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Monopole Excitation in the Giant Resonance Region of ^{208}Pb[+]

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ABSTRACT

Inelastic scattering of 45 MeV protons and 70 MeV ^{3}He-particles has been used to study the giant resonance region of ^{208}Pb. The giant resonance is found to be highly structured with states of different multipolarities, such as dipole, quadrupole and octupole. A monopole state is found at 9.11 MeV which exhausts about 13% of the monopole sum rule strength.

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Among the important open questions in studies of giant resonances is the location of the monopole state. This breathing mode of the nucleus is particularly important because it gives information on the compressibility of nuclear matter, a property which has not experimentally been determined up to present. Theoretical estimates of the excitation energy of the monopole state vary considerably because they depend strongly on the choice of effective interaction.

Recent experimental attempts to observe a giant monopole resonance have centered on ^{208}Pb but have not been conclusive. As a result of inelastic electron scattering experiments Pitthan et al.[1] proposed a monopole state at 8.9 MeV which exhausts 50% of the sum rule strength. However, it was shown by Schwierczinski et al.[2] that this state could equally well be quadrupole. Also in (γ,n) studies a quadrupole resonance was found at this energy.[3] Marty et al.[4] have compared inelastic deuteron and proton scattering and found that a possible explanation of the differences in the spectra obtained could be a giant monopole resonance at 13 MeV.

In an attempt to clarify the questions raised above we have studied the giant resonance region in ^{208}Pb using high resolution, high statistics inelastic proton and ^{3}He scattering. To summarize the results, we find that the giant resonance region is highly structured and that the structure is angle dependent in a way that indicates that some of the peaks are pure dipole, quadrupole and octupole excitations. One peak has a very definite L=0 angular distribution and hence may comprise part of the long sought giant monopole resonance. Additional evidence for the monopole character of this state is found from the absence of the peak in the ^{3}He inelastic scattering spectra in agreement with expectations for this type of excitation.

The experiments were performed with 45 MeV protons and 70 MeV ^{3}He-particles from the Michigan State University Cyclotron. The scattered particles were detected in a delay line counter[5] on the focal plane of an Enge split-pole spectrograph. The energy resolution (35 keV for protons and 45 keV for ^{3}He-particles) was limited by the thick targets (5.4 and 1.8 mg/cm^2, respectively) required to keep impurities to a minimum relative to the ^{208}Pb. A plastic scintillator provided time-of-flight information. This information permitted the elimination of most of the slit scattered particles which arrived at the detector 3-10 ns later than the real inelastic events. Long runs were taken to eliminate statistical fluctuations in the spectra. Non-linearities in the detector system create a gradual modulation of the spectra at about a maximum excursion of 5%. That the structure discussed in the present paper is not due to these non-linearities was checked by comparing spectra taken at different field settings.

The raw proton spectra at 12° and 33° are compared in Fig. 1. Gross structure (widths of 300 keV or more) is observed in agreement with electron scattering and proton scattering experiments.[6-8] In addition a strong fine structure is observed (widths limited by the 35 keV resolution) which is very angle dependent. There are narrow peaks which show up mainly at forward angles indicated by cross hatching in the 12° spectrum. There are also other peaks which are dominant in larger angles, e.g. at 9.35 and

10.3 MeV. This angle dependence of the fine structure indicates excitation of a variety of multipolarities. The angular distributions for some of the states with characteristic angle dependence are shown in Fig. 2 along with DWBA predictions. To determine the intensities a background was assumed of the type shown in Fig. 1. The L=3 excitation at 9.35 MeV is not a narrow state and could not be resolved from other states (mainly L=2 states) nearby. Therefore only the central part with a width of 40 keV is plotted in Fig. 2.

The DWBA calculations were carried out with microscopic and folding-type form factors. For dipole, quadrupole and octupole transitions, collective model transition densities were folded with a Serber nucleon-nucleon force. For the radial form a Gaussian with a range of 1.68 fm was used, leading to a volume integral of 446 MeV fm^3. This interaction is consistent with the force used to describe few nucleon systems[9] and is close to that used for other (p,p') calculations.[10] The results are insensitive to the choice of transition density between the Jensen-Steinwedel[11] or Goldhaber-Teller model[12] for dipole excitations or between simple surface derivative or the Tassie model[13] for higher multipoles. Becchetti-Greenlees optical model parameters were used.[14] Details of the calculations will be presented elsewhere. For the monopole excitations a microscopic 1p1h calculation was performed in the manner described in Ref. 15. The calculated transition density is consistent with collective model transition densities.[16] All of the calculations included Coulomb excitation, which is important for the forward angles studied. The general shape of angular distributions was quite insensitive to various arbitrary choices of models and parameters and is therefore considered to be a reliable indication of the multipolarity.

Five resonances at 7.32, 7.39, 7.91, 8.21 and 8.39 MeV show the rapidly falling angular dependence which is consistent only with an L=1 assignment. It is interesting to note that they are concentrated in a small energy region. The possible nature of these states (some of them were identified as M2 states by Lindgren <u>et al</u>.17)) will be discussed elsewhere. In addition to the quadrupole strength which is dominant in this energy region (see e.g. ref. 8) there is octupole strength concentrated in the gross structure at 9.35 and 10.3 MeV.

Only one state is observed to have a definite L=0 angular distribution. It is shown in Fig. 1 to lie at 9.11 MeV. Further evidence for the L=0 nature of this excitation was obtained by ^{3}He scattering at 70 MeV. ^{3}He scattering at this energy is not very L-dependent, but a monopole excitation is predicted to be very weak (about an order of magnitude smaller than quadrupole) using the models described above. The gross structure located above 9 MeV which shows up clearly in ^{3}He scattering is definitely of quadrupole and octupole character. The monopole state observed in the present experiment undoubtedly contributes to the structure in the electron scattering data of refs. 1, 6, but (with exception of ref. 2) could not have been resolved from the gross structure because of relatively poor energy resolution of these experiments. In the case of ref. 2, the statistics are not sufficient to observe the state clearly.

The microscopic transition density which gives the good DWBA fit to the 9.11 MeV state yields an E0 matrix element $<r^2>_{TR}$ of 88 fm^2. Its strength exhausts about 13% of the energy weighted monopole sum rule strength. At lower excitation energies we find no monopole strength. Also the high resolution (p,p') experiment of Wagner et al.[18] shows no monopole excitation below 7 MeV. (Pairing vibration states at 4.86 and 5.24 MeV are not excited in proton scattering). Our monopole matrix element corresponds to 4 single particle units[19] and is the largest found so far. Its strength is too large to be accounted for by n particle-n hole configuration mixing in contrast to E0 matrix elements found in light nuclei.[20] This clearly indicates a 1p1h excitation which has a significant fraction of the giant monopole state. Currently we are investigating higher excitation energies to search for further pieces of the giant monopole excitation.

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FIGURE CAPTIONS

Fig. 1. 12° and 33° spectra from the ^{208}Pb(p,p') reaction at 45 MeV. The contaminant peaks are marked black and the L=0 and L=1 peaks are cross hatched. A typical background used to determine the intensity is indicated for two of the peaks. The insert shows part of a 10° spectrum from the ^{208}P(^{3}He,^{3}He') reaction at 70 MeV.

Fig. 2. Angular distributions for several states observed in the ^{208}Pb(p,p') spectra. The curves represent the DWBA calculations described in the text. The error bars are statistical only and do not include the uncertainty of estimating the background.

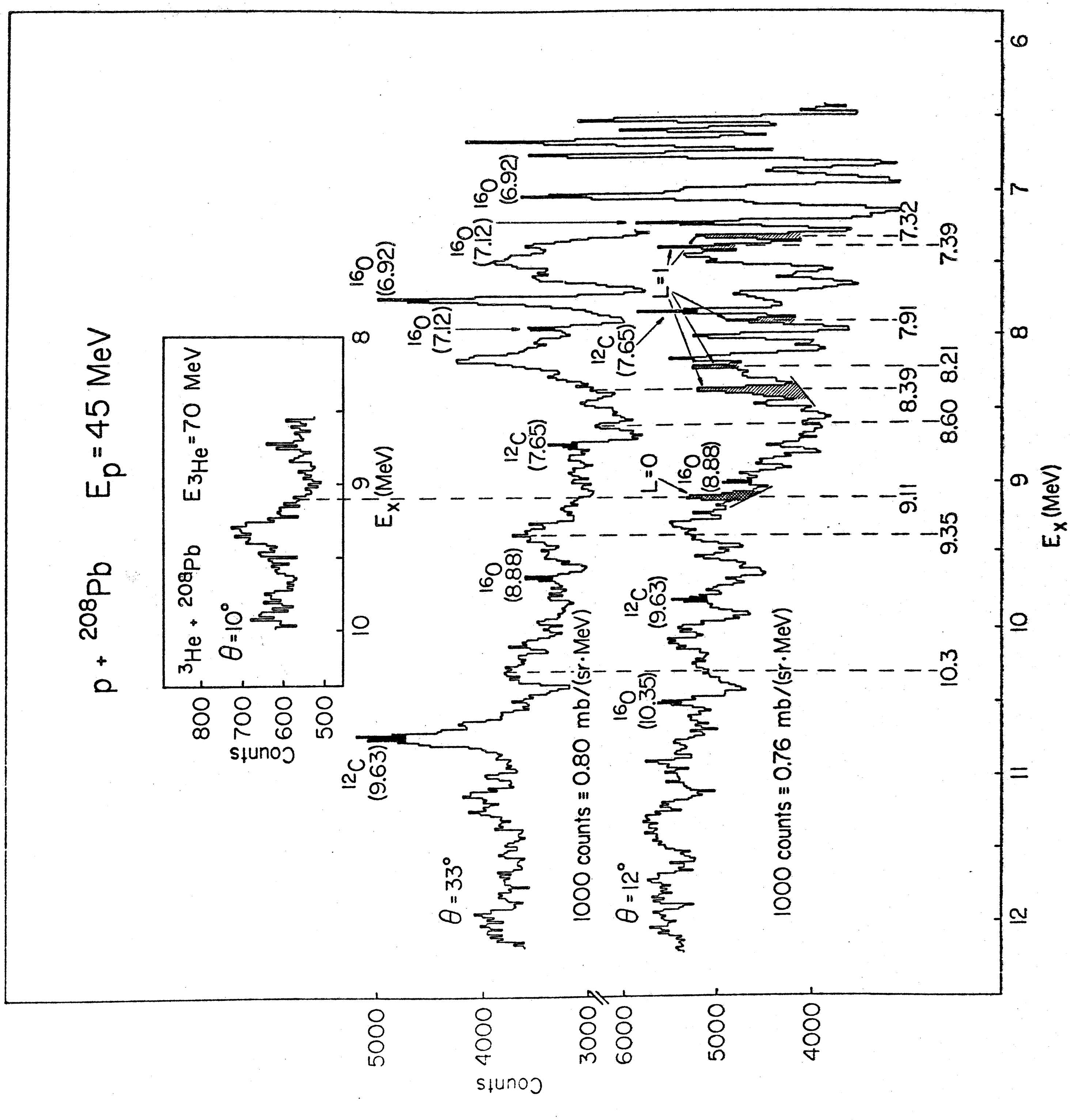
p + ^{208}Pb E$_p$ = 45 MeV
^{3}He + ^{208}Pb E$_{^3He}$ = 70 MeV
θ = 10°
Counts
800
700
600
500
10
9
8
E$_x$ (MeV)
θ = 33°
θ = 12°
1000 counts ≡ 0.80 mb/(sr·MeV)
1000 counts ≡ 0.76 mb/(sr·MeV)
^{12}C (9.63)
^{16}O (8.88)
^{12}C (7.65)
^{16}O (7.12)
^{16}O (6.92)
^{16}O (10.35)
^{12}C (9.63)
L=0
^{16}O (8.88)
^{12}C (7.65)
L=1
^{16}O (7.12)
^{16}O (6.92)
10.3
9.35
9.11
8.60
8.39
8.21
7.91
7.39
7.32
5000
4000
3000
6000
5000
4000
Counts
12
11
10
9
8
7
6
E$_x$ (MeV)

Fig. 1

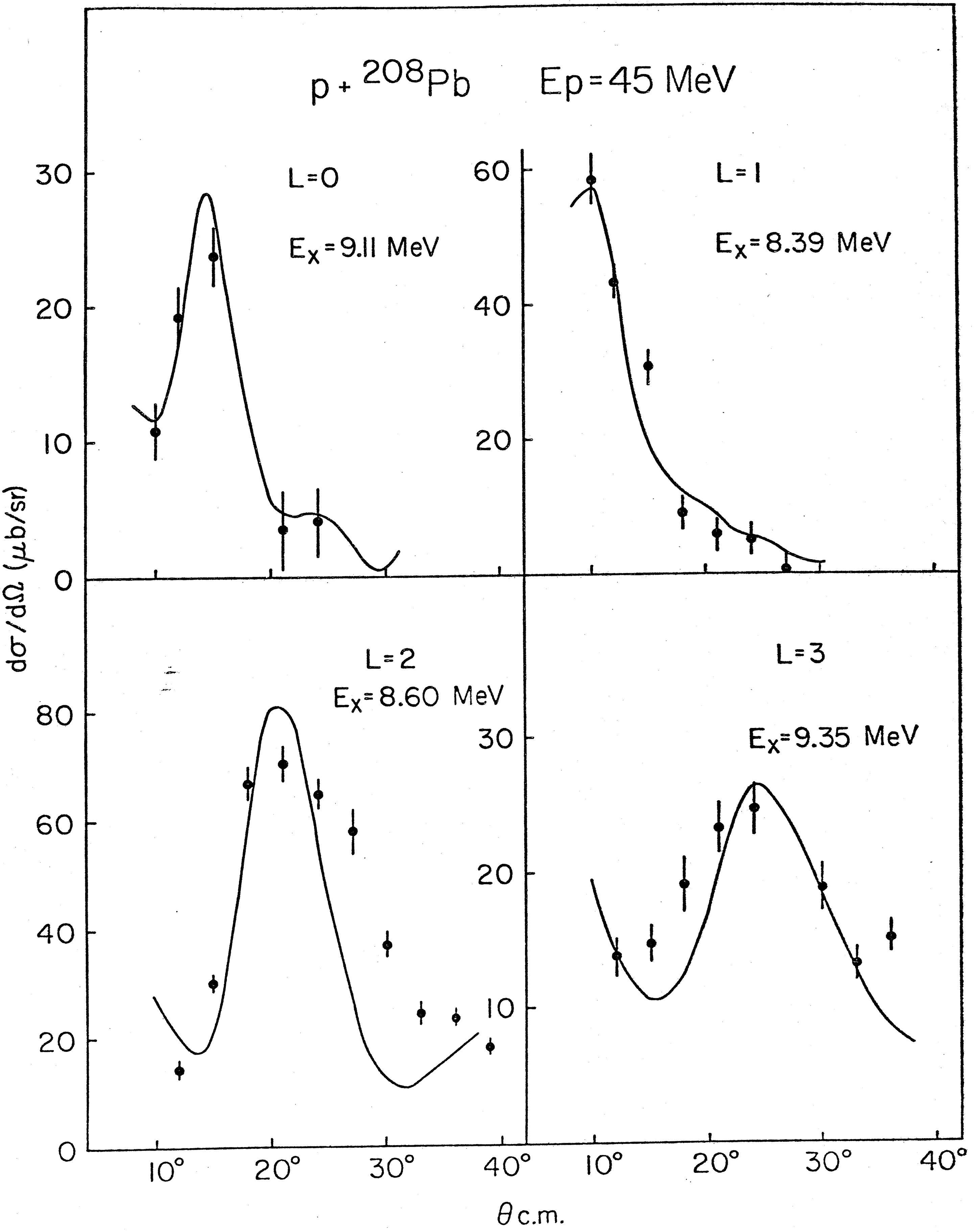
p + ^{208}Pb Ep=45 MeV
L=0
Ex=9.11 MeV
L=1
Ex=8.39 MeV
L=2
Ex=8.60 MeV
L=3
Ex=9.35 MeV
dσ/dΩ (μb/sr)
θc.m.
0
10
20
30
40
60
80
10°
20°
30°
40°

Fig. 2