Evidence for giant quadrupole excitation in 208Pb by 200 MeV 12C scattering

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EVIDENCE FOR GIANT QUADRUPOLE EXCITATION IN ^{208}Pb BY 200 MeV ^{12}C SCATTERING

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In inelastic ^{12}C scattering from ^{208}Pb a peak, corresponding in excitation energy, width and strength to the well-known GQR is observed. The underlying broad continuum is probably due to ^{13}C breakup rather than to excitation of giant resonances with $L > 2$.

During the last few years much attention has been paid to the observation of collective motion at high excitation energy in nuclei. Many experiments have been performed to study the excitation of giant resonances over a wide range nuclei using electron and light-ion scattering [1]. The excitation of collective modes by heavy-ion ($A > 4$) inelastic scattering is of special interest. The larger angular momentum transfer that is possible offers the possibility to excite new resonances with $L > 2$ and to establish multipolarity assignments of known resonances. Moreover, the role of giant resonances as the primary step of energy dissipation in deep inelastic collisions was pointed out by Broglia et al. [2]. This model invokes the giant resonances (especially the giant quadrupole resonance) to explain the large energy dissipation and mass and charge transfer which in a macroscopic framework are attributed to frictional forces.

Giant resonance excitation by inelastic scattering of ^{6}Li-ions has been observed for ^{208}Pb at $E_{^6\mathrm{Li}}$ = 156 MeV [3] and for ^{90}Zr at $E_{^6\mathrm{Li}}$ = 74 MeV [4]. Recently the inelastic ^{12}C-scattering on ^{27}Al [5] and ^{208}Pb [6] has been studied at a bombarding energy of 82 MeV and 120 MeV, respectively. In both cases a broad continuum extending up to 20 to 30 MeV excitation was observed, of which a part was interpreted as due to the excitation of giant quadrupole resonances. However, for ^{208}Pb [6], there is a discrepancy between the deduced width obtained in ^{12}C-scattering (6 MeV) and the one observed by light-ion excitation ($\simeq$ 3.0 MeV) [1], which caused some concern and confusion.

We have studied the ^{12}C + ^{208}Pb system at a bombarding energy of 200 MeV. The excitation of a peak which agrees in excitation energy, width and strength to the GQR is clearly observed. This peak is superimposed on a broad continuum extending to about 55 MeV in excitation energy.

Experiments were performed with the momentum analysed ^{12}C beam of the KVI cyclotron at an energy of 200 MeV. Selfsupporting ^{208}Pb targets with thicknesses of 350 μg/cm^2 and 500 μg/cm^2 were used. The emerging particles were detected in two ΔE–E solid state counter telescopes with thicknesses of 100 μm and 2 mm, respectively. Complete isotope identification for particles up to ^{14}C was obtained. Special attention was paid to the contribution of the ^{11}C and ^{13}C channels in the excitation region investigated. Elastic and inelastic angular distributions were measured with a horizontal acceptance angle of 0.7°. Absolute cross sections were obtained by comparing the elastic cross section with the prediction of an optical-model calculation. Cross sections calculated in this way agreed within 15% with cross sections deduced from target thickness, current integrator and detector geometry. Contamination of the target due to C build-up was frequently checked by separate runs on a ^{12}C foil.

Spectra of the ^{208}Pb(^{12}C, ^{12}C$'$)^{208}Pb reaction at θ_{lab} = 23.5° and 25.5° are shown in fig. 1. In addi-

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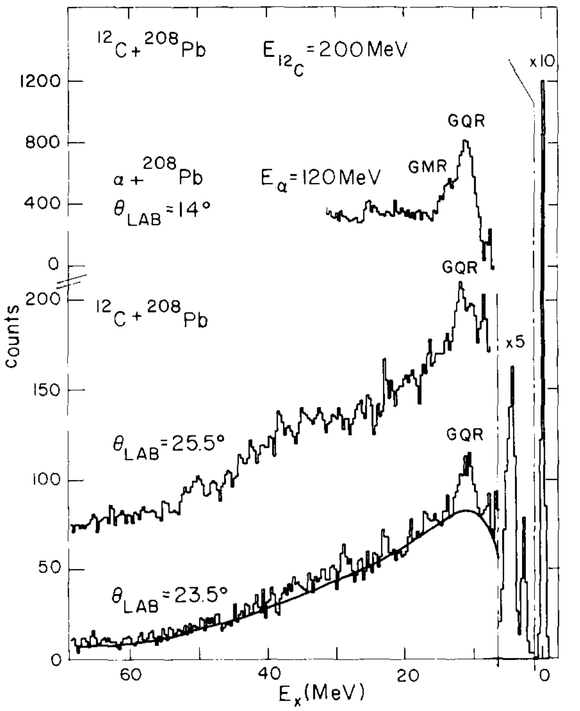

Fig. 1. Spectra of the ^{208}Pb(^{12}C, ^{12}C')^{208}Pb reaction at $E_{^{12}C}$ = 200 MeV. For comparison a spectrum of ^{208}Pb(α, α') ^{208}Pb at $E_α$ = 120 MeV is presented. The right-hand side shows the low excitation retion of the ^{208}Pb(^{12}C, ^{12}C') ^{208}Pb reaction at θ_{lab} = 23.5°.

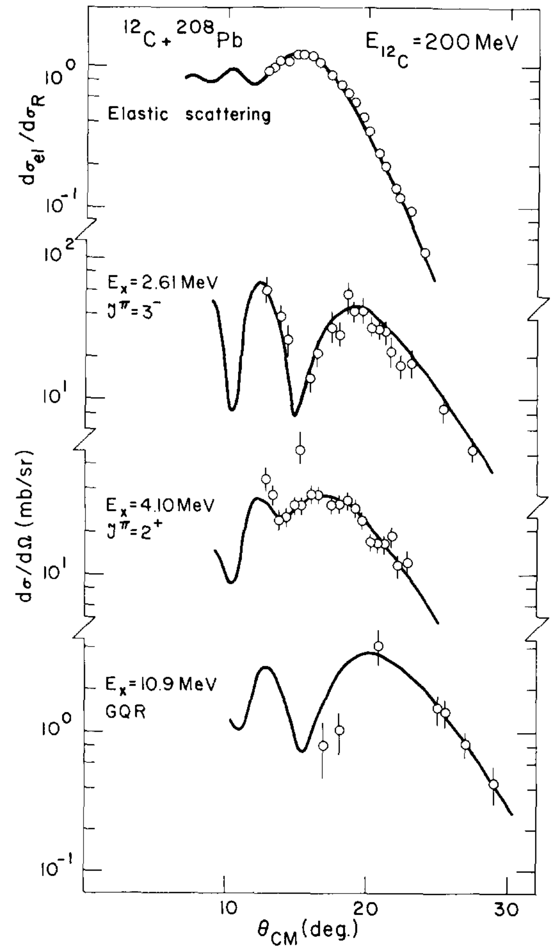

Fig. 2. Angular distributions for the elastic scattering and target excitations in the ^{208}Pb(^{12}C, ^{12}C')^{208}Pb reaction at $E_{^{12}C}$ = 200 MeV. The solid lines are the results of DWBA calculations.

tion to the strong Doppler-broadened peak due to the excitation of the E_x = 4.43 MeV state in ^{12}C, target excitation to states at E_x = 2.61 MeV ($J^\pi = 3^-$), E_x = 4.10 MeV ($J^\pi = 2^+$) superimposed on the projectile excitation and E_x = 10.9 MeV are observed. In the upper part of fig. 1 a spectrum of the high excitation region obtained from inelastic α scattering at $E_α$ = 120 MeV and θ_{lab} = 14° is shown [7]. This comparison shows that the peak observed in inelastic ^{12}C scattering agrees in position and width with the one observed in inelastic α-scattering.

The new resonance located at E_x = 13.9 MeV, observed in inelastic α-scattering [7, 8] is not excited in the present experiment. It is considered to be the giant monopole resonance which will be weakly excited due to the large angular momentum mismatch. The peak at E_x = 10.9 MeV is superimposed on a broad continuum which is quite different from the one observed in a α-scattering. Whereas in α-scattering the continuum is approximately flat and extends to very high excitation energies, in ^{12}C-scattering it is very low at high excitation energies and becomes large around 10 to 20 MeV excitation. The possible origin of the continuum between 10 and 55 MeV will be shortly discussed later. Angular distributions for elastic scattering and target excitations are shown in fig. 2. The GQR was fitted with a gaussian-shaped peak superimposed on the continuum as indicated in the lower part of fig. 1. Uncertainties in the GQR cross section due to the choice of the continuum are estimated to be less than 20%. The increasing continuum cross section at smaller angles permits the observation of the GQR only in a small angular range. The solid lines are the results of a DWBA calculation performed with the DWIS code [9], which is a version of DWUCK [10] modified for heavy-ions.

Optical-model parameters obtained from a fit to the elastic scattering data were $V = 45$ MeV; $W = 35$ MeV; $r = 1.25$ and $a = 0.61$. The inelastic cross sections are not very sensitive to the parameter set used. The numerical integration of the transition amplitude for the nuclear form factor, which was the derivative of the elastic complex potential, was made out to 20 fm for 300 partial waves. For the Coulomb part, with βR = constant, the integration was performed to 100 fm with 450 and 300 partial waves for $L = 2$ and $L = 3$ transfers, respectively. The deformation lengths ($\beta_\lambda R$) for the low-lying states at $E_x = 2.61$ MeV and $E_x = 4.10$ MeV are $\beta_2 R = 0.60$ and $\beta_3 R = 0.96$, respectively, slightly higher than the values obtained from other light-ion and heavy-ion experiments (see e.g. ref. [11]). Even at these high ^{12}C-energies strong Coulomb–nuclear interference effects in the inelastic cross sections are observed. The deformation parameter for the GQR was found to be $\beta_2 R = 0.59$ corresponding to 96 ± 20% of the isoscalar E2 energy-weighted sum rule, in perfect agreement with light-ion results [7, 8].

The continuum underlying the GQR, integrated from 10 to 55 MeV excitation increases from $d\sigma/d\Omega = 20$ mb/sr at $\theta_{lab} = 27°$ to $d\sigma/d\Omega = 270$ mb/sr at $\theta_{lab} = 14°$. In order to find out whether the continuum could be explained by inelastic excitation of higher multipole giant resonances, calculations were performed assuming a 100% exhaustion for the giant octupole (3^-) and hexadecapole (4^+) resonances. For $\theta_{lab} = 20°$ the sum of the cross sections of the 3^- and 4^+ giant resonances, located at $E_x = 15$ MeV, would amount only to about 15 mb/sr while the continuum cross section between 10 and 55 MeV excitation is 140 mb/sr at the same angle. So clearly the bulk of the continuum must be due to other processes.

Strong mutual excitation in the $^{13}C + {}^{207}Pb$ channel was observed ($d\sigma/d\Omega = 150$ mb/sr at $\theta_{lab} = 20°$) for particle bound states in ^{13}C. Since one might expect that particle unbound states are excited with comparable strengths one can easily account for the observed continuum cross section. Thus it seems that mutual excitation processes (transfer and subsequent breakup) are more important than the excitation of multipole resonances. The same mechanism is known to contribute to the continuum in inelastic ^{6}Li-scattering [4] and α-scattering [12].

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