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MASTER

RESONATING-GROUP STUDY AND IMPORTANCE OF EXCHANGE EFFECTS IN THE $\alpha + {}^{6}Li$ SYSTEM†

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Abstract: The resonating-group method in the one-channel approximation is used to investigate the $\alpha + {}^{6}Li$ system. The result shows that, especially at relatively high energies, reasonable agreement with experiment can be obtained. In particular, the cross-section rise in the backward angular region is well accounted for. The effects of internuclear antisymmetrization, represented by various nucleon-exchange terms in the kernel function, have also been carefully examined. Here some of the interesting findings are that the blocking effect is quite significant in this system and the two-exchange terms (sometimes even the three-exchange terms) seem to have only minor influence on the scattering cross section.

1. Introduction

The effects of internuclear antisymmetrization in nucleus-nucleus scattering have recently been studied[1,2] by examining the general structures of the exchange-normalization and exchange-Hamiltonian kernel functions in the resonating-group formulation.[3] From this study, one of the most interesting findings was that, if a local potential is adopted to represent the effective internuclear interaction, then the real central part of this potential must generally contain a Majorana or odd-even ℓ-dependent component. In addition, it was shown that, especially in scattering systems where the nucleon-number difference of the interacting nuclei is small, this odd-even component has significant effects and its inclusion in the internuclear potential is imperative for a satisfactory explanation of the cross-section behavior at backward angles when the scattering energy is relatively high. For instance, in $^3He + \alpha$ scattering at a center-of-mass energy of 44.5 MeV (i.e., about 26 MeV/nucleon), the omission of this component in a local-potential-model analysis causes the 180^o cross section to be substantially smaller by about three orders of magnitude.[4]

To achieve a detailed understanding of the odd-even effect is apparently not an easy task. Aside from its dependence on the nucleon-number difference mentioned above, it also seems to be significantly influenced by the dynamical structures of the interacting nuclei. For example, in a resonating-group study of the $n + {}^6Li$ system,[5] it was found that in the channel-spin 3/2 state the presence of two nucleons in the nonclosed 1p-shell of the ^6Li nucleus introduces a blocking effect (see also ref. 6)) which drastically affects the odd-even nature of the effective internuclear potential. Furthermore, one anticipates that the degree of cluster formation in the incident and target nuclei must also play a significant role. This seems to be intuitively obvious, but has so far not been explicitly examined.†

In this investigation, we make a resonating-group study of the $\alpha + {}^{6}Li$ system††, treated in the three-cluster $\alpha + (\alpha + d)$ configuration. The main purpose is to obtain a better understanding of nucleon-exchange effects which lead, in particular, to the odd-even dependence of the internuclear potential[1,2]. We choose this particular system for a detailed study, because the nucleon-number difference of the interacting nuclei is small and the blocking effect may have an appreciable influence. Indeed,

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†Because of limitations in our formulation, clustering effects will also not be examined in this investigation.

††There are other resonating-group calculations for the $\alpha + {}^{6}Li$ system.[7,8] These calculations were, however, performed at very low energies where the odd-even effect is less apparent. In addition, we should mention that the $\alpha + {}^{6}Li$ system has also been studied by Bohlen et al.[9] This latter study, though not microscopic, is interesting because it does take exchange effects approximately into consideration.

there is some experimental evidence which indicates the presence of notable odd-even feature in this system. The measured angular distribution at 99.6 MeV[10] (i.e., 41.5 MeV/nucleon), which cannot be well described by using the conventional optical model containing no Majorana potential, does in fact show a rather sharp cross-section rise in the backward angular region. On the other hand, the cross sections at angles close to 180^o are considerably smaller than those for other light systems, such as p + ^{3}He [ref. [11]] and d + α [ref. [12]] systems, at energies of about 40 MeV/nucleon. This is an indication that the blocking effect is likely important and, thereby, the degree of odd-even dependence is substantially reduced.

A brief description of the formulation of the α + ^{6}Li problem is given in the next section. In sect. 3, we present the results obtained for the phase shift and the differential cross section. Sect. 4 is devoted to a discussion of exchange effects, with particular emphasis being paid to the odd-even nature of the effective internuclear potential. Finally, in Sect. 5, concluding remarks are made.

2. Resonating-group formulation

Since the emphasis of the present study is to examine nucleon-exchange effects, we shall simplify the calculation by adopting a purely central nucleon-nucleon potential. With this simplification, the single-channel resonating-group trial wave function can then be written as

$$\psi = \mathcal{A}\left[\phi_{\alpha 1} \phi_{\alpha 2} \phi_d \, \chi(\underset{\sim}{\rho}) F(\underset{\sim}{R}) \xi(s,t) Z(\underset{\sim}{R}_{cm}) \right], \qquad (1)$$

where $\mathcal{A}$ is an antisymmetrization operator, ξ is an appropriate spin-isospin function, and $Z(\underset{\sim}{R}_{cm})$ is any normalizable function describing the c.m. motion of the entire system. The functions $\phi_{\alpha 1}$, $\phi_{\alpha 2}$, and ϕ_d represent the spatial structures of the incident α particle, the α cluster in ^{6}Li and the deuteron cluster, respectively; they are given by

$$\phi_{\alpha 1} = \exp\left[-\frac{1}{2}\alpha_1 \sum_{i=1}^{4} (\underset{\sim}{r}_i - \underset{\sim}{R}_{\alpha 1})^2\right] , \tag{2}$$

$$\phi_{\alpha 2} = \exp\left[-\frac{1}{2}\alpha_2 \sum_{i=5}^{8} (\underset{\sim}{r}_i - \underset{\sim}{R}_{\alpha 2})^2\right] , \tag{3}$$

$$\phi_{d} = \exp\left[-\frac{1}{2}\alpha_d \sum_{i=9}^{10} (\underset{\sim}{r}_i - \underset{\sim}{R}_{d})^2\right] , \tag{4}$$

where $\underset{\sim}{R}_{\alpha 1}$, $\underset{\sim}{R}_{\alpha 2}$, and $\underset{\sim}{R}_d$ are c.m. coordinates of the various clusters. The function $\chi(\underset{\sim}{\rho})$ describes the relative motion of the deuteron and α clusters in ^{6}Li and is chosen to be

$$\chi(\underset{\sim}{\rho}) = \exp\left(-\frac{2}{5}\beta\rho^2\right) . \tag{5}$$

To substantially reduce the computational effort, we shall use the approximation of adopting a common value of 0.35 fm^{-2} for the internal width parameters of the three clusters†; i.e., we assume

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†To make this compromise choice, we use the fact that the width parameter of an α particle has a value larger than 0.35 fm^{-2}, while the width parameters of the α and deuteron clusters in ^{6}Li have somewhat smaller values.

$$\alpha_1 = \alpha_2 = \alpha_d = 0.35 \ fm^{-2} \quad (6)$$

The d + α relative-motion width parameter β is then chosen to yield nearly the experimentally determined rms matter radius of ^{6}Li. The resultant value is

$$\beta = 0.25 \ fm^{-2} \quad (7)$$

It should be noted that the values of α and β, given by eqs. (6) and (7), are quite similar. This indicates that the degree of deuteron and α clustering in the ^{6}Li wave function adopted here is only moderately stronger than that implied by the oscillator shell-model function of the lowest $(1s)^4(1p)^2$ configuration[13].

The function F($\underset{\sim}{R}$), which describes the relative motion between the incident α cluster and the ^{6}Li cluster, satisfies the following integrodifferential equation:

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V_D(R) - E\right] F(\underset{\sim}{R}) + \int K(\underset{\sim}{R},\underset{\sim}{R}') F(\underset{\sim}{R}') d\underset{\sim}{R}' = 0 , \quad (8)$$

where E is the relative energy of the two clusters in the c.m. system, and V_D is the direct potential consisting of a nuclear part V_N and a Coulomb part V_C. The quantity K($\underset{\sim}{R}$, $\underset{\sim}{R}'$) is an energy-dependent kernel function†, representing the nonlocal interaction between the clusters. It has a very lengthy expression and contains all information concerning the effects of intercluster antisymmetrization.

The nucleon-nucleon potential used is the one described in ref. [15]. It contains an exchange-mixture parameter y (for the definition of y, see eq. (9) of ref. [16]), which is adjusted to yield the $\alpha + {}^6Li$ separation energy of 3.74 MeV in the first excited $\ell = 0$, $J^{\pi} = 1^+$ state of ^{10}B [ref. [17]]. The value so obtained is

$$y = 0.78 \quad . \tag{9}$$

With this value of y, there exists also an $\ell = 2$ bound state which has an α - particle separation energy of 0.25 MeV. This state will be split into a triad of 3^+, 2^+, and 1^+ states, if a noncentral component is also included in the nucleon-nucleon potential.

3. Phase-shift and differential cross-section results

In fig. 1, we show the $\alpha + {}^6Li$ phase shifts at c.m. energies less than 50 MeV. Here one sees that, at about 5 MeV, there is a rather sharp $\ell = 4$ resonance level. This is a member of the ground-state rotational band, with the $\ell = 0$ and 2 levels located below the $\alpha + {}^6Li$ threshold as mentioned in the preceding paragraph. Furthermore, it is noted that a negative-parity rotational band also exists in the low-energy region. In fact, there is even an indication for the existence of an excited

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† The exchange-Coulomb part of this kernel function will be approximately treated by using the procedure described in ref. [14]

positive-parity band. The states in this latter band are, however, quite broad and, consequently, their presence will be hard to verify experimentally.

To make a comparison between calculated and experimental differential cross sections, we introduce a phenomenological imaginary potential into the formulation. What we do is to simply multiply the V_N-part of the direct potential V_D by a factor $(1 + i\mathcal{Y})$. The single parameter $\mathcal{Y}$ is then adjusted at each energy to yield a best over-all agreement with the measured result.

The calculated differential cross section at 8.42 MeV is shown by the solid curve in fig. 2, together with the measured values of Bingham et al.[18] To obtain the calculated curve, we have used $\mathcal{Y} = 0.03$, which results in a total reaction cross section of 566 mb. As is seen, the calculation yields the general features of the experimental data, but there is no detailed agreement. The reason for this is probably that we have not considered spin-orbit effects in this investigation. In the low-energy region where rather sharp resonance levels exist (see fig. 1), the omission of such effects may lead to relatively undesirable consequences. In addition to this, it is possible that the use of an imaginary potential to take reaction effects into account may not adequately represent the influence on the elastic channel of strong inelastic scattering to the excited $\ell = 2$ rotational states of ^{6}Li.

The above-mentioned defects tend to become less serious at higher energies. Thus, one anticipates that the fit to experiment will improve as the energy increases. That this is indeed so can be seen from fig. 3, where a comparison between calculation and experiment[10,19] for the cross-section ratio $\sigma(\theta)/\sigma_C(\theta)$ is made at 62.4 and 99.6 MeV. For the calculated curves, the values of $\mathcal{f}$ used are equal to 0.60 and 0.65, respectively, with the corresponding total reaction cross sections being 702 and 638 mb. From this figure, one sees that the calculation does yield quite satisfactory results. In particular, the measured angular distribution at 99.6 MeV in the backward angular region is reasonably described. This is in contrast to the description obtained with the conventional optical model which employs a local, ℓ - independent potential for its real central part. With this latter model, it was shown[10] that the cross-section rise at backward angles cannot at all be accounted for. As is mentioned in the Introduction, this is of course a demonstration of the fact that exchange effects are significant in this system, and these effects are properly taken into consideration by the use of a totally antisymmetric wave function in our present calculation.

4. Effects of internuclear antisymmetrization

In this section, we make a detailed examination of the effects of internuclear antisymmetrization. What we shall do is to first obtain a qualitative understanding by using the considerations given in a previous publication[2]. Then, based on the information so obtained, we shall study the phase-shift and cross-section behaviour in order to learn the importance of various nucleon-exchange processes in this system.

4.1. QUALITATIVE STUDY OF THE KERNEL FUNCTION

A procedure to study qualitatively the effects of internuclear antisymmetrization is described in detail in ref.[2]; however, for the sake of the following discussion, it will still be useful to give here a brief review of some essential points. As was discussed there, the kernel function $K(\underset{\sim}{R}, \underset{\sim}{R}')$ in eq. (8) can be written as a sum of nucleon-exchange terms, i.e.,

$$K(\underset{\sim}{R},\underset{\sim}{R}') = \sum_x \sum_q K_{xq}(\underset{\sim}{R},\underset{\sim}{R}') , \tag{10}$$

where x is the number of nucleons interchanged between the α and ^6Li clusters (x = 1, 2, 3, 4) and q denotes the interaction type for each value of x. For x = 1, 2, and 3, there are four interaction types which are denoted by the index q = a, b, c, and d [for a detailed discussion, see ref.[2]], while for x = 4 (i.e., core-exchange), there are only three types, namely, q = a, c, and d. Each nucleon-exchange term, represented by the function K_{xq}, consists of essentially an exponential factor multiplied by a polynomial factor. The exponential factors, depending on the nucleon numbers of the clusters involved, determine the general features of antisymmetrization, while the polynomial factors contain information concerning more specific features, such as blocking and clustering effects. In both ref.[2] and this subsection, the discussion is directed mainly only toward the exponential factors of the exchange terms.

For an understanding of the roles played by the various nucleon-exchange terms, the procedure used in ref.[2] is as follows. One constructs effective local energy-dependent potentials $\tilde{V}_{xq}$ which yield, in the Born approximation, the same scattering amplitudes as these exchange terms, and then examine the properties of the characteristic range R_{xq} and the characteristic energy E_{xq} † which each of these potentials possesses.

In order to use the various formulae listed in ref. [2)] without modification, we assume in this qualitative study that all internal width parameters and the d + α relative-motion width parameter take on nearly the same average value of 0.31 fm^{-2}. Then, based on the discussion given in that reference, one finds that the effective potentials $\tilde{V}_{xq}$ with x = 1 and 2 are Wigner-type potentials which yield large Born scattering amplitudes only at forward angles, while the effective potentials $\tilde{V}_{xq}$ with x = 3 and 4 are Majorana-type potentials which yield large Born scattering amplitudes only at backward angles.

In table 1, the values of the characteristic range R_{xq} and the characteristic energy E_{xq} are listed. From this table, one observes the following interesting features:

(i) Some of the one-exchange and four-exchange characteristic ranges have values which are quite close to the value of 2.70 fm for the characteristic range of the direct nuclear potential V_N [see eq. (74) of ref. [2)]]. In addition, one notes that the characteristic energies of the one-exchange and four-exchange effective potentials are quite large. These results suggest that, at energies under consideration in this investigation, these exchange contributions must always be taken into consideration.

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†The characteristic energy E_{xq} is determined from the characteristic wave number k_{xq} [see ref. [2)]] by the relation $E_{xq} = \hbar^2 k_{xq}^2 / 2\mu$.

(ii) The characteristic ranges of the two-exchange and three-exchange effective potentials are considerably shorter than the characteristic range of the direct nuclear potential. This indicates that in situations where strong absorption exists in the interior region, these exchange potentials will contribute insignificantly to the scattering cross section.

(iii) The characteristic energies of the one-exchange effective potentials are much larger than those of the two-exchange effective potentials. Consider, for instance, the most important type, namely, type c. The characteristic energy in the one-exchange case is almost seven times larger than that in the two-exchange case. Thus, at sufficiently high energies, it is expected that the two-exchange terms will make much less contribution than the one-exchange terms and, hence, can be omitted from the calculation.

(iv) The characteristic energies of the three-exchange effective potentials are smaller than those of the four-exchange effective potentials. However, it is noted that the characteristic energy of the three-exchange type-b term is not substantially smaller. This means that especially for a satisfactory explanation of the cross-section behaviour in the backward angular region, this particular term may need to be properly considered.

As has been mentioned already, these are general features of antisymmetrization in the $\alpha + {}^6Li$ system, which can be learned by studying in the Born approximation the exponential factors of the kernel functions. In the following, we shall use these features as a qualitative guide to interpret the results of our phase-shift and cross-section calculations.

4.2 ODD-EVEN BEHAVIOUR OF THE PHASE SHIFT

In the upper part of fig. 4, we show the α + ^{6}Li phase-shift result at 50 MeV (i.e., 20.8 MeV/nucleon). From this one sees that there is indeed a distinct odd-even behaviour. However, it is noted that, even though partial waves up to ℓ = 12 contribute significantly, the odd-even feature shows up clearly only for $\ell \lesssim 7$. This is in contrast to the d + α phase-shift behaviour[20] shown in the lower part of fig. 4 at a similar energy per nucleon. In this latter case, one finds instead that the odd-even feature does seem to extend to all partial waves which contribute.

The above-mentioned α + ^{6}Li odd-even feature can be seen somewhat more clearly by employing a procedure which has been frequently used.[2] In this procedure, one assumes an intercluster effective potential which has a nuclear part (in addition to the Coulomb part V_C) of the form

$$\tilde{V}_\ell (R) = C_\ell \, V_N (R) , \tag{11}$$

and adjusts the ℓ-dependent parameter C_ℓ to yield exactly the phase-shift values of the resonating-group calculation. In fig. 5, the result at 50 MeV is shown by the solid dots. Here one sees that the line joining the C_ℓ points does have a pronounced zigzag feature for $\ell \lesssim 7$, but become comparatively smooth for higher-ℓ values.†

The α + ^{6}Li phase-shift structure found here is somewhat unexpected

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†As a contrast, the C_ℓ behaviour in ^{3}He + α scattering shown in fig. 6 of ref. [2] is of interest.

from the viewpoint of the discussion given in subsect. 4.1 which, we emphasize again, is based solely on the properties of exponential factors in the kernel functions. According to that discussion, it would be reasonable to expect that, at the energy of 50 MeV, the four-exchange terms should have a larger influence than the three-exchange terms. Since one notes from table 1 that four-exchange characteristic ranges are comparable to the characteristic range of the direct nuclear potential, one would anticipate that the odd-even feature should extend to all contributing partial waves, just as in the case of d + α scattering. That this turns out not to be so is likely a consequence of the fact that, because of the large probability for the presence of two nucleons in the nonclosed 1p shell of ^{6}Li, the blocking effect[5)] may have a substantial influence in this case. As a result of this, the four-exchange processes, which involve the exchange of a larger number of nucleons between the clusters, become somewhat less important and, consequently, both three exchange (especially type-b term) and four-exchange terms must be considered for a proper understanding of the odd-even behaviour in this particular system.

If the above explanation is indeed correct, then the finding that the α + ^{6}Li odd-even behaviour is more pronounced for $\ell \lesssim 7$ can be easily accounted for. From table 1 one sees that the characteristic range of the three-exchange type-b term is only about half as large as that of the direct nuclear potential. This means that this dominant three-exchange term is expected to contribute significantly only to partial waves of lower-ℓ values.

To show the reasonableness of our suggestion concerning the importance of the blocking effect, we have made a study in which the two-exchange and three exchange terms are omitted,† and the resultant phase-shift values are analyzed by using the C_ℓ -procedure described above. The result of this analysis is shown by open circles also in fig. 5. From this figure, it is indeed seen that for $\ell \lesssim 7$ the degree of the odd-even dependence does become substantially reduced, thus confirming our assertion that the contribution of three-exchange terms is quite appreciable at these ℓ values. In addition, one notes that with these exchange terms omitted, the over-all odd-even behaviour, shown by the dashed line, is not greatly pronounced.††. This is again a demonstration that the blocking effect is likely to be significant in the $\alpha + {}^6$Li system and, consequently, the effects of core exchange (i.e., $x = 4$ in the $\alpha + {}^6$Li case and $x = 2$ in the $d + \alpha$ case) are not as important as those in the $d + \alpha$ system which has the same nucleon-number difference.

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†Note that, from the discussion of subsect. 4.1, the two-exchange terms are expected to have only minor influence at this energy.

††The slight dip at $\ell = 0$ is a result of omitting two-exchange terms in this study.

4.3. EFFECTS OF OMITTING NUCLEON-EXCHANGE TERMS ON THE DIFFERENTIAL CROSS SECTION

Based on Born-approximation considerations, we have mentioned in subsect. 4.1 that one-exchange and two-exchange effective potentials have Wigner character, while three-exchange and four-exchange effective potentials have Majorana character. In this subsection, we shall demonstrate these specific features by performing calculations at a relatively high energy to study the effects on the differential cross section of omitting some of the nucleon-exchange terms.

In fig. 6, we show a comparison of differential cross sections at 50 MeV in the no-absorption ($\mathcal{J}$ = 0) case, calculated with the full kernel function (i.e., resonating-group or r-g calculation, denoted by solid dots), and with two-exchange and three-exchange terms turned off (denoted by solid curve). From this figure it is seen that, at angles less than about 130^o, the results obtained from these two calculations are quite similar, indicating that two-exchange terms are indeed rather unimportant at this energy. At angles greater than 130^o, however, it is noted that the cross-section values differ from each other by an order of magnitude. This means that three-exchange terms do contribute significantly in the backward angular region, in agreement with the conclusion reached by studying the phase-shift behaviour in the preceding subsection.

To gain a quantitative measure of the importance of one-exchange terms, we have also performed a calculation in which the kernel function $K(\underset{\sim}{R}, \underset{\sim}{R}')$ in eq. (8) is set as zero, but the nuclear part V_N of the direct potential is multiplied by a factor of 1.4. The result obtained for the differential cross section is shown by the dashed curve also in fig. 6. Here one sees that the resonating-group cross-section behaviour for $\theta \lesssim 110^{\circ}$ can be reasonably accounted for by such a simplified calculation, but the rise in the backward direction cannot be explained. Thus, we conclude that the one-exchange terms do make very appreciable contribution at this energy, but taking these terms alone into consideration will not yield all the essential features of the resonating-group angular distribution.

By comparing the back-angle cross sections of the three calculations shown in fig. 6, one can also gain additional information. This information is that, although four-exchange contributions are reduced due to blocking effects, they must still be properly considered if a satisfactory description of the cross-section behaviour in the backward angular region is desired.

In subsect. 4.1, it was further mentioned that, in the strong-absorption case, three-exchange terms may become relatively unimportant because of their short characteristic ranges. To demonstrate this, we have made a calculation at 50 MeV with $\mathcal{J} = 0.5$, and with two-exchange and three-exchange terms omitted. The result is shown by the solid curve in fig. 7, where we see that there is indeed a good agreement with the resonating-group calculation (denoted by solid dots) at nearly all angles. In particular, it is shown that with grazing partial waves now dominating, even cross-section values at large angles can be satisfactorily reproduced by taking only one-exchange and four-exchange terms into consideration.†

†Note that the cross-section rise in the backward angular region comes mainly from four-exchange terms.

5. Conclusion.

In this investigation, the $\alpha + {}^6Li$ system is studied with the resonating-group method in the one-channel approximation. The result shows that, especially at rather high energies, reasonable agreement with experiment can be obtained. In particular, the cross-section behaviour in the backward angular region can be well accounted for, which is of course a consequence of the fact that, in our calculation, a totally antisymmetric wave function is used. At lower energies, on the other hand, our calculation seems to yield only the essential features of measured angular distributions, indicating that for a satisfactory description of this system at these energies, one may need to extend the present calculation to include spin-orbit effects and perhaps also inelastic channels involving low-lying rotational states of ${}^6Li$.

The effects of internuclear antisymmetrization, represented by various nucleon-exchange terms in the kernel function, are carefully examined at relatively high energies. By studying both the phase-shift and the cross-section behaviour, it is found that the one-exchange terms are very important and must always be properly considered. The two-exchange terms are, however, shown to have only minor influence and can, therefore, be reasonably omitted from the calculation.

Another interesting finding is that, just as in the $n + {}^6Li$ case, the blocking effect is quite significant in this system. As a consequence, both three-exchange and four-exchange terms are generally required for a proper description of the cross-section behaviour at large angles. In situations where strong absorption is present in the interior region, however, the three-exchange terms do become much less important. The reason for this is that the characteristic ranges of the effective potentials representing these exchange terms turn out to have rather small values.

Together with our previous studies in the $^{3}He + \alpha$ and $\alpha + {}^{16}O$ systems,[2)] the present investigation shows that, in a practical calculation, it may be an allowable approximation to omit some of the nucleon-exchange terms. Clearly, this is a very useful finding, because in any future attempt to deal microscopically with a heavy-ion system involving a large number of nucleons, it would obviously be a difficult task if one had to take all these exchange terms into consideration.

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Table 1

Characteristic range $R_{x q}$ and characteristic energy $E_{x q}$ of the effective potential $\tilde{V}_{x q}$.

X	Interaction type q	$R_{x q}$ (fm)	$E_{x q}$ (MeV)
1	a	2.18	24
	b	1.41	24
	c	2.24	116
	d	1.96	30
2	a	0.96	9
	b	0.21	9
	c	1.19	18
	d	0.89	10
3	a	1.20	11
	b	1.36	23
	c	0.62	11
	d	1.11	13
4	a	2.54	32
	c	1.60	32
	d	2.25	41

Figure Captions

Fig. 1: Calculated phase shifts for $\alpha + {}^6Li$ scattering.

Fig. 2: Comparison of calculated and experimental differential cross sections at 8.42 MeV.

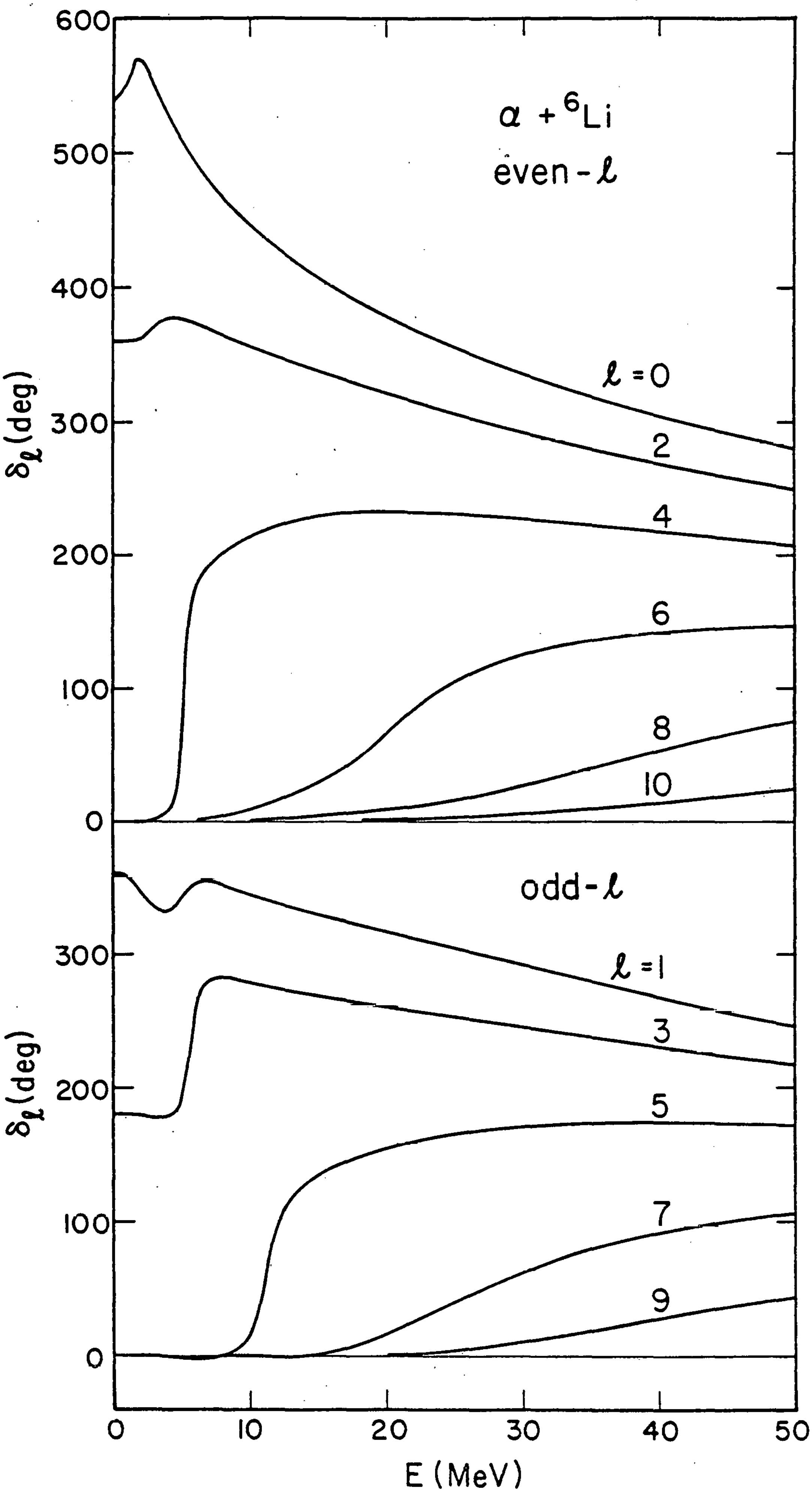
Fig. 3: Comparison of calculated and experimental values for the ratio $\sigma(\theta)/\sigma_C(\theta)$ at 62.4 and 99.6 MeV.

Fig. 4: Phase shifts as a function of ℓ for $\alpha + {}^6Li$ scattering at 50 MeV and $d + \alpha$ scattering at 30 MeV.

Fig. 5: The parameter C_ℓ as a function of ℓ for $\alpha + {}^6Li$ scattering at 50 MeV. The solid dots represent the resonating-group results, while the open circles represent results obtained with two-exchange and three-exchange terms omitted.

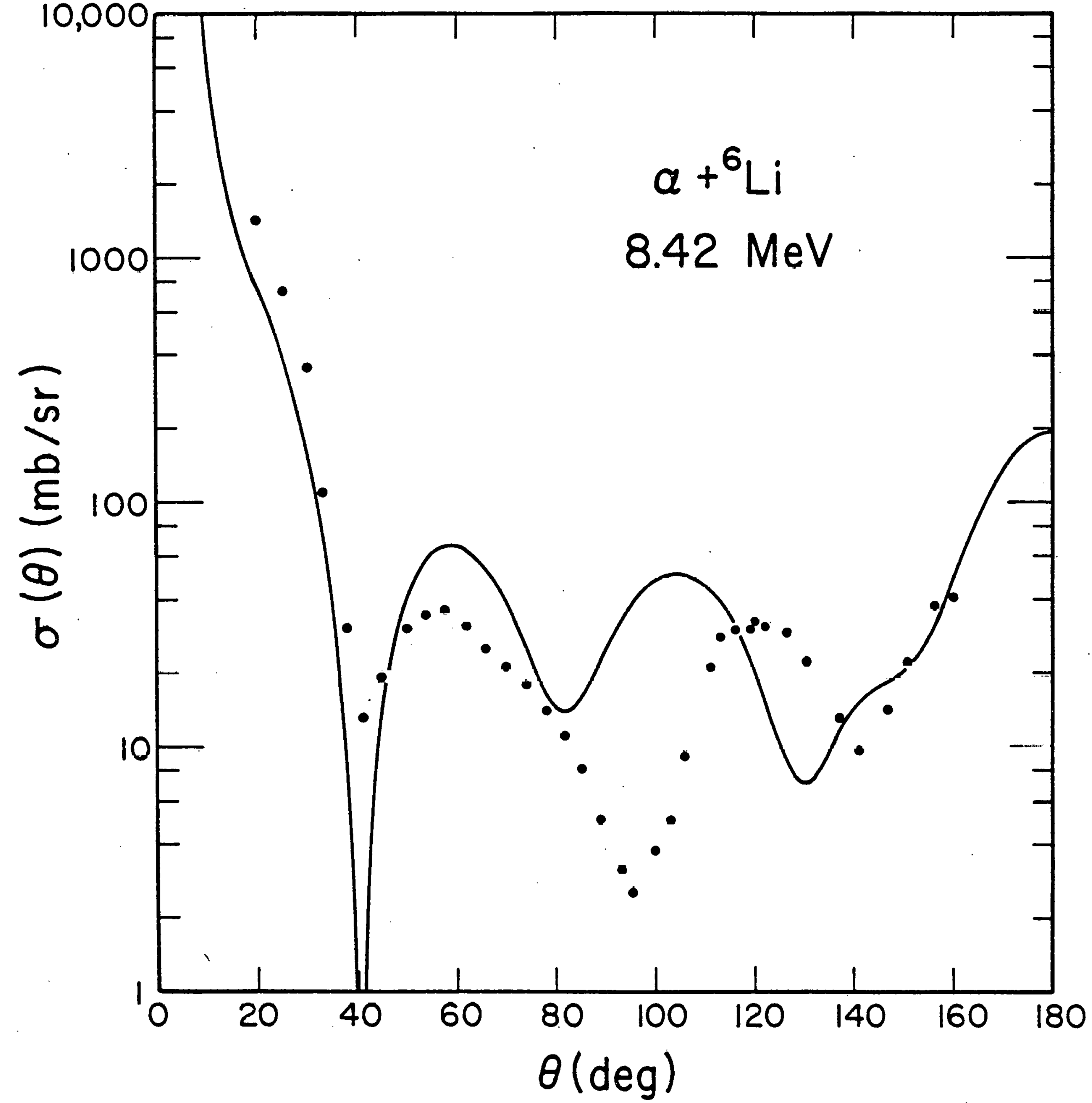
Fig. 6: Comparison of calculated differential cross sections at 50 MeV in the no-absorption case. The solid dots represent results from the resonating-group calculation, the solid curve represents results obtained with two-exchange and three-exchange terms omitted, while the dashed curve represents results obtained with the kernel function entirely omitted but the direct nuclear potential multiplied by a factor of 1.4.

Fig. 7: Comparison of calculated differential cross sections at 50 MeV in the strong-absorption case. The solid dots represent results from the resonating-group calculation, while the solid curve represents results obtained with two-exchange and three-exchange terms omitted.



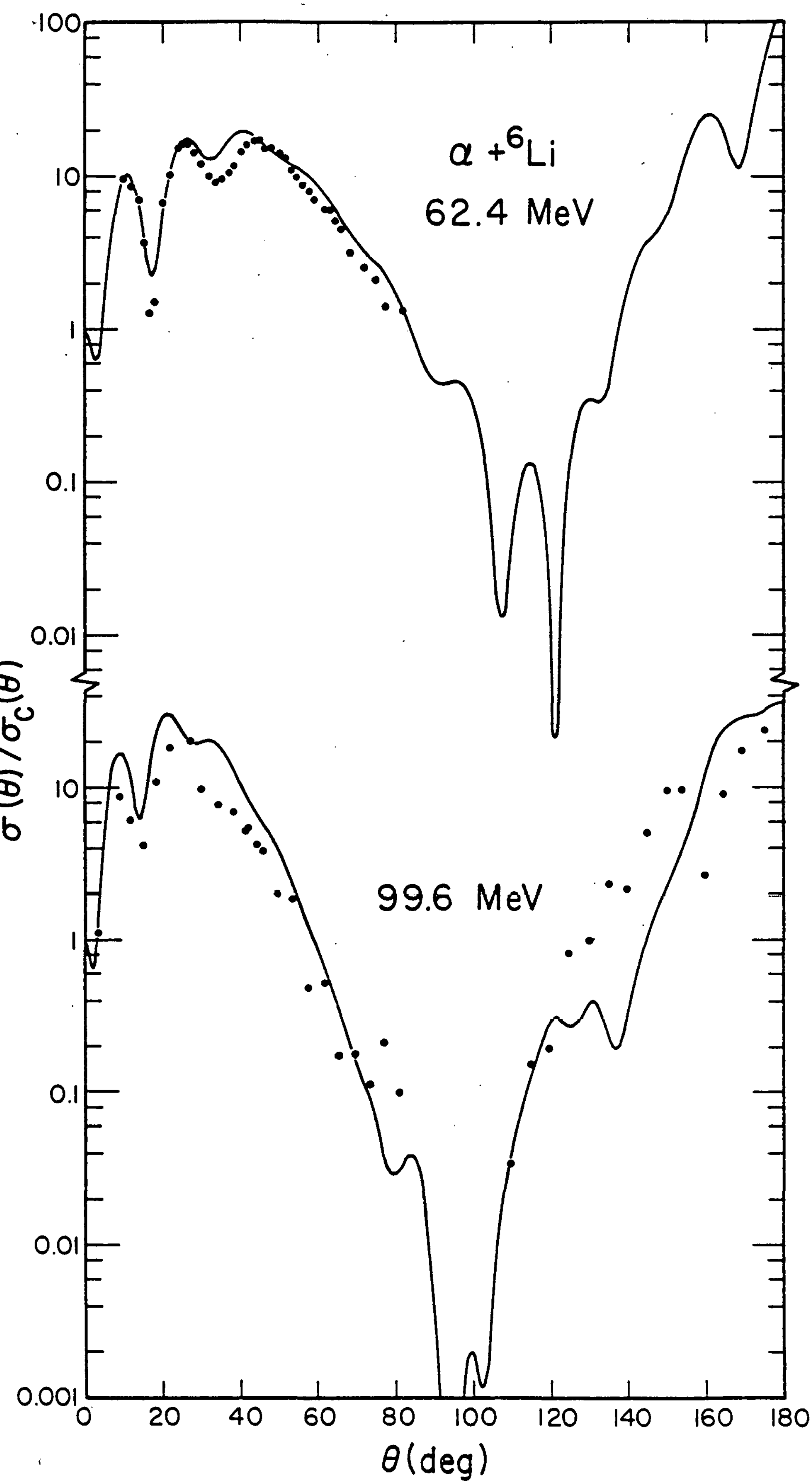
α + ⁶Li
even-ℓ
ℓ = 0
2
4
6
8
10
odd-ℓ
ℓ = 1
3
5
7
9
δℓ (deg)
δℓ (deg)
600
500
400
300
200
100
0
300
200
100
0
0
10
20
30
40
50
E (MeV)

Fig. 1



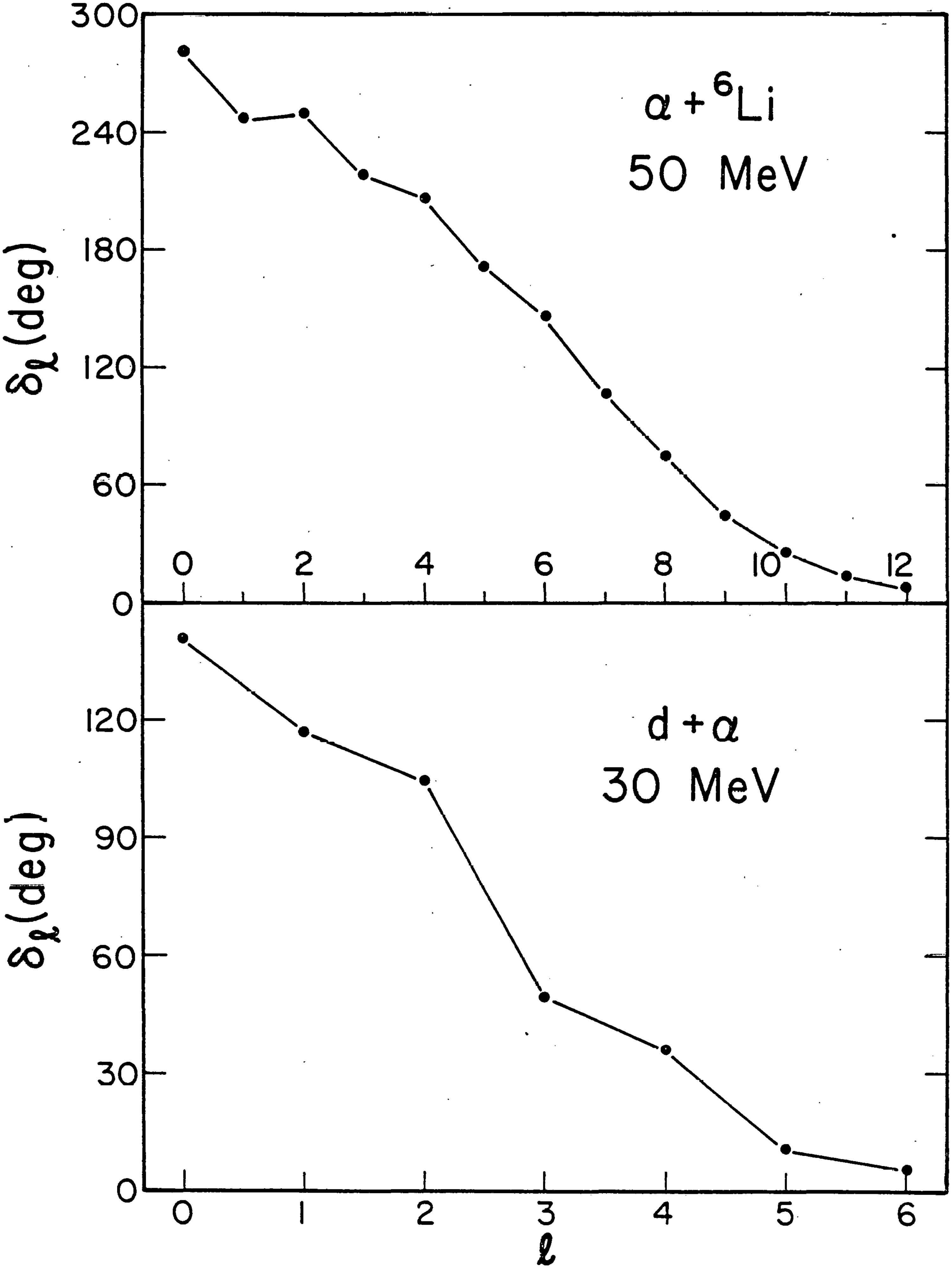
α + ^{6}Li
8.42 MeV
10,000
1000
100
10
1
σ (θ) (mb/sr)
0
20
40
60
80
100
120
140
160
180
θ (deg)

Fig. 2



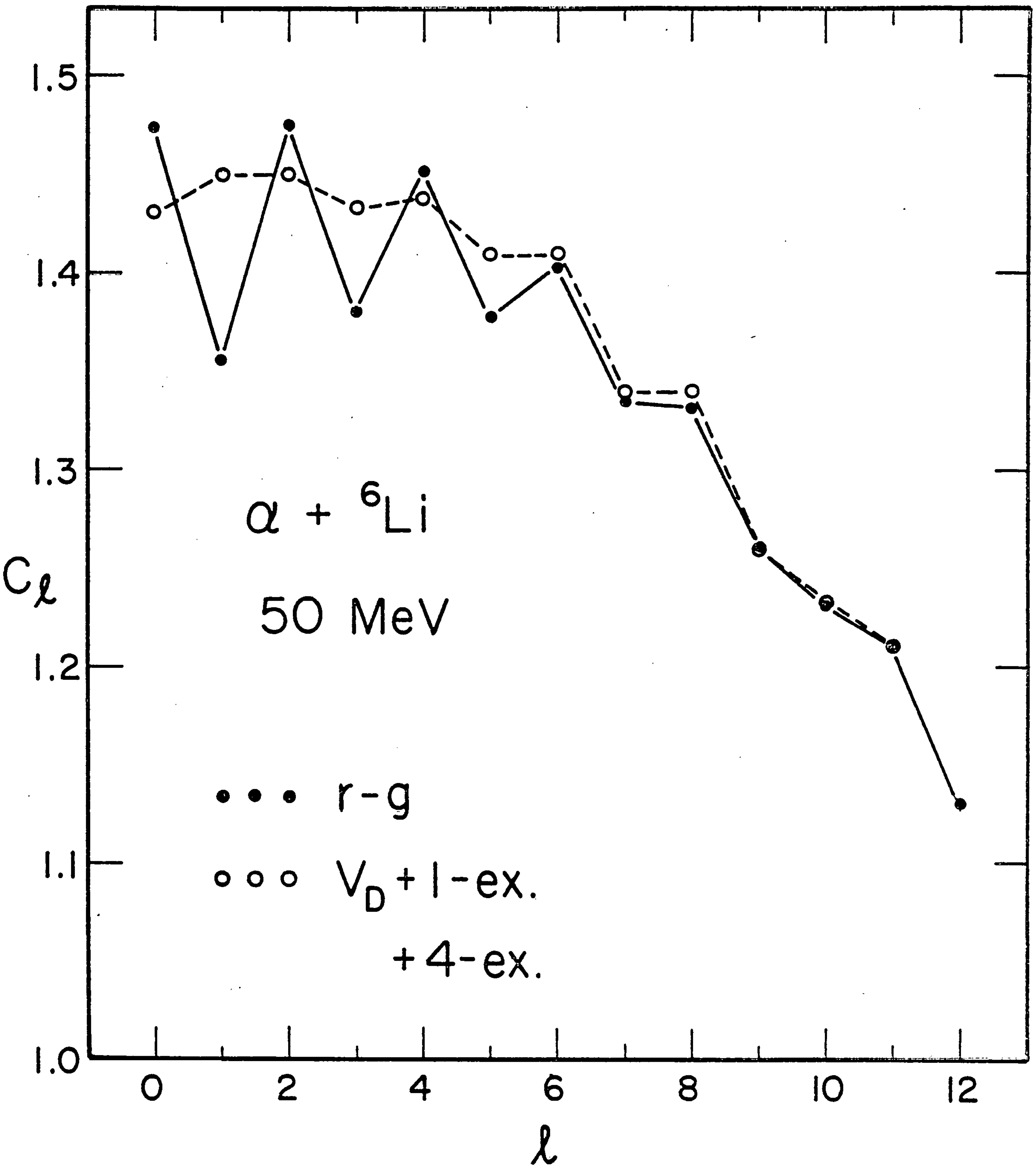
α +⁶Li
62.4 MeV
99.6 MeV
σ(θ)/σ_C(θ)
θ(deg)
100
10
1
0.1
0.01
0.001
0
20
40
60
80
100
120
140
160
180

Fig. 3



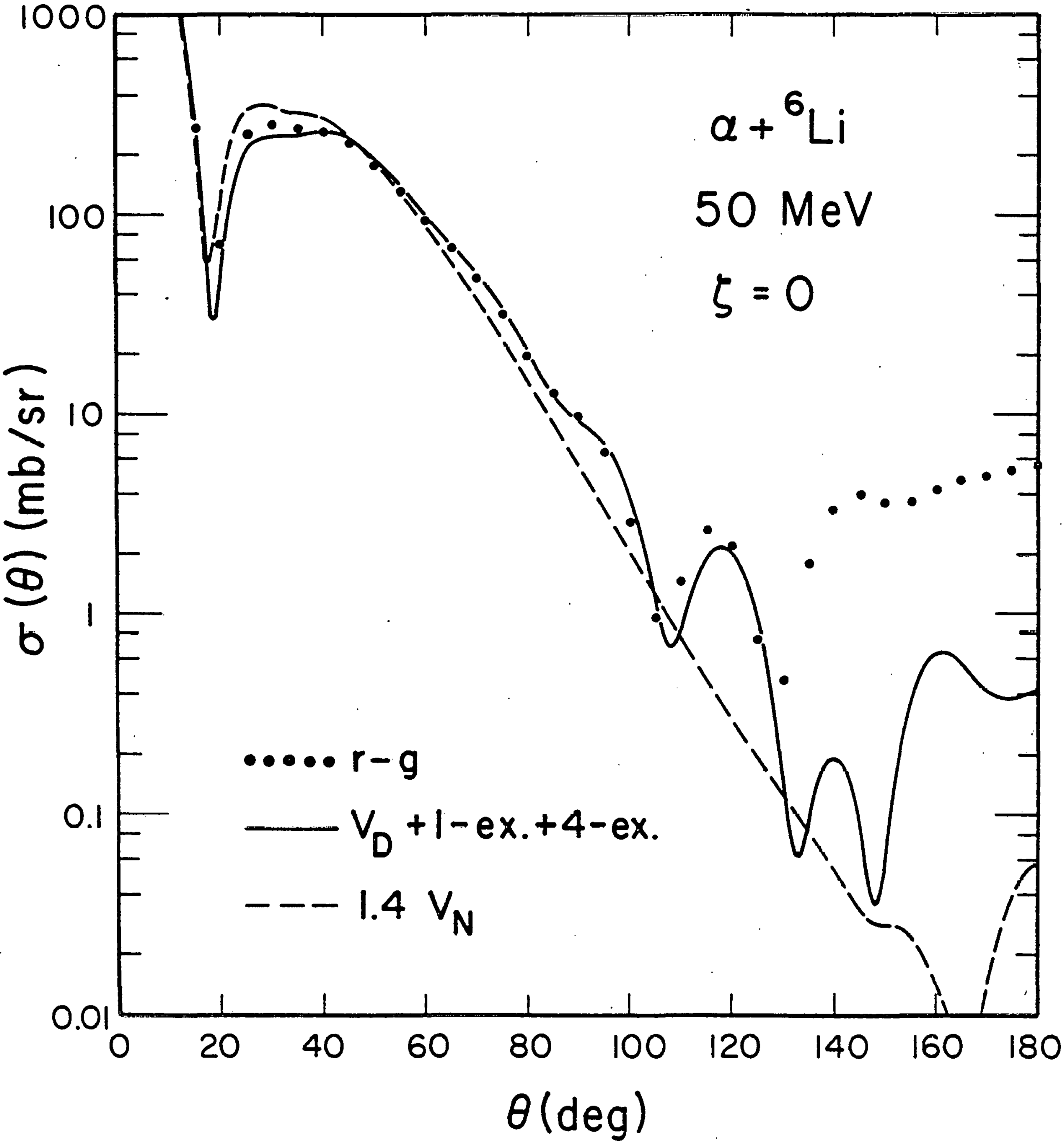
300
240
180
120
60
0
δ_ℓ (deg)
$\alpha + {}^6Li$
50 MeV
0 2 4 6 8 10 12
0
120
90
60
30
0
δ_ℓ (deg)
$d + \alpha$
30 MeV
0 1 2 3 4 5 6
ℓ

Fig. 4



1.5
1.4
1.3
1.2
1.1
1.0
C_ℓ
0
2
4
6
8
10
12
ℓ
$\alpha + {}^6Li$
50 MeV
• • • r-g
○ ○ ○ V_D + 1-ex. + 4-ex.

Fig. 5



α + ^{6}Li
50 MeV
ζ = 0
r−g
V_D + 1−ex. + 4−ex.
1.4 V_N
σ (θ) (mb/sr)
θ (deg)
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
120
140
160
180

Fig. 6

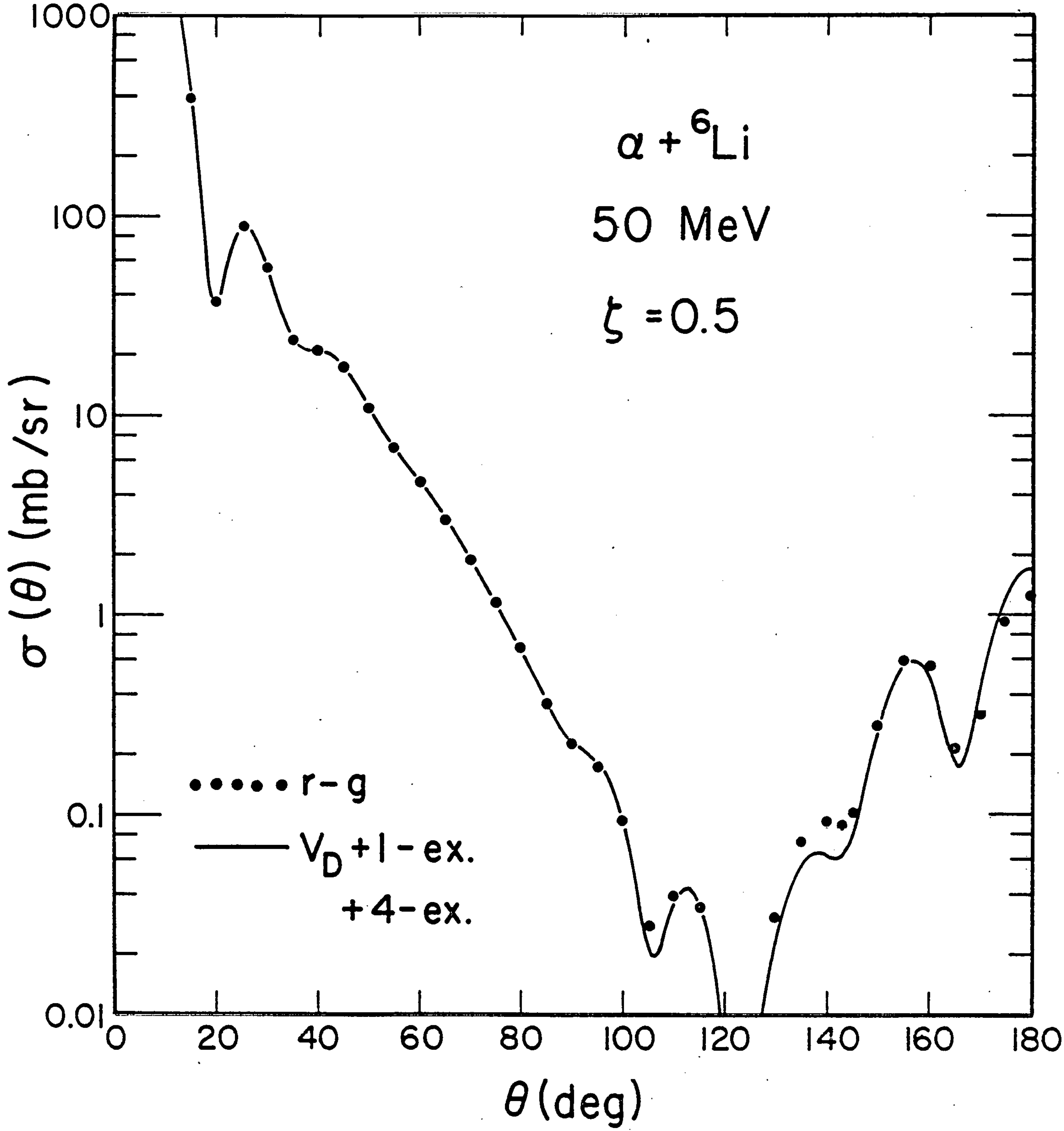

α + ⁶Li
50 MeV
ζ = 0.5
• • • • • r-g
——— V_D + 1-ex. + 4-ex.
σ (θ) (mb/sr)
θ (deg)
1000
100
10
1
0.1
0.01
0
20
40
60
80
100
120
140
160
180

Fig. 7