Excitation of the Isovector Giant Quadrupole Resonance in ^{208}Pb by Coulomb Inelastic Scattering

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We have employed intermediate energy heavy-ion inelastic scattering to excite the Isovector Giant Quadrupole Resonance (IVGQR) in heavy nuclei. The peak-to-background ratio is sufficiently good to permit identification of the strength in the IVGQR. In addition, the technique suppresses excitation of higher multipole and isoscalar excitations in the same energy region.

1. IVGQR

Reliable data on the strength distribution of the isovector giant quadrupole resonance (IVGQR) are notably missing from the existing systematics on electric giant resonances [1]. Evidence for an IVGQR has been reported from (e,e′) experiments on medium-mass and heavy nuclei [2]. These data are subject to substantial systematic uncertainty because of very large backgrounds and possible contributions from a variety of other modes not differentiated by the experiments. A few more specific and sensitive experiments involving (n,γ) and (γ,n) reactions are available [1], along with one example of (HI,HI′) [3] and (HI, HI′γ) [4]. These latter experiments seem to confirm the basic results of the (e,e′) analyses, but carry little detailed information about the distribution of ΔT=1 E2 strength [1]. On the other hand, studies employing the $(\pi^{\pm}, \pi^0)$ reaction, which should excite isovector states strongly, show no evidence of IVGQR strength at all [5].

2. Technique

Systematic analysis of resonance and continuum excitation by intermediate-energy heavy ions indicates that heavy-ion scattering in the bombarding energy range from 100 to 200 MeV/nucleon should be an excellent tool for studying the IVGQR. The systematics predict that (^{36}Ar,^{36}Ar′) at 150 MeV/nucleon will excite the IVGQR in ^{208}Pb with a peak to continuum ratio of better than 1:1 [4], as shown in Fig. 1, which is substan-

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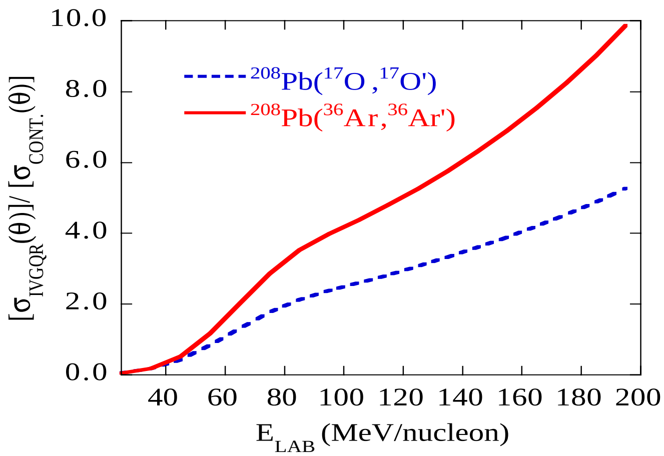

Figure 1. Continuum excitation compared with IVGQR excitation vs. lab energy of the projectile.

tially better than that of most of the data on which the systematics for the isoscalar GQR are based. The IVGQR cross-sections are large, so that experiments can be done in reasonable times, even for low-beam intensities. Heavy-ion scattering excites the IVGQR almost exclusively by Coulomb excitation. Coulomb excitation cross sections for high-lying strength decrease rapidly with increasing multipolarity, providing a powerful filter against the broad structures with $L > 2$, which probably occupy the same energy region as the IVGQR. Most of the $L > 2$ strength in the vicinity of the IVGQR is expected to be isoscalar, and will, therefore, also be excited by the hadronic interaction in heavy-ion scattering. To discriminate against this isoscalar strength, we employ the projectile dependence of the excitation cross section. The cross-section for target Coulomb excitation scales as Z^2 of the projectile, while the hadronic excitation scales roughly as A of the projectile. Comparison of spectra obtained with two probes of significantly different Z can be used to isolate exclusively Coulomb-excited strength, as is clear from comparing the two curves in Fig. 1. These considerations imply that data acquired with two probes of different Z should provide enough information to unequivocally identify the IVGQR, and to reveal details of the strength distribution. A more quantitative comparison of these

Table 1
Predicted peak cross sections for scattering from Pb at 150 MeV/A.

L	T	Ar(mb/sr)	O(mb/sr)	Ratio
1	1	36181	7428	4.9
2	0	6790	1938	3.8
2	1	2590	516	5.0
3	0	1025	491	2.1
continuum		150	75	2.0

effects is shown in Table 1. Here it is clear that in comparing the relative excitation of isoscalar vs. isovector states by the different probes, there should be a dramatic difference in the spectra in the vicinity of strong isovector excitations.

3. Experiment

The measurements were made at the National Superconducting Cyclotron Laboratory of Michigan State University. The beams employed were ^{17}O and ^{36}Ar, each at 150*A MeV, 2550 MeV and 5400 MeV, respectively, with intensities as high as 0.3 nA. The beams impinged on targets of ^{90}Zr and ^{208}Pb, each of which was 2 mg/cm^2 in thickness. Results for the Pb only are reported here. The scattering measurements were made using the S800 spectrometer [6], set at a central scattering angle of 5°. This spectrometer has a theoretical momemtum acceptance of 5%, energy resolution of 10^{-4} and an angular acceptance approximately 10° by 7°. This angular acceptance is well matched to our

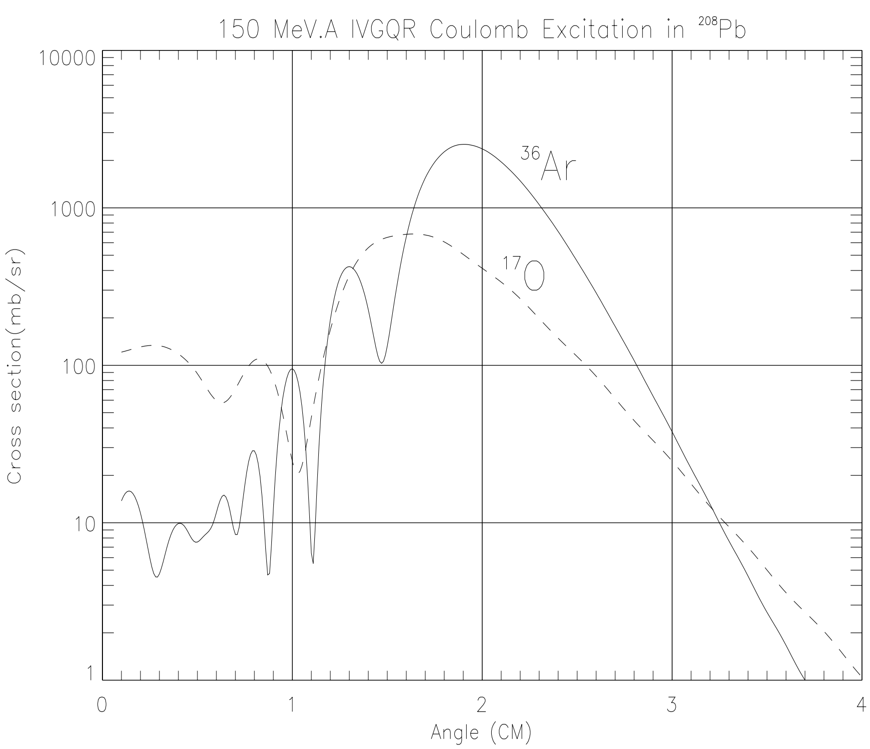

Figure 2. DWBA estimates of the angular distributions for excitation of the IVGQR in Pb, using the beams O and Pb. The calculations were done using Ptolemy with corrections for relativistic kinematics.

experiment as is apparent from DWBA estimates of the angular distributions shown in Fig. 2. The beamline was setup for dispersion mode analysis of the incident beam. The energy resolution achieved in our analysis to date is about 2.5×10^{-4}, which corresponds to 1.3 MeV for Ar and 0.5 MeV for O.

This experiment was one of the first experiments to measure continuum inelastic scattering using the S800. It was necessary to stop the beam on a slit at the entrance to the S800, which limited the smallest scattering angle at which data could be obtained. In addition, shutters were developed and installed at the focal plane of the S800, to block elastic scattering from the focal plane during the measurement. This limited the range of low excitation energies available. Finally, because there were some slit-scattered particles entering the spectrometer, another shutter was positioned to block those particles, which appear at an apparent excitation energy of 70 to 100 MeV. In the end, the measurement encompassed 0.4° to 10° in angle and 3 to 50 MeV in excitation energy.

The detection system used was the standard S800 set [7] of two CRDC chambers for position and angle determination, an ion chamber for particle identification by energy loss, and two plastic scintillators of thickness 5 mm and 5 cm for total energy measurement. The projectile-like hits were identified on E-ΔE maps obtained from the ion chamber and total deposited energy data.

4. Preliminary Results

Our preliminary analysis of the data yields the result in Fig. 3. In this figure, the plotted yields were generated by summing over the peak angles of the IVGQR angular distribution from 1.4° to 2.4° for Ar scattering and from 1.3° to 2.4° for O scattering. The bins for the O scattering are limited by the preliminary state of the analysis. The resulting yield curves were then normalized to each other in the excitation energy region from 35 to 40 MeV, well-above the region of giant resonance excitation. This normalization should reduce hadronic scattering effects in comparing the angular distributions, but is strictly a qualitative tool. As is clearly visible, there is a substantial strength in the Ar excitation above the region of the IVGDR, which we claim results almost entirely from Coulomb excitation of low L strength. Since the candidates for this strength are limited to the L = 1 and L = 2 isovector modes, and since the shape of the tail of the IVGDR is well known in this excitation energy region, the quantative extraction of the L = 2 isovector strength should be possible.

To further enhance the qualitative comparison of these angular distributions we have computed a "Coulex asymmetry parameter," which is

$$\frac{Y^{Ar}(E) - Y^{O}(E)}{Y^{Ar}(E) + Y^{O}(E) - 2 \times background(E)} \tag{1}$$

in which Y(E) is the normalized yield as a function of excitation energy. As can be seen, this parameter accentuates the difference of the two measurements, enhancing the (more strongly Z dependent) Coulomb excitation cross-section. The resulting curve, shown with visible uncertainties in Fig. 3, shows strong enhancements in the vicinity of the IVGDR and the IVGQR, and a supression in the region of known isoscalar strength (∼ 18 MeV). The low excitation enhancement of the curve results from the broad elastic tail resulting from the poorer resolution in the Ar scattering.

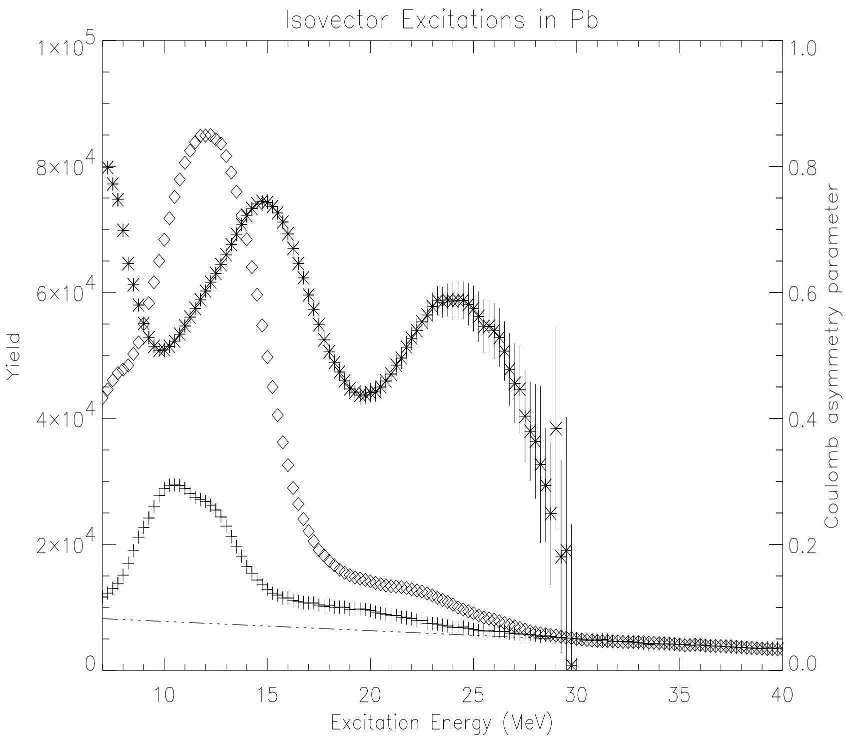

Figure 3. Preliminary results for inelastic excitation in the continuum of Pb, using Ar and O beams at 150 MeV/A. The diamond curve is Ar, the "+" curve is O, the dash-dot line is a background, extrapolated from the region of 35 to 40 MeV in excitation. See the text for details of the relative normalizations. The points with uncertainties are a qualitative "Coulex asymmetry parameter" described in the text.

5. Conclusion

The analysis presented in the previous section is qualitative, and intended to illustrate the potential of the method. Quantitative results on mean energy, width, and strength of the IVGDR must await the completion of the more detailed and complete analysis now in progress. Nevertheless, the clear presence of Coulomb excited strength in this region suggests this technique will be quite valuable in discerning IVGQR strength which has previously been difficult to observe in detail.

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