shape isomers this mode must be considered. There is still the question of hindrance of the $E0$ mode. Unfortunately, there are no accurate measurements of 0^+ state lifetimes in this region. For essentially no decay via an 8-keV transition, we extract from τ a monopole matrix element $\rho = 0.07^{+0.02}_{-0.01}$. This ρ is a factor of 5 smaller than those observed from 0^+ β-type vibrational states in deformed rare-earth nuclei. While these β-vibrational states are in a different region, the differences in ρ are suggestive that retardation has occurred as expected for a shape isomer. It is necessary to calculate the monopole strength in a coexistence model before predictions of shape isomerism really can be tested. Indeed, these 0^+ states provide sensitive tests of future calculations.

*On leave from the Institute for Nuclear Studies, Tokyo, Japan.

†Work supported in part by a grant from the Energy Research and Development Administration.

‡UNISOR is a consortium of fourteen institutions and is supported by them and by the U. S. Energy Research and Development Administration.

§Research sponsored by the U. S. Energy Research and Development Administration under contract with Union Carbide Corporation.

[1]J. H. Hamilton *et al.*, Phys. Rev. Lett. 35, 562 (1975).

[2]F. Dickman and K. Dietrich, Z. Phys. 271, 417 (1974).

[3]S. Frauendorf and V. V. Pashkevich, Phys. Lett. 55B, 365 (1975).

[4]D. Kolb and C. Y. Wong, Nucl. Phys. A245, 205 (1975).

[5]J. Bonn, G. Huber, H. Kluge, and E. W. Otten, Phys. Lett. 38B, 308 (1972).

[6]A. Faessler, U. Götz, B. Slavov, and T. Ledergerber, Phys. Lett. 39B, 579 (1972).

[7]M. Cailliau, J. Letessier, H. Flocard, and P. Quentin, Phys. Lett. 46B, 11 (1973).

[8]N. Rud *et al.*, Phys. Rev. Lett. 31, 1421 (1973).

Observation of Giant Resonances in ^{24,25,26}Mg and ^{27}Al by Inelastic α Scattering

A. Kiss, C. Mayer-Böricke, M. Rogge, P. Turek, and S. Wiktor

Institut für Kernphysik der Kernforschungsanlage Jülich, D-5170 Jülich, Germany

(Received 7 July 1976)

The $E2$ giant-resonance region in *sd*-shell nuclei was studied by inelastic scattering of 106-, 120-, 145-, and 172.5-MeV α particles. Strong excitation in this region was observed for all investigated nuclei (^{24,25,26}Mg and ^{27}Al) at the higher incident energies. At lower incident energies, the tail of the giant resonance tends to be obscured by another broad distribution. In the $E2$ giant-resonance region, there is more fine structure in the Mg isotopes than in ^{27}Al.

This Letter is written in view of very recent work[1] concerning the excitation of giant quadrupole resonances in various nuclei by inelastic α scattering at 96 and 115 MeV. The authors of Ref. 1 claim that in going from heavy nuclei to lighter ones ($A < 32$) a qualitative change occurs in the isoscalar giant quadrupole resonance (GQR). From their experiments no GQR peaks were apparent for nuclei with $A < 32$. Therefore, they conclude that for these light nuclei the $E2$ strength is no longer clustered in a single broad peak but must be fragmented among many levels over a wide energy range. Moreover, investigations of $E2$ strength distributions in light nuclei[2] with radiative capture experiments indicate a fragmented distribution of $E2$ strength which is spread out over about 15 MeV, with very little strength in the region of the expected position of the GQR ($63A^{-1/3}$ MeV). On the other hand, there are experimental indications that quadrupole strength in light nuclei is concentrated (^{12}C,[3] ^{16}O,[4,5] ^{24}Mg,[6] ^{20,22}Ne, ^{28}Si,[7] and ^{27}Al[8]), exhausting a considerable amount of the energy-weighted sum rule (EWSR).

In order to investigate in more detail the question of strength concentration in the GQR region in light *sd*-shell nuclei, inelastic scattering experiments were performed on ^{24,25,26}Mg and ^{27}Al nuclei by use of 106-, 120-, 145-, and 172.5-MeV α beams of the Jülich isochronous cyclotron JULIC. The idea was that possibly there is an energy dependence in the yield of the GQR in (α, α') experiments which may explain part of the controversial results mentioned above. Great efforts were made to optimize the beam properties and to avoid slit scattering.[9] The targets were self-supporting foils of highly enriched ^{24}Mg, ^{25}Mg, and ^{26}Mg and a foil of natural ^{27}Al.

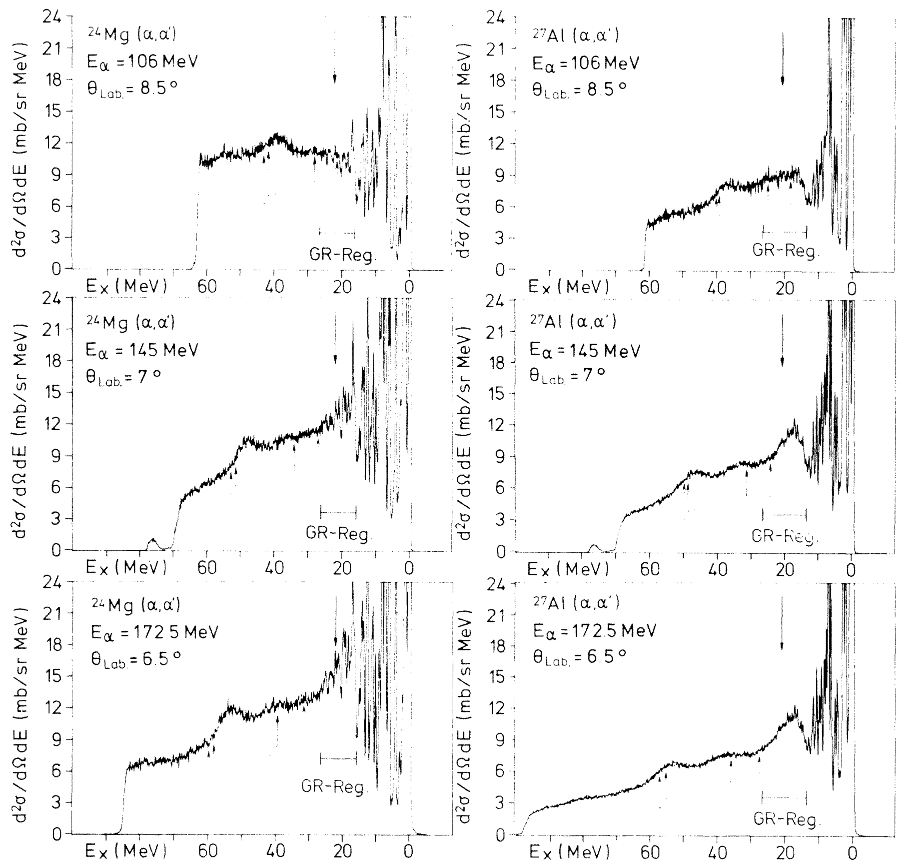

FIG. 1. Spectra of α particles scattered inelastically by ^{24}Mg and ^{27}Al at 106, 145, and 172.5 MeV incident energies. The "GR region" indicated in the figures is suggested empirically from the strongly excited region surrounding the expected GQR ($\Delta T = 0$) location at $\cong 63A^{-1/3}$ MeV (upper arrows). The kinematic limits for ^{5}He and ^{5}Li breakup contributions are indicated by solid and dashed arrows, respectively.

The scattered particles were detected by detector telescopes operating in the $\Delta E - E$ mode. The experimental details are described in Ref. 9. Spectra were taken for all targets and bombarding energies in the vicinity of the first minimum of the elastic cross section ($\theta_{lab} = 6.5° - 8.5°$) in order to provide constant momentum transfer.

In Fig. 1, spectra for ^{24}Mg and ^{27}Al are displayed. Similar spectra have also been obtained at 120 MeV. All spectra show strong excitation in the giant resonance (GR) region around $63A^{-1/3}$ MeV excitation (upper arrows) for the higher incident energies. At lower incident energies the excitation in the GR region becomes less visible in accordance with Ref. 1.

An important feature which emerges from the spectra taken at 172.5 and 145 MeV is the appearance of two broad peaks beyond the GR region, e.g., around 55 and 37 MeV in the 172.5-MeV ^{27}Al spectrum in Fig. 1. These peaks, carrying considerable intensity, move to lower excitations with decreasing incident energy. The lower one merges in the GR region in the 106-MeV case and can therefore obscure the shape of the tail of the peak in the GR region. This seems to be one reason why the strength concentration in the GR region was not seen before at these lower energies.[1] The movement of these two broad peaks is in accordance with that of the kinematical limits for α particles originating from the decay of ^{5}He (full lower arrows) and from ^{5}Li nuclei (dashed lower arrows) created in pick-up reactions (see Fig. 1). Even if such details as the intensity distribution including the two broad peaks remain to be understood more quantitatively, it is tempting to assume, in accordance with Ref. 1, that this distribution originates mainly from ^{5}He and ^{5}Li α decays. This is supported also by the fact that in all cases where the lower arrows are very close (due to Q values) the spectra show a more pro-

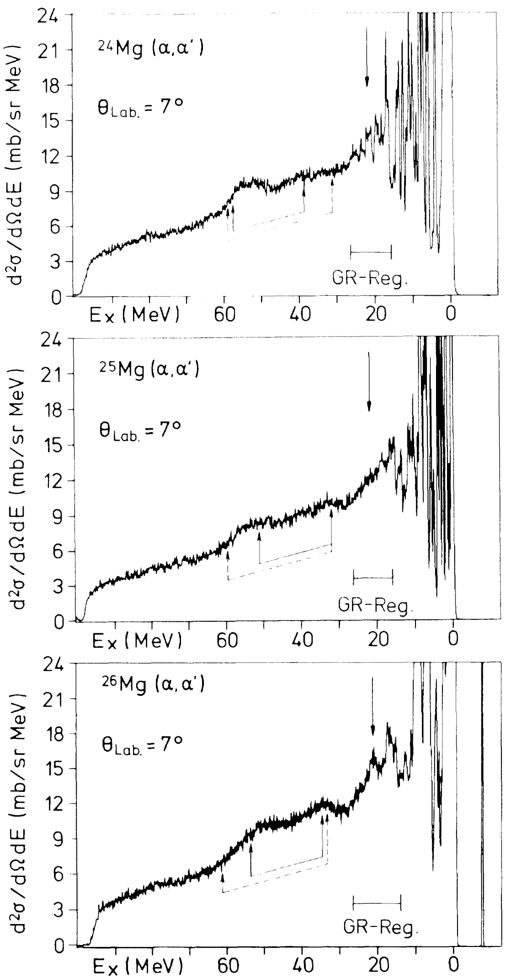

FIG. 2. Spectra of α particles scattered inelastically by ^{24}Mg, ^{25}Mg, and ^{26}Mg at 172.5 MeV incident energy.

nounced bump (e.g., in the ^{25}Mg and ^{26}Mg spectra of Fig. 2). Furthermore, when the kinematical limits for ^{5}He and ^{5}Li α decays are widely separated, the broad peak observed at lower excitation energies tends to be grouped into two parts (e.g., in the ^{24}Mg spectra taken at 172.5 MeV).

The 172.5-MeV spectra were evaluated by subtracting the continuum as indicated in Fig. 1. Because of the intensity hidden under the "lower" peaks from the ^{5}Li and ^{5}He α decays, the dividing lines may have to be lowered considerably. This would increase the intensity of the GR peak extracted from the data, especially in the case of the lower incident energies.

The ^{27}Al 106-MeV spectrum (Fig. 1) is similar in structure to that shown in Ref. 1. There is no peak apparent in the GR region. However, the two ^{27}Al spectra taken at 145 and 172.5 MeV exhibit a pronounced GR peak with a full width at

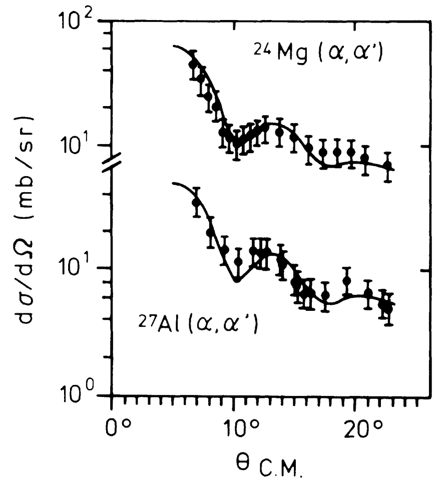

FIG. 3. Experimental angular distributions of the giant resonance in ^{24}Mg and ^{27}Al at 172.5 MeV incident energy (points). The curves represent DWBA calculations with $L=2$ (real coupling).

half-maximum (FWHM) of 7.6 MeV and a centroid energy of approximately 18.5 MeV, which is somewhat lower than expected from the $63A^{-1/3}$-MeV formula. The fine structure on the compact GR peak of ^{27}Al shows up in the same way in the spectra taken at 145 and 172.5 MeV. Obviously, the yield for the GR peak increases if the α energy is increased from 106 to 172.5 MeV, while the continuum yield remains roughly the same. This may be another reason why the strength concentration in the GQR region was not seen before[1] in the sd-shell nuclei.

The spectra of ^{24}Mg (Fig. 1) taken at 145 and 172.5 MeV display again strong excitation in the expected GQR region. However, the strength in this region is split into many components. Altogether the strength is not less than that in ^{27}Al and the overall FWHM of this strength distribution is even somewhat smaller than that of the compact peak in the GQR region of the ^{27}Al spectra. Similar to the ^{27}Al case, the excitation in the GR region is less visible for lower incident energies. The details of the split structure in the GR region are seen in spectra both at 172.5 and 145 MeV. The main structure can even be seen in the 106-MeV ^{24}Mg spectrum.

Figure 2 shows the spectra of the Mg isotopes obtained at 7° for 172.5 MeV incident energy, all measured with the same energy resolution. All three spectra show strong excitation in the GR region. The GR strength, however, is split into several peaks, whose number and position vary with A value. For ^{24}Mg there is a tendency for the amplitudes of the fine-structure peaks to decrease with increasing excitation energy.

Figure 3 shows the angular distribution of the GR for these nuclei at 172.5 MeV incident energy. These experimental data show a structure which can be described in distorted-wave Born-approximation (DWBA) calculations with $L=2$. Similar results have been obtained at 145 MeV. This supports the predominant isoscalar quadrupole nature of the strong excitation in the GR region. On the basis of calculations similar to those of Ref. 4, the isoscalar $E2$ EWSR limit is estimated to be depleted in both cases to about 40–70%. The observed increase of the GR cross section with incident α energy at the same momentum transfer is in agreement with DWBA predictions made with extrapolated optical-model parameters.

Finally, the question remains as to why so little $E2$ strength in the GQR region of light nuclei was seen in capture reactions.[2] Possibly, in addition to the configurations involved in the $E2$ excitation in capture reactions, other configurations carrying $E2$ strength can be excited in (α, α') scattering.

We thank Professor Aaron Galonsky for discussions.

[1]D. H. Youngblood, J. M. Moss, C. M. Rozsa, J. D. Bronson, A. D. Bacher, and D. R. Brown, Phys. Rev. C 13, 994 (1976).

[2]S. S. Hanna, in *Proceedings of the International Conference on Nuclear Structure, Amsterdam, 1974*, edited by H. P. Blok and A. E. Dieperink (Scholar's Press, Amsterdam, 1974), Vol. 2, p. 249; E. Kuhlmann, E. Ventura, J. R. Calarco, D. G. Mavis, and S. S. Hanna, Phys. Rev. C 11, 1525 (1975).

[3]H. V. Geramb, K. Amos, R. Sprickmann, K. T. Knöpfle, M. Rogge, D. Ingham, and C. Mayer-Böricke, Phys. Rev. C 12, 1697 (1975).

[4]K. T. Knöpfle, G. J. Wagner, H. Breuer, M. Rogge, and C. Mayer-Böricke, Phys. Rev. Lett. 35, 779 (1975).

[5]M. N. Harakeh, A. Arends, M. J. A. de Voigt, S. Y. van der Werf, A. G. Drentje, and A. van der Woude, University of Groningen, Netherlands, Annual Report, 1975 (unpublished), p. 3.

[6]I. Lovas, M. Rogge, U. Schwinn, P. Turek, D. Ingham, and C. Mayer-Böricke, Institut für Kernphysik der Kernforschungsanlage Jülich Annual Report (1975) No. KFA-IKP 10/76 (unpublished), p. 8.

[7]T. Bauer, H. Breuer, A. Kiss, K. T. Knöpfle, C. Mayer-Böricke, P. Paul, M. Rogge, and G. J. Wagner, Institut für Kernphysik der Kernforschungsanlage Jülich Annual Report (1975) No. KFA-IKP 10/76 (unpublished), p. 17.

[8]M. B. Lewis and F. E. Bertrand, Nucl. Phys. A196, 337 (1972).

[9]A. Djaloeis, A. Kiss, M. Rogge, P. Turek, S. Wiktor, and C. Mayer-Böricke, "Excitation of Giant Resonance in ^{89}Y by Deuteron, ^{3}He, and α-Particle Scattering" (to be published).

Similarity of Cross Sections for Peripheral Collisions at 20 MeV/A and 2.1 GeV/A*

M. Buenerd,† C. K. Gelbke, B. G. Harvey, D. L. Hendrie, J. Mahoney, A. Menchaca-Rocha,‡ C. Olmer, and D. K. Scott
Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 23 August 1976)

Peripheral collisions between ^{16}O and ^{208}Pb are investigated at a laboratory energy of 315 MeV. The relative cross sections are remarkably similar to published cross sections measured at 33.6-GeV laboratory energy. They are compared with statistical models involving dinuclear systems and projectile fragmentation.

The measurement of cross sections for particles produced by heavy ions of relativistic energies at forward scattering angles[1,2] has evoked substantial theoretical study.[3-7] At these energies, the relative velocities of the colliding nuclei considerably exceed the Fermi velocities of the nucleons in the target and projectile. Consequently, the interactions between the two nuclei occur on time scales short compared with the time required for nuclear relaxation. However, the rather small momentum transfers and the distribution of the particle yields observed in these peripheral reactions have suggested that the comparatively slow statistical decay of the primary reaction products is important for a quantitative understanding of the experimental findings.[3-7] The abrasion-ablation model[7] is an example of such a two-step process in which the initial abrasion of nucleons from projectile and target is followed by the statistical decay of the highly excited remnants. In contrast, diffusion and equilibration phenomena of the target-projectile complex[8-10] are observed in heavy-ion reactions at energies only a few (1–3) MeV/A above