Probing surface distributions of a clusters in ^{20}Ne via α-transfer reaction

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Probing surface distributions of α clusters in ^{20}Ne via α-transfer reaction

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Abstract. Although several analyses of the α-transfer reaction ^{16}O(^{6}Li, d)^{20}Ne using the distorted wave Born approximation have been performed with the aim to clarify the α-cluster structure of ^{20}Ne, they have resulted in poor information on the clustering due to insufficiency of models for the analyses. In this work we propose a precise model employing the coupled-channels Born approximation with the microscopically calculated cluster wave function to elucidate the surface manifestation of the α-particle in the ground state of ^{20}Ne. Our calculation has shown improvement of the theoretical calculation compared with that in the previous analyses. We have confirmed numerically that the angular distributed cross section at the forward angles probes only the surface region of the α-cluster wave function. The breakup effect of ^{6}Li has been investigated and concluded that only the back coupling is important for the (^{6}Li, d) reaction.

1. Introduction

So far a large number of theoretical and experimental studies have been carried out to investigate the α-cluster state in nuclei. Nevertheless no direct evidence of the clustering in bound states of nuclei is obtained. In particular for the α-cluster structure of ^{20}Ne in its ground state, several experimental works using the α-transfer reaction ^{16}O(^{6}Li, d)^{20}Ne [1–3] and its inverse reaction ^{20}Ne(d,^{6} Li)^{16}O [4] were reported. However in these papers the discussions on the clustering in the ground state are not enough. Furthermore due to ambiguities in reaction models with the distorted-wave Born approximation (DWBA) used for their analyses, unphysical values of the spectroscopic factor were reported, i.e., some of them exceed unity. In this work we reanalyze the α-transfer reaction reported previously by adopting a precise theoretical framework described below. We aim to extract the information of the surface manifestation of the α-cluster structure in the ground state of ^{20}Ne.

2. Theoretical framework

The transfer reaction is described with the coupled-channels Born approximation (CCBA), in which the three-body (α+d+^{16}O) model is adopted to explicitly take into account the excitation of ^{6}Li into the $\alpha + d$ continuum. The excitation to the continuum, i.e., the virtual breakup, is

handled by means of the continuum-discretized coupled-channels (CDCC) method [5–7]. The relative wave function of the α-^{16}O system in the ground state of ^{20}Ne is calculated by the microscopic cluster model with generator coordinate method (GCM) [8–10].

The input interactions of our model are the optical model potential (OMP) of the α (d)-^{16}O system, the $\alpha + d$ binding potential, and the effective nucleon-nucleon interaction in the GCM calculation. For the OMP we adopt a phenomenological potential [11, 12] for each subsystem, whereas the binding potential is assumed to be a multi-range Gaussian interaction [13]. The Volkov No. 2 effective interaction [14] is used in the GCM calculation. The detail of the calculation is expressed in our full paper [15].

3. Results and discussion

In Fig. 1(a) we compare the calculated transfer cross sections at 20.0 (solid line) and 42.1 MeV (dashed line) as a function of the deuteron emitting angle θ with the experimental data [1, 2]. The cross section at 20.0 MeV is multiplied by 10. Each lines are normalized to the data with a factor of 0.261 (0.769) at 20.0 (42.1) MeV. One of our main achievements is that description of the diffraction pattern, in particular the first and second peak of the cross section at the forward angles, is significantly improved at each incident energy compared to the previous DWBA analyses [1, 2]. Furthermore we obtain the reasonable values of the normalization factor compared to them reported in the previous DWBA as 2.70 [2] and 2.59 [1] at 20.0 and 42.1 MeV, respectively. Note that the normalization factor exceeding unity is unphysical because it expresses the probability of the cluster configuration in ^{20}Ne. It is found that the ambiguities of both the ^{6}Li-OMP and the α-^{16}O wave function cause the unphysical normalization. In our CCBA model based on the three-body model, the ambiguity of ^{6}Li-OMP is reduced because we use only the OMPs of the subsystems. In addition, our microscopic cluster model of ^{20}Ne can be regarded to be precise because, as shown in Ref. [16], the calculated spectra of the ground-state band as well as the root-mean-square radius of ^{16}O are consistent with the measured ones.

Another important finding is that the transfer cross section probes only the tail of the α-^{16}O wave function. This is numerically confirmed by comparison of the calculated cross

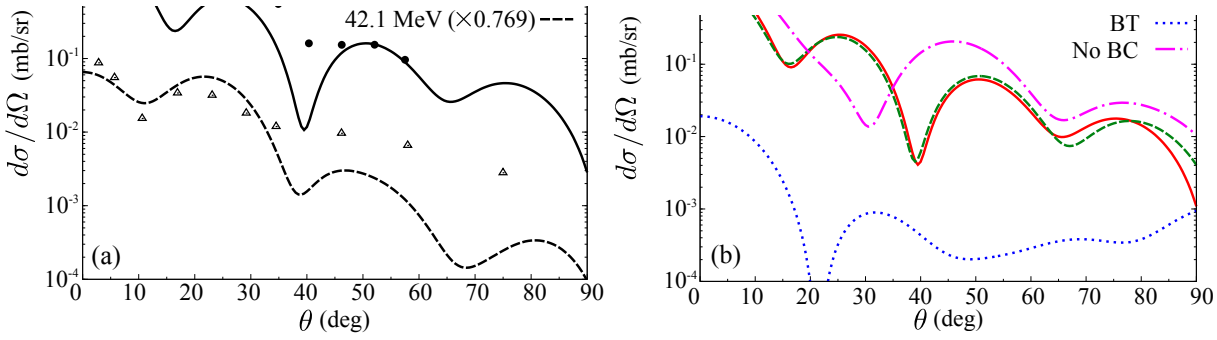

Figure 1. (a) Comparison of the calculated cross section of ^{16}O(^{6}Li, d)^{20}Ne at 20.0 (solid line) and 42.1 MeV (dashed line) with the experimental data [1, 2]. Each line is normalized by multiplying by a factor indicated in the legend. At 20.0 MeV the line and the dots are multiplied by 10. (b) Effect of each transfer process on the cross section at 20.0 MeV. The results of the ET and BT are shown by the dashed and dotted lines, respectively. The solid line is the result involving both the ET and BT, whereas the dash-dotted line is the ET one without the BC.

section employing the microscopic cluster wave function with that employing a phenomenological Woods-Saxon potential for the α-^{16}O system. From a detailed analysis [15], we conclude that at 20.0 (42.1) MeV the transfer cross section at the forward angles $\theta \lesssim 40^\circ$ probes the wave function at surface region $r \gtrsim 5$ (4) fm, where r is the relative distance between α and ^{16}O.

Next we investigate the reaction mechanism by decomposing the transition process into two paths. One is the transition from the ground state of ^{6}Li, which is called the elastic transfer (ET). The other is the breakup transfer (BT), which describes the transition from the continuum state of ^{6}Li. Note that the ET involves the breakup effect as the back coupling (BC), which is the channel coupling between the ground and continuum states. In Fig. 1(b) the calculated cross sections of each transition process at 20.0 MeV are shown. We see that the full result (solid line) involving both the ET and the BT coincides well with that only with the ET, whereas the calculation of the ET without the BC (dash-dotted line) results in the significantly different shape. Moreover the result of the BT (dotted line) is negligibly small. These facts indicate that only the BC plays an essential role. We have similar conclusion for the 42.1 MeV case. It should be noted that this does not mean failure of conventional DWBA analyses employing a ^{6}Li-OMP because such an OMP should contain the BC implicitly in its imaginary part if it is constructed properly. Same conclusion as in the present study was mentioned in Ref. [17] for another α-transfer reaction ^{13}C(^{6}Li, d)^{17}O. In Ref. [18] although the importance of the breakup effect of ^{6}Li in ^{12}C(^{6}Li, d)^{16}O was reported, whether only the BC is essential was not investigated. To clarify the universality of the breakup effect in (^{6}Li, d) reactions, further analyses with the CCBA model are necessary.

4. Summary

We have analyzed the α-transfer reaction ^{16}O(^{6}Li, d)^{20}Ne by means of the CCBA model with the microscopic cluster wave function. We have obtained the improvement in terms of the shape of the angular distribution as well as the normalization factor compared to the previous DWBA analyses. It has been found that the cross section at the forward angles probes only the tail region of the α-^{16}O relative wave function. As for the breakup effect of ^{6}Li, it has been pointed out that only the BC plays an important role.

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