Temperature dependence of the GDR width in ^{120}Sn

P. Heckman[a,b], D. Bazin[a], J. R. Beene[c], Y. Blumenfeld[a,*], M. J. Chromik[a,†], M. L. Halbert[d], J. F. Liang[e], E. Mohrmann[f], T. Nakamura[a,‡], A. Navin[a,§], B. M. Sherrill[a,b], K. A. Snover[f], M. Thoennessen[a,b], E. Tryggestad[a,b] and R. L. Varner[c]

[a]National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824

[b]Department of Physics & Astronomy, Michigan State University, East Lansing, MI 48824

[c]Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831

[d]University of Tennessee, Knoxville, TN 37996

[e]Oak Ridge Associated Universities, Oak Ridge, TN 37831

[f]Nuclear Physics Laboratory, Box 354290, University of Washington, Seattle, WA 98195

The giant dipole resonance built on highly excited states in ^{120}Sn was measured by inelastic scattering of 80 MeV/nucleon ^{17}O. Gamma-ray spectra were measured for the apparent excitation energies of 30 to 90 MeV. In the preliminary analysis, the γ-ray spectral shapes for low initial excitation energies (assuming full inelastic energy transfer) populated in ^{17}O scattering were found to be similar to those previously measured in inelastic α-scattering, suggesting similar widths deduced from the two reactions.

1. INTRODUCTION

One area of major experimental and theoretical efforts in the study of the giant dipole resonance (GDR) is the angular momentum and temperature dependence of the GDR width. Recently different experimental techniques have been applied to study the angular momentum dependence and the temperature dependence independently [1–5]. Gamma-ray multiplicity measurements in fusion-evaporation reactions allow the gating on different angular momentum ranges at approximately the same temperature [1,2]. Inelastic α-scattering at forward angles involves only small angular momenta while populating different excitation energies [3–5].

*Permanent address: IN_2P_3-CNRS, 91406 Orsay Cedex, France

†Present Address: Ludwig Maximilian Universität München, 85748 Garching, Germany

‡Permanent address: Department of Physics, Tokyo Institute of Technology, 2-12-1 O-Okayama, Meguro, Tokyo, 152-8551 Japan

§Permanent Address: Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400 085, India

The α-scattering experiments have several advantages but also some additional uncertainties compared to the fusion-evaporation reactions. The advantages include the possibility to measure the whole excitation function within one experiment by gating on the different energy losses of the projectile, and to measure the properties of the hot GDR in stable nuclei where the results can directly be compared to the ground state values. In addition, the GDR can in principle be measured at lower temperatures because it is not limited by the Coulomb barrier in the entrance channel. One of the major disadvantages is the uncertainty in the determination of the excitation energy. It has been shown that the full energy loss of the projectile is not converted into equilibrated excitation energy in the target nucleus [6,7]. Other processes like knock-out or pickup-decay reactions can contribute to the inelastic spectrum and have to be taken into account in the analysis.

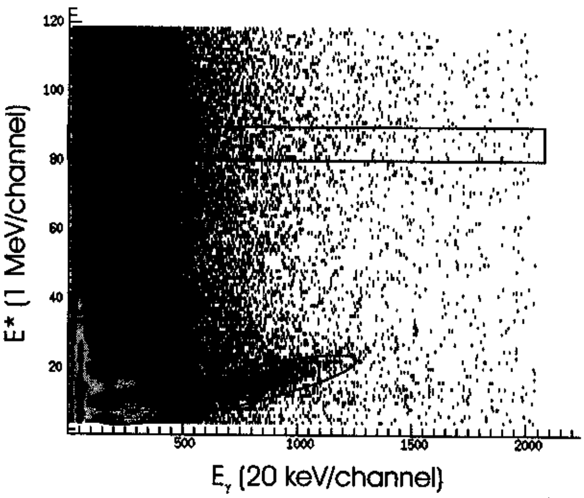
The most extensive studies of the hot GDR have been performed in Sn nuclei. There are apparent differences between the GDR widths inferred from fusion-evaporation and the $(\alpha,\alpha'\gamma)$ experiments [8]. The widths from the latter reaction lie somewhat above the fusion-evaporation results. To understand these differences and to further explore the excitation energy deposition in inelastic scattering experiments we studied the reaction ^{120}Sn(^{17}O,^{17}O$'$) at 80 MeV/nucleon. Oxygen was chosen as the projectile because the yield of nucleon knock-out reactions is expected to be much smaller in heavy-ion scattering than in α-scattering reactions [9]. In addition, the neutron binding energy is small so that projectile excitations are limited to low excitation energies.

2. EXPERIMENTAL METHOD AND ANALYSIS

The experiment was performed at the National Superconducting Cyclotron Laboratory (NSCL). A 7.45 mg/cm^2 thick ^{120}Sn target was bombarded by 80 MeV/nucleon ^{17}O particles extracted from the K1200 cyclotron. The inelastically scattered ^{17}O and other reaction products were measured in the S800 spectrometer, which was set at a scattering angle of 7°. The angular acceptance of the S800 is 5°, which allows for scattering angles between 2° and 12°; the grazing angle for this reaction is about 2.2°. The energy acceptance of the S800 is approximately 10%, which corresponds to 136 MeV. This acceptance is sufficient to measure the whole excitation function with one setting.

Particle identification and energy loss was accomplished by using the S800 focal plane. The S800 focal plane consists of a pair of Cathode Readout Drift Chamber (CRDC) detectors for fragment position and tracking, a multi-segmented Ion Chamber (IC) gas detector for fragment energy loss, and three plastic stopping scintillators for fragment identification [10].

The high-energy γ rays were detected with the ORNL - Texas A&M - MSU BaF_2 array, consisting of 136 BaF_2 scintillators, in coincidence with fragments in the S800. The scintillators were arranged in two close-packed arrays of 68 detectors each. The arrays were placed at a distance of $\approx$ 50 cm from the target at angles of $\pm 90^o$ with respect to the beam axis. The high-energy γ rays were separated from the high energy neutrons using fast vs. slow signals, while the low energy neutrons were separated using the energy signals from the individual BaF_2 detectors vs. time of flight measurements relative to the cyclotron radio-frequency signal. A new gate was made every 10 runs on the energy vs. time of flight plot to account for any small time drifts.



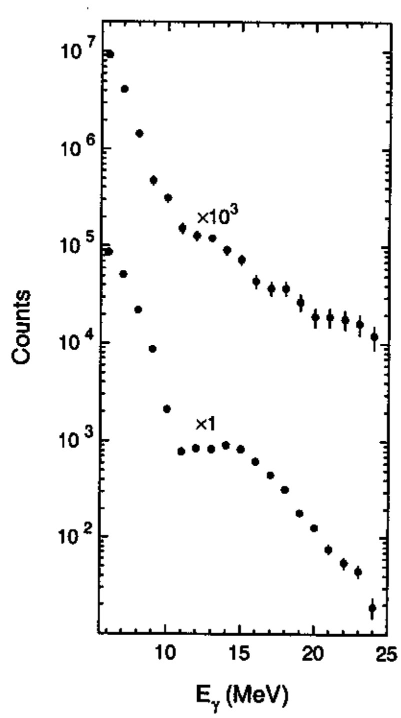


Figure 1. Left: Plot of excitation energy vs. γ-ray energy. Right: The top γ-ray spectrum corresponds to excitation energies of 80–90 MeV, as gated by the upper band in the left plot. The bottom γ-ray spectrum corresponds to decays back to the ground state, as gated by the lower band in the left plot.

The gating technique described above allowed for the γ rays to be effectively separated from neutrons. In order to improve the response of the array, a "shower" routine was applied in the analysis, which summed the γ-ray energy deposited in neighboring detectors and treated those events as one γ ray.

In the preliminary analysis the excitation energy of the target was directly determined from the energy loss of the scattered ^{17}O particles assuming full equilibration. In a future analysis, contributions from incomplete energy transfer will be extracted from the spectra of twelve CsI telescopes which were placed in the scattering chamber to detect light particle emissions from the target. The detectors were mounted above the target covering angles of 30° to 150°.

The left side of Figure 1 shows the two-dimensional plot of the apparent excitation energy (initial beam energy minus measured energy of the scattered particle) vs. γ-ray energy. The diagonal band at low energies ($E_\gamma \leq 25$ MeV) represents the kinematical limit and shows that the applied identification and reconstruction is correct. The events below the kinematic limit are due to random coincidences which have not been subtracted from the left plot in Figure 1. Gating on the diagonal allows for the analysis of the GDR built on the ground state including the γ-decay branch back to the ground state. The

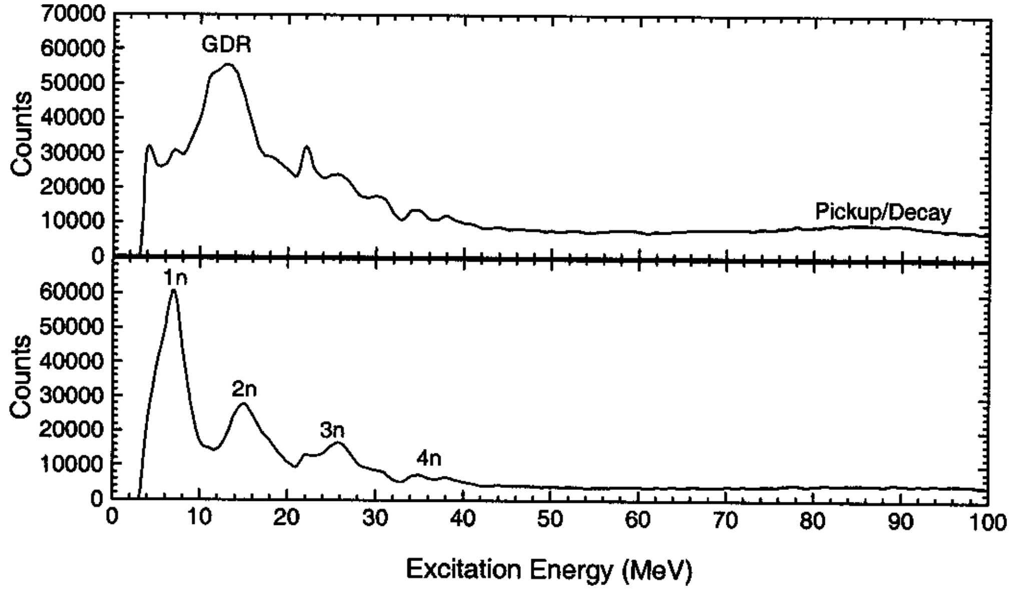


Figure 2. Top: ^{17}O Singles spectrum. Bottom: ^{17}O in coincidence with γ rays with $E_\gamma \geq 4$ MeV.

corresponding γ-ray spectrum is shown at the bottom of the right side of Figure 1.

3. PRELIMINARY RESULTS

In order to extract the GDR parameters of the excited Sn nuclei it is necessary to gate the two-dimensional excitation energy vs γ-ray energy spectrum for a given excitation energy range and project the γ-ray spectrum. Such a gate is shown in the left plot of Figure 1 for an excitation energy range of 80–90 MeV. The corresponding γ-ray spectrum is shown as the top spectrum on the right side of Figure 1. The GDR parameters can then be extracted by fitting the spectra with a modified version of the statistical model code CASCADE [11] and folding the calculated spectrum with the response function of the detector array.

For these calculations it is necessary to include the correct initial angular momentum and excitation energy population in the code. As mentioned earlier the conversion from energy loss to excitation energy is not straightforward and the spectra of the CsI detectors have to be analysed first.

However, it is possible to get some indication of the deposited excitation energy by plotting the energy loss spectrum gated by γ rays with $E_\gamma \geq 4$ MeV. Figure 2 shows the ^{17}O singles data (top) as well as the coincidence data (bottom). In the singles spectrum, the ground-state GDR is apparent around 15 MeV. There is also an enhancement potentially due to pickup/decay contributions around 80 MeV. The spectrum gated by γ rays

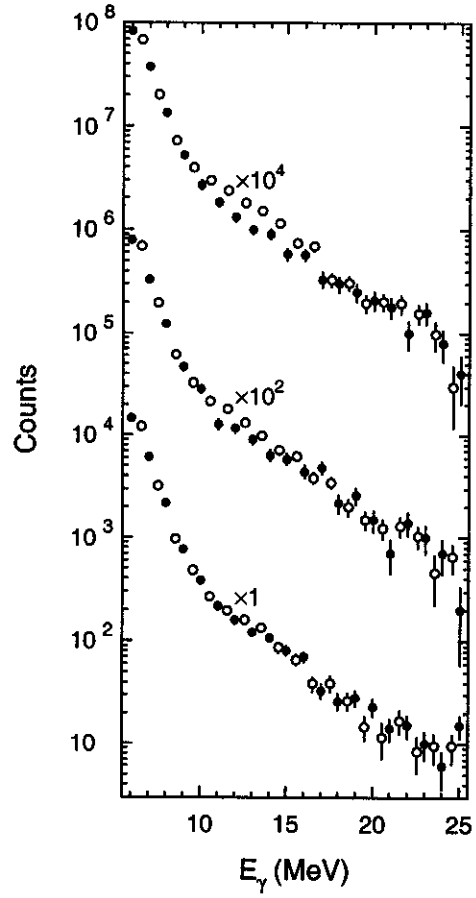


Figure 3. Comparison of the γ spectra following ^{17}O scattering (filled circles) and α-scattering (open circles). The spectra correspond to excitation energies of 70–80, 50–60, and 30–40 MeV respectively from top to bottom.

shows distinct peaks which can be interpreted as successive openings of neutron evaporation channels [12]. These structures would be washed out if there is not a correlation between energy loss and excitation energy. These peaks can be identified up to 40 MeV corresponding to the 4n channel.

Although no detailed CASCADE calculations with fits to the data have been performed, it is possible to compare the extracted excitation energy gated γ-ray spectra with the results from the (α,$\alpha'\gamma$) experiment. Figure 3 shows the present data (solid circles) and the (α,$\alpha'\gamma$) data (open circles) for excitation energy ranges of 30–40 MeV, 50–60 MeV, and 70–80 MeV. The spectra were normalized with respect to each other at 7 MeV. While the data at the two lower excitation energies are similar for the two reactions, the 70–80 MeV spectra seem to have reduced strength in the energy range of the GDR for the ^{17}O data. This could be an indication of other mechanisms (for example pickup/decay) contributing to the γ-ray spectrum. The fact that the low-energy spectra are similar for the two reactions suggests that the extracted GDR parameters will also be similar. Thus the ^{17}O reaction would confirm the GDR width increase extracted from the α-scattering experiments. However, this has to be confirmed in the final analysis because the experimental conditions were not exactly the same, for example the response function for the detector arrays was different.

4. CONCLUSIONS

Inelastic scattering of ^{17}O particles was used to study the GDR built on excited states in ^{120}Sn. Preliminary results show that the shapes of the γ-ray spectra are similar to the spectra from the α-scattering experiment at low excitation energies. It does appear that there is less strength at higher excitation energies compared to the $(\alpha,\alpha'\gamma)$ experiment.

Before the final GDR widths as a function of excitation energy can be extracted for the present experiment it is necessary to incorporate the correct relation of projectile energy loss and target excitation energy. This information should be able to be extracted from the light charged particle spectra of the CsI detectors.

ACKNOWLEDGEMENTS

This work is supported in part by the National Science Foundation grant number PHY95-28844 and the Department of Energy grant number DE-FG03-97ER41020/A000. Oak Ridge National Laboratory is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725.

REFERENCES

1. A. Bracco *et al.*, Phys. Rev. Lett. **74**, 3748 (1995).
2. M. Mattiuzzi *el al.*, Nucl. Phys. **A612**, 262 (1997).
3. E. Ramakrishnan *et al.*, Phys. Rev. Lett. **76**, 2025 (1996).
4. E. Ramakrishnan *et al.*, Phys. Lett. **B383**, 252 (1996).
5. T. Baumann *et al.*, Nucl. Phys. **A635**, 428 (1998).
6. D. Fabris *et al.*, J. Phys. **G23**, 1377 (1997).
7. G. Viesti *et al.*, Nucl. Phys. **A652**, 17 (1999).
8. D. Kusnezov, Y. Alhassid, and K. A. Snover, Phys. Rev. Lett. **81**, 542 (1998).
9. A. van der Woude *et al.*, Nucl. Phys. **A569**, 383c (1994).
10. J. Yurkon *et al.*, Nucl. Instr. and Meth. **A422**, 291 (1999).
11. F. Pühlhofer, Nucl. Phys. **A280**, 267 (1977).
12. M. Thoennessen *et al.*, Phys. Rev. **C43** R12 (1991).