresponding to the nuclear temperature $T \leq 2$ MeV, the width of the GDR built on excited states is observed to increase rapidly with bombarding energy (by approximately a factor of 2 by going from 0 to 2 MeV) due to the increase of the spin-induced deformation, and the thermal shape fluctuations [8]. In this regime the global systematics of the GDR width are reasonably well described with calculations made within the thermal shape fluctuation model and using the $T = 0$ MeV value of the collisional damping width (namely assuming the intrinsic width equal to that of the photo-absorption cross section) [8, 9]. In very hot nuclei with the excitation energy larger than $E^* \geq 100$ MeV, there is an open question whether the width of the GDR saturates or increases [9]. This has been newly addressed particularly in relation to the problem of how well one can determine the excitation energy of the nucleus on which the GDR is built. Up to now almost all the performed measurements are essentially inclusive and particularly at the highest excitation energies ($E^* > 100$ MeV) exclusive measurements are necessary for the understanding of this problem. In this paper we report on recent measurements in which both high-energy γ -rays and light charged particle (LCP) emission in coincidence with (heavy) evaporation residues are measured using the GARFIELD [10] plus HECTOR [11] setup. In order to evaluate the contribution of the pre-equilibrium emission we have chosen two different reactions leading to the same excitation energies. The measured reactions were the symmetric $^{64}\text{Ni} + ^{68}\text{Zn}$ at $E_{\text{beam}} = 300, 400$ and 500 MeV ($E^* = 100, 150$ and 200 MeV) and the asymmetric $^{16}\text{O} + ^{116}\text{Sn}$ at $E_{\text{beam}} = 130$ and 250 MeV ($E^* = 100$ MeV and 200 MeV).

2. Experimental method

The experiment has been made using the GARFIELD setup combined with the eight BaF_2 detectors of the HECTOR array. The GARFIELD vacuum scattering chamber was equipped with one of the two drift chambers of the GARFIELD apparatus (gaseous microstrips coupled with CsI(Tl) crystals) from $\theta = 30^\circ$ to 90° , while the BaF_2 was positioned at backward angles between 125° and 160° . In the forward direction, between 4° and 12° , two couples of PSPPACs were positioned symmetrically with respect to the beam. Two Si (Li) detectors were positioned between each couple of PSPPAC at the larger angles. The pulsed beam (with the repetition period of 800 ns) was provided by the LNL TANDEM+ALPI accelerator system. The targets were ^{68}Zn and ^{116}Sn with a thickness of $500 \mu\text{g cm}^{-2}$ and $450 \mu\text{g cm}^{-2}$, respectively. The BaF_2 detectors were calibrated using standard γ sources and with the reaction $^2\text{D}(^{11}\text{B}; n, \gamma)^{12}\text{C}$ which gives a high-energy γ -ray of 15.1 MeV. The GARFIELD apparatus was calibrated with the elastic scattered beam of the above-described reactions and the two nuclear reactions $^{12}\text{C} + ^{12}\text{C}$ and $^{32}\text{S} + ^{64}\text{Ni}$ at $E_{\text{lab}} = 70$ MeV and 140 MeV, respectively. With the system GARFIELD+HECTOR we could measure both γ -rays and charged particles in coincidence with residual nuclei detected in PSPPAC detectors [12–16].

3. Data analysis and results

The main aim of the analysis was to extract the information about the temperature and pre-equilibrium energy loss and therefore to gain a deeper understanding of the evolution of the system towards thermal equilibrium. The experimental LCP kinetic energy spectra have been analysed using a moving source fit in which the particles are assumed to be emitted isotropically from two different moving sources, one with approximately the beam velocity which is responsible for the pre-equilibrium, and a second with the velocity approximately similar to the compound which is responsible for the statistical emission. The α -particle spectra

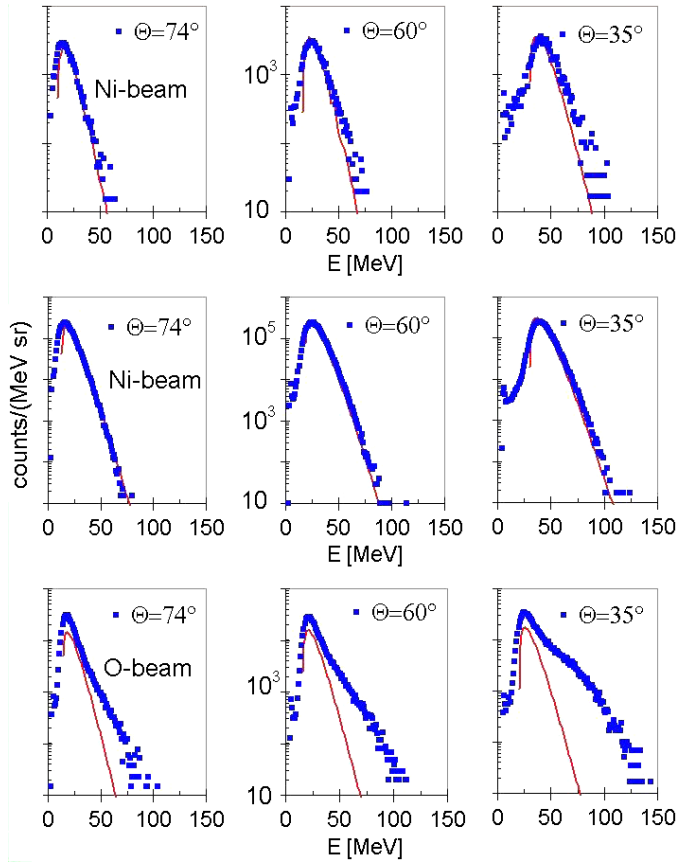


Figure 1. Alpha-particle spectra in coincidence with evaporated residues. The upper ($E_{\text{lab}} = 500$ MeV) and middle ($E_{\text{lab}} = 400$ MeV) panels show the measured (filled points) and calculated evaporation source fit (thin line) for the Ni-induced reaction of different detection angles. The lower panel shows measured α -particle spectra (filled points) for the more asymmetric case of the O-induced ($E_{\text{lab}} = 250$ MeV) reaction for three different detection angles and the calculated evaporation source fit (thin line), which in contrast to the symmetric reaction does not reproduce the particle spectra, due to pre-equilibrium contributions.

clearly show that the pre-equilibrium emission is practically absent in the Ni-induced reactions as only an evaporative behaviour from a source with quite standard emission parameters has been measured. In fact (see figure 1, upper rows), it has been obtained that only one evaporative source with velocities $V_{\text{source}}(E_{\text{beam}} = 500 \text{ MeV}) = 1.9 \text{ cm ns}^{-1}$ and $V_{\text{source}}(E_{\text{beam}} = 400 \text{ MeV}) = 1.7 \text{ cm ns}^{-1}$ is needed to describe the measured spectra. This is in agreement with standard statistical model calculations without pre-equilibrium contribution (PACE4 [17]) where $V_{\text{evap,source}}(E_{\text{beam}} = 500 \text{ MeV}) = 1.88 \text{ cm ns}^{-1}$ and $V_{\text{evap,source}}(E_{\text{beam}} = 400 \text{ MeV}) = 1.69 \text{ cm ns}^{-1}$. Therefore in the symmetric case with the highest excitation energy one can say that the pre-equilibrium emission is negligible. The analysis of the O-induced reaction shows (see figure 1, lower part) that a large part of the cross section cannot be described by a single evaporative component only. A second pre-equilibrium source has to be added to the evaporative part to fit the spectra (work in progress [18]). On the basis of the α -particle experimental spectra we obtain the preliminary result that the system losses a significant part of

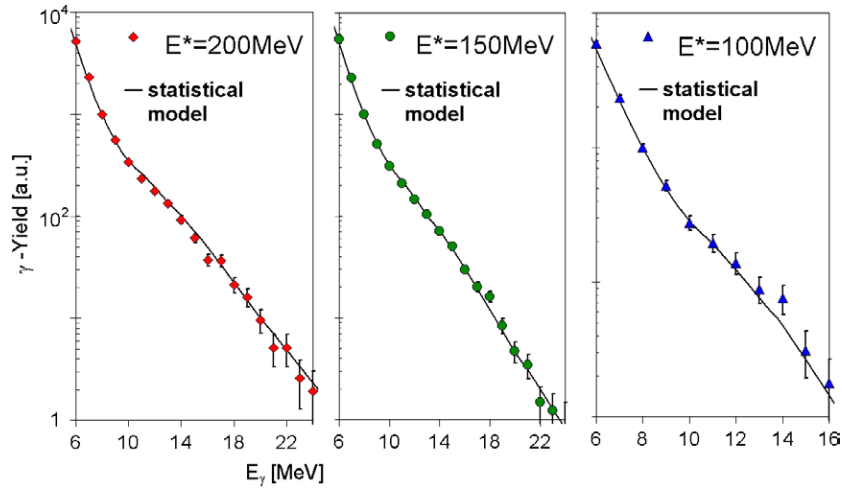


Figure 2. The panels show (filled points) the measured, binned and normalized Ni-induced high-energy γ -ray spectra for $^{132}\text{Ce}^*$ at 200, 150 and 100 MeV of excitation energy. The experimental γ -spectra are obtained in coincidence with evaporated residues. The thin continuous line shows the result of statistical model calculations with a GDR centroid fixed at 14 MeV and the width following [23], namely $\Gamma = 9.6$ MeV, $\Gamma = 12.9$ MeV and $\Gamma = 13.7$ MeV at $E^* = 100$ MeV, 150 MeV and 200 MeV, respectively. The calculations have been performed assuming a fully thermalized compound nucleus.

Table 1. Values for the GDR used in the statistical model simulation were deduced from [23] using an intrinsic width of 5 MeV. $\langle\beta\rangle$ is the average nuclear deformation and $\langle J\rangle$ is the initial average angular momentum of the compound system.

E_{beam} (MeV)	E^* (MeV)	$\langle J\rangle$	$\langle\beta\rangle$	GDR width (MeV)
500	200	50	0.6	13.7
400	150	50	0.5	12.9
300	100	50	0.4	9.6

its excitation energy due to pre-equilibrium emission in the case of the $E_{\text{lab}} = 250$ MeV $^{16}\text{O} + ^{116}\text{Sn}$ reaction [18].

The analysis of the obtained γ -ray spectra has been performed with statistical model. To reproduce the γ -ray spectra of the reaction $^{64}\text{Ni} + ^{68}\text{Zn}$ simulations based on the Cascade code [19] were performed. For the level density description the Reisdorf [20] formalism of Ignatyuk [21] has been used; this means small shell correction and with a nearly constant level density parameter of $a \approx A/9$. The obtained spectra are then folded by the experimental set-up response function calculated using the GEANT [22] libraries. We used a single Lorentzian strength function for the GDR position and width. A sum rule strength of 100% is assumed in all calculations. As a first trial to reproduce the γ -spectra, we used the GDR parameters according to [23], obtained with the thermal fluctuation model predictions (table 1). In a future work more accurate statistical model fits, using χ^2 minimizations, will be done [24]. Figure 2 shows the experimental measured high-energy γ -rays and the statistical model calculations. From figure 2 it is evident that the statistical model calculations and the GDR parameters of table 1 well reproduce all experimental spectra.

4. Conclusion

From the present preliminary analysis of the data we found a strong entrance channel effect in the compound nucleus formation with $A \approx 130$ when we use O-beam as compared with Ni-beam. The analysis of the γ -ray spectra for the reaction induced by O is in progress. With the symmetric reaction $^{64}\text{Ni} + ^{68}\text{Zn}$ we show that it is possible to study the GDR in the region $E^* = 100\text{--}200$ MeV. In fact, in this case also at the highest excitation energy ($E^* \approx 200$ MeV) the system is fully thermalized and the pre-equilibrium emission is negligible. Particle and γ -ray spectra are both well reproduced with the statistical model of CN emission. In addition, the observed GDR width has a value in qualitative good agreement with the thermal fluctuation model which reproduces the general increase of the width with excitation energy.

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