Cluster configurations in ^{7}Li

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The effects of adding the $d+^5He$ cluster configuration to a formulation consisting of $^3H+\alpha$, $n+^6Li$, and $n+^6Li^*$ cluster configurations are examined. The result shows that, because of the reduction effect of the Pauli principle, the improvement in the $^3H+\alpha$ ground-state cluster separation energy and scattering phase shift is only moderate. On the other hand, the calculation also indicates that the deuteron spectroscopic factor in the ground state of ^{7}Li is likely to have an appreciable magnitude, in agreement with experimental finding.

In a recent investigation,[1] hereafter referred to as FT, we have studied the interplay of various cluster configurations in determining the properties of the seven-nucleon system. The main finding was that, for a satisfactory explanation of the essential characteristics of this system, the $n+^6Li(I=0)$ and $n+^6Li^*(I=2)$ cluster configurations need to be included in the calculation, in addition to the dominant $^3H+\alpha$ cluster configuration. In this Brief Report, we discuss the result of a further study, the main purpose of which is to supplement the information learned in FT by carefully examining the role played by the $d+^5He$ cluster configuration. For clarity in presentation, this study will be simplified by performing the calculation only in the $L=1$ state, since, as was discussed in FT, it is in this particular orbital angular-momentum state that the contribution of the $d+^5He$ configuration is expected to be most significant.

Unless otherwise stated, the notation used will be the same as that adopted in FT. Also, the formulation of the problem involving $^3H+\alpha$, $n+^6Li$, $n+^6Li^*$, and $d+^5He$ cluster configurations[2] has already been given in FT and a recent report;[3] hence, it will not be further described here.

In Table I, we list the $^3H+\alpha$ cluster separation energies $\tilde{E}$ in the ground state of ^{7}Li, calculated in various model spaces consisting of different combinations of cluster configurations. From this table, we note the following interesting features:

(i) For a reasonable $\tilde{E}$ result, the $^3H+\alpha$ cluster configuration must be included in the calculation. In addition, it is noted that the value of $\tilde{E}$ obtained in the SC1 calculation is much better than that obtained in the SC2 calculation. These findings confirm the $^3H+\alpha$ configuration as the dominant configuration in the ground state of ^{7}Li.

(ii) The results for $\tilde{E}$ in the DC3 and TC1 calculations are about the same, indicating that, in the ^{7}Li ground state, the $d+^5He$ cluster configuration is similar in significance to the $n+^6Li$ plus $n+^6Li^*$ cluster configurations.

(iii) The improvement effected by the addition of the $d+^5He$ cluster configuration depends quite sensitively on the chosen model space. The difference in $\tilde{E}$ values obtained in the SC1 and DC3 calculations is 1.30 MeV, while that obtained in the DC1 and TC2 calculations is 0.59 MeV, and that obtained in the TC1 and QC calculations is only 0.25 MeV. This shows that this particular difference becomes smaller as the model space becomes larger, a clear demonstration of the reduction effect caused by the Pauli principle.[4]

(iv) The difference in $\tilde{E}$ values obtained in the TC2 and QC calculations, being only 0.06 MeV, is quite small. This implies that the QC result of 3.50 MeV for $\tilde{E}$ probably cannot be improved much more. Any further calculation with a larger model space employing additional multicluster configurations will definitely require a vast increase in computational effort and, in our opinion, would no longer be worthwhile.

TABLE I. $^3H+\alpha$ cluster separation energies $\tilde{E}$ in the ground state of ^{7}Li.

Model space	Cluster configurations	$\tilde{E}$ (MeV)
Single configuration 1 (SC1)	$^3H+\alpha$	2.00
Single configuration 2 (SC2)	$n+^6Li$	−1.06
Double configuration 1 (DC1)	$^3H+\alpha$, $n+^6Li$	2.85
Double configuration 2 (DC2)	$n+^6Li$, $n+^6Li^*$	1.59
Double configuration 3 (DC3)	$^3H+\alpha$, $d+^5He$	3.30
Triple configuration 1 (TC1)	$^3H+\alpha$, $n+^6Li$, $n+^6Li^*$	3.25
Triple configuration 2 (TC2)	$^3H+\alpha$, $n+^6Li$, $d+^5He$	3.44
Quadruple configuration (QC)	$^3H+\alpha$, $n+^6Li$, $n+^6Li^*$, $d+^5He$	3.50

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Recently, Warner *et al.*[5] have performed a ^{7}Li(p, pd) knockout-reaction experiment using 200-MeV protons and found that the deuteron spectroscopic factor in ^{7}Li is comparable in magnitude to that in ^{6}Li, where the predominance of $d+\alpha$ clustering is well established.[6] In view of our finding about the significance of the $d+^5$He cluster configuration discussed above, this is not at all surprising. Again, because of the reduction effect of the Pauli principle,[7] the assertion of an appreciable magnitude for the deuteron spectroscopic factor does not in any way contradict the statement that the ground state of ^{7}Li has predominantly a $^3H+\alpha$ cluster configuration.

Next, we examine the behavior of the $^3H+\alpha$, $L=1$ phase shift δ_1 (denoted as $\delta^{\frac{1}{2}}_{1,1}$ in FT) in various model spaces. The results are depicted in Fig. 1, where the dashed curve, solid circles, solid curve, and dash-double-dot curve represent phase-shift values obtained in SC1, DC3, TC1, and QC calculations, respectively. Here one finds again, by comparing DC3 and TC1 results, that the contribution from the $d+^5$He cluster configuration is similar to that from the $n+^6$Li plus $n+^6$Li* cluster configurations. With all four cluster configurations included (i.e., the QC calculation), it is seen that, in the energy region considered, the δ_1 values are better than those obtained in the TC1 calculation with $^3H+\alpha$, $n+^6$Li, and $n+^6$Li* configurations by an average of about 5°.

In summary, we find that, because of the reduction effect of the Pauli principle, the addition of the $d+^5$He cluster configuration to a formulation consisting of $^3H+\alpha$, $n+^6$Li, and $n+^6$Li* cluster configurations causes only a moderate improvement in the $^3H+\alpha$ cluster separation energy and scattering phase shift. However, the calculation also shows that, in the ground state of ^{7}Li, the magnitude of the deuteron spectroscopic factor is likely to be rather appreciable, which is in agreement with a recent experimental finding.

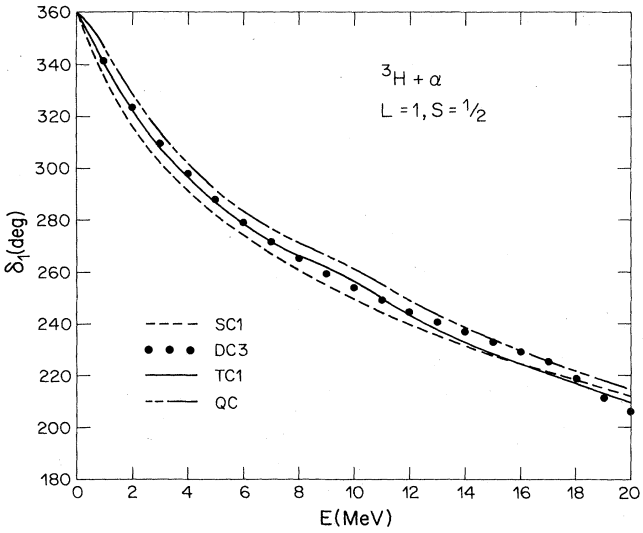

FIG. 1. Comparison of $^3H+\alpha$, $L=1$ phase shifts obtained in SC1, DC3, TCl, and QC cases.

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[1]Y. Fujiwara and Y. C. Tang, Phys. Rev. C **31**, 342 (1985).

[2]It should be mentioned that a calculation including these cluster configurations has also been reported by H. M. Hofmann, T. Mertelmeier, and W. Zahn, Nucl. Phys. **A410**, 208 (1983). The emphasis of that calculation is, however, not the same as that of ours here.

[3]Y. Fujiwara and Y. C. Tang, University of Minnesota Report No. UM-RGM2. In this report, the general formulation of a three-cluster resonating-group method for a system consisting of an α cluster and two s-shell clusters, based on the coupled-channel formalism, is given.

[4]For a detailed discussion of the effect of the Pauli principle in reducing the differences between seemingly different cluster structures, see K. Wildermuth and Y. C. Tang, *A Unified Theory of the Nucleus* (Vieweg, Braunschweig, Germany, 1977).

[5]R. E. Warner (private communication).

[6]See, e.g., R. E. Warner, R. S. Wakeland, J. Q. Yang, D. L. Friesel, P. Schwandt, G. Caskey, A. Galonsky, B. Remington, and A. Nadasen, Nucl. Phys. **A422**, 205 (1984).

[7]Y. C. Tang, K. Wildermuth, and L. D. Pearlstein, Nucl. Phys. **32**, 504 (1962).