CONF-890686--1

Excitation and Decay of Giant Multipole Resonances in Intermediate Energy Heavy Ion Reactions

CONF-890686--1

DE89 017770

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ABSTRACT: The role of intermediate energy heavy ions in the study of giant multipole resonances is explored, with emphasis on gamma decay coincidence experiments. Experiments on ^{208}Pb bombarded by 84 MeV/nucleon ^{17}O are discussed and compared with earlier work at 22 MeV/nucleon. The role of Coulomb excitation in the 84 MeV/nucleon data is emphasized and some consequences for study of isovector resonance strength are explored. A comparison of the excitation and decay of the isovector giant dipole resonance in ^{208}Pb and ^{209}Bi excited with 84 MeV/nucleon ^{17}O scattering is presented.

1. INTRODUCTION

The study of simple nuclear excitations, such as single particle states or giant multipole resonances (GR), has taught us a great deal about the physics of nuclei. This talk is concerned with recent experiments carried out by our group at ORNL and GANIL on the excitation and decay of giant resonances.

The isovector giant dipole resonance has been studied almost since the beginning of quantitative experimental nuclear physics (Danos and Fuller 1965). The field was broadened considerably with the identification of non-dipole resonances in the early 1970's (Bertrand 1981). Since that time, a great deal of information on the gross properties (excitation energy, width, strength) has been accumulated. As an illustration, a sample of multipole vibrations which have been identified in ^{208}Pb (only those that can be ascribed to vibrations in ordinary space; spin and spin-isospin excitations, e.g., are omitted) are listed in Table 1. The prefix isoscalar (IS) or isovector (IV) refer to whether the oscillation of protons and neutrons is predominantly in phase (IS) or out of phase (IV). Of the resonances listed only the IVGDR, ISGQR and ISGMR are well established as compact peaks which exhaust a large fraction of the relevant energy weighted sum rule (EWSR) in a wide range of nuclei.

While much has been learned, there are still many open questions. For example there is good data on several isoscalar resonances, but except for the venerable IVGDR, there is little systematic evidence for strong compact IV states. Our knowledge of high multipolarity resonances (L > 3) is meager and sometimes contradictory, in part because the high L strength

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*Operated by Martin Marietta Energy Systems, Inc. under contract DE-AC0521400 with the U.S. Department of Energy.

appears to be broadly fragmented. There is little information on concentrated collective strength between the IVGDR and the nucleon resonances (Δ, etc.). Multiphonon giant resonances or other exotic collective states might populate this "desert." Finally there is little data on the microscopic structure of the GR states, or on the interaction of these simple, highly excited states with the large number of more complex states of the nuclear continuum at the same excitation (i.e., the damping process).

Table 1

Resonance in ^{208}Pb	IS/IV	Excitation Energy	Designation in this Paper
Dipole	IV	13.6 MeV	IVGDR
Dipole	IS	17 ?	ISGDR
Quadrupole	IS	10.6	ISGQR
Quadrupole	IV	22 ?	IVGQR
Monopole	IS	13.9	ISGMR
Monopole	IV	32?	IVGMR
Octupole	IS	20	ISGOR
Hexadecapole	IS	12	ISGHR

The experiments which we will discuss involve excitation of resonances (mostly in ^{208}Pb) using inelastic ^{17}O scattering, and the study of the subsequent photon decay of the resonance region in coincidence with the scattered particle. Most of the talk deals with data acquired at the French facility GANIL, using 84 MeV/nucleon ^{17}O beams. Some 22 MeV/nucleon data acquired at ORNL will also be discussed. These experiments represent first steps in an effort to address some of the questions mentioned above.

2. HEAVY ION EXCITATION OF GIANT RESONANCES

For the past decade heavy ions have been touted as potentially important tools in the study of GR. They are just beginning to live up to this promise. Generally speaking, heavy ions have not proved useful in conventional singles studies of GR by inelastic scattering because the angular distributions are not very sensitive to angular momentum transfer. The real virtue of heavy ions lies in the large excitation cross sections which can be achieved, making coincidence studies of resonance decay feasible, and perhaps making the identification of multiphonon GR states possible.

The cross section for GR excitation increases rapidly as the bombarding energy is increased. This is illustrated in Fig. 1, which shows the angular distribution for excitation of the ISGQR in ^{208}Pb by ^{17}O scattering at a range of energies, and in Fig. 2 which shows the peak differential cross sections (at an angle just inside the grazing angle) for excitation of various multipoles, all assumed to lie at an excitation energy of 14 MeV, and all assumed to exhaust 100% of the respective EWSR. The ratio of GR peak cross section to that of the underlying continuum also increases rapidly with bombarding energy. This is illustrated in Fig. 3, which shows the inelastic singles spectra observed with the ^{208}Pb(^{17}O,^{17}O') reaction at 22 MeV/nucleon and 84 MeV/nucleon. The latter spectrum shows a peak-to-continuum ratio at least three times better than the best observed with any other probe.

As the bombarding energy increases Coulomb excitation plays an increasingly important role. This has two important effects. (1) Unlike nuclear excitation, Coulomb excitation excites IS and IV states equally well. This makes study of IV states feasible in inelastic hadron scattering at high energy. (2) The excitation of quadrupole and especially dipole states, which benefit most from Coulomb excitation, increase much more rapidly than the cross section for excitation of the L = 0 or L > 2 GR. This is evident in Fig. 2, and is further illustrated in Fig. 4 which is a semiclassical Coulomb excitation calculation (Bertulani and Baur 1985) extending to much higher energy. Note that the excitation probability of the GDR continues to increase with bombarding energy eventually substantially exceeding the geometrical cross section. Consequently systematic study of multiphonon GDR excitation is a real possibility with relativistic heavy ions.

The probability of n-phonon resonance excitation scales roughly as Z^{2n} where Z is the charge of the exciting ion. Hence high Z ions will play an important role in future experiments. We will return to this topic briefly at the end of this talk. In the more modest experiments reported here, we chose ^{17}O as a projectile because it has only three particle-stable states. This simplifies the inelastic spectra, since if the ^{17}O projectile is excited above 3.8 MeV, it breaks up and is not detected as ^{17}O.

3. EXPERIMENTS

The experiments reported here involved inelastic scattering of ^{17}O by various targets at 22 MeV/nucleon (carried out at ORNL) and 84 MeV/nucleon (at GANIL). The reader interested in experimental details should consult Beene *et al.* (1989a and b) and (1988), Bertrand *et al.* (1988) and Barrette *et al.* (1988). A very brief outline will be given here.

In the 84 MeV/nucleon experiments at GANIL, the inelastically scattered ^{17}O particles were detected and identified in the SPEG energy loss magnetic spectrometer over a range of scattering angles from ~1° to 5°. Gamma rays in coincidence with inelastic scattering were detected in arrays of BaF_2 scintillators, and distinguished from neutrons by time of flight. Two gamma detector configurations have been used. In one case twenty-eight 10 cm x 14 cm long BaF_2 crystals with hexagonal cross section were arranged in four clusters of seven detectors. The second configuration was made up of six of these 7-pack arrays together with three groups of nineteen 6 cm x 20 cm long hexagonal cross section crystals.

The 22 MeV/nucleon experiments employed the ORNL Spin Spectrometer (a 70 detector, nearly 4π NaI detector crystal ball) for gamma detection, and a ring of six cooled surface barrier E-ΔE telescopes for ^{17}O detection and identification. The particle detectors were all positioned at θ = 13°, with opening angles Δθ = 3° and Δϕ = 9°.

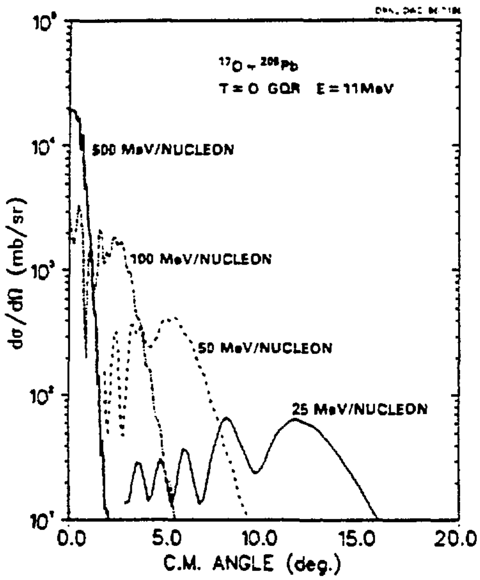

Fig. 1. Calculated angular distributions for the isoscalar giant quadrupole resonance excited by inelastic scattering of various energy ^{17}O ions.

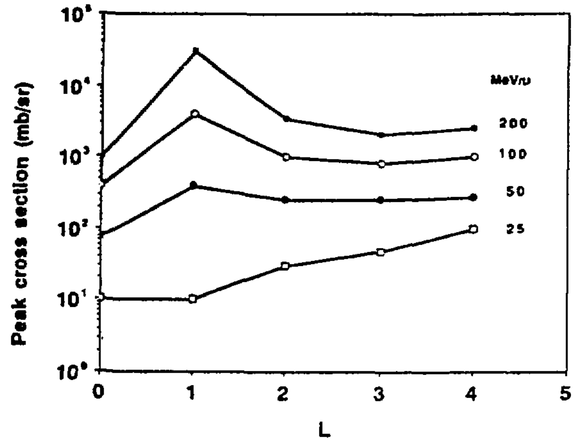

Fig. 2. The peak differential cross section as a function of multipolarity for fictitious states at 14 MeV having 100% of the corresponding EWSR, in the reaction $^{208}Pb(^{17}O,^{17}O')$ at the bombarding energies (MeV/nucleon) given. The L = 1 state is assumed to be isovector; all other isoscalar.

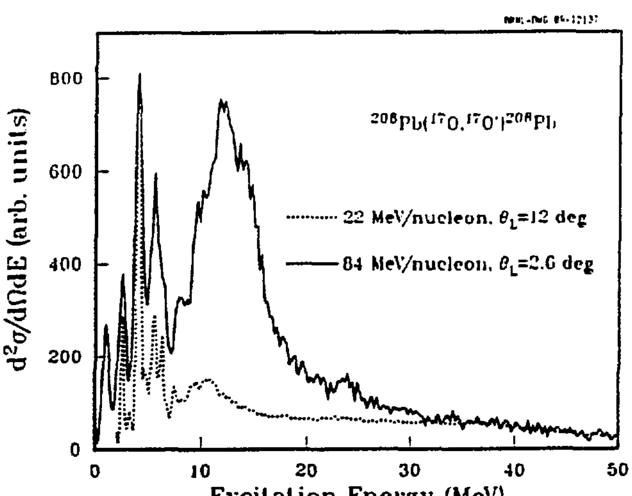

Fig. 3. Spectra from inelastic scattering of 84 (Barrette *et al.* 1988) and 22 (Beene *et al.* 1989b) MeV/nucleon ^{17}O from ^{208}Pb. The two spectra are normalized in the unstructured continuum near 40 MeV.

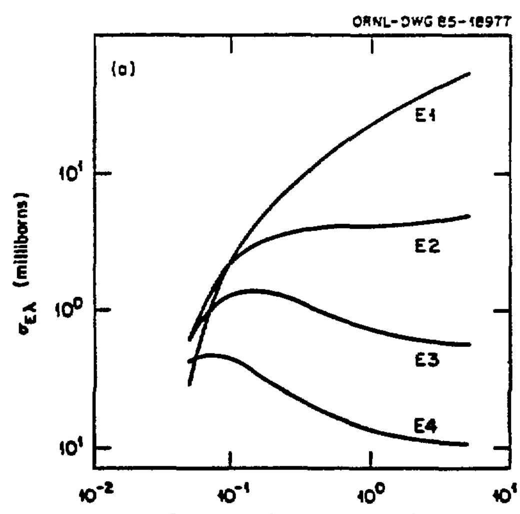

Fig. 4. Total cross section for excitation of a fictitious state at 22 MeV in ^{208}Pb which exhausts the full EWSR for the multipolarity given. The beam is ^{18}O.

4. EXCITATION AND DECAY OF THE IVGDR

In the $^{208}Pb(^{17}O,^{17}O')$ reaction at 22 MeV/nucleon, near the grazing angle, excitation of the ISGQR dominates the inelastic singles spectrum in the giant resonance region. This is illustrated in Fig. 5 which shows the decomposition of the GR region (Beene *et al.* 1989) (after an empirical background was subtracted). This decomposition is not a free fit, but was based on states observed in high resolution (p,p') (Bertrand *et al.* 1986) and photonuclear (Veyssiere *et al.* 1970) experiments. The main point here is that the IVGDR is very weakly excited (energy integrated cross sections are ~35 mb/sr for the GQR and ~5 mb/sr spread over a much larger energy range for the GDR). This was an important feature of the 22 MeV/nucleon experiment and made it possible to study the ground state gamma decay of the ISGQR, since if the IVGDR is strongly excited it will dominate the ground state gamma spectrum. The reason for this is illustrated in Fig. 6 which shows the relative ground state gamma decay width of a sharp giant resonance state of exhausting 100% of its EWSR, relative to the E1 GDR.

A similar decomposition (Barrette *et al.* 1988) of an 84 MeV/nucleon singles spectrum is shown in Fig. 7. In this case the IVGDR dominates the inelastic spectrum, with a cross section of almost 2.5 barns/sr, compared to about 700 mb/sr for the ISGQR. In Fig. 8, the spectrum resulting from requiring ground state gamma coincidences in the 84 MeV per nucleon data is shown. According to the spectral decomposition of Fig. 7, and the width ratios of Fig. 6, we would expect that the spectrum above ~9 MeV ought to be almost entirely due to the IVGDR. That this is indeed the case is demonstrated in Fig. 9 and Fig. 10 which show angular correlations between ground state gamma rays and the ^{17}O ejectile. In Fig. 9, this correlation is shown as a function of ^{17}O angle for fixed gamma detection angle. The solid line is a calculated result assuming pure Coulomb excitation of the GDR. The overall normalization of the calculation is adjusted to fit the data, giving an energy integrated ground state gamma branch for the IVGDR of $\Gamma_{\gamma 0}/\Gamma = 0.017 \pm .002$. Figure 10 shows the angular correlation for fixed ^{17}O angle ($\theta_{cm} = 2.7°$), as a function of gamma detection angle, compared with DWBA predictions for pure E1 excitation ($1^- \rightarrow 0^+$ decay). Clearly the E1 calculations describe the data in both Fig. 9 and Fig. 10 remarkably well.

The ground state gamma branch from the IVGDR can be accounted for quantitatively by applying the multistep compound emission (MSCE) formalism (Feshbach *et al.* 1980; Hussein and McVoy 1979; and Dias *et al.* 1986). Such calculations have been discussed extensively for both the 22 MeV/nucleon (Beene *et al.* 1989b and Beene *et al.* 1988), and the 84 MeV/nucleon data (Beene *et al.* 1988 and Beene *et al.* 1989a). In the MSCE calculations the total ground state gamma coincidence cross section is assumed to consist of an incoherent sum of terms which are interpreted as arising from successively more complicated stages of the reaction:

$$\sigma(X,X'\gamma_0) = \sum_{i=1}^{r} \sigma_i \ .$$

In the case of GR excitation and decay the first stage (i = 1) is the coherent 1p-1h resonance state which acts as a primary doorway state for the reaction process. This simple collective state eventually is damped into the continuum of complex compound states (r^{th} stage of the sum) which occupy the same region of excitation energy. The intermediate stages

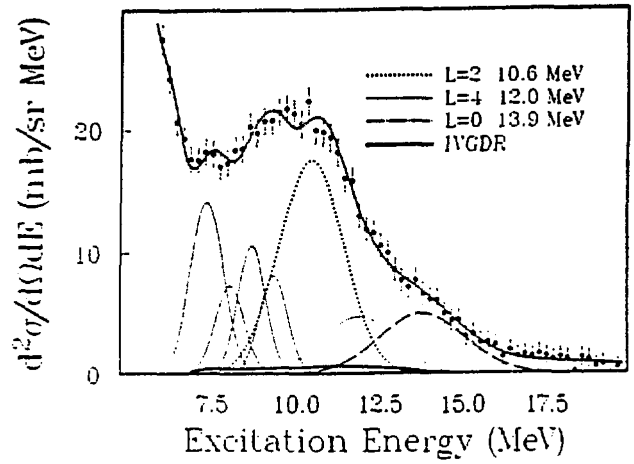

Fig. 5. Decomposition of a ^{208}Pb(^{17}O,^{17}O') inelastic singles spectrum taken at 22 MeV/nucleon and θ_{cm} = 14° (see Beene *et al.* 1989b).

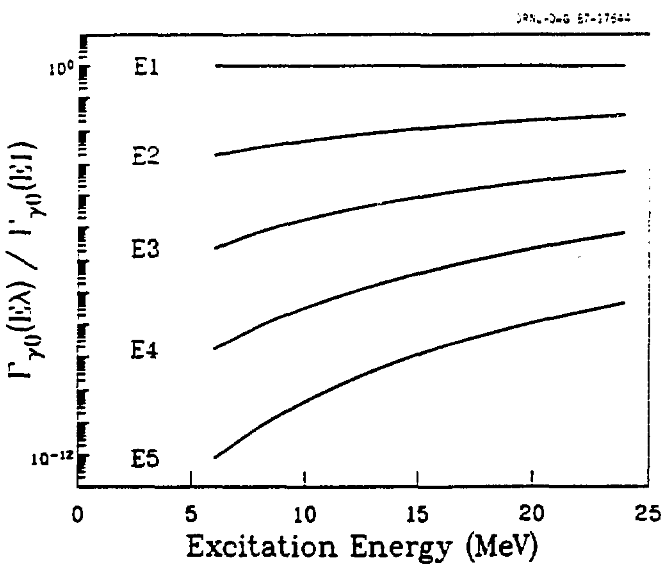

Fig. 6. Ground-state gamma widths of hypothetical sharp states fully exhausting the appropriate isovector or isoscalar energy weighted sum rule as a function of the excitation energy of the state, relative to the E1 width.

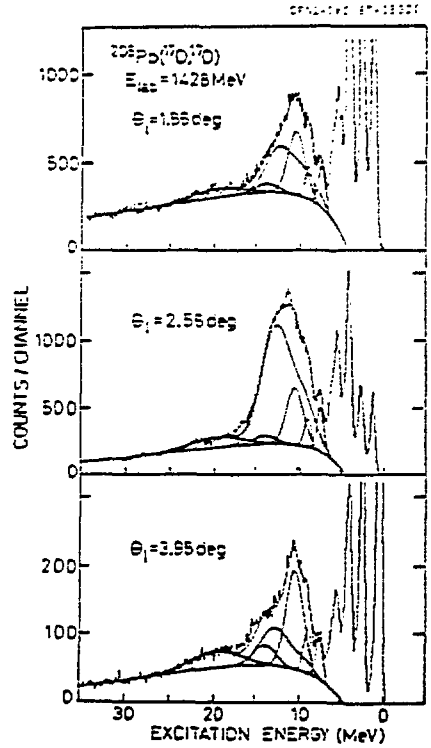

Fig. 7. Inelastic scattering spectra at θ_{lab} = 1.86°, 2.56°, and 3.98° from the ^{208}Pb(^{17}O,^{17}O') reaction at 1428 MeV. The solid curves show a decomposition of the spectra into resonance peaks at ~10.6 MeV (ISGQR), ~13.6 MeV (IVGDR), 14 MeV (ISGMR), 7.5 MeV, 9.1 MeV and a broad, undefined, peak centered at ~20 MeV and an underlying continuum (Barrette *et al.* 1988).

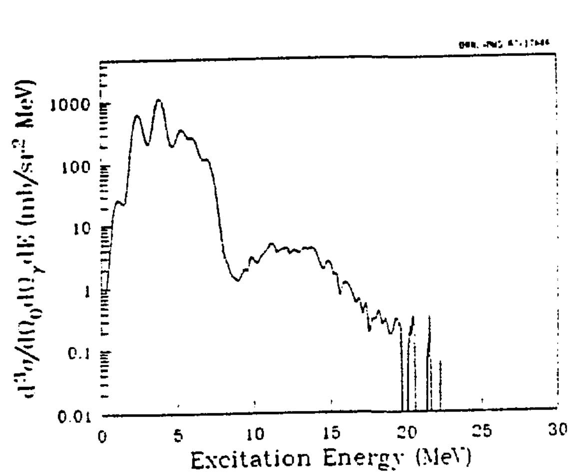

Fig. 8. Inelastic spectrum in coincidence with gamma rays to the ground state. (The ^{17}O angles are $\theta = 2.0°-3.5°$ in this case, the gamma detector angles are given in the text.)

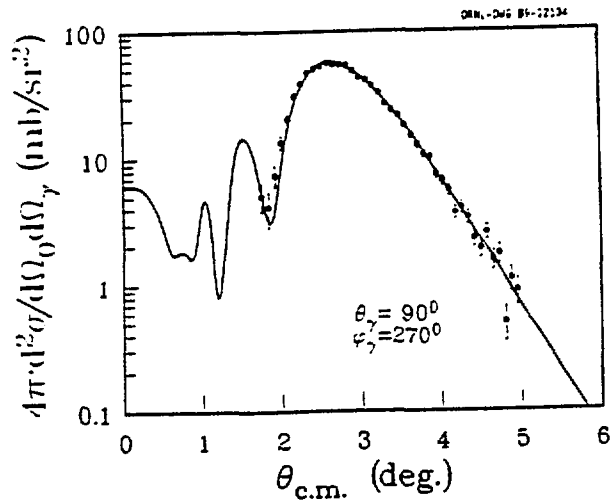

Fig. 9. $^{17}O-\gamma_0$ angular correlation for the $^{208}Pb(^{17}O,^{17}O')$ reaction at 84 MeV/nucleon, for fixed γ angle $\theta_\gamma = 90°$, $\phi_\gamma = 270°$.

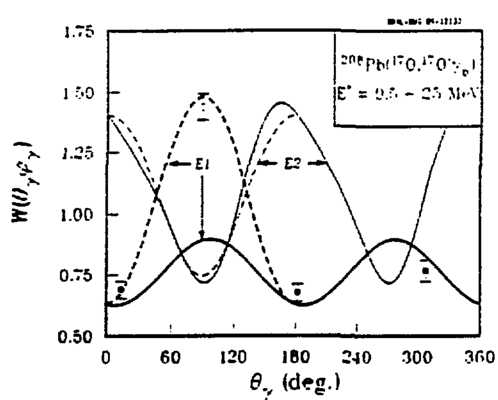

Fig. 10. The same correlation as fig. 15, but for fixed ^{17}O angle (θ - 2°-3°) and varying γ angle. The lines are from theoretical calculations assuming pure Coulomb excitation of the GDR. Filled data points and the solid curve lie in the reaction plane (ϕ = 0° and 180°). (For convenience the ϕ = 180° half plane is labeled by θ + 180°.) The open point and dashed line refer to the ϕ = 270° half plane.

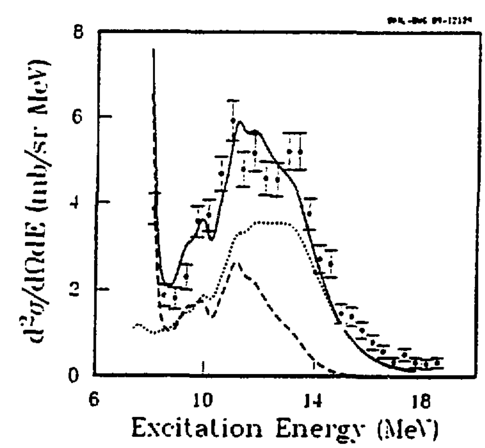

Fig. 11. The ground state gamma coincidence yield for 84 MeV/nucleon ^{17}O scattering on ^{208}Pb, compared with calculations as discussed in the text. The dashed line shows the compound contribution, and the dotted line the doorway contribution. The solid line is the sum.

$1 < i < r$ can in this case be taken to be the hierarchy of increasingly complex 2p-2h, 3p-3h etc. states through which the damping proceeds. Each stage in this damping process can contribute to the ground state gamma decay. In order to carry out quantitative calculations we have assumed that the most important contributions to the ground state gamma decay of giant resonances come from the first (1p-1h) stage and the r^{th} or compound stage. An example of the application of this formalism is shown in Fig. 11 which shows the experimental distribution in excitation energy of the ground state gamma decay coincidences compared with a MSCE calculation considering only the IVGDR, with its strength distribution taken from the photonuclear data of Veyssiere *et al.* (1970). The calculation which involves no adjustable parameters agrees very well with both the distribution of γ_0 strength and the energy integrated branching ratio obtained from the fit in Fig. 9. The calculated branch is $\Gamma_{\gamma 0}/\Gamma = 0.016$ compared to the experimental value 0.017 ± 0.02.

The separate contribution of the "doorway" (dash-dot line) and compound (dotted line) contributions to the γ_0 coincidences are also shown in Fig. 11. The compound contribution is significant on the low energy side of the resonance but becomes increasingly less important at higher energy as the neutron decay branch of the compound states increases. The doorway contribution to the γ_0 decay depends only on the collective properties of the resonance (strength, spreading width, etc.) which change very slowly with A and Z from nucleus to nucleus. However, the compound contribution can be very dependent on the details of the nucleus being studied. Therefore a very sensitive test of the MSCE calculations can be made by comparing the γ_0 decay from pairs of judiciously chosen neighboring nuclei. A good case is the pair ^{209}Bi and ^{208}Pb. Figure 12 shows the singles inelastic spectrum at $\theta_{cm} = 2.5°$ for excitation of ^{208}Pb (solid) and ^{209}Bi (dashed). The distribution of excitation cross section (which is dominated by the IVGDR) is almost identical in the two cases. Figure 13 shows the ratio of ground state gamma decay cross sections for these two nuclei. Clearly the decay is not so similar as the excitation. The γ_0 yield in the region where compound emission is important for ^{208}Pb is much larger in ^{208}Pb than in ^{209}Bi. This is precisely what is predicted by the MSCE calculations, shown as a dotted line of Fig. 13. The compound γ_0 emission is smaller in ^{209}Bi since the density of available states in ^{208}Bi is much larger than in ^{207}Pb, resulting in larger relative neutron emission probability and consequently a smaller gamma decay branch. The agreement between the data and the MSCE calculations shown in Figs. 11 and 13 and for 22 MeV/nucleon data in Beene *et al.* (1989), is remarkable, especially in view of the approximations made. [A more rigorous application of MSCE ideas to this problem has been outlined by Dias *et al.* (1986).] The MSCE model has played a major role in the interpretation of charged particle and neutron decays of GR (e.g., Wagner 1980, Bracco *et al.* 1988 and 1989 and Brandenburg *et al.* 1987). We regard the success of the model in describing the relative simple electromagnetic decay case as an important demonstration of its applicability to GR decay.

A further interesting point can be made from the excitation cross section data in Fig. 12. It has been postulated (Nolte *et al.* 1986) that the total GDR strength in ^{209}Bi might be substantially larger than in ^{208}Pb as a result of meson exchange currents. An estimate of the size of the effect (Nolte *et al.* 1986) has been made using the renormalization of the ^{209}Bi ground state magnetic moment (again due to meson exchange effects). The near identity of the two spectra in Fig. 12 can only be understood if the GDR strength are the same in ^{209}Bi and ^{208}Pb within ~3%!

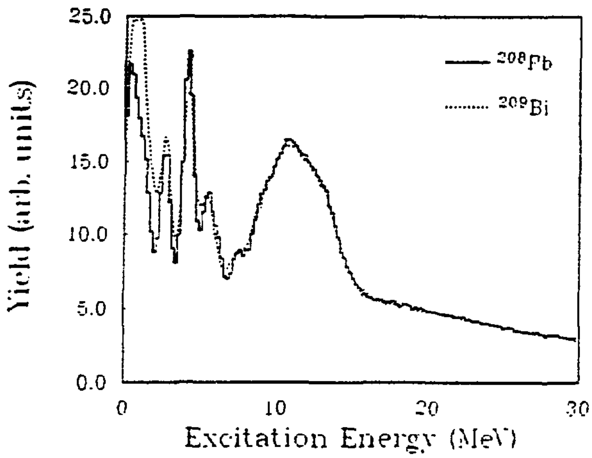

Fig. 12. Singles spectrum for 84 MeV/nucleon ^{17}O inelastically scattered by ^{208}Pb and ^{209}Bi at θ_{cm} ~ 2.7°.

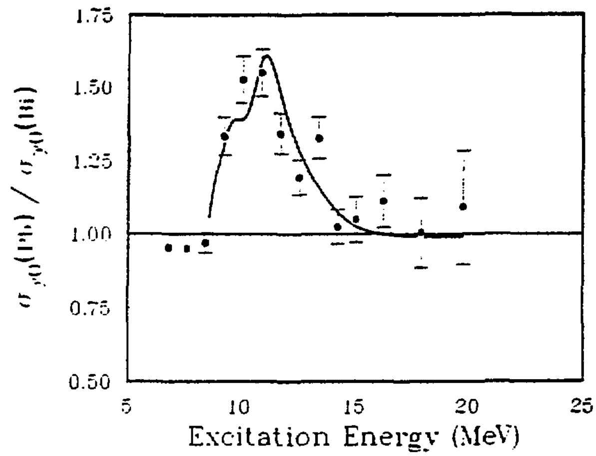

Fig. 13. Ratio of γ_0-coincident spectra for 84 MeV/nucleon ^{17}O scattered by ^{208}Pb and ^{209}Bi (points). The curve is the ratio predicted by the MSCE calculation (see text).

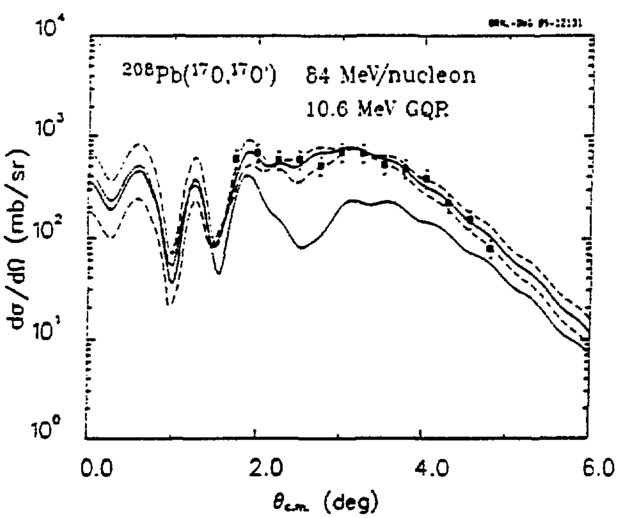

Fig. 14. The experimental angular distribution for the 10.6 MeV ISGQR in ^{208}Pb (data points). The lines are described in the text.

5. ISOSPIN CHARACTER OF THE 10.6 MeV GQR IN ^{207}Pb

Significant localized quadrupole strength (i.e., a GQR) was first identified in the early 1970's (Bertrand 1981) and has been studied systematically throughout the periodic table. It has been widely assumed that this is an isoscalar resonance, i.e., an in-phase vibration of neutrons and protons with approximately equal amplitude. This implies that neutrons and protons should contribute to the excitation matrix elements (see Satchler 1987 for details) in the ratio $M_n/M_p \sim N/Z$ (= 1.54 for ^{208}Pb). Recent pion scattering data have, however, been interpreted as implying that the 10.6 MeV GQR in ^{208}Pb is mostly a neutron excitation ($M_n/M_p \sim 3.8$) with an electromagnetic strength $B(E2\uparrow) \approx 1100$ e^2fm^2, which is almost 5 times smaller than would be expected from an isoscalar state exhausting ~60-100% of the isoscalar energy weighted sum rule (EWSR). In our work at 22 MeV/nucleon we have isolated the ground state gamma decay branch from the 10.6 MeV GQR in ^{208}Pb, and deduced a value $B(E2\uparrow) \sim 5300$ e^2fm^4 for the L = 2 strength near 10.6 MeV in ^{208}Pb, corresponding to $M_n/M_p \sim 1.5 \pm 0.5$ and contradicting the pion scattering result (Beene *et al.* 1989b and Horen, Beene and Bertrand 1988).

Further support for the essentially isoscalar character of the 10.6 MeV resonance can be obtained from the 84 MeV/nucleon inelastic singles data. From Fig. 8 it can be seen that the IVGDR and the 10.6 MeV GQR account for a very large fraction of the excitation cross section in the GR region. From the evidence presented in Section 4 we believe that the IVGDR excitation can be accounted for extremely accurately using photonuclear strength distributions and Coulomb excitation calculations [it is important to take into account the excitation energy dependence of the Coulomb excitation process (Beene *et al.* 1989a and Bertrand *et al.* 1988)]. We can therefore extract the excitation cross section for the 10.6 MeV GQR very well. The resulting angular distribution is presented in Fig. 14.

The importance of Coulomb excitation for L = 2 states at 84 MeV/nucleon means that these data are extremely sensitive to the electromagnetic strength (i.e., proton matrix element) of the resonance. We have carried out an analysis of the data in which M_n/M_p is treated as a free parameter which is reported in more detail in Beene *et al.* (1989a). The basic idea of the analysis (see e.g. Satchler 1987, Bernstein *et al.* 1981, Rychel 1987 and Horen, Beene and Bertrand 1988) is that the nuclear excitation of the GQR depends on the sum of neutron and proton matrix elements $[\alpha(M_n + M_p)^2]$ while the Coulomb excitation is proportional to $B(E2\uparrow) = e^2M_p^2$. The Coulomb nuclear interference region just inside the grazing angle is very sensitive to $|M_n/M_p|$, while the total cross section, because of the strong Coulomb excitation is most sensitive to M_p. The best fit result is illustrated on Fig. 14 as a solid line which corresponds to $|M_n/M_p| = 1.7 \pm 0.4$ and $B(E2\uparrow) = 3980 \pm 450$. The dashed lines on either side of the solid line in Fig. 14 show the effect of changing M_n/M_p by one standard deviation, while the dotted line represents the cross section that would be expected for the transition potential with $M_n/M_p = 3.8$, deduced from pion scattering. If additional L = 2 strength at 8.9 and 9.1 MeV (which would not have been resolved from the 10.6 MeV peak in our 22 MeV/nucleon data, or the pion data) is included assuming the same M_n/M_p as deduced here for the 10.6 MeV peak, we obtain a total $B(E2\uparrow) = 5200 \pm 800$ for the GQR region. Clearly the results of pion scattering data grossly underestimate the electromagnetic strength (proton matrix element) of the 10.6 MeV GQR. These results for the electromagnetic strength of 10.6 MeV GQR are in remarkably good agreement with recent (e,e'n) data from Bolme *et al.*

(1988). This is illustrated in Fig. 15 which compares our B(EL)↑ distribution with the (e,e'n) data. This is especially gratifying in view of the long history of disagreement between electron and hadron scattering results for the ISGQR.

6. THE IVGQR IN ^{208}Pb

The principal motivation for our initial ^{208}Pb(^{17}O,^{17}O') experiments at 84 MeV/nucleon was to try to isolate the IVGQR In ^{208}Pb using a gamma-gamma coincidence technique. In our early work at 22 MeV/nucleon on the ISGQR, we found that the E1 decay branch from the ISGQR to the 3^- 2.6 MeV state in ^{208}Pb was many times smaller than would be expected from naive statistical arguments. This result was explained by two theoretical papers (Bortignon *et al.* 1984 and Speth *et al.* 1985) as partly due to cancellation between neutron and proton transition matrix elements which results from the isospin character (IS) of the ISGQR. These authors pointed out that the IVGQR should, on the other hand, have a very large gamma decay branch to the 3^- 2.6 MeV state. Our experiments (Bertrand *et al.* 1989) have mapped out the distribution of gamma-gamma coincidence yield resulting from this decay above an excitation energy of ~15 MeV (Fig. 16). If this triple coincidence yield is interpreted as arising form the IVGQR it implies the following properties of the strength distribution: $\langle E \rangle = 22.6 \pm 0.4$ MeV, $\sigma \sim 6 \pm 2$ MeV and strength ~50% of the EWSR.

7. HIGH LYING STRENGTH AND MULTIPHONON STATES

The search for collective strength in the large gap between the known nuclear giant resonances and the nucleon resonances is an exciting area of current research. Interesting but controversial results are already available from the Orsay group (e.g., Chomaz *et al.* 1986). The availability of good quality beams of higher energy high Z ions should make an important contribution to this search. Recent papers by Baur and his collaborators (Baur and Bertulani 1986 and 1989 and Baur and Baron 1989) and proposals by Braun-Munzinger *et al.*(1985) and Emling (1987) have emphasized the crucial role which Coulomb excitation using the intense field produced by high Z collision partners in intermediate energy and high energy heavy ion collisions. We believe the distinctive electromagnetic decay of states which involve coherent excitation of a GDR phonon will make it possible to isolate these particular two phonon states in the continuum, even in experiments carried out near 100 MeV per nucleon, using coincidences between inelastically scattered heavy ions and de-excitation photons. A combination of the observation of these distinctive particle gamma-gamma coincidences, and the strong excitor Z dependence of the excitation cross section (scales like Z^{2n}, where n is the phonon number) may make it possible to identify the 2 phonon strength even in a much more intense background of 1 phonon and more complex continuum excitations. This offers the near-term prospect of relatively high resolution spectroscopic studies of two phonon strength at facilities such as GANIL where high quality beams and magnetic spectrographs are available.

8. CONCLUSION

The results presented in this talk represent the early stages of quantitative use of intermediate energy heavy-ion scattering in the study of giant resonances. We have stressed the importance of Coulomb excitation of L = 1 and 2 states, and the very large excitation cross sections which make possible the quantitative study of weak decay branches. Our experiments

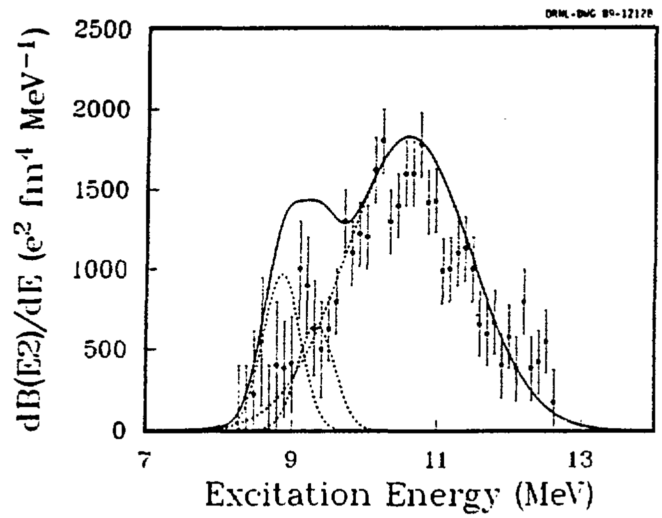

Fig. 15. The distribution of B(E2)↑ in the giant resonance region as obtained from the ^{208}Pb(^{17}O,^{17}O'γ) measurements of Beene *et al.* (1989) (solid curve) and the (e,e'n) movements of Bolme *et al.* (1988) (points with error bars). The contributions of the 8.8 and 9.3 MeV states and the 10.6 MeV state are shown separately as dashed curves.

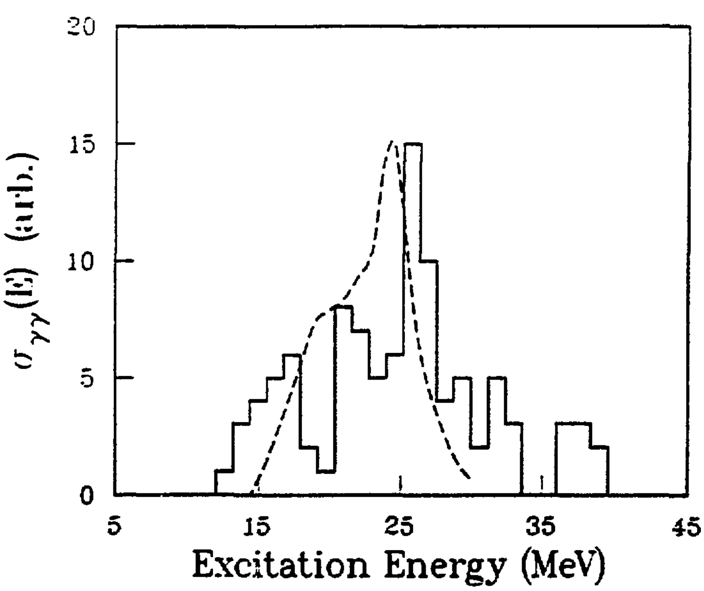

Fig. 16. The histogram is the triple coincidence data, $\gamma_1\gamma_2{}^{17}$O', (γ_1 > 10 MeV, γ_2 = 2.6 MeV). The curve is the predicted (Bertrand *et al.* 1989 distribution if IVGQR strength convoluted with the energy dependence of the probability of excitation by 84 MeV/nucleon ^{17}O on ^{208}Pb.

have already led to significant information on giant resonance gamma decay mechanisms and the isospin character of resonance states. We have begun to utilize the large Coulomb excitation cross sections to investigate isovector strength above the IVGDR. There is reason to hope that intermediate-energy experiments done with somewhat heavier projectiles will, along with gamma decay coincidences, enable us to investigate, in some detail, two phonon states with one or both the phonons being a GDR mode.

The experiments described here were carried out in collaboration with D. J. Horen, R. L. Auble, B. L. Burks, J. Gomez del Campo, M. L. Halbert, D. C. Hensley, J. E. Lisantti, R. L. Robinson, R. O. Sayer, and R. L. Varner from Oak Ridge; W. Mittig and Y. Schutz from GANIL; B. Haas and J.P. Vivien of Strasbourg, and J. Barrette, N. Alamanos, F. Auger, B. Fernandez, and A. Gillibert from Saclay, and A. Nathan from the University of Illinois.

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