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THE PROTON PARTICLE-HOLE STATES IN ^{208}Pb[*]

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ABSTRACT

The structure of ^{208}Pb has been investigated using the ^{209}Bi(d,^{3}He)^{208}Pb reaction at 50 MeV. ^{3}He angular distributions have been measured from 10° - 50° lab for fifteen levels in ^{208}Pb. These states in ^{208}Pb are considered to be populated through their $[1h_{9/2}(n\ell j)^{-1}]$ proton particle hole components. Spectroscopic factors have been extracted for each state and compared with those predicted by a recent random phase approximation calculation of Kuo and Brown. Generally good agreement between theory and experiment results.

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I. INTRODUCTION

Many of the low lying states of doubly closed shell nuclei should be describable in terms of simple shell model states of one particle-one hole character, with an effective interaction acting between the particle and hole. In the past few years there has been considerable progress in understanding these effective interactions, and it is now fairly well established that their dominant parts can be deduced from a free nucleon-nucleon potential such as the Hamada-Johnson potential.[1,2] Kuo[3] has pointed out that a major advantage in studying effective interactions in the Pb region is that the pure spherical shell model is likely to be a better approximation here than anywhere else in the periodic table, and hence comparisons between theory and experiment in the Pb region provide a more direct test of the effective interaction. Calculations of the wave functions of nuclei in the Pb region using both a realistic effective interaction based on the Hamada-Johnson potential[3,4] and phenomenological effective interactions[5] have recently been performed. It is of great interest to subject these wave functions to experimental test. A very elegant comparison has recently been made by Alford, Schiffer and Schwarz[6] for the nucleus ^{208}Bi. Some 31 low lying states of ^{208}Bi were shown to have very pure proton particle-neutron hole structure, in close agreement with the calculation of Ref. 3.

In recent years the neutron particle-hole states of ^{208}Pb have been extensively studied[7,8,9] but the proton particle-hole states have by comparison received but scant attention. The only direct information, previous to the present data, on the proton particle-hole states of ^{208}Pb has come from Bjerregaard et al.[10] who studied the ^{209}Bi$(t,\alpha)^{208}$Pb reaction at 13 MeV. At this low bombarding energy the angular distributions are dominated by the

Coulomb effect, and it was possible to reliably identify the ℓ-transfers only to four low lying states of less than 4 MeV excitation. Spectroscopic factors were extracted for these states and shown to be in reasonable agreement (within a factor of 2) with the random phase approximation calculations of Kuo and Brown)[4] and Gillet.[11]

The low-lying proton particle-hole states of ^{208}Pb may also be populated by the (d,^{3}He) reaction on ^{209}Bi. The ^{208}Pb(d,^{3}He)^{207}Tl [12] and ^{208}Pb(t,α)^{207}Tl [13] reactions have already been studied; up to an excitation of 3.5 MeV the only states populated were the first five known single proton hole states. The first four of these states are probably very pure single hole states, since they alone exhaust the expected spectroscopic strength. Thus, if ^{209}Bi is assumed to consist of an $h_{9/2}$ proton coupled to an unperturbed ^{208}Pb core, the ^{209}Bi(d,^{3}He)^{208}Pb reaction will populate states of the form $\pi[1h_{9/2}(n\ell j)^{-1}]$, where $(n\ell j)^{-1}$ represents a proton hole in the core, i.e. a state of ^{207}Tl. The four lowest lying configurations of this type are $\pi[1h_{9/2}(3s_{1/2})^{-1}]$, $\pi[1h_{9/2},(2d_{3/2})^{-1}]$, $\pi[1h_{9/2}(1h_{11/2})^{-1}$ and $\pi[1h_{9/2},(2d_{5/2})^{-1}]$, their unperturbed energies correspond respectively to 4.23, 4.58, 5.57 and 5.90 MeV of excitation is ^{208}Pb. In the absence of mixing, these configurations should give rise to ten positive parity and twelve negative parity states in ^{208}Pb. However, since many states with other proton and neutron particle-hole configurations lie in this same region of excitation, some mixing should be expected.

These considerations have led us to study the ^{209}Bi(d,^{3}He)^{208}Pb reaction at 50 MeV, the same bombarding energy as the previous ^{208}Pb(d,^{3}He)^{207}Tl investigation.[12] Fourteen groups up to an excitation energy of 5.7 MeV in

^{208}Pb have been identified and assigned to the above configurations. In the later sections of this paper we discuss our results and compare the extracted spectroscopic factors to those obtained from Kuo-Brown ^{208}Pb wave functions.[4]

II. EXPERIMENTAL PROCEDURE

The experiment was performed using the 50 MeV deuteron beam of the Berkeley 88-inch cyclotron. After energy analysis to 0.1% $\Delta E/E$ a beam spot size of about 2 mm horizontal by 4 mm vertical was obtained at the target. Beam currents used varied in the range 0.04 to 1.5 μA, depending on the scattering angle. The beam was collected in a Faraday cup and the total charge for each run was determined by a current integrator.

The target was a self supporting ^{209}Bi foil prepared by vacuum evaporation. The target thickness, measured by weighing several known areas, was found to be 310 ± 30 μgms cm^{-2}. From the recorded ^{3}He and alpha spectra, the only target impurities identified were small amounts of ^{12}C and ^{16}O. During the entire experiment a counter fixed at 20° lab was used to monitor the elastically scattered dueterons. A pulser which electronically simulated ^{3}He events was used to monitor electronic gain shifts and to measure dead time losses.

Outgoing reaction products were detected in two cooled silicon counter telescopes. Each telescope consisted of a 0.25 mm phosphorous diffused ΔE counter, backed by a 1.5 mm lithium-drifted E counter. Both ^{3}He and alpha particles from each telescope were recorded at each angle; particle separation was achieved by the use of a Goulding-Landis particle identifier.[14]

Windows were set very conservatively on the ^{3}He particle-identifier pulses, to ensure 100% efficiency, and so a small leak through of alphas into the ^{3}He spectra occured. It was thus necessary to accumulate alpha spectra in order to monitor the possible presence of alpha peaks in the ^{3}He spectra. At each angle therefore, two ^{3}He and two alpha spectra were recorded in 1024 channel groups of 4096 channel analyzer; the two particle identifier spectra were separately recorded. Data were taken from 10° to 50° lab., generally in 2.5° steps.

III. RESULTS

A typical ^{3}He spectrum is shown in Fig. 1. The overall energy resolution varied from 60 - 75 keV FWHM. The peaks in Fig. 1 are identified by their excitation energies in ^{208}Pb. For energy calibration the ^{89}Y(d,^{3}He)^{88}Sr reaction was also investigated. Using five low-lying states of ^{88}Sr plus the well known 3.198, 2.615 and 0.0 states of ^{208}Pb, a reliable calibration extending to 8 MeV of excitation in ^{208}Pb was found. An error of ± 20 keV is assigned to the excitation energies. Fourteen groups, up to an excitation energy of 5.7 MeV are identified in Fig. 1 as due to excited states in ^{208}Pb. With better resolution Bjerregaard <u>et al</u>.[10] were able to identify 20 groups in the same excitation range of ^{208}Pb. The excitation energies assigned from the two reactions are in very good agreement. The group in Fig. 1 at 5.364 MeV was not identified in the (t,α) study. The peaks in Fig. 1 above 5.7 MeV can all be identified as being due to target contaminants or (d,α) reactions, the other counts in this region could be attributed either to alpha background or to very weak excitation of higher states in ^{208}Pb.

Some of the (d,^{3}He) angular distributions are displayed in Figs. 2 - 6. The solid lines in these figures are smooth curves drawn through the ^{208}Pb(d,^{3}He)^{207}Tl data,[12] appropriately normalized and superimposed on the ^{209}Bi(d,^{3}He)^{208}Pb data points. The error bars shown are our estimates of the total experimental uncertainty, including errors arising from statistical, peak separation and background subtraction uncertainties. The absolute cross sections are estimated to be accurate to about ± 15%.

The extraction of spectroscopic factors from the present data is particularly simple. Since the ^{209}Bi(d,^{3}He)^{208}Pb results were taken at the same deuteron beam energy as the previous ^{208}Pb(d,^{3}He)^{207}Tl data,[12] the experimental differential cross sections for the four hole states in ^{207}Tl were used to normalize the present results. Thus it was not necessary to rely on cross sections calculated by the DWBA. This method assumes that the hole states in ^{207}Tl are pure, and that the ^{208}Pb core is undisturbed in ^{209}Bi. It also does not account for Q-value dependence in the (d,^{3}He) reactions, which is expected to be a small effect at our bombarding energy.

In the nine cases shown in Figs. 3 - 6, the solid curves match the present experimental data very well, this indicates that these groups are predominantly populated by a single value of j-transfer in proton pickup. However, since the ground state of ^{209}Bi has spin 9/2, and since some of the observed groups are due to more than one state in ^{208}Pb, several j-transfers are allowed. If we assume that all the ^{208}Pb groups between 2.6 and 5.7 MeV are due to pickup of $3s_{1/2}$, $2d_{3/2}$, $1h_{11/2}$ and $2d_{5/2}$ particles, then ideally each group should be fitted by a combination of all four types of pickup.

However, such a procedure leads to ambiguous results since there are too many parameters and also since the $2d_{3/2}$ and $2d_{5/2}$ distributions are almost indistinguishable. The procedure adopted was to fit the groups between 2.6 and 4.7 MeV with a combination of $3s_{1/2}$ and $2d_{3/2}$ pickup, and to fit the groups between 4.9 and 5.7 MeV with a combination of $1h_{11/2}$ and $2d_{5/2}$ pickup. Because the unperturbed energies of the two groups of configurations are separated by 1.25 MeV this method should be reliable except perhaps for the weak states around 4.7 MeV. Thus, for each ^{209}Bi(d,^{3}He)^{208}Pb angular distribution the quantity

$$\chi^2 = \sum_i \frac{K_1\sigma_a + K_2\sigma_b - \sigma_{exp}}{\Delta\sigma_{exp}}$$

was minimized by adjusting the constants K_1 and K_2. Here σ_{exp} is the ^{209}Bi(d,^{3}He)^{208}Pb differential cross section measured at a given angle, σ_a and σ_b represent the ^{208}Pb(d,^{3}He)^{207}Tl differential cross sections at the same angle, and $\Delta\sigma_{exp}$ is the experimental error in σ_{exp}. The sum is over the sixteen angles at which data were available for both reactions. The value of K_1 or K_2 at the minimum of χ^2 determined for each angular distribution the portion of the cross section in the ^{209}Bi(d,^{3}He)^{208}Pb reaction attributable to pickup of an ($n\ell j$) particle. The experimental spectroscopic factors are thus defined as follows:

$$S_{exp} = \frac{(2j+1)\sigma[h_{9/2},(n\ell j)^{-1}]}{\sigma(n\ell j) - 1} = (2j+1)K$$

where $\sigma(n\ell j)^{-1}$ is the cross section for pickup of an $(n\ell j)$ particle in the ^{208}Pb(d,^{3}He)^{207}Tl reaction.

The spectroscopic factors determined in this way are listed in Table I. Most of the ^{208}Pb groups observed are apparently due to a single type of proton pickup. However, the method is generally not sufficiently accurate to detect a configuration admixture of less than about 15%. Since the ^{208}Pb(d,^{3}He)^{207}Tl cross sections to the first four hole states are all about the same order of magnitude, this lack of sensitivity to small components does not discriminate against observation of the full strength of any one type of pickup. In fact, the summed spectroscopic factors for $3s_{1/2}$, $2d_{3/2}$ and $2d_{5/2}$ pickup are all within 10% of the sum-rule limit. The summed $1h_{11/2}$ pickup strength is about 10% lower than any of the others, which may mean that some of the $1h_{9/2}$ $(1h_{11/2})^{-1}$ states lie higher than 5.7 MeV. The spectroscopic factors for $3s_{1/2}$ pickup to states below 4 MeV can be compared with those determined from the (t,α) data.[10] The present values are uniformly about 20% larger than the previous values.

IV. DISCUSSION

The most striking feature of the ^{209}Bi(d,^{3}He)^{208}Pb spectrum is its almost total dissimilarity to the ^{207}Pb(d,p)^{208}Pb spectrum. This immediately shows the small amount of overlap between the $\nu[(n\ell j),(3p_{1/2})^{-1}]$ particle-hole states excited by the (d,p) reaction and the $\pi[h_{9/2},(n\ell j)^{-1}]$ particle-hole states found in the present work. However, a detailed comparison of the present results with the (d,p) data, and especially with the ^{208}Pb(p,p')^{208}Pb isobaric analogue data, is more difficult, and is probably not meaningful. For example, in the (p,p') data of Moore et al.,[8] 45 excited states of ^{208}Pb were observed between 3 and 6 MeV, which implies that the density of neutron particle-hole states in this region is very high. Since the energy resolution in the present work was 70 keV, and there is a 20 keV uncertainty in energy calibration, positive identification of states observed in the (d,^{3}He) data with those observed in the 10 keV resolution (p,p') data[8] is only possible below 4 MeV in excitation.

The first excited state observed in the present work is the collective 3^- state at 2.615 MeV. As expected, it is weakly excited in the transfer reaction. The 5^- state at 3.198 MeV, which is known to be predominantly a $\nu[2g_{9/2},(3p_{1/2})^{-1}]$ particle-hole state[7,8,9] is also weakly excited in the (d,^{3}He) reaction. Although both $2d_{3/2}$ and $2d_{5/2}$ transfers would be also allowed to this 5^- state, the transition appears to have a pure $s_{1/2}$ angular distribution. The well known 4^- state at 3.475 MeV never appears in our (d,^{3}He) spectra. This state is known to have an almost pure $\nu[2g_{9/2},(3p_{1/2})^{-1}]$ configuration[7,8,9] and so its absence from the (d,^{3}He) spectra is consistent with this interpretation. The second 5^- state at 3.708 MeV appears to be formed purely by $3s_{1/2}$ pickup in our data, but the spectroscopic factor of 0.42 is less than one half of that expected for a pure $\pi[1h_{9/2},(3s_{1/2})^{-1}]$ configuration. Some of the missing strength is undoubtedly due to a neutron component, since the (p,p') cross section to this state is large at the $g_{9/2}$ resonance. A doublet at 3.73, 3.76 MeV has been observed in the ^{207}Pb(d,p)^{208}Pb work of Mukherjee and Cohen.[15] Bardwick and Tickle[9] have also observed a doublet in this energy region. This doublet has been assigned as having a $g_{9/2}$ angular distribution,[9] implying that both states have $[g_{9/2}(n\ell j)^{-1}]$ neutron particle-hole components. It is strange, therefore, that only one state is observed at 3.702 MeV in the 9 keV resolution (p,p') work of Moore et al.,[8] at any of the analogue resonances. The group at 3.961 MeV is somewhat of a puzzle, since it appears to account for some 65% of the $s_{1/2}$ pickup strength and so is probably not a single state. A state at 3.961 MeV in ^{208}Pb has been observed in γ-decay studies and labelled as 4^-, 5^- or 6^-. The 6^- spin assignment was favored since no γ-decay to the 2.614 MeV 3^- state was observed. However, since the group we observe at 3.96 MeV appears to be populated exclusively by $s_{1/2}$ pickup it must consist of states of spin 4^- or 5^-. At least one of the states must have spin 4^-. States at 3.913, 3.955 and 3.992 MeV have been observed in analog state studies[8] but no spins have been assigned. Very recently, yet another state at 3.940 MeV has been observed in analog state studies[16] and assigned as having a $\nu[2g_{9/2}(3p_{1/2})^{-1}]$ particle-hole component. It is thus very possible that there are two or more states near 3.96 MeV with spins 4^- or 5^- and this could account for the fact that the $s_{1/2}$ strength we measure to the group at 3.961 MeV is too large to correspond to excitation of a single state.

At excitation energies above 4 MeV, and particularly in the region where $h_{11/2}$ and $d_{5/2}$ pickup are important, the groups that are seen in the present work very likely consist of several states. In fact, only three groups with significant $d_{5/2}$ strength, and only five groups with significant $h_{11/2}$ strength are observed. These numbers are smaller than the number of states predicted, even without mixing. On the other hand, it is clear that there is some mixing among states with $s_{1/2}$ strength, since at least three and probably five such groups are observed, one of which is probably not a single state. Five groups with $d_{3/2}$ strength are also observed. One of these is the collective 3^- state at 2.614 MeV which is weakly excited, so that another 3^- state with $d_{3/2}$ strength is expected. The 4.278 MeV group which has both $s_{1/2}$ and $d_{3/2}$ strength is known to be a doublet.[13] Also the 4.387 MeV group which has only $d_{3/2}$ strength is known to be a doublet[13] and so both states must have $d_{3/2}$ strength. Thus, the $d_{3/2}$ strength appears to be spread over atleast six states two of which are weakly excited, and so the indication is that some, but not much mixing may be occuring.

The experimental spectroscopic factors are compared with theoretical ones calculated with the Kuo-Brown wave functions,[4] in Fig. 7. The theoretical spectroscopic factors are defined as follows:

$$S_{\text{theor}} = \frac{(2j+1)}{(2J_i+1)} \chi^2_{n\ell j}$$

where J is the spin of the final state in ^{208}Pb, J_i is the spin of ^{209}Bi and $\chi_{n\ell j}$ is the calculated amplitude of the component $\pi[1h_{9/2}(n\ell j)^{-1}]$ in a state of spin J. The $\pi[1h_{9/2}(1h_{1/2})^{-1}]$ multiplet data are not shown in Fig. 7 since the wave functions for the positive parity states in ^{208}Pb beyond the 5^+ were not available.

The general agreement of the calculated positions and widths of the three multiplets in ^{208}Pb with the experimental data is readily apparent. The observed clustering of the $s_{1/2}$ and $d_{3/2}$ strength near 4.2 MeV and the $d_{5/2}$ strength near 5.6 MeV is predicted. However, the Kuo-Brown wave functions predict considerable configuration mixing which our data is in general unable to confirm, except in the case of the $\pi[1h_{9/2},(3s_{1/2})^{-1}]$ multiplet.

This is certainly due in part to the fact that many of the predicted closely-spaced levels would not have been resolved. However, the predicted $d_{5/2}$ strength between 5.8 and 6.2 MeV is large enough to have been plainly visible in the experimental spectra, but it is not found.

Finally it is of interest to compute the calculated and observed centroid energies of the various particle-hole multiplets. The unperturbed multiplet energies are easily calculated from the relation

$$E_0[1h_{9/2}(n\ell j)^{-1}] = {}^{209}\mathrm{Bi} + {}^{207}\mathrm{Tl} - 2\ ({}^{208}\mathrm{Pb})$$

where ^{209}Bi and ^{208}Pb are the ground state masses of these nuclei, and ^{207}Tl is the mass of the state $(n\ell j)^{-1}$ of this nucleus. An attempt was made to perform the full multipole decomposition analysis of Moinester et al.[17] on the $\pi[1h_{9/2},(2d_{3/2})^{-1}]$ multiplet. Even in this most favorable case, various plausible gusses as to the assignments of small components gave rise to very large changes in the values for the higher moments.

The experimental and theoretical centroid energies of a multiplet are given by

$$\overline{E}_{\mathrm{exp}} = \sum_i S_{i_{\mathrm{exp}}} E_i/(2j+1)$$

$$\overline{E}_{\mathrm{theor}} = \sum_i S_{i_{\mathrm{theor}}} E_i/(2j+1) \quad .$$

The values of $\overline{E}_{\mathrm{exp}}$ and $\overline{E}_{\mathrm{theor}}$ so calculated are shown in Table II. Both the experimental and theoretical values $\overline{E}$ are lower in excitation energy than the unperturbed positions, and the shifts are approximately equal for all multiplets. However, the predicted shifts are generally a factor of 1.5 - 2 smaller than the observed shifts. For neutron particle-hole states, on the other hand, the Kuo-Brown wave functions tend to overestimate the energy shifts.[18] For ^{208}Bi, the predictions were generally quite accurate.[6] Some of the discrepancy between theory and experiment for the present data may be due to unrecognized states at higher excitations. However, since we have accounted for almost all of the expected pickup strength for the $s_{1/2}$ through $d_{5/2}$ cases, and since the predicted wave functions indicate the strengths are strongly clustered close to the unperturbed positions, it is unlikely that this can account for the entire difference between theory and experiment.

CONCLUSIONS

The low lying proton particle-hole states of ^{208}Pb have been studied via the ^{209}Bi(d,^{3}He)^{208}Pb reaction. Essentially all of the expected $s_{1/2}$, $d_{3/2}$, $h_{11/2}$ and $d_{5/2}$ proton pickup strength has been accounted for and shown to populate states in ^{208}Pb between 2.6 and 5.7 MeV. The comparison with Kuo-Brown wave functions[4] for ^{208}Pb has shown general but not detailed agreement in the positions, widths and centroid shifts of the proton particle hole multiplet observed in this study. With the present data it has not, in general, been possible to confirm the considerable configuration mixing predicted for the low-lying particle-hole states of ^{208}Pb predicted by the Kuo-Brown calculations except for the $h_{9/2}(s_{1/2})^{-1}$ multiplet which has been shown to be spread over at least five states. The calculated and observed proton particle-hole residual interaction energies are shown to be attractive, but their absolute values of 350 and 200 keV are in some disagreement.

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Table I. Experimentally determined spectroscopic factors of proton particle-hole states of ^{208}Pb excited by the ^{209}Bi(d,^{3}He)^{208}Pb reaction at 50 MeV. The hole $(n\ell j)^{-1}$ is noted in the table, for all cases the particle is $1h_{9/2}$.

State Energy (MeV)	S_{exp}
2.614	$0.18\,(2d_{3/2})^{-1}$
3.198	$0.08\,(3s_{1/2})^{-1}$
3.708	$0.42\,(3s_{1/2})^{-1}$
3.961	$1.28\,(3s_{1/2})^{-1}$
4.134	$0.04\,(3s_{1/2})^{-1} + 0.70\,(2d_{3/2})^{-1}$
4.278	$0.14\,(3s_{1/2})^{-1} + 1.10\,(2d_{3/2})^{-1}$
4.387	$1.56\,(2d_{3/2})^{-1}$
4.708	$0.29\,(2d_{3/2})^{-1}$
4.914	$1.38\,(1h_{11/2})^{-1}$
5.073	$1.50\,(1h_{11/2})^{-1}$
5.196	$5.71\,(1h_{11/2})^{-1}$
5.364	$0.70\,(2d_{5/2})^{-1}$
5.545	$0.32\,(1h_{11/2})^{-1} + 3.28\,(2d_{5/2})^{-1}$
5.689	$1.09\,(1h_{11/2})^{-1} + 1.63\,(2d_{5/2})^{-1}$

Table II. Energies of the proton particle-hole multiplets in ^{208}Pb.

Multiplet	E_o[a] (MeV)	$\bar{E}_{exp}$[b] (MeV)	$\bar{E}_{theor}$[c] (MeV)	ΔE_{exp} (keV)	ΔE_{theor} (keV)
$\pi[1h_{9/2},(3s_{1/2})^{-1}]$	4.225	3.901	4.029	-324	-196
$\pi[1h_{9/2},(2d_{3/2})^{-1}]$	4.575	4.252	4.377	-323	-198
$\pi[1h_{9/2},(1h_{11/2})^{-1}]$	5.565	5.209	--	-356	--
$\pi[1h_{9/2},(2d_{5/2})^{-1}]$	5.895	5.553	5.757	-342	-138

[a] Unperturbed energies calculated from ^{209}Bi(d,^{3}He), and ^{208}Pb(d,^{3}He) Q-values.

[b] Experimentally observed multiplet centroids in the present ^{209}Bi(d,^{3}He)^{208}Pb data.

[c] Calculated multiplet centroids from the Kuo-Brown wave functions.[4]

FIGURE CAPTIONS

Fig. 1. Spectrum of ^{3}He particles at 27.5° lab from ^{209}Bi(d,^{3}He)^{208}Pb at 50 MeV.

Fig. 2. Angular distribution of the ^{209}Bi(d,^{3}He)^{208}Pb reaction showing $1h_{9/2}$ transfer.

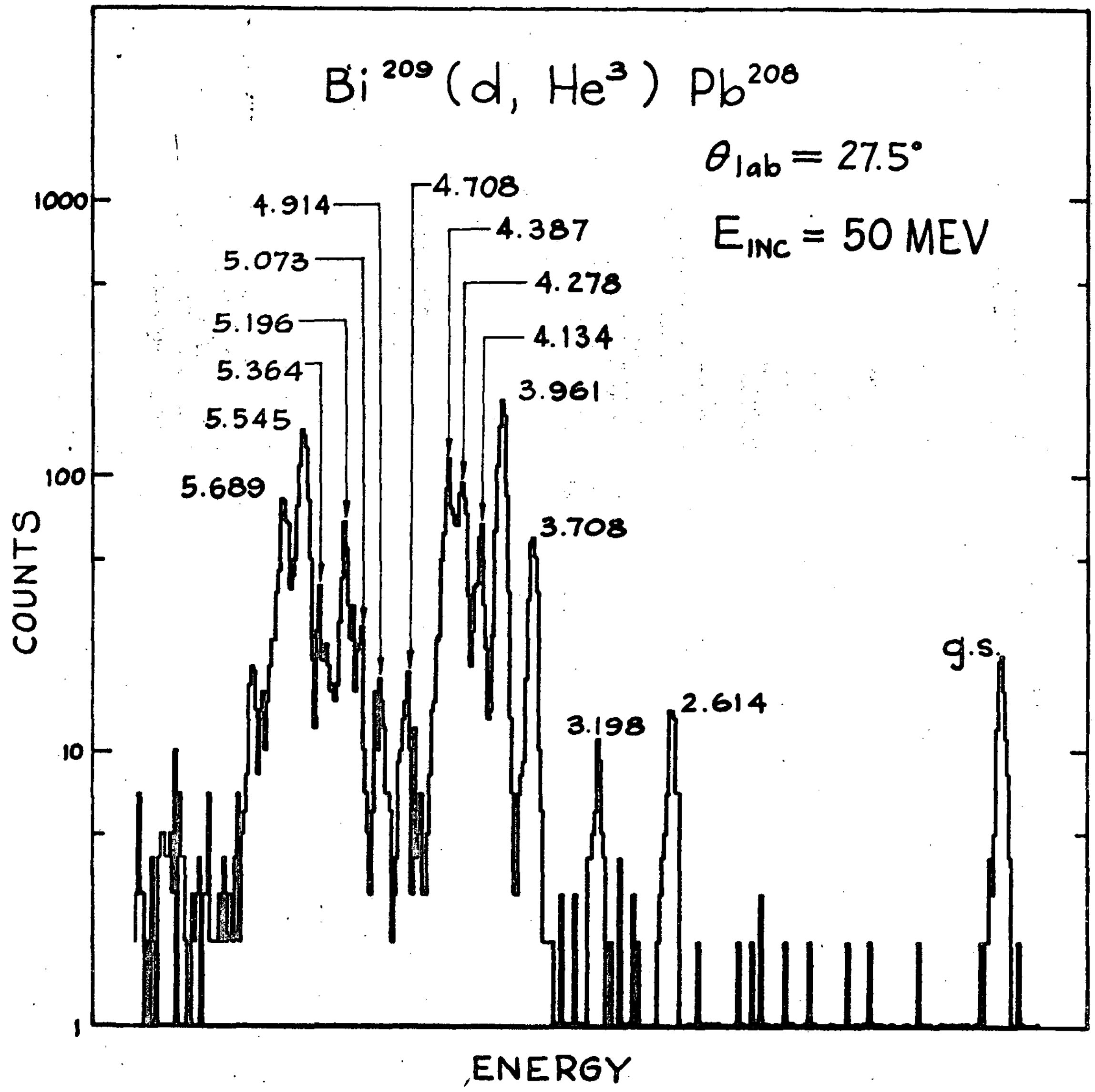
Fig. 3. Angular distribution of the ^{209}Bi(d,^{3}He)^{208}Pb reaction showing $3s_{1/2}$ transfer.

Fig. 4. Angular distribution of the ^{209}Bi(d,^{3}He)^{208}Pb reaction showing $2d_{3/2}$ transfer.

Fig. 5. Angular distribution of the ^{209}Bi(d,^{3}He)^{208}Pb reaction showing $1h_{11/2}$ transfer.

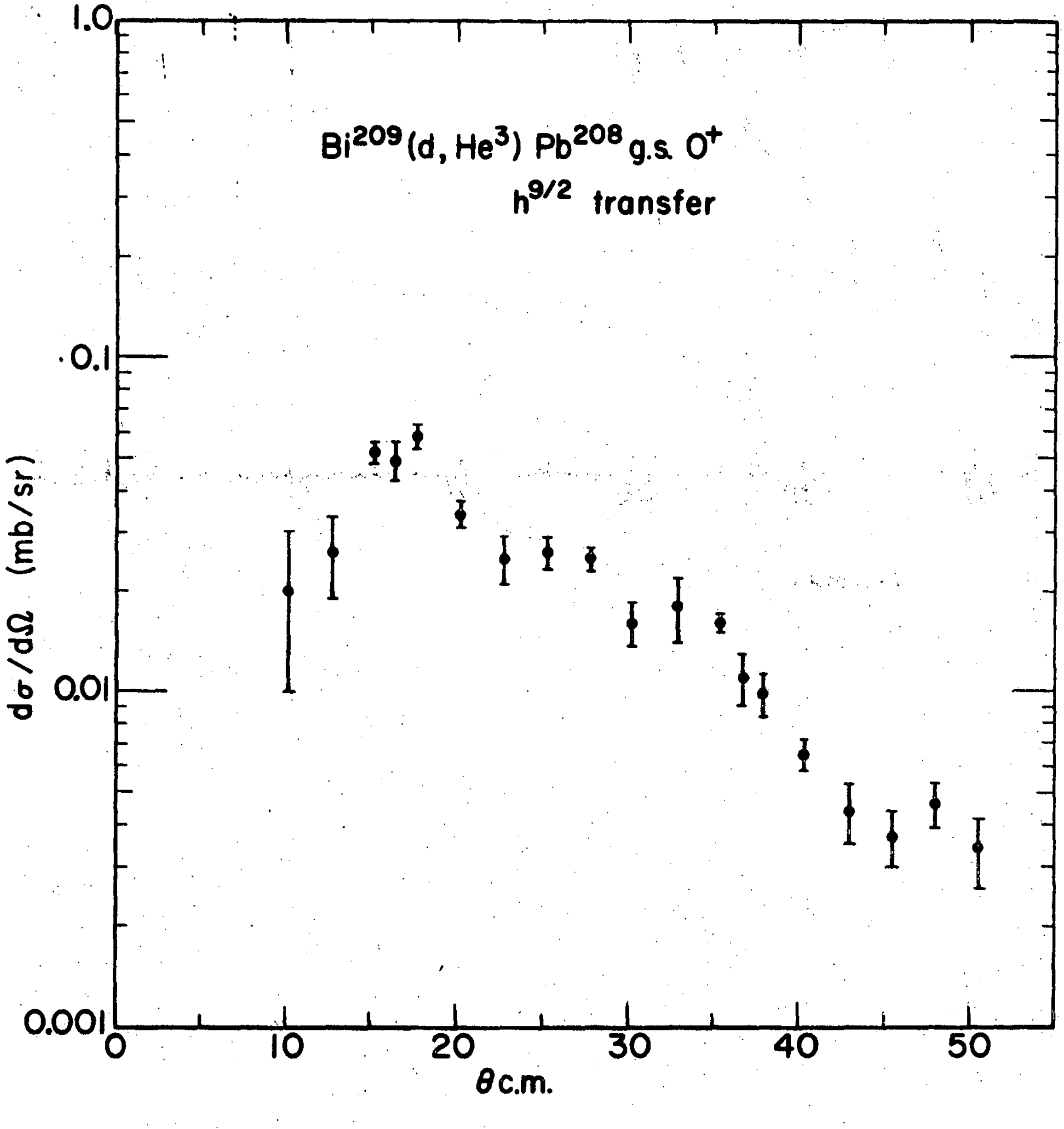
Fig. 6. Angular distribution of the ^{209}Bi(d,^{3}He)^{208}Pb reaction showing $2d_{5/2}$ transfer.

Fig. 7. Comparison of the theoretical and experimental spectroscopic factors for the ^{209}Bi(d,^{3}He)^{208}Pb reaction.



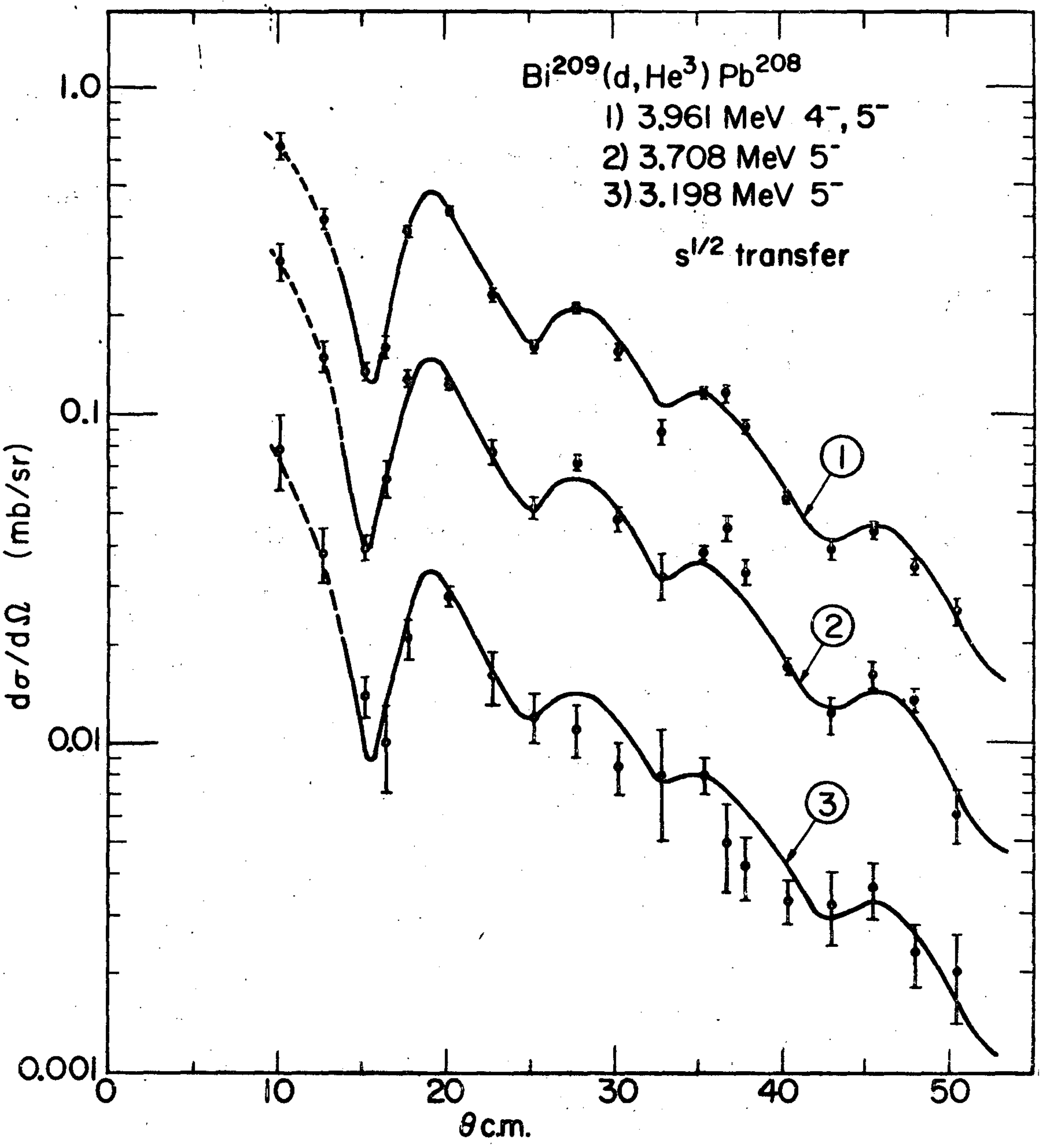
XBL 6910-5855

Fig. 1



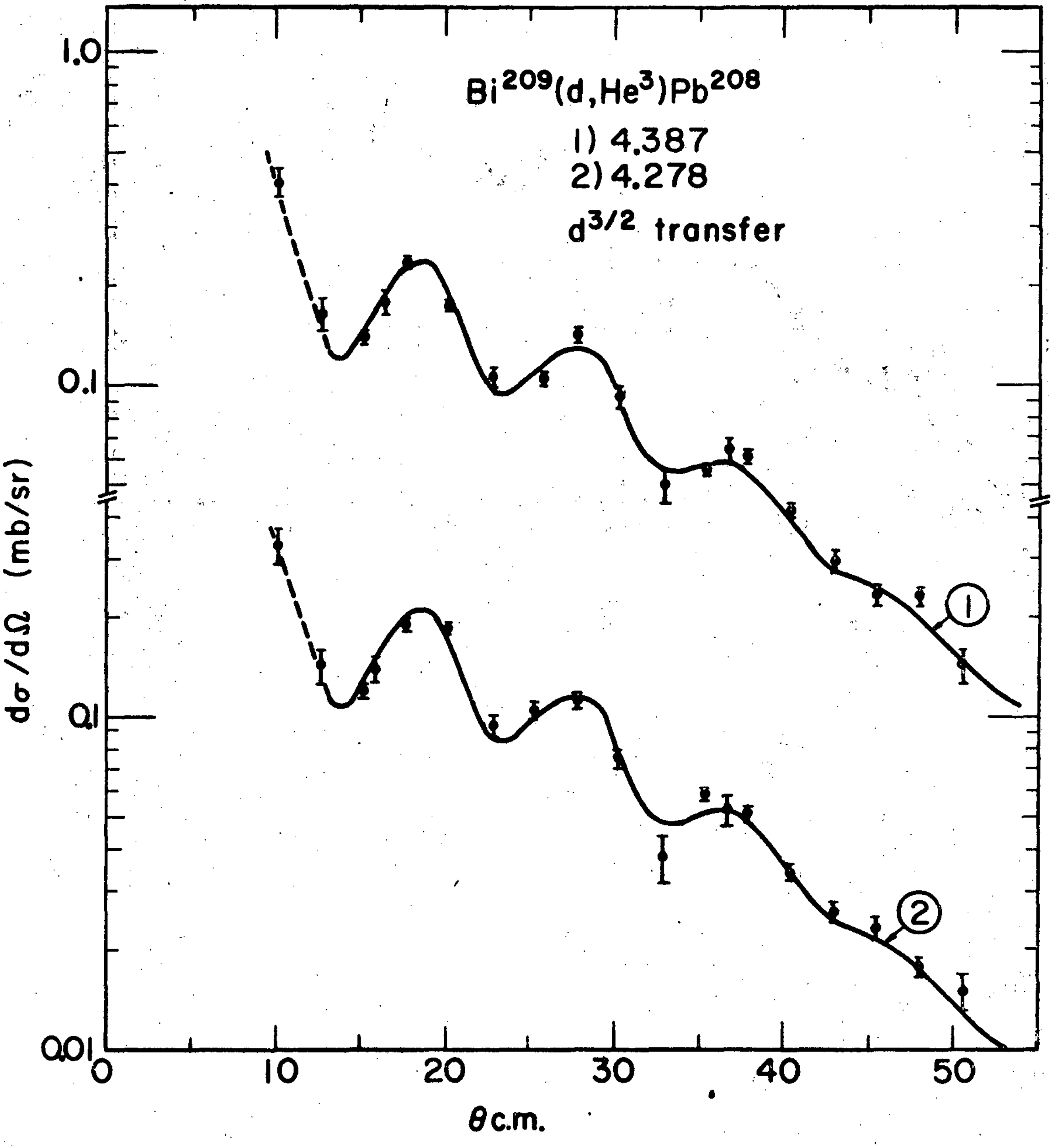
$Bi^{209}(d, He^3) Pb^{208}$ g.s. 0^+
$h^{9/2}$ transfer
1.0
0.1
0.01
0.001
$d\sigma/d\Omega$ (mb/sr)
0
10
20
30
40
50
θ c.m.
XBL684-2391

Fig. 2



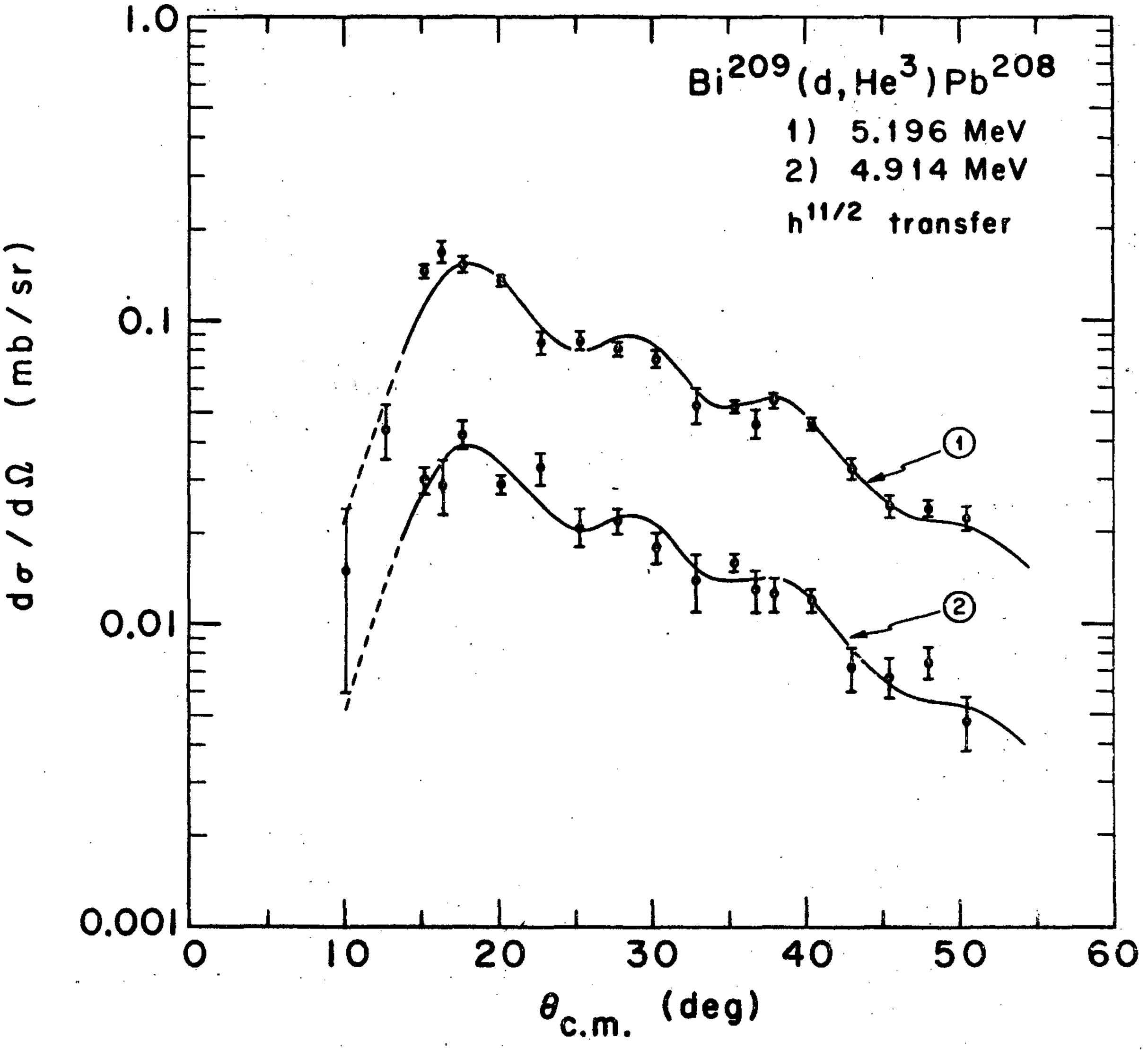
XBL684-2389

Fig. 3



XBL684-2387

Fig. 4



XBL684-2412

Fig. 5

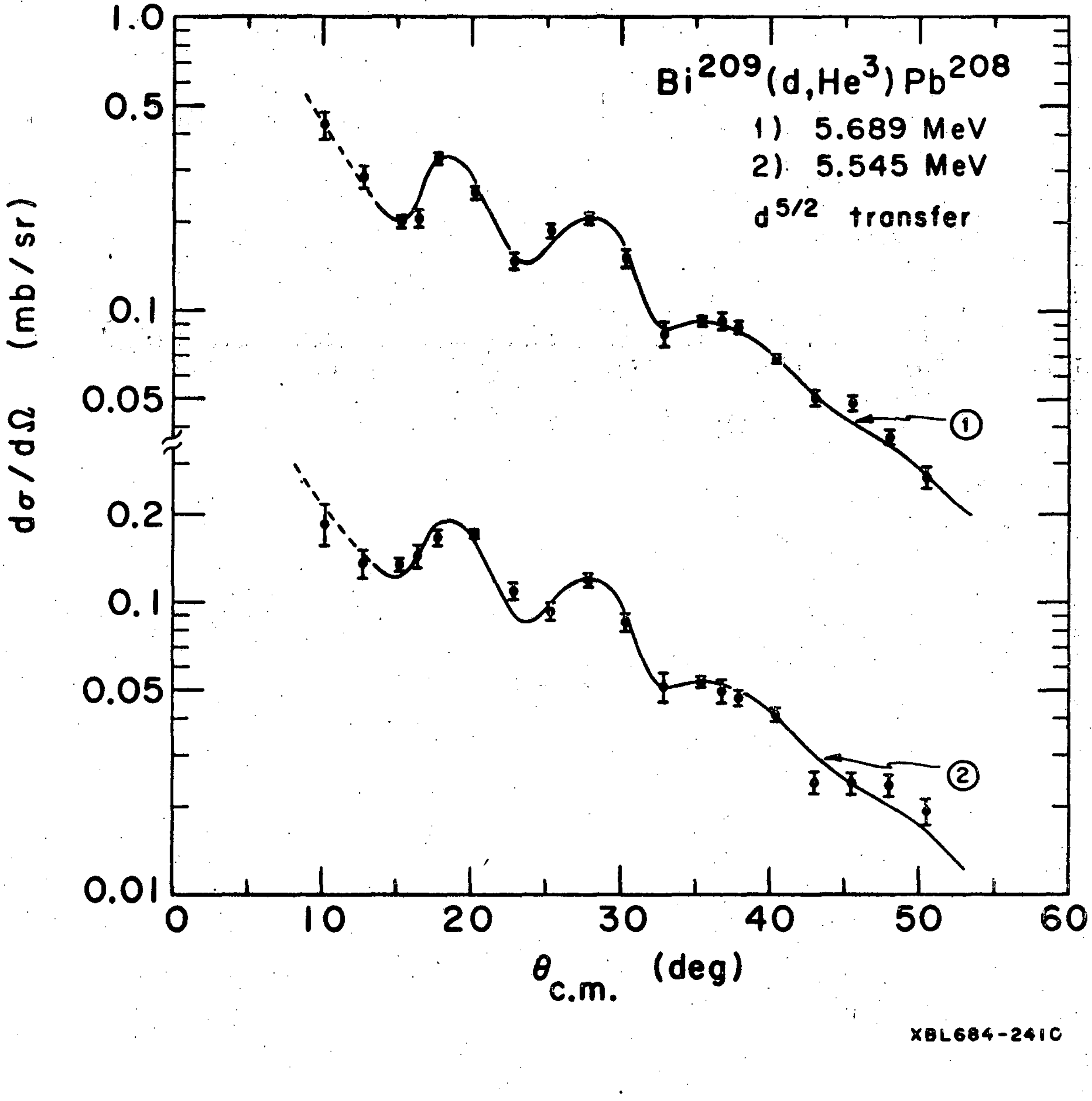

1.0
0.5
0.1
0.05
0.2
0.1
0.05
0.01
$d\sigma/d\Omega$ (mb/sr)
0
10
20
30
40
50
60
$\theta_{c.m.}$ (deg)
$Bi^{209}(d,He^3)Pb^{208}$
1) 5.689 MeV
2) 5.545 MeV
$d^{5/2}$ transfer
①
②
XBL684-241C

Fig. 6

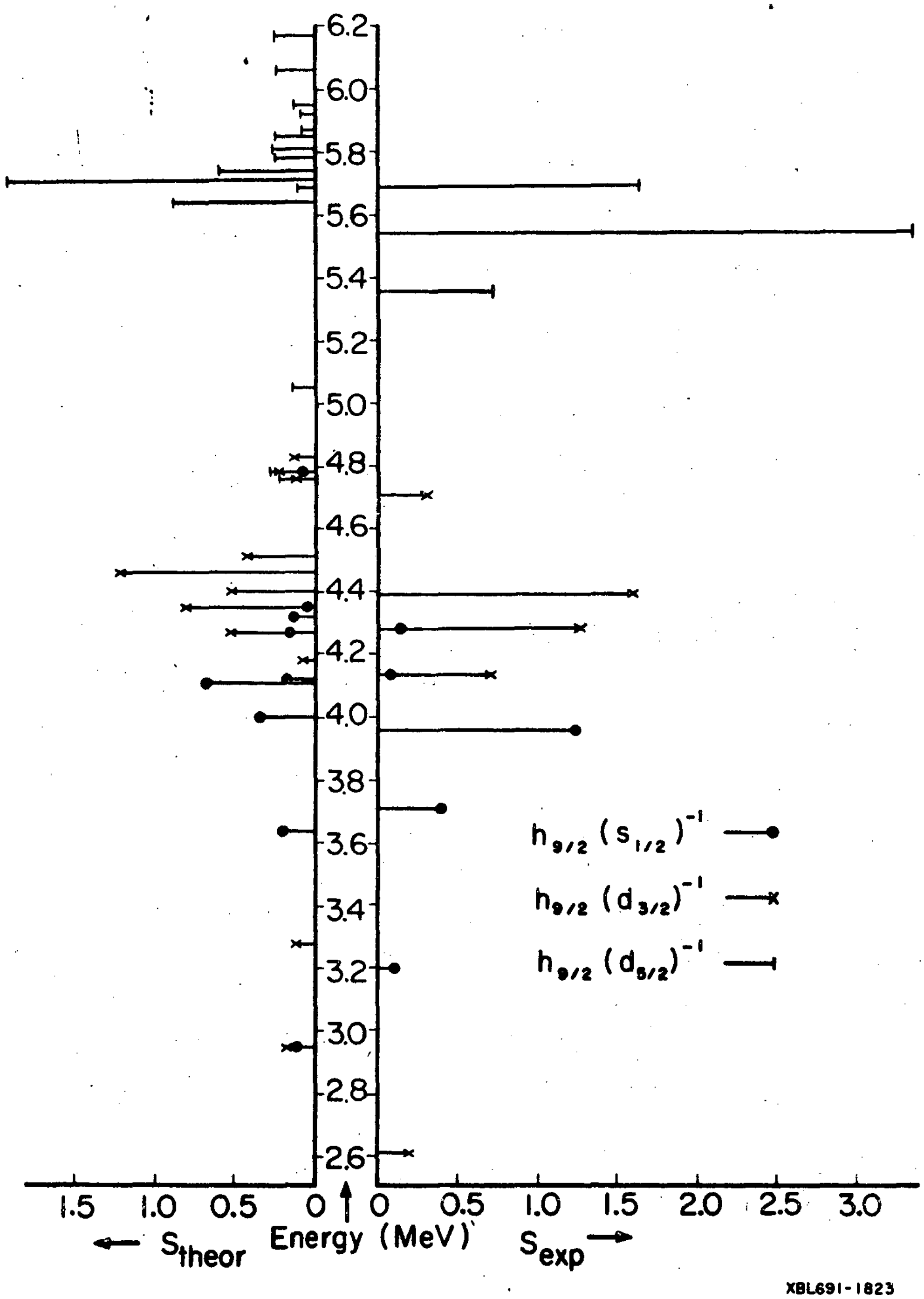

6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
1.5 1.0 0.5 0
0 0.5 1.0 1.5 2.0 2.5 3.0
← S_{theor}
Energy (MeV)
S_{exp} →
$h_{9/2}(s_{1/2})^{-1}$ ●
$h_{9/2}(d_{3/2})^{-1}$ ×
$h_{9/2}(d_{5/2})^{-1}$ ⊣
XBL691-1823

Fig. 7

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