Comment on the characterization of the giant quadrupole resonance in ^{208}Pb as reported from π^+/π^- scattering

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Studies of π^+/π^- inelastic excitation of the giant quadrupole resonance in ^{208}Pb have been interpreted as implying a quadrupole matrix element ratio for neutron to proton excitations of $M_n/M_p=3.8$, and a reduced electric transition rate of $B(E2)\uparrow=1010\pm600$ e^2fm^4. These values are in strong disagreement with the results of a large body of inelastic light-ion scattering data as well as recent electron scattering results, all of which are consistent with a predominantly isoscalar character for this resonance. A similar situation prevails for the scattering of 400-MeV ^{16}O and 1428-MeV ^{17}O ions where Coulomb excitation is important, and the inelastic cross sections are very sensitive to $B(E2)\uparrow$ as well as the hadronic interaction strength. Studies of the photon decay of the giant quadrupole resonance are also in good agreement with random phase approximation calculations that imply a predominantly isoscalar character; this agreement would be destroyed if the interpretation of the pion experiment were correct.

The conclusions that can be derived from experiments which excite the giant quadrupole resonance (GQR) can be to some degree dependent upon the assumptions made pertaining to its detailed structure. In this Comment we wish to note that the recently reported[1] ratio of neutron to proton matrix elements for the GQR in ^{208}Pb deduced from a comparison of π^+/π^- inelastic scattering is inconsistent with results from other experiments when the latter are analyzed using the same assumptions for the GQR. Measurements of $T_\pi=162$ MeV pion inelastic scattering on ^{208}Pb resulted in a value of the cross section ratio $\sigma(\pi^-)/\sigma(\pi^+)=2.72\pm0.49$ for the 10.6 MeV GQR. These results have been interpreted as implying a matrix element ratio $M_n/M_p=3.8$ and reduced transition probabilities $B(E2)\uparrow=1010\pm600$ e^2fm^4 for the protons and $B(N2)\uparrow=(1.45\pm0.36)\times10^4$ fm^4 for the neutrons.

This large difference in neutron and proton matrix elements would imply that the 10.6 MeV GQR in ^{208}Pb is not a predominantly "isoscalar" resonance (i.e., an in-phase oscillation of neutrons and protons with approximately equal amplitudes), as has been assumed heretofore, but rather that its excitation exhausts only 48 ± 7 % of the isoscalar energy-weighted sum rule (ISEWSR), together with 16 ± 8 % of the isovector (IVEWSR). These % EWSR follow directly from the $B(N2)\uparrow$ and $B(E2)\uparrow$ noted above.

In contrast to these results, a considerable body of hadron scattering data has been interpreted successfully in terms of a model of the GQR oscillation[2] in which it is assumed that the neutron and proton deformations are equal, implying $M_n/M_p\approx N/Z\approx1.5$. While such a state is not strictly "isoscalar" unless $N=Z$, in ^{208}Pb it would contain an isovector component of only about $[(N-Z)/A]^2\simeq4\%$. A recent high resolution proton experiment,[3] analyzed in this way, yielded a strength of 70% of the ISEWSR for the 10.6 MeV GQR. This agrees within uncertainties with a large body of alpha and proton scattering data and would imply a $B(E2)\uparrow\approx5000$ e^2fm^4, which is about five times larger than that deduced from the pion data. Recent electron scattering results[4-6] are in good agreement with those from hadron scattering.

In contrast with the situation for light ions, inelastic scattering of heavy ions is particularly sensitive to the proton excitations because of the large contribution of Coulomb excitation to the cross section. Furthermore, the Coulomb excitation increases rapidly relative to the hadronic excitation with increasing bombarding energy. Figures 1 and 2 show data for inelastic scattering on ^{208}Pb of 400 MeV ^{16}O ions[7] and 1428 MeV ^{17}O ions,[8] respectively. The solid and dashed curves are from DWBA calculations using optical potentials deduced from fits to differential elastic scattering data[7,8] and the deformed optical potential model.[2] Using reasonable assumptions, it can be shown[9] that the isovector component of the nuclear interaction is considerably weaker than the isoscalar component. Hence, we neglect the nuclear isovector potential in our calculations. (Since its phase is opposite that of the isoscalar nuclear potential, inclusion of the nuclear isovector potential would tend to reduce the magnitude of the calculated cross sections.) The interaction then consists of a nuclear isoscalar transition potential with a deformation length $(\beta R)_N$ chosen to represent the % ISEWSR and the Coulomb potential with a deformation length determined for the appropriate $B(E2)\uparrow$. The nuclear and Coulomb amplitudes add coherently.

The solid curves in Figs. 1 and 2 are from DWBA calculations using 70% ISEWSR to calculate both the nuclear deformation lengths and $B(E2)\uparrow$, and show good agreement with the data at both 25 MeV/nucleon and

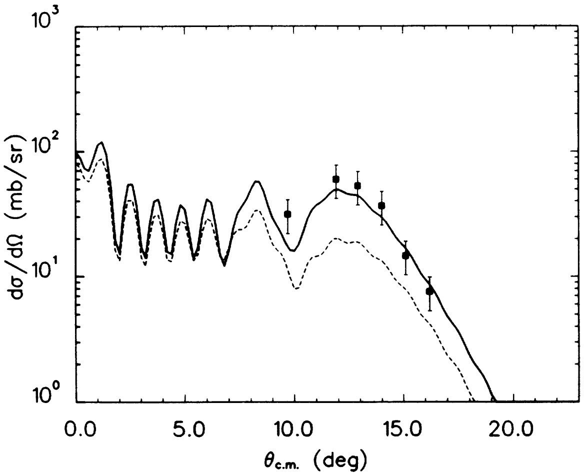

FIG. 1. Data for excitation of the 10.6 MeV GQR in ^{208}Pb by 400 MeV ^{16}O ions (Ref. 7). The calculations shown as solid and dashed lines are described in the text. The optical potential of Ref. 7 was used in the calculations, which were carried out with the code PTOLEMY.

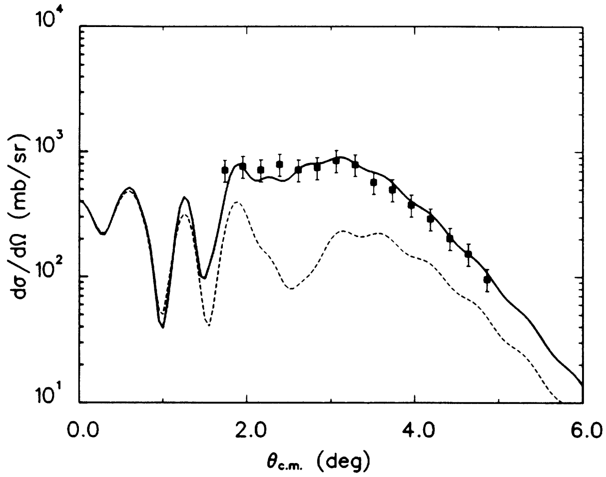

FIG. 2. Data for the excitation of the 10.6 MeV GQR in ^{208}Pb by 1428 MeV ^{17}O. The experiment in which these data were acquired will be described in a forthcoming paper (Ref. 8). The calculations represented by the solid and dashed lines are described in the text. The optical potential used in the calculations was obtained from a fit to elastic scattering.

84 MeV/nucleon. The dashed curves are obtained using the π^+/π^- results; the nuclear deformation length corresponds to 48% ISEWSR and $B(E2)\uparrow = 1010\ e^2\text{fm}^4$ as reported in Ref. 1. As can be seen in Fig. 1, at 25 MeV/nucleon the π^+/π^- calculation underestimates the data by a factor ~ 2.5, and at 84 MeV/nucleon by a factor of ~ 4. Note that whereas the shapes of the calculated differential cross sections are fairly similar at 25 MeV/nucleon, they are quite different at 84 MeV/nucleon. This difference arises primarily because of the strong increase of the Coulomb interaction with increasing energy of the projectile. At the lower energy the nuclear and Coulomb amplitudes are comparable near the maximum of the differential cross section ($\theta_{\text{c.m.}} \sim 12.5°$), whereas at the higher energy the Coulomb amplitude is dominant ($\theta_{\text{c.m.}} \sim 3.0°$). The shapes of the calculated curves reflect the coherent addition of the nuclear and Coulomb amplitudes and also serve as a sensitive test of the neutron/proton character of the transition.

Two other recent results which come from photon decay experiments[10,11] also contradict the description of the 10.6 MeV GQR as presented in Ref. 1. These data concern the strength of the ground state $E2$ gamma decay of the 10.6 MeV resonance as well as the decay branch to the 2.61 MeV 3^- state.

The strength of the ground state $E2$ photon decay from the GQR yields a reaction-independent $B(E2)\uparrow$ of 5000–7000 $e^2\text{fm}^4$, which also agrees with the homogeneous model, but which is much larger than the 1010 $e^2\text{fm}^4$ reported[1] from the pion work.

The $E1$ photon decay of the GQR to the 2.618-MeV 3^- state should also be sensitive to isovector mixing in the resonance. A study of the photon decay of the GQR following excitation by 381-MeV ^{17}O ions shows that this decay branch is quite small (4 ± 4 % of the ground state branch). Two recent calculations[12,13] have predicted just such a small cascade to ground-state branching ratio for a predominantly isoscalar GQR. A major reason for the strong suppression of this branch in both calculations is the almost complete cancellation of matrix elements arising from neutron and proton components of the GQR. This cancellation is thus exquisitely sensitive to the relative amplitudes of the neutron and proton components of the GQR. An increase in the ratio of the neutron to proton composition in the GQR as required by the pion results would destroy this balance, and lead to a significant increase in the cascade to ground-state branching ratio, thus destroying the good agreement with the observed value.

We conclude that all of the experimental results discussed here are incompatible with a large excess of neutron strength and a consequently large isovector component in the observed GQR.

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