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Exclusive studies of the GDR in excited nuclei

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The GDR in ^{164}Er at 62 MeV excitation energy has been studied in coincidence with the evaporation residues, selected using the Argonne fragment mass analyzer (FMA). The statistical model fit to the data indicate that $^{164}\text{Er}^*$ has a prolate shape with deformation similar to the ground state.

1. Introduction

The giant dipole resonance (GDR) built on highly excited states of compound nuclei produced in heavy-ion induced fusion reactions has been used to study nuclear properties at high temperature. The nuclear deformations and shape changes have been deduced by studying the temperature and spin dependence of the width of the GDR in $A \sim 110$ and $A \sim 160$ nuclei [1]. In addition to the γ rays of interest, the high-energy photon spectrum can have contributions from target contaminants (e.g. C, O) as well as from other competing processes like fission and deep-inelastic collisions, especially at high excitation energy and angular momentum. Although some attempts have been made to minimize these contaminant contributions, it has not been proven that such contributions are negligible in the inclusive experiments. A few exclusive measurements [2-4] have shown that the GDR spectrum gated with the residue is considerably narrower than the singles GDR spectrum, which may compromise the conclusions based on the inclusive results.

Recently, we have therefore carried out an experiment to measure the high energy γ -spectra in the compound nucleus ^{164}Er at 62 MeV excitation energy in coincidence with the evaporation residues, selected using the FMA, the results of which are reported here.

2. Experimental Details

The experiment was carried out using ^{40}Ar beam of 160 MeV from the ATLAS accelerator at Argonne National Laboratory on a 1 mg/cm^2 thick ^{124}Sn target. A rotating target holder was used to avoid excessive target heating. The high-energy photons were

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detected in the LEPPEX array while the evaporation residues were identified in the focal plane detector of the FMA.

Figure 1. The high-energy peaks from the decay of the GDR in ^{12}C to the ground state (22.56 MeV) and the first excited state (18.12 MeV). A GEANT simulation spectrum (solid line) is also shown for comparison.

Figure 2. High energy γ -ray spectrum in the decay of ^{164}Er gated with $A=160$ (open circle) and $A=159$ (filled circle). The solid line is the statistical model fit (see text). Inset shows the mass spectrum obtained in the focal plane of the FMA.

The LEPPEX array consists of 16 large BaF_2 detectors ($5 \times 5 \times 25 \text{ cm}^3$) surrounded by a plastic scintillator shield for cosmic ray rejection. The sub-nanosecond fast component of BaF_2 allows n- γ discrimination at a distance of 30 cm from the target. The response of the LEPPEX array was characterized using the standard $^{11}\text{B}(p,\gamma)$ ($E_p = 7.2 \text{ MeV}$) reaction to populate the GDR in ^{12}C which decays to the ground state with a 22.56 MeV γ -ray. The high-energy photons (22.56 MeV, 18.12 MeV) observed in this reaction, together with the low energy sources (0.898 MeV, 1.836 MeV and 6.13 MeV), provided the energy calibration over the entire region of 0-23 MeV. The observed energy resolution can be described as, $\frac{\Delta E}{E} \propto \frac{1}{E^{0.41}}$ with $\frac{\Delta E}{E} = 20\%$ at 1 MeV. The experimental spectrum obtained with the $^{11}\text{B}(p,\gamma)$ reaction is shown in Figure 1. The simulated spectrum obtained from GEANT simulations is also shown for comparison. The observed line shape is well reproduced by adding a small exponential tail to the gaussian folding function as described in Ref. [5],

$$T(E) = Ce^{D(E-E_0)}(1 - e^{-(E-E_0)^2/2\sigma^2}) \quad E < E_0 \quad (1)$$

where $C = 0.007E^{0.41}$ is the fraction of the peak from where the tail is added and $D = 0.21E^{0.41}$ is the slope of the exponential, E_0 and σ are the centroid and the width of the gaussian, respectively.

3. Results and Discussion

Figure 2 shows the high-energy γ ray spectrum in coincidence with A=160 (open circles) and A=159 (filled circles). The solid line in the figure is the calculation (best fit) using the statistical model code CASCADE [6] after folding with the detector response, as explained in the previous section. The CASCADE output cannot be directly compared with the residue gated experimental spectrum. We have therefore followed the approximate procedure of Van Schagen et al. [7] to generate the equivalent theoretical spectrum from CASCADE. The total fusion cross section was taken from the data of Reisdorf et al. [8] and the initial angular distribution was derived using the extra-extra push model [9]. We have assumed the classical sum rule (100%). The GDR parameters, centroid energy, deformation and width of the two components, were allowed to vary in order to get best fit. The calculated CASCADE spectrum for the 4n decay channel was normalized to data in the low energy region (5-7 MeV). The χ^2 in the GDR region was then determined for this 'normalized' spectrum and parameters were varied to minimize this χ^2 . The best fit parameters are shown in Table 1. It should be noted that the high-energy tail of GDR is very sensitive to the level density parameter 'a'. We have used $a=A/7.5$. Figure 2 also shows the calculated GDR spectrum for the 5n decay channel with best fit parameters obtained from the 4n decay channel together with the data.

Figure 3. Divided plots (see text) for the experimental data together with the statistical model fit (solid line). The ordinate Y is proportional to photoabsorption cross section.

Figure 4. The absorption cross section obtained from the best fit to the data is compared with a thermal shape fluctuation calculation for $J = 44\hbar$, $T_{eff} = 1.0$ MeV, $E_{av} = 13.8$ MeV.

Figure 3 shows the data and the best fit divided by a calculated spectrum obtained with a constant E1 strength on a linear scale for better visualization.

In Figure 4, the absorption cross section corresponding to the GDR parameters for the best fit is compared with that based on thermal shape fluctuation calculations [10] for $E_{av} = 13.8$ MeV (as obtained from the fit to data), $J=44\hbar$ and the effective final temperature of 1.0 MeV. It can be seen that the theory does not describe data very well. The reasons for this discrepancy will be investigated.

Table 1

Fit parameters for $^{124}\text{Sn}(^{40}\text{Ar}, 4n)$ at $E^*=62$ MeV, $l_{\text{max}}=47\hbar$. The errors are obtained from a χ^2 analysis of the fit.

S_1	E_1 MeV	Γ_1 MeV	S_2	E_2 MeV	Γ_2 MeV	E_{av} MeV
0.4(.05)	11.9(0.3)	3.6(0.4)	0.6(0.07)	15.1(0.3)	6.4(0.8)	13.8(0.4)

4. Conclusion

In conclusion, we have studied the GDR in ^{164}Er at 62 MeV excitation energy gated with the residue ^{160}Er . We find that ^{164}Er has a prolate shape at $T\sim 1$ MeV with a deformation similar to the ground state with $\beta = 0.27 \pm 0.02$. The GDR centroid energy is consistent with ground state systematics. A further analysis using a Monte Carlo Cascade code is in progress. Also incorporating theoretical strength function into cascade for different E^* and J values will provide a better comparison with the theory.

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