Corroboration of the Quadrupole Assignment for the 11-MeV Giant Resonance in ^{208}Pb[†]

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(Received 20 March 1973)

Inelastic scattering of protons with incident energy of 66 MeV has been used to study details of the giant-resonance region for several targets. Examination with high resolution of the recently observed resonance in ^{208}Pb at $E = 11$ MeV reveals fine structure. The data were compared with theoretical predictions for $L = 2$ and $L = 0$ angular distributions. Only the quadrupole interpretation was found to be consistent with the data.

Recently, there have been a number of reports of a new giant resonance discovered in inelastic scattering of electrons,[1-3] protons,[4-7] and He ions.[8] This resonance is consistently located about 2–3 MeV below the giant dipole resonance in the excitation energy spectra, and has been interpreted as a giant quadrupole or giant monopole excitation. Reliable measurements of the angular distribution of the new resonance are difficult because it is incompletely resolved from the giant dipole resonance and is superimposed upon a large continuum background. By making the simplest assumptions as to the shape of the latter, it has been shown that the proton angular distributions are consistent with $L = 2$, and the cross sections are large enough to nearly exhaust the energy-weighted isoscalar sum rule. The results of electron scattering angular distributions were found to be consistent with only $L = 2$ or $L = 0$, the latter having the same theoretical angular distribution as the former.

The question of the monopole interpretation of the resonance, while not seriously considered in Refs. 4 and 5, was later examined by Satchler[7] for the proton scattering data. The theoretical $L = 0$ angular distribution, assuming a "breathing mode" mechanism, is quite different from the $L = 2$ angular distribution for the usual collective model. Nevertheless, because of the large uncertainties (±50%) quoted in Ref. 4, the proton angular distributions were found to be consistent with either the quadrupole or monopole interpretation. However, the cross sections obtained in the proton scattering in the region $\theta = 20–30°$ for ^{60}Ni and 25–35° for ^{209}Bi were found to somewhat favor the quadrupole resonance interpretation. Also the cross sections in the He ion inelastic scattering were found to be too large to be explained[8] by a giant monopole resonance.

The earlier proton studies were hampered by spectral uncertainties at small angles caused by corrections for reaction and collimator "tails" in the counter-telescope system.[9] Using 66-MeV incident protons we have reexamined the inelastic proton spectra with a broad-range magnetic spectrometer, thus eliminating many corrections required in counter experiments.

Protons were detected on photographic plates, and the data were plotted in 150–300-keV wide bins to yield ≈3% statistical uncertainty. The excitation spectrum for $E \approx 8–25$ MeV was studied at the scattering angles 20 and 28°. The spectrographic acceptance angle was ±2°. Plots of the 20° spectra in the resonance region for targets of natural Al, Cu, In, and Pb are shown in Fig. 1. The excitation energy of the resonance peak is given in the figure, along with the corresponding positions of the giant-dipole-resonance peak (GDR) for each element. A calibration is also inserted to provide an approximate energy scale. The mass dependence of the energy of the resonance peak in the spectra substantiates the $E_p \approx 63A^{-1/3}$ form established earlier.[4] After consideration of the contributions of the GDR, a reasonable estimate of the widths of the resonances is about 3–4 MeV, although there are indications of finer structure in the Al and Pb spectra.

Comparison of the spectra obtained for ^{208}Pb-(p,p') at $\theta_L = 20$ and 28° is shown in Fig. 2. The data are plotted on a semilogarithmic scale to emphasize the similarity in the shapes of the 11-MeV resonance at the two angles. No corrections for possible target contaminants were found necessary. To determine the relative angular dependence of the "peak" below the dipole resonance, we proceeded as follows. From the systematics of the over-all shape of the continuum[10] as a function of angle, it can be seen that the underlying continuum approximates a smooth curve whose shape is angle-dependent. It is roughly flat at small angles ($\theta \lesssim 20°$) becoming sloped with increasing angle. Therefore, at $\theta = 20°$ we have assumed a background as shown by the broken curve in Fig. 2. Contributions from the GDR were estimated by fitting a Lorentz shape with $\Gamma = 4$ MeV and $E_0 = 13.4$ MeV[11] to the spectrum. This is shown by the dashed line in the 20° spectrum. It is clear from this type of analysis that the contribution by the GDR to that portion of the resonance below about 11 MeV is small. The 28° data were analyzed in a similar fashion except the underlying background was assumed to be sloped toward lower excitation energy. The broken curve shown for this analysis is that background which (in conjunction with the GDR) leads to a shape for 28° spectrum which is consistent with the resonance shape at 20°.

The (p, p') results for ^{208}Pb seem to qualitatively substantiate the fine structure seen in electron

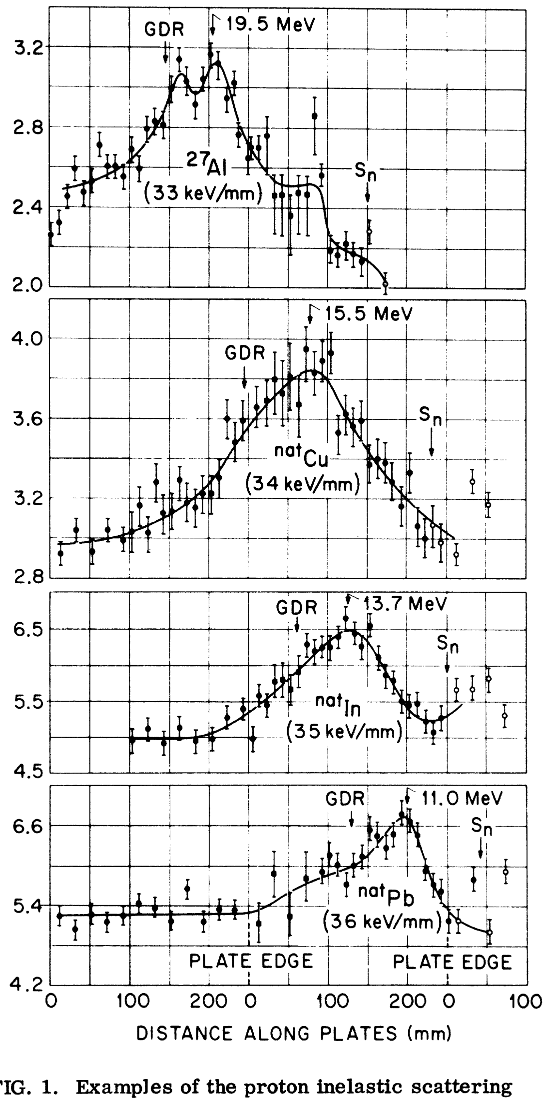

FIG. 1. Examples of the proton inelastic scattering spectrum in the giant-resonance region for Al, Cu, In, Pb with $E_p = 66$ MeV, $\theta_{lab} = 20°$. The known resonance energy for giant dipole state (GDR $= E_0$) is indicated along with a calibration for each target. S_n is neutron separation energy. Open circles (○) indicate points below S_n; solid circles (●) indicate points above S_n; solid squares (■) are points corrected for contaminants.

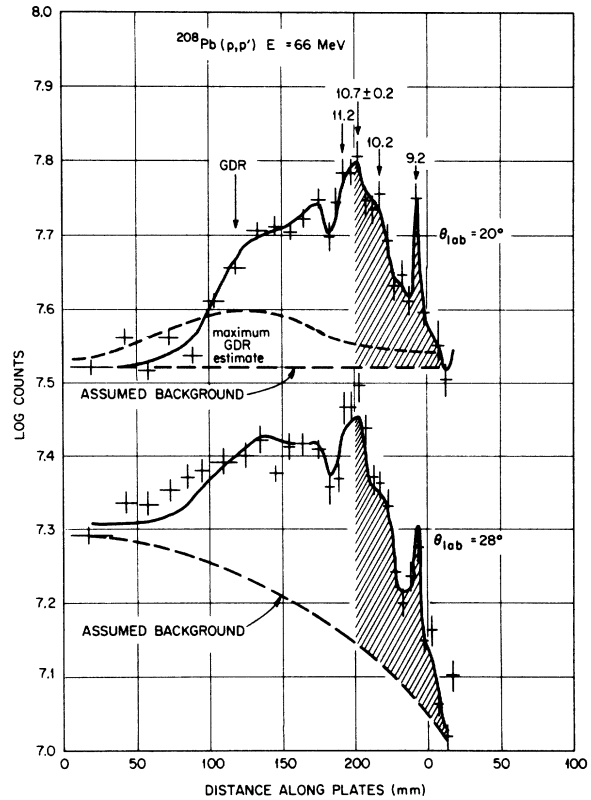

FIG. 2. The details of the ^{208}Pb(p, p') spectra at $\theta_L = 20$ and 28°. The shapes of the two spectra are nearly identical except for a modification of the background curve. Note that the plot is semilogarithmic.

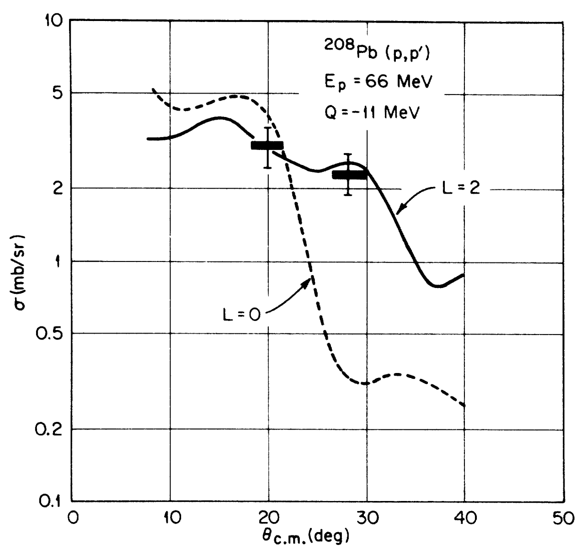

FIG. 3. Cross sections for the ^{208}Pb(p, p') reaction exciting the 11-MeV resonance. $E_p = 66$ MeV. The curves are based upon theoretical estimates (Refs. 5 and 7) for the excitation of giant isoscalar quadrupole and monopole states. Data points are normalized to the $L = 2$ curve at 20° and the uncertainties are relative values.

scattering at $E^*(\pm 0.2) = 11.2$, 10.6, 10.0, 9.4, and 8.9 MeV. A multipole assignment of $L = 2$ or 0 has been reported[3] for all these groups. According to the reaction models of Satchler,[5,7] this quadrupole-monopole ambiguity can be resolved by proton angular distributions. This is shown in Fig. 3 where the predicted differential cross sections for excitation of a giant isoscalar $E2$ and $E0$ state in ^{208}Pb are given. Plotted on the same figure are the relative experimental cross sections, corresponding to the excitation of the new resonance region below 11 MeV (the shaded region in Fig. 2). These have been normalized to the $L = 2$ curve at $\theta = 20°$. A preliminary estimate of the measured absolute cross section at 28° was noted to be at least 2.0 mb/sr, much larger than the prediction for a giant monopole resonance. We conclude that this analysis is consistent only with the quadrupole interpretation of the 11-MeV resonance in ^{208}Pb.

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†Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

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