MSUCL-243
August 1977

Excitation of Giant Resonance in ^{90}Zr by Inelastic ^{6}Li Scattering

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ABSTRACT

Inelastic ^{6}Li scattering by ^{90}Zr was measured at 74 MeV. A broad structure, which appears to be the giant quadrupole resonance, was observed at 13.8 MeV excitation energy. This observation is in agreement with previous work done with ions lighter than ^{6}Li.

*Work supported in part by the U.S. National Science Foundation.

Inelastic scattering has proven to be the main source of information on giant resonances other than the giant electric dipole resonance. A large part of this information has come from comparisons among the spectra and yields produced by different projectiles. It is logical, therefore, to extend this study beyond the present limit, the alpha-particle, into the heavy-ion region. Heavy ions are expected to have two advantages over the lighter ones for studies of the giant resonances with L>2. These are: (1) larger incoming angular momentum and (2) lower background yield from evaporation and from other three body reactions in the continuum. Opposed to these advantages is the relatively poorer kinematic matching conditions which reduce the yield at high excitation energies.

Although the giant quadrupole resonance (GQR) is well established at $E_x \approx 63A^{-1/3}$ MeV, heavy-ion inelastic scattering should give one more piece of information. Evidence for giant resonances with L>2 is very sparse, and no single experiment is convincing by itself. The evidence for E3 giant resonances has been summarized by Satchler.[1] The L=4 component, which is predicted to lie near the GQR, has never been observed.

In this experiment ^{6}Li ions, inelastically scattered from a 1.0 mg/cm^2 ^{90}Zr target (97.8% enrichment), were analyzed in the focal plane of an Enge split-pole spectrograph using a charge-division wire counter. A plastic scintillator behind the wire counter gave total-energy and time-of-flight information, allowing unique identification of ^{6}Li ions. Events which fulfilled two-dimensional gating requirements of ΔE, E, and time-of-flight versus position were accumulated in one-dimensional position spectra. Beams of 5-20 na (electrical) of 74 MeV $^{6}Li^{3+}$ ions were provided by the MSU cyclotron. The overall resolution was approximately 175 keV FWHM for the low-lying states of ^{90}Zr. The major contribution to the resolution came from the target thickness. An angular distribution was taken in 2^{o} steps from 11^{o} to 25^{o}. Angles forward of 11^{o} were not useful because of scattering from hydrogen in the target and because of the large tail from elastic scattering.

Figure 1 shows the spectrum of events accumulated at a laboratory angle of 15.0 degrees. At the higher excitation energies (above 10 MeV) one observes broad enhancements of the cross section at 13.8±0.3 MeV and at 22.3±0.6 MeV. The smooth curve shown in the figure is a least-squares fit to the data and is described below. A very strong yield is also observed in the 6-9 MeV region.

The backgrounds in the vicinity of these structures were analyzed empirically. Regions surrounding the enhancements were visually identified as background-only regions. These regions, marked in Figure 1 as an example, were fitted

with a quadratic plus an exponential tail. The exponential tail was used to fit the sharply-falling backgruond in the excitation region around 10 MeV. The 14-MeV peak region was fitted with a Gaussian peak shape superimposed on this background. The results of these fits were compared to the integral of counts in the region after subtraction of background and to centroids directly obtained from the data. Agreement between these two methods was generally within 10% for total yield and 0.15 MeV for centroids. A Lorentzian peak shape fitted to the region did not produce as acceptable a fit to the data. Therefore, the results quoted in this paper are based on the fits to the data using a Gaussian fit. The resulting angular distribution for this region, as well as for the 2.75-MeV 3^{-} state, is shown in Figure 2, while the energy centroid, width, and percentage exhaustion of the energy-weighted sum rule (EWSR) are given in Table 1. The error bars shown in Figure 2 reflect statistical uncerainties in the data and in the background fits, as well as an estimate of the relative uncertainties between angles. Uncertainties due to different choices of background dependence or background regions are not included.

The analysis of the angular distributions for the low-lying states as well as for the other regions of interest was carried out using the DWBA code DWUCK.[2] The optical-model parameters used in the analysis are shown in Table

2. The 74 MeV ^{6}Li optical parameters used are from results of Huffman, Galonsky, and Markham,[3] which do not differ much from the 50-MeV values of Chua et al.[4] The DWBA-computed cross sections were normalized to fit the cross section for the 2.75-MeV state assuming $\beta R(2.75)=0.82$ ($r_R^o=1.3$ fm). This required scaling the DWBA results by a factor of 0.36.

The analysis for the 14-MeV peak results in a centroid energy of 13.8±0.3 MeV with a width of 3.8±0.4 MeV. The measured angular distribution shown in Figure 2 has a rather flat distribution up to the drop-off at 20°. The corresponding DWBA angular distributions do not permit a distrinction between differing L values to be made on the basis of the angular distribution.

The EWSR's which apply to inelastic scattering excitation of giant multipole resonances have been described by Halbert et al.[5] The specific form of these rules which is applicable here has been summarized by Youngblood et al.[6] The assumption of various multipolarities for the 13.8-MeV resonance yields various percentages of exhaustion of the EWSR. These are summarized in Table I. Uncertainties in the EWSR values quoted are estimated to be 20%. The data exhausts 533% of the L=0 EWSR, thus ruling out the monopole breathing mode as a possibility. If one assumes that the resonance is the giant quadrupole resonance, 58% of the EWSR is observed. This assumption is consistent with the interpretation of the resonance observed at an excitation energy of ≈14 MeV

in inelastic electron, proton, ^{3}He, and α scattering as the giant quadrupole (E2) resonance. Assuming the 13.8-MeV resonance is of a higher multipolarity than quadrupole implies a much smaller exhaustion of the corresponding EWSR, as is seen in Table I.

The spectrum in Fig. 2 shows a broad structure at 22.3 MeV excitation with a width of about 4 MeV. This peak appeared to be a new giant resonance since its kinematics as a function of angle matched what one would expect for a highly excited state in ^{90}Zr. A peak in ^{122}Sn at the same $E_x A^{+1/3}$ was observed, and this was taken as a confirmation. However, as a check against the breakup processes[7] which plagued the earlier α-scattering work on giant resonances, the experiment was re-run on ^{90}Zr at 60 and 67 MeV and on ^{92}Zr at 67 MeV. The results are consistent with the assumption that this structure is due to the process

$$^{90}Zr+^{6}Li\rightarrow^{89}Zr+^{7}Li^{*}(7.467\ \text{MeV})\rightarrow^{89}Zr+^{6}Li+n.$$

The peak changes apparent excitation energy with beam energy and target according to the kinematics of this breakup process, and not in accord with inelastic ^{6}Li-scattering.

In the 6-9 MeV region of excitation energy, a very broad enhancement is observed underlying the sharp states. An angular distribution obtained for the sum of the sharp states is consistent with an assignment of L=1, 3, or 4. The angular distribution for the underlying broad structure is monotonically decreasing with angle. The centroid of this region is slghtly higher in energy than the 1hω, L=3 resonance which has been reported by others[8] at ≈7 MeV.

In summary, these results indicate that breakup mechanisms can produce giant-resonance-like structures in heavy-ion scattering but that the giant quadrupole resonance at E_x≈14 MeV, seen previously in various inelastic-scattering experiments, is easily observable.

References

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TABLE I.--Giant-Resonance Parameters Obtained from (^{6}Li,$^{6}Li'$).

Excitation Energy	(MeV)	% EWSR E0	E2	E3	E4
13.8±0.3 MeV	3.8±0.4	533%	58%	20%	9%

TABLE II.--Optical Parameters Used in DWBA Calculations.

V_R(MeV)	r_R^o(fm) a)	a_R(fm)	V_I(MeV) b)	r_I^o(fm) a)	a_I(fm)
241.9	1.3	0.68	13.9	1.7	0.91

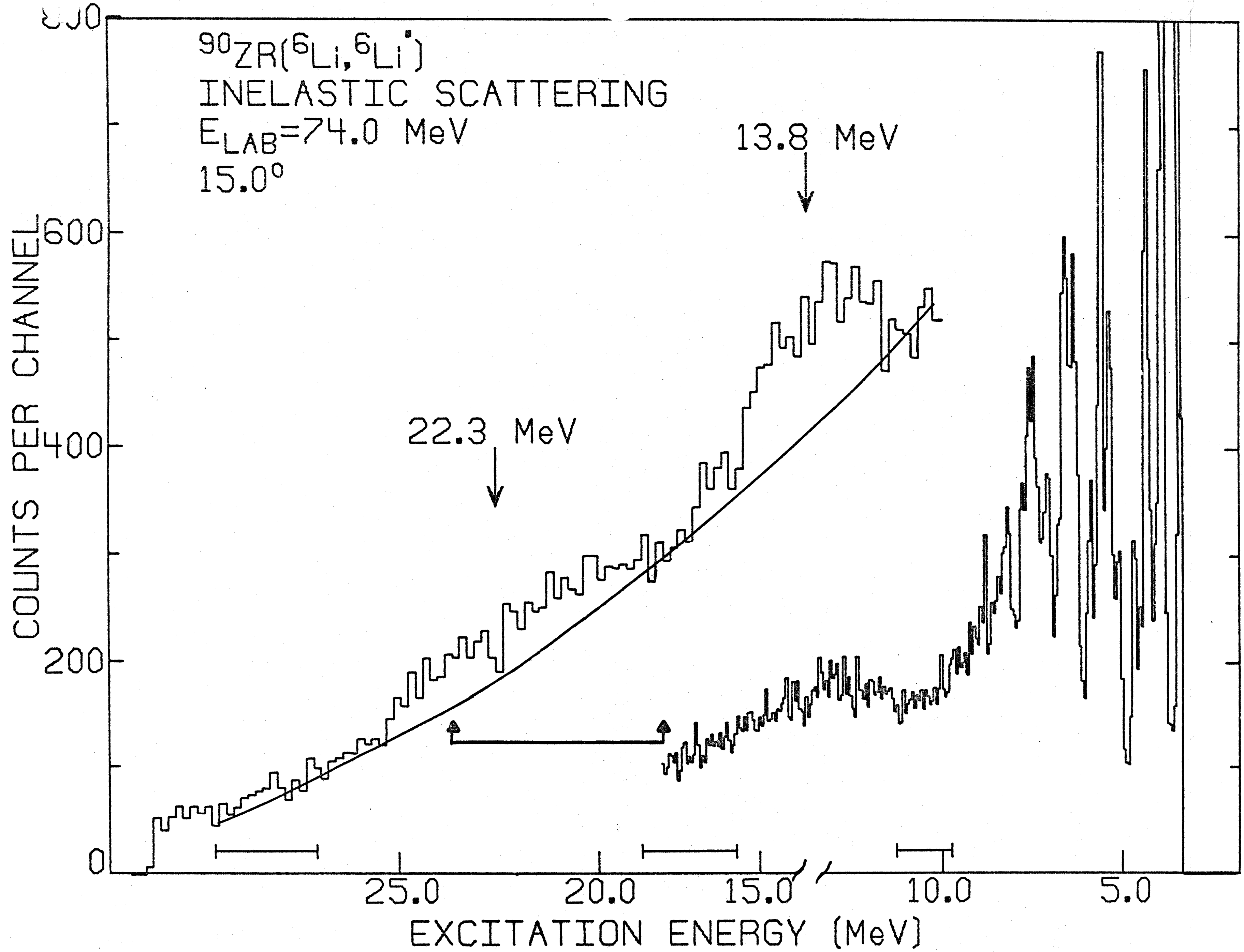
a) $R=r^oA^{1/3}$

b) Volume Imaginary well

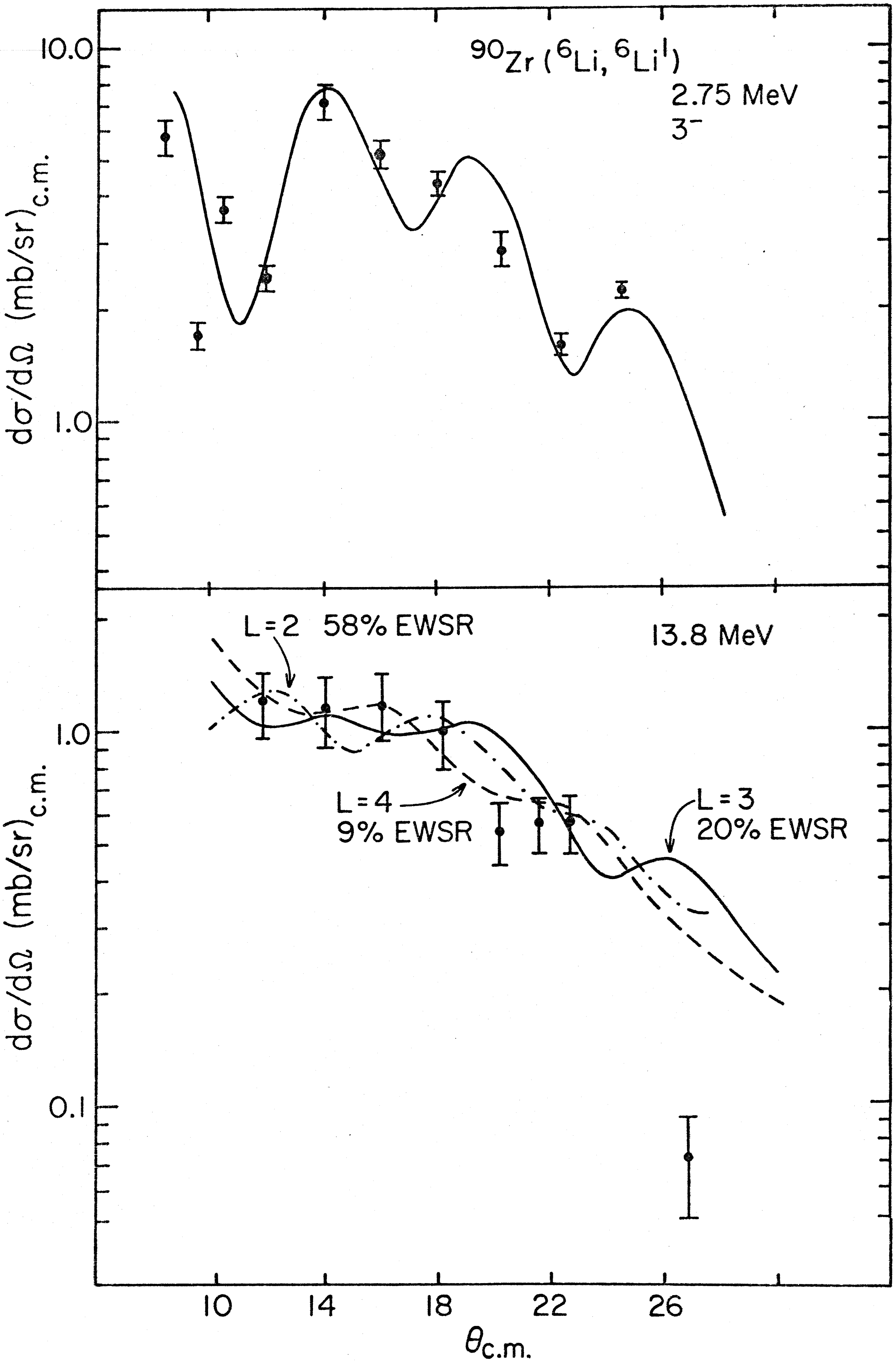
Figure Captions

FIG. 1.--Spectra of events observed in $^{90}Zr(^{6}Li,^{6}Li')$. The spectrum spanning the energy region of $E_x \geq\approx 10$ MeV has an average slope of .19 MeV/ch. The spectrum spanning the lower excitation energy region has an average slope of .03 MeV/ch. The connected arrows span the energy region where the ^{7}Li breakup mechanism (see text) is expected to contribute events.

FIG. 2.--Angular distributions obtained in this experiment. The smooth curves are DWBA fits to the data after normalization to the 2.75-MeV state as described in text.



90ZR(6Li,6Li*)
INELASTIC SCATTERING
ELAB=74.0 MeV
15.0°
13.8 MeV
22.3 MeV
COUNTS PER CHANNEL
0
200
400
600
25.0
20.0
15.0
10.0
5.0
EXCITATION ENERGY (MeV)



$^{90}Zr(^6Li, ^6Li')$
2.75 MeV
3^-
13.8 MeV
L=2 58% EWSR
L=4
9% EWSR
L=3
20% EWSR
$d\sigma/d\Omega$ (mb/sr)$_{c.m.}$
10.0
1.0
0.1
10
14
18
22
26
$\theta_{c.m.}$