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Evidence for the giant monopole resonance in ^{208}Pb from strong energy dependence in α scattering

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The giant-resonance region of ^{208}Pb was studied using α beams of energies between 100 and 172 MeV. Relative to the excitation of the giant quadrupole resonance located at $E_x = 10.9$ MeV the new resonance at $E_x = 13.8$ MeV was found to be more strongly excited at higher incident energies. This yields a new piece of evidence for the monopole character of this new resonance.

[NUCLEAR REACTIONS ^{208}Pb(α,α'), E_α=100–172 MeV. Measured $\sigma(\Theta,E)$ for giant-resonance excitations. Calculated cross section for $L=0$ and $L=2$. Deduced $E0$ strength from energy dependence.]

Recently, evidence has been accumulated for the existence of a giant monopole resonance at an excitation energy of ~$80A^{-1/3}$ MeV in heavy nuclei. Marty *et al.*[1] have compared inelastic deuteron and α spectra and found that a possible explanation of the differences in the spectra could be due to a giant monopole resonance at 13 MeV in ^{208}Pb. From inelastic electron scattering experiments Sasao and Torizuka[2] have shown that their spectra for ^{208}Pb are consistent with the existence of a breathing mode state. However, this interpretation is critically dependent on the model used for the description of the giant dipole state. Clear evidence for a new resonance at ~$80A^{-1/3}$ MeV has been found in recent work at Groningen[3] using a 120 MeV α beam. A small bump was observed on the high energy shoulder of the giant quadrupole resonance. Its angular distribution has pronounced structure and could be well described assuming a giant monopole excitation. Unfortunately, $L=0$ and $L=2$ angular distributions are very similar in α scattering, except at very small angles, so that $L=0$ could not be assigned unambiguously. The difference in the small angle behavior was utilized by Youngblood *et al.*[4] in a 96 MeV α-scattering experiment to distinguish between these multipolarities. Although the background is extremely high in this small angle region, implying large experimental uncertainties, the analysis strongly supports a concentration of $L=0$ strength at ~13.7 MeV.

In an attempt to obtain further information on the character of the new resonance we have studied the giant-resonance region in ^{208}Pb using α scattering of energies between 100 and 172 MeV. We find that the new resonance exhibits a strong increase in cross section as a function of incident energy. Such a behavior of the cross section can be obtained only for a monopole excitation.

The experiment was performed using a momentum analyzed α beam from the Jülich isochronous cyclotron JULIC. The scattered particles were detected by two counter telescopes consisting of 2 mm silicon and 24 mm Ge-Li detectors for the ΔE and E counters, respectively. The overall energy resolution was 180 keV. ^{208}Pb targets of 5–8 mg/cm^2 were used, which contained only very small contamination from ^{12}C and ^{16}O. Figure 1

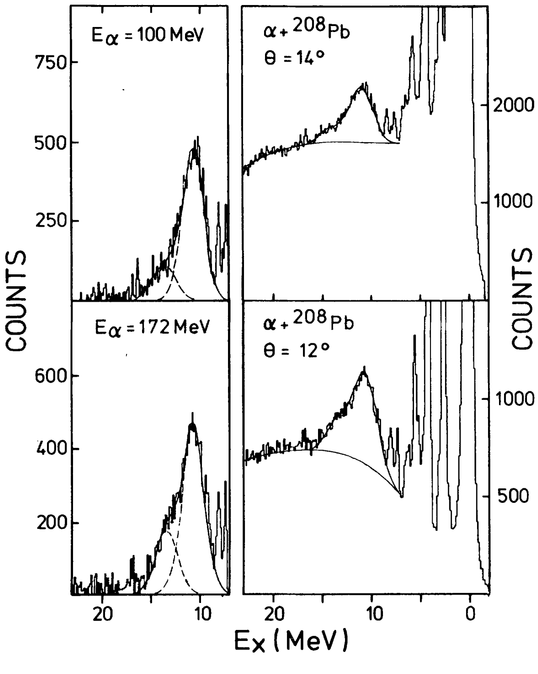

FIG. 1. Spectra of α particles scattered inelastically from ^{208}Pb at incident energies of 100 and 172 MeV. The background line and the Gaussian fits to the resonances are indicated. The left-hand side shows the giant-resonance peak after background subtraction.

shows spectra at α energies of 100 and 172 MeV. The data have been analyzed by fitting the giant-resonance region with two Gaussian peaks superimposed on a continous background as illustrated in Fig. 1. The larger peak at an excitation energy of 10.9 ± 0.3 MeV corresponds to the giant quadrupole resonance observed in hadron and electron scattering.[2-5] The other resonance[3] has an excitation energy of 13.8 ±0.3 MeV. For both resonances a width of 2.6 ± 0.3 MeV was obtained. This is in excellent agreement with the data of Refs. 3 and 4. In our data analysis the largest uncertainties are due to the uncertainty in the shape of the nuclear continuum. Above the giant resonance, in most spectra a perfectly linear continuum has been observed up to large excitation energies. This high energy background has been extended into the low energy discrete spectrum by a smooth polynomial fit. The uncertainties in the resonance cross section are expected to be ±25%. In the 100 MeV spectrum the background in the low excitation region is much higher than in the 172 MeV spectrum, caused by a comparatively large tail of the elastic peak. This is partly due to much smaller inelastic cross sections with respect to the elastic yield. It should be mentioned that in the spectra little has been observed from the ^{5}He and ^{5}Li α-breakup channels. The kinematical limits for these reactions correspond to excitation energies well above the giant resonance (>19 MeV for the more important ^{5}He channel). These decay α particles are therefore not expected to affect the present analysis. On the left-hand side of Fig. 1 the giant resonance bump is displayed after background subtraction. The lines represent the double Gaussian fit. It is quite obvious that at 172 MeV the relative peak height of the 13.8 MeV resonance is much larger than at the lower beam energy. This fact indicates a different character of the two giant resonance peaks.

At the energy of 172 MeV complete angular distributions have been obtained between 8° and 18°. They show a diffraction pattern typical for direct excitation and are discussed in Ref. 6. At three other α energies cross sections were measured in the angular region from 12° to 17°. Cross sections at the third diffraction maximum (for $L=0,2$) averaged over several data points are displayed in Fig. 2. In the measured energy region, a sharp rise by a factor of about 4.5 is observed in the cross section of the 13.8 MeV resonance. This is much stronger than the increase in the cross section of the giant quadrupole excitation at 10.9 MeV, which amounts only to a factor of 2.

The results of microscopic distorted-wave Born approximation (DWBA) calculations are presented in Fig. 2. In these calculations folding-type form factors were used in which an effective nucleon-nucleon interaction was folded into an α density and a transition density for the target excitation. The details of these calculations are similar to those in Refs. 7 and 8. The transition density for the monopole excitation was taken from the collective model of Ref. 9. An energy independent optical potential has been used in the DWBA calculations, with the parameters as follows: $V=155$ MeV, $r_v=1.282$ fm, $a_v=0.677$ fm, W (volume) $=23.26$ MeV, $r_w=1.478$ fm, $a_w=0.733$ fm, and $r_c=1.3$ fm. This potential yields a quite good description of our elastic scattering data at 120 and 172 MeV; the inclusion of an energy dependence in the optical potential has little effect on the inelastic cross sections in Fig. 2.

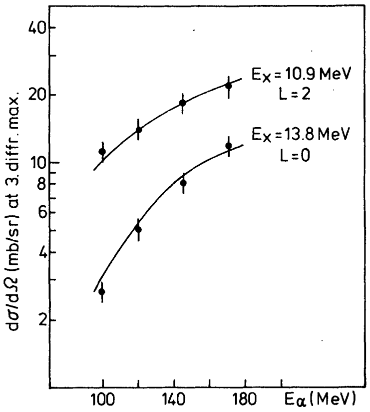

FIG. 2. Cross section (at the third diffraction maximum) for excitation of the two giant resonances at E_x $=10.9$ and 13.8 MeV as a function of incident α energy. The data points correspond to the cross sections at angles of 15°, 13.5°, 12°, and 11° for 100, 120, 145, and 172 MeV, respectively. The solid lines correspond to theoretical calculations discussed in the text.

The results of these calculations yield an excellent description of the energy dependence of both experimental resonance cross sections (Fig. 2). For the giant quadrupole resonance the absolute cross section is reproduced assuming an $L=2$ strength of 70% of the isoscalar energy weighted sum rule.[8] In addition, a small $L=4$ strength of 10% of the energy weighted sum rule strength was assumed. This was found[6] to be important to describe the 172 MeV angular distribution data and is consistent with results of microscopic random-phase approximation (RPA) studies[10] which indicate a sizable $L=4$ strength in this region. The strong dependence on incident energy as observed for the cross section of the 13.8 MeV resonance can be obtained only for $L=0$. The good fit to the data for this resonance in Fig. 2 is obtained if a monopole strength is assumed which exhausts 85%

of the energy weighted sum rule.[8] Such a monopole strength is consistent with estimates in Refs. 3 and 4. It should be noted that RPA calculations[11] also predict significant contributions of higher multipolarity in the region of the 13.8 MeV resonance. These contributions, however, are more spread out in excitation energy and are therefore expected to contribute mainly to the subtracted background. In a plot as in Fig. 2 the energy dependence of such components was found to be no more pronounced than that of the giant quadrupole resonance.

In summary, the strong increase of the (α,α') cross section of the new resonance between 100 and 172 MeV incident α energy can be explained only by assuming a monopole excitation. This provides additional evidence for the giant monopole resonance in ^{208}Pb and illustrates a new method for the identification of monopole strength.

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