Title

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35 MeV PROTON INELASTIC SCATTERING FROM LOW-LYING STATES IN ^{207}Pb*

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Abstract:

Differential cross sections for the excitation of the $2f_{5/2}$, $3p_{3/2}$, $1i_{13/2}$, and $2f_{7/2}$ neutron hole states in ^{207}Pb by 35 MeV protons are presented. The results of theoretical microscopic distorted wave approximation (DWA) calculations are discussed and compared with the experimental data. Estimates of contributions from core polarization and from non-central and central imaginary components in the projectile-target interaction have been made. Core polarization plays an essential part in the excitation of these levels.

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At present, it is widely accepted that ^{208}Pb is the best available "closed-shell" nucleus and that nuclei in the Pb region offer an important test of the nuclear shell model.[1] To say that ^{208}Pb is a good "closed-shell" nucleus is not to imply that it behaves as an inert core in nearby nuclei. The need for an effective charge[2] to explain E2 γ-transition rates in these neighboring systems is direct evidence that there is coupling between the ^{208}Pb core and any additional valence nucleons or holes. Detailed information about this coupling is essential to the construction of an accurate picture of the structure of nuclei in this region of the periodic table.

With these ideas in mind, a high resolution experimental study of inelastic proton scattering in the Pb region has been undertaken using incident protons in the cyclotron energy region. Recent progress in the microscopic interpretation of inelastic proton scattering in this energy region[3] has greatly enhanced the value of this reaction as a spectroscopic tool. An important feature of the (p,p') reaction is that it provides some information about the coupling of valence particles to core excitations of relatively high multipolarity,[4-6] in contrast to electromagnetic measurements which give information primarily on coupling to quadrupole and octupole core excitations. It is the expectation then, that inelastic proton scattering can extend the present knowledge of core polarization effects in the Pb region.

This letter is the initial report on this new study of the (p,p') reaction in the Pb region. We present here differential cross sections for the excitation of Q = -0.570, -0.894, -1.633, and -2.33 MeV levels in ^{207}Pb by 35 MeV protons. We have also measured the differential cross sections for the excitation of the doublet occuring at 2.6 MeV in this same target. This doublet was not resolved during the present run. Similar measurements have been made previously by a group at Berkeley using 20.2 MeV protons.[7]

The experiment was carried out using the 35 MeV proton beam from the Michigan State University cyclotron. A self-supporting target, enriched to 99.14% ^{207}Pb, was prepared by rolling. It's thickness was 6.9 mg/cm^2. Particle detection and identification was accomplished using a position sensitive proportional counter and backup scintillator-phototube[8] in the focal plane of an Enge splitpole spectrometer. Carbon and oxygen contaminants in the target masked some of the states of interest at certain angles. The absolute normalization of the data was determined by comparing - with emphasis on forward angle data - the measured elastic cross section with the optical model prediction obtained using the best fit parameters of Becchetti and Greenlees[9] for ^{208}Pb. This normalization is probably reliable to ±5%.

Single-nucleon transfer studies[10] indicate that the Q = -0.570, -0.894, -1.633, and -2.33 MeV levels in ^{207}Pb are the $2f_{5/2}$, $3p_{3/2}$, $1i_{13/2}$, and $2f_{7/2}$ neutron hole states, respectively, while the ground state is a $3p_{1/2}$ neutron hole. The $5/2^+$ - $7/2^+$ doublet occuring at 2.6 MeV in ^{207}Pb arises from the coupling of the $3p_{1/2}$ neutron hole to the 2.6 MeV octupole vibration in ^{208}Pb.[11] A "collective" model calculation for this doublet gave β_3 = .11, in rough agreement with results obtained in other (p,p') studies[11,12] of the 2.6 MeV excitations in ^{207}Pb and ^{208}Pb. The optical model parameters used in the calculation and throughout this work are the same as were used in normalizing the data.[9]

The data for the single hole transitions has been analyzed using the microscopic model described in Ref. 3-6. In this model it is assumed that the projectile-target interaction is given by the bound state G matrix or some other "comparable" two-body interaction. Cross sections are calculated using the distorted wave approximation and contributions from "knock-on" exchange are included explicitly. This prescription has been tested in several cases where nuclear transition densities are known from inelastic electron scattering experiments.[3,13] We emphasize that in order to obtain information about core polarization from inelastic proton scattering data, it is essential to have these independent tests of the projectile-target interaction.

Theoretical cross sections have been calculated using the long range part of the Hamada-Johnston (HJ) potential[3,5,6,13] as the projectile-target interaction and assuming pure neutron hole wave functions for the target. The HJ interaction is a central interaction. In the calculations "knock-on" exchange contributions have been included by means of an approximation developed elsewhere[14] and harmonic oscillator radial wave functions have been used with the oscillator well parameter $\alpha = (M\omega/\hbar)^{1/2} = 0.405\ F^{-1}$.

The results are compared with the experimental data in Fig. 1a. Only the contributions from the "non-spin-flip" amplitudes are shown, i.e. LSJ-transfer 202, 202, 404, and 707 for the $3p_{3/2}$, $2f_{5/2}$, $2f_{7/2}$, and $1i_{13/2}$ excitations, respectively, as the contributions from "spin-flip", i.e. S = 1 amplitudes, are negligible. This is primarily due to the fact that the spin dependent part of the proton-neutron component of the HJ interaction is approximately 9 times smaller than the spin-independent part. The theoretical results fall from 3 to 10 times below the experimental data, in fair agreement with results obtained previously at 20.2 MeV[15] using the same interaction and an exact treatment of "knock-on" exchange.

Recent studies[5,16] indicate that spin-orbit and tensor components in the projectile-target interaction are important in some transitions. We have made additional calculations, still assuming pure single hole wave functions, to gain some estimate of the importance of these non-central interaction components in the transitions being considered here. We have used the interaction proposed in Ref. 5 in these calculations. This interaction has a central component which gives cross sections similar to the HJ interaction, a tensor component which is similar to the OPEP tensor force, and a spin-orbit component which has a strength consistent with the spin-orbit part of the optical potential. The tensor force is predominately a triplet even interaction while the spin-orbit force is nearly triplet odd in character. The calculations have been made with the computer code DWBA 70[17] which not only allows the inclusion of vector and tensor forces, but also allows an exact treatment of "knock-on" exchange.

In Fig. 1b. we compare the results obtained using only the central part of the interaction with those obtained using the complete interaction. The effects of the non-central interaction components are not large. They produce some changes in the shapes of the angular distributions and increase the magnitude of the cross sections somewhat by about a factor of three in the case of the $13/2^{+}$ excitation where the effects are largest. These differences are due almost entirely to tensor force which contributes only through the $S = 1$ amplitudes. The spin-orbit force was found to be relatively unimportant. This is opposite to the results for proton excitations presented in Ref. 5 and can be understood by examining the exchange character of the interaction.

One other set of calculations was made to investigate the differences between the use of harmonic oscillator radial wave functions and radial wave functions generated from a finite Woods-Saxon well. The finite well wave functions were generated from a potential with radius $1.2A^{1/3}$F, diffuseness 0.70 F, spin-orbit strength 25 times the Thomas term, and depth adjusted to give the correct binding energy. The results obtained using these wave functions were quite similar to the results obtained with the harmonic oscillator wave functions, except at forward angles where the former gave somewhat larger cross sections.

It is clear from the results shown in Fig. 1 that the low lying states in ^{207}Pb cannot be adequately described by pure neutron hole wave functions. This was, of course, anticipated. More realistic wave functions, which contain 2 hole-1 particle (2h-1p) admixtures, are available for these levels.[6] The 2h-1p components in the wave functions have been estimated using first order perturbation theory and a coupling interaction which is quite similar to the HJ interaction being used here to describe inelastic proton scattering. These core excited admixtures in the neutron hole wave functions produce an enhancement of $S = 0$ amplitudes and a retardation of $S = 1$ amplitudes.[6] The former is the origin of the effective charge and the latter is analogous to the well known retardation of magnetic moments. From the results of Ref. 6, it is estimated that $S = 1$ contributions to the (p,p') cross sections are reduced by factors typically on the order of three.

Theoretical cross sections have been calculated using the wave functions of Ref. 6, the HJ interaction, and the approximate treatment of "knock-on" exchange. Only the contributions from $S = 0$ amplitudes have been included in the calculations. It is estimated that the retardation of the $S = 1$ amplitudes from core polarization is sufficient to cancel any increase in these amplitudes arising from the tensor force. This assertion probably should be checked more carefully in the case of the $13/2^+$ excitation.

The results of these calculations are compared with the experimental data in Fig. 2a. In Table I we give the values of e_{eff} and ε_p which provide a measure of the effect of the 2h-1p components in the ^{207}Pb wave functions. The quantity ε_p gives the enhancement of a (p,p') cross section due to core polarization, i.e. $\sigma = \varepsilon_p^2 \sigma_v$ where σ and σ_v are the cross sections with and without core excited admixtures in the wave functions. The agreement between thoery and experiment is quite good. Also shown in Fig. 2a are the results obtained by including an imaginary component in the projectile-target interaction.[18] As was the case in earlier studies,[5,6,18,19] we find that the addition of this imaginary interaction component tends to improve agreement between theory and experiment.

We have made an alternative analysis of the effect of core polarization in these transitions using a phenomenological model proposed by Love and Satchler.[20] With this model, which makes use of a macroscopic "collective" description of the core and a closure assumption, an estimate of the effective charge can be made directly from the inelastic proton scattering data. Again, only the contributions from S = 0 amplitudes have been included in the calculations. The differential corss sections which have been obtained are shown in Fig. 2b and the extracted values of e_{eff} and ε_p are given in Table I. The results compare favorably with the results obtained using the wave functions of Ref. 6. A similar analysis of the 20.2 MeV data,[7] which assumed a phenomenological projectile-target interaction and neglected "knock-on" exchange, gave slightly higher values of e_{eff} than we have obtained here.

We conclude that core polarization is important in the excitation of the low lying neutron hole states in ^{207}Pb by 35 MeV protons. Non-central components of the projectile-target interaction play at best, a small part in the excitation of these levels. In the case of the two L = 2 transitions we have considered, the contribution from core polarization to the (p,p') cross sections is in good agreement with previous γ-decay data. The effect of core polarization in the L = 4 transition is comparable to the effect observed for the L = 2 transitions. A similar observation was made in a recent study of the $1h_{9/2} \longrightarrow 2f_{7/2}$ single proton transition in ^{209}Bi.[4] The effect of core polarization in the L = 7 transition is appreciable, but considerably weaker than in the case of the L = 2 and L = 4 transitions.

FOOTNOTES AND REFERENCES

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Table I. Values of e_{eff} and ε_p obtained using microscopic wave functions of Ref. 9 and macroscopic model of Ref. 22.

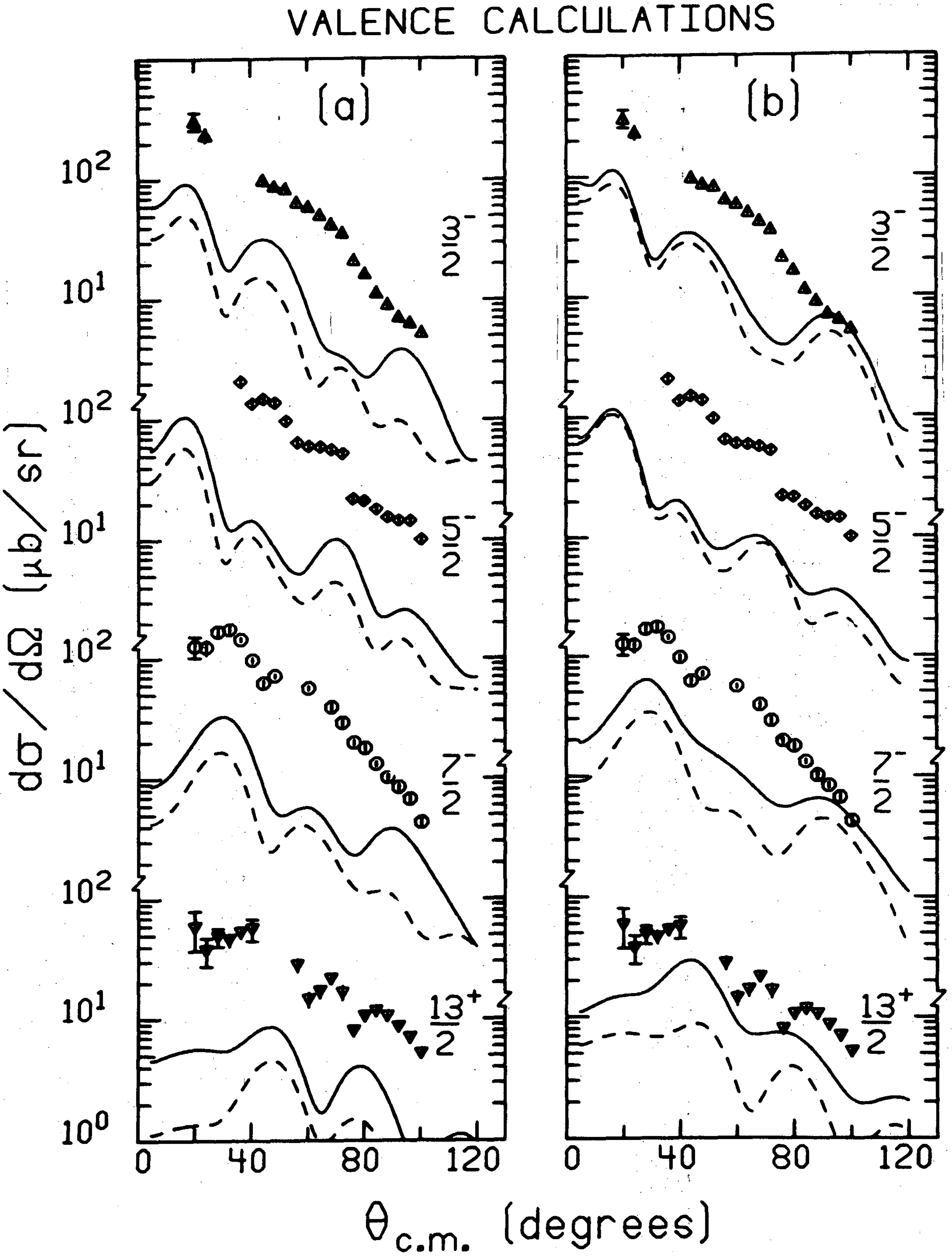
Transition	L S J	Microscopic		Macroscopic		Exp[a]
		e_{eff}	ε_p	e_{eff}	ε_p	e_{eff}
$3p_{1/2} \longrightarrow 3p_{3/2}$	202	.87	2.05	.74	2.08	.75
$3p_{1/2} \longrightarrow 2f_{5/2}$	202	.85	2.23	.95	2.69	.93
$3p_{1/2} \longrightarrow 2f_{7/2}$	404	.78	1.99	.61	2.52	-
$3p_{1/2} \longrightarrow 1i_{13/2}$	707	.42	1.77	.43	2.76	-

[a] From Ref. 2.

FIGURE CAPTIONS

Fig. 1. Results of calculations assuming pure single hole wave functions for ^{207}Pb. (a) Results obtained using central HJ interaction. Direct and direct plus exchange contributions are shown as dashed and solid curves, respectively. (b) Results obtained using interaction of Ref. 6. Here the dashed and solid curved are results obtained with central and central plus non-central interactions, respectively.

Fig. 2. Results of calculations which include contributions from core excited admixtures in the ^{207}Pb wave functions. (a) Results obtained using wave functions of Ref. 6. Results with HJ interaction and HJ plus imaginary interaction are shown as dashed and solid curves, respectively. (b) Results obtained using phenomenological model of Ref. 20. Here the dashed and solid curves are the results obtained with and without core polarization, respectively.



VALENCE CALCULATIONS
(a)
(b)
10^2
10^1
10^0
$\frac{3}{2}^-$
$\frac{5}{2}^-$
$\frac{7}{2}^-$
$\frac{13}{2}^+$
$d\sigma/d\Omega$ ($\mu b/sr$)
0
40
80
120
$\theta_{c.m.}$ (degrees)

Fig. 1

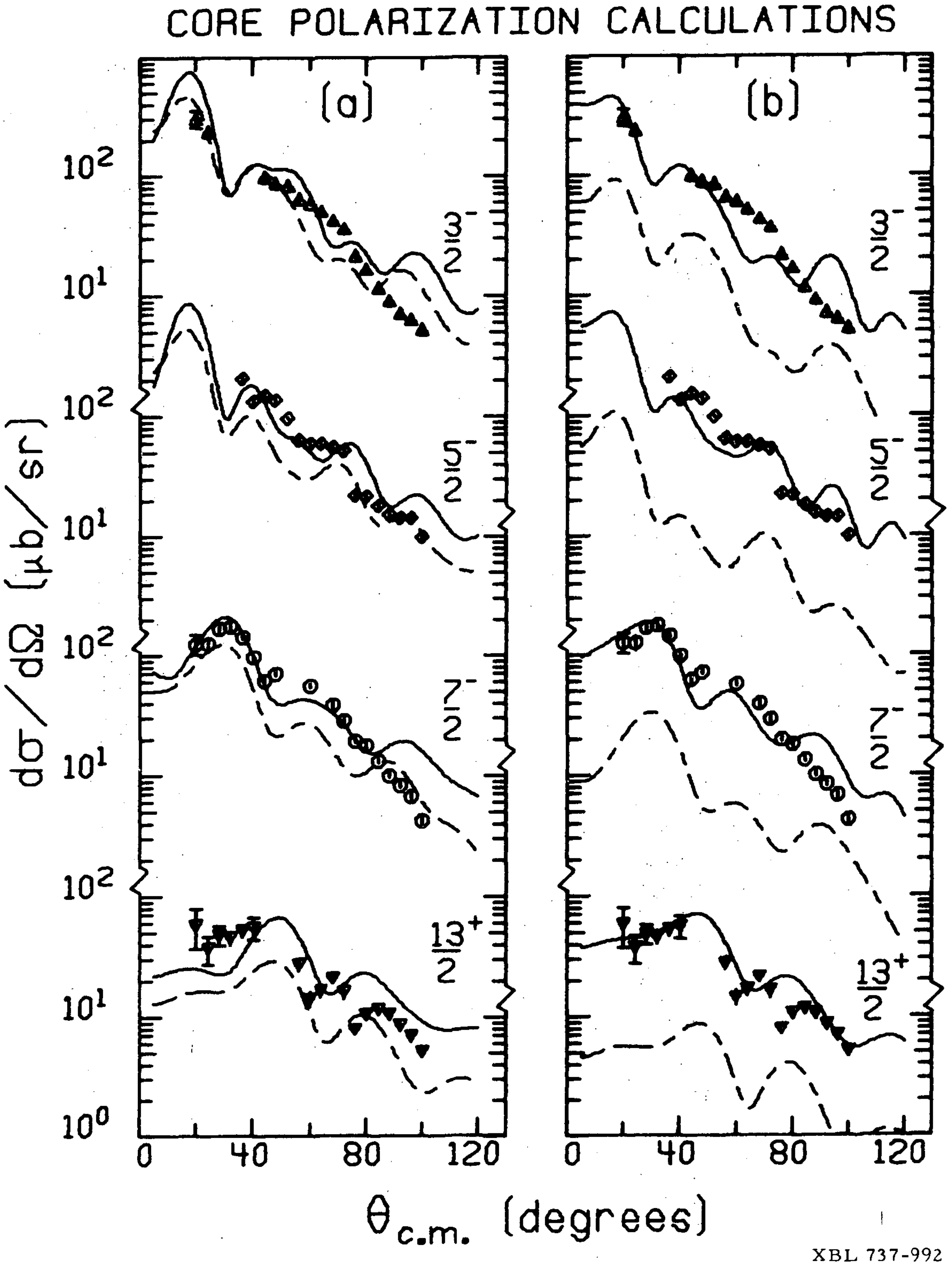

CORE POLARIZATION CALCULATIONS
(a)
(b)
3⁻/2
5⁻/2
7⁻/2
13⁺/2
dσ/dΩ (μb/sr)
θc.m. (degrees)
10²
10¹
10⁰
0
40
80
120
XBL 737-992

Fig. 2

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