Effect of the exit reaction channels on ^{6}Li + ^{18}O elastic scattering

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The most pronounced reaction channels in the ^{6}Li + ^{18}O system were studied by means of the continuum-discretized coupled-channel and coupled-reaction-channel methods to investigate their effects on the elastic scattering. It is shown that, whereas breakup coupling provides no contribution to the observed rise in the backward-angle elastic scattering angular distribution, coupling to the single-neutron pickup alone enhances the elastic scattering cross section in this region by up to two orders of magnitude.

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I. INTRODUCTION

In a series of inverse kinematics experiments involving relatively light beams and targets, it has been found that the large angle elastic scattering cross sections for many systems are much greater than would be expected if they were produced by pure potential scattering. For systems where the projectile and target differ by a single nucleon, a ^{3}He or even an alpha particle, the increased cross sections have been shown to arise from elastic transfer of single nucleons or clusters between the projectile and target during the scattering process. A recent measurement of ^{6}Li + ^{18}O elastic scattering [1,2], however, showed an enhanced large angle cross section where elastic transfer would be expected to be small, since it would involve transfer of a ^{12}B cluster. Previous experiments [3] have shown that this possibility is unlikely due to the small overlap of ^{18}O with a ^{12}B + ^{6}Li cluster.

The purpose of the present work is to investigate the effect of the breakup process on elastic scattering with emphasis on its possible contribution to the large angle cross section as well as to study the impact of the other strongly coupled direct reaction processes. This work is made possible by advances in our understanding of more microscopic scattering potentials as well as increased computing capabilities that allow the strongest processes to be included in a single coupled-reaction-channel (CRC) calculation.

References [1,2] report detailed angular distributions for scattering and reactions produced by bombarding a ^{6}Li target with a 114 MeV ^{18}O beam and then detecting both the heavy and light particle reaction products at forward angles, thus yielding a data set with both forward- and backward-angle scattering and reaction products. The experimental data for both the scattering and reactions were analyzed in Refs. [1,2] with direct reaction models that did not isolate the results of couplings to the breakup channels or the influence of single-nucleon transfer on the large angle cross sections. Moreover, the optical model (OM) potentials needed for the reaction calculations were fitted to the data, which may obscure important underlying strong coupling effects.

The results of CRC calculations using a microscopic OM potential based on the $\alpha + d$ cluster model of ^{6}Li are reported in this work. The advantage of this model is that it has no adjustable parameters. The angular range where the breakup effects influence the elastic scattering is clearly shown and the contribution of couplings to the single-neutron pickup channels to the large angle scattering is clearly demonstrated. All calculations presented here were performed with the code FRESCO [4].

II. THE ROLE OF ^{6}Li BREAKUP

The effect on the elastic scattering of ^{6}Li breakup into α and d in the field of a target nucleus has been intensively investigated starting from the pioneering theoretical work of Thompson and Nagarajan [5], including experiments with polarized ^{6}Li beams [6] and their interpretation. It is now well established that breakup has a large effect on the elastic scattering cross section and is the source of the surprisingly large measured analyzing powers [7]. Thus, the first question that arises concerning the ^{6}Li + ^{18}O elastic scattering is how the measured angular distribution is affected by the ^{6}Li breakup.

The most natural technique to investigate the $^6\text{Li} \rightarrow \alpha + d$ breakup is the $\alpha + d$ cluster model of ^{6}Li [8] with the continuum-discretized coupled-channel (CDCC) method [9]. In the present CDCC calculations the cluster model employed previously in an analysis of ^{6}Li + ^{28}Si scattering was used

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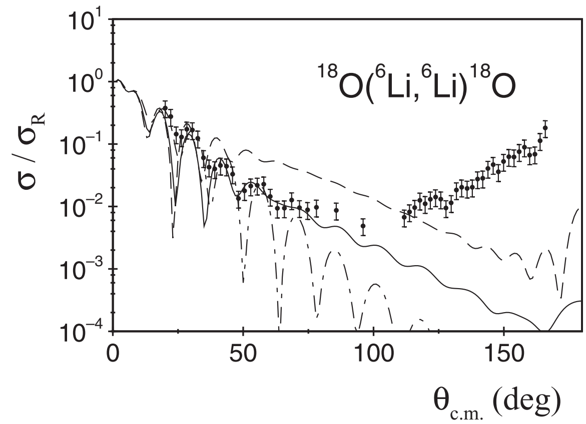

FIG. 1. Comparison of model calculations with the elastic scattering data. The solid curve denotes the result of a microscopic CDCC calculation that includes the effect of ^{6}Li breakup. The dashed curve shows the result with the breakup couplings omitted while an OM calculation using a global ^{6}Li potential [13] is plotted as the dot-dashed curve.

[10]. Details are given in Ref. [10] and are not repeated here. All the interactions, including the diagonal (*bare*) OM potential and the coupling potentials between the ground, resonant, and nonresonant states of ^{6}Li were generated from empirical OM potentials describing elastic scattering of α particles and deuterons from ^{18}O [11,12] so that the CDCC calculations did not contain any adjustable parameters.

The result of the CDCC calculation is denoted by the solid curve in Fig. 1. The forward scattering data up to about $\theta_{\text{c.m.}} = 100^\circ$ are well described but the backward scattering data are a few orders of magnitude above the model predictions. The effect of the ^{6}Li breakup is shown by the difference between the solid and dashed curves, since the dashed curve shows the result of an OM calculation with the bare potential only, without any couplings to the breakup channels. For the sake of comparison, the results of an OM calculation with the $^6\text{Li} + {}^{18}\text{O}$ potential derived from the global prescription of Cook [13] is given by the dot-dashed curve. This global potential describes the far-forward-angle scattering quite well but it is clearly more oscillatory than the data.

The effect of the breakup coupling is very pronounced at forward angles but gives no enhancement in the large-angle region. The backward rise of the elastic scattering differential cross section must therefore be attributed to other reaction channels. At the incident ^{18}O energy of the present data the only other credible source of the observed strong backward-angle enhancement of the elastic scattering is transfer reactions. In order to study their influence on the elastic scattering the CRC method must be used.

III. EFFECT OF THE SINGLE-NEUTRON PICKUP REACTION

While many reaction channels were observed in the experiment (see Fig. 1 of Ref. [1]) the most pronounced was the ^{18}O(^{6}Li,^{7}Li)^{17}O one-neutron pickup leading to different states in ^{17}O [2].

The first ingredients needed to understand the influence of coupling to these neutron transfer reactions on the elastic scattering through the CRC method are the distorting potentials for the various channels. The CDCC calculations described in the previous section have shown that breakup couplings do not contribute to the observed backward-angle rise in the elastic scattering angular distribution. Therefore, in the present CRC calculations the influence of the ^{6}Li breakup was included in an approximate way, by means of an effective OM potential in the entrance channel. This potential consisted of a bare term (diagonal cluster-folding potential as in the CDCC calculations) and a dynamic polarization potential (DPP) that simulates the effect of ^{6}Li breakup couplings in an OM calculation [14]. The DPP may be extracted from the CDCC result using the trivially equivalent method [15]. In the present work such a DPP was extracted from the CDCC result and tested in an OM calculation, generating results very close to those of the original CDCC result. In the exit channel, two OM potentials were tried — that from the global prescription of Cook [13] and that proposed by Rudchik *et al.* (Table 2 of Ref. [2]).

The other important ingredients of the CRC calculations were the wave functions of the $^7\text{Li} = {}^6\text{Li} + n$, $^7\text{Li}^* = {}^6\text{Li} + n$, $^{18}\text{O} = {}^{17}\text{O} + n$ and $^{18}\text{O} = {}^{17}\text{O}^* + n$ overlaps, including their spectroscopic amplitudes. For ^{7}Li, the wave functions consisted of $p_{3/2}$ and $p_{1/2}$ configurations with spectroscopic amplitudes taken from Ref. [16]. Their values, including the signs, were tested in experiments with polarized ^{7}Li beams [17]. The main single-neutron configurations of the ^{7}Li ground and first excited states are those with a nonexcited ^{6}Li core [16]. Therefore, the influence of the ^{6}Li excited states on the one-neutron pickup reactions is expected to be negligible. The spectroscopic amplitudes for ^{18}O were adopted from Table 1 of Rudchik *et al.* [2]. Neutron transfer channels leading to the ground state and five excited states (0.871, 3.055, 3.841, 4.553, and 5.379 MeV) of ^{17}O as well as to the ground and first excited states of ^{7}Li were explicitly taken into account. The geometries of the Woods-Saxon potentials binding the neutron to the ^{6}Li or ^{17}O core were assumed to have “standard” parameters of $r_0 = 1.25$ fm and $a_0 = 0.65$ fm.

For ^{7}Li, the simple rotational model was assumed with $M(E2)$ and quadrupole deformation length values taken from Ref. [18].

In Fig. 2 the experimental data for the one-neutron pickup reaction leading to the ground and first excited states of ^{17}O are compared with the model calculations. Like the CDCC calculations, these results are free of any adjustable parameters. The dotted curves represent the CRC results with the global potential of Cook [13] in the exit channel, while the solid and the dashed curves denote the results with the $^7\text{Li} + {}^{17}\text{O}$ OM potential of Rudchik *et al.* [2]. The latter has a more diffuse imaginary part than the global potential. The CRC calculations give similar results at forward angles but at backward angles the results of the calculations differ by a few orders of magnitude, with that using Rudchik’s OM potential giving the best reproduction of the large-angle rise in cross section of the neutron transfer.

The difference between the dashed and solid curves is due to the form of the interaction potential in the CRC calculations.

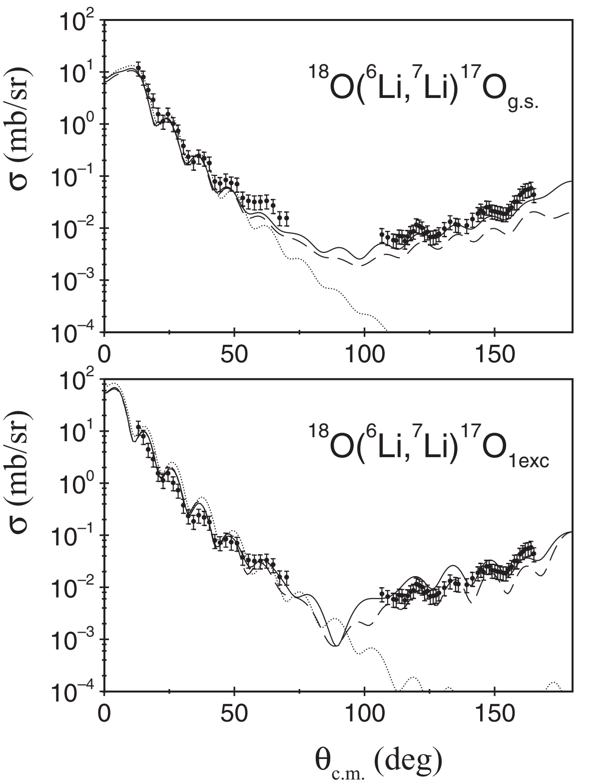

FIG. 2. Angular distributions of the one-neutron pickup reactions leading to the ground and first excited states of ^{17}O. The dotted curves correspond to a CRC calculation with the OM potential in the exit channel taken from Ref. [13]. The other curves denote the results of calculations with the effective OM potential obtained by Rudchik *et al.* [2] in the *prior* (solid curves) or *post* (dashed curves) representation. See text for details.

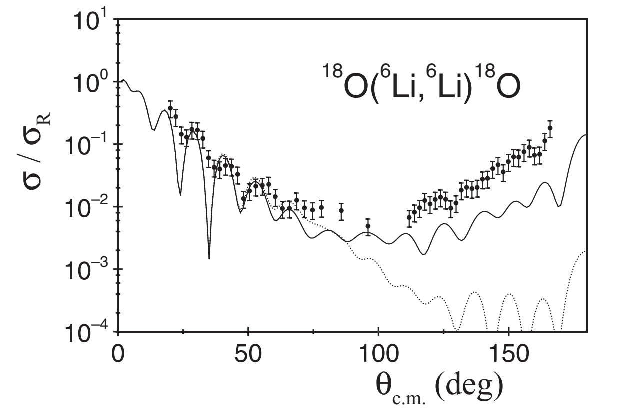

FIG. 3. Effect of the pickup channels on the elastic scattering of $^{6}Li + ^{18}O$. The curves correspond to CRC calculations with the exit channel OM potential from [2] (solid) and from [13] (dotted), as in Fig. 2.

The interaction potential (in the *post* or *prior* form) was calculated from the ^{7}Li, ^{18}O binding potentials, the optical model potentials in the exit and entrance channels, as well as the potential for the core-core scattering ($^{6}Li + ^{17}O$). The latter was adopted from the global prescription of Cook [13]. To take into account the non-orthogonality of the wave functions in the entrance and exit channels the "non-orthogonality remnant" option of the code FRESCO was used [4]. Such an approach should in principle give results that do not depend on the choice of the *post* or *prior* form for the interaction potential [4]. The results of the calculations with the two forms are plotted in Fig. 2 as the solid (*prior*) and dashed (*post*) curves. At forward angles they are almost identical while at backward angles they differ slightly, leading to a difference in the integrated cross sections of less than 5%. This may be considered as the accuracy of the CRC calculations presented in this paper [4].

The CRC calculation using the *prior* form better describes the transfer data, therefore its effect on the elastic scattering is shown in Fig. 3. As in Fig. 2, the dotted curve denotes a calculation with the global $^{7}Li + ^{17}O$ potential of Cook [13] while the solid curve denotes a CRC calculation using the potential of Ref. [2] in the exit channel. Comparing the results of the CRC calculations plotted in Figs. 2 and 3 as the solid and dotted curves it becomes evident that the transfer channels and the elastic scattering are intimately linked. The effect of this coupling on the backward-angle elastic scattering is very large, enhancing it by up to two orders of magnitude, but *only* if the exit channel $^{7}Li + ^{17}O$ OM potential is such that the backward angle rise of the *transfer* data is well described. Coupling to a single transfer partition is therefore able to account for almost all of the observed backward-angle rise in the elastic scattering angular distribution. The remaining small discrepancy between the observed and calculated large-angle elastic scattering may be ascribed to other, presumably somewhat weaker, couplings to transfer reactions such as the $^{18}O(^{6}Li,^{5}Li)^{19}O$ and $^{18}O(^{6}Li,^{5}He)^{19}F$ single-neutron and single-proton stripping.

IV. CONCLUSIONS

In conclusion, CRC model calculations were performed for the scattering and one-neutron pickup reactions in the $^{6}Li + ^{18}O$ system at an ^{18}O beam energy of 114 MeV. The main goal of the present study was to assess the role of ^{6}Li breakup and pickup reactions as possible sources of the rise of the backward-angle elastic scattering differential cross section. These calculations did not contain any adjustable parameters. The results clearly show that the breakup of ^{6}Li does not contribute to this effect and they further show that coupling to the $^{18}O(^{6}Li,^{7}Li)^{17}O$ single-neutron pickup channels is responsible for most (two orders of magnitude) of the observed rise at scattering angles larger than 90°. To the best of our knowledge this is the first time that such an effect has been firmly ascribed to a simple transfer coupling, as opposed to an elastic transfer.

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